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MARSHALL ISLANDS RADIOLOGICAL SAFETY PROGRAM REVIEW

May 21 and 22, 1981

Safety and Environmental Protection Division

Brookhaven National Laboratory

HISTORICAL SYNOPSIS

HISTORICAL SYNOPSIS

Schedule 189's and Field Task Proposals

Marshall Islands Radiological Safety Program
and Rongelap/Utirik Dose Reassessment Project
-A Historical Synopsis

SCHEDULE 189

ADDITIONAL EXPLANATION FOR OPERATING COSTS

Brookhaven National Laboratory
Laboratory

RZ-Operational Safety
Program

1. Contractor:
Associated Universities, Inc.

Contract No.: AT(30-1)-16

Task No.:

2. Project Title:
Safety Studies and Development of Operational Guidelines
Marshall Islands Radiological Safety Program

189 No.: RZ-1

3. Budget Activity No.:
RZ-03

4. Date Prepared:
May 1974

5. Method of Reporting:
Annual report to Division of Operational Safety

6. Working Location:
Brookhaven National Laboratory

7. Person in Charge:
C. B. Meinhold

Principal Investigator:
N. Greenhouse
F. Haughey
A. Hull

8. Project Term:

From: To:

Project will be initiated in FY 1975.

9. Man-Years:

	FY 1974	FY 1975	FY 1976
Sci., Res. Assoc. (Ph.D. or Equiv.)	---	1.0	1.0
Prof. (B.S. or Equiv.)	---	0.5	0.5
Sci. & Prof. - Total	---	1.5	1.5
Others	---	1.0	1.0
Guests & Research Collaborators	---	---	---
Total	---	2.5	2.5

10. Costs (In Thousands of Dollars):

	FY 1974	FY 1975	FY 1976
Labor (including benefits)	0	30	66
Mats., Trav., Dev. Subcont., Spec'l Proc.	0	75	37
Reactor, Accel., and/or Computer Usage	0	2	1
Allocated Technical Services	0	3	1
Gen. & Adm. Overhead	0	15	32
Total Research Cost	0	125	137
Equipment Obligations	0	20	0

11. Reactor Concept:

12. Materials:

13. Publications:

None

14. Scope:

Now that Micronesians are returning to the islands affected by weapons testing, a comprehensive, continuing radiation safety program is required. Such a program would be developed for the Division of Operational Safety using the facilities and personnel of the Brookhaven National Laboratory Health Physics and Safety Division. This project is intended to provide Operational Safety with a single focal point for their needs in this area. Areas needing scientific investigation will be suggested to the Division of Biomedical and Environmental Research, and other support activities to the Division of Operational Safety.

The specific goal of this project is to gather and evaluate previous and current data on the radiological situation as they relate to actual and projected land use. Significant exposure pathways will be identified as a basis for establishing a continuing environmental monitoring program. Using this information, annual surveys in the islands will be designed and performed in conjunction with the Brookhaven Medical Survey. Environmental samples will be returned to Brookhaven National Laboratory for analysis. In addition to those samples required to estimate the accuracy of the dose predictions, specific samples relating to the Medical Survey Group's interest will be collected and analyzed. Our close relationship with the Medical Survey Group will permit us to respond rapidly to their needs.

15. Relationship to Other Projects:

a) The facilities and personnel of the Brookhaven National Laboratory Health Physics and Safety Division Environmental Monitoring Group will be the basic element in the project.

b) Mutual assistance will exist with the Brookhaven Medical Survey Team. The annual radiological survey would be conducted during their visits to the islands when possible.

c) Extensive use will be made of the data and experience of previous studies in the islands. This will include consultation as needed with the personnel from the Lawrence Livermore Laboratory, Southwest Radiological Health Laboratory, AEC Health and Safety Laboratory, etc. Close cooperation with the University of Washington is anticipated for the radiological analysis of marine biota in the Marshallese diet.

16. Technical Progress in FY 1974:

Health Physics and Safety Division staff members will assist in the March 1974 medical survey in the islands in order to familiarize these

(See Continuation Sheet)

16. Technical Progress in FY 1974: (Cont'd)

personnel with the area and enable them to anticipate technical and administrative difficulties.

17. Expected Results in FY 1975:

The project will be initiated in FY 1975 when the first detailed surveys in the islands will be designed and performed.

18. Expected Results in FY 1976:

A radiation protection program for the islands will be fully implemented with the expectation that this project is to be continued for an indefinite period.

19. Description and Explanation of Major Materials, Equipment and Subcontract Items:

In FY 1975, capital equipment funds of $20,000 is requested for a 800 channel analyzer and its associated hardware. The equipment is required to bring our environmental monitoring facilities to the "state of the art."

20. Proposed Obligations for Related Construction Projects:

None

SCHEDULE 189

ADDITIONAL EXPLANATION FOR OPERATING COSTS

Brookhaven National Laboratory — Laboratory

RW-Operational Safety — Program

1. Contractor: Associated Universities, Inc.

Contract No.: E(30-1)-16

Task No.:

2. Project Title: Safety Studies and Development of Operational Guidelines Marshall Islands Radiological Safety Program

189 No.:

3. Budget Activity No.: RW-03-(a)

4. Date Prepared: May 1976

5. Method of Reporting: Annual Report to Division of Operational Safety, monthly visits to DOS, Scientific Meetings and Journals

6. Working Location: Brookhaven National Laboratory

7. Person in Charge: C. B. Meinhold

8. Project Term: Continuing

From: To:

Principal Investigator:

N. A. Greenhouse
J. R. Naidu
A. P. Hull

9. Man-Years:

Direct Man-Years	FY 1976	Transition Period	FY 1977	FY 1978
Scientific & Professional	2.5	0.5	2.0	2.0
Others	1.0	0.3	1.0	1.0
Guests & Research Collaborators	---	---	---	---
Total	3.5	0.8	3.0	3.0

10. Costs (In Thousands of Dollars):

	FY 1976	Transition Period	FY 1977	FY 1978
Research Costs	140	30	140	150
Equipment Obligations	30	10	15	10

11. Reactor Concept:

12. Materials:

13. Publications:

Greenhouse, N. A. and McCraw, T. F. Marshall Islands Radiological Followup. Proc. Ninth Midyear Topical Symposium. Operational Health Physics. Denver. February 1976, P. L. Carson, Ed., pp. 742-7, Health Physics Society, Central Rocky Mountain Chapter, Boulder, Colorado, 1976.

14. Scope:

A comprehensive and continuing radiological safety program is required for the Bikini and Enewetak people who desire to reinhabit their home atolls. The program includes analyses of external radiation levels, soil and ground water contamination levels, and radioactivity in terrestrial and marine biota which comprise the human food chain. From these data, both external and internal doses and dose commitments will be made. In addition, projections of future radiological conditions will be postulated in order to provide appropriate guidance on projected land use and living patterns. Earlier dose assessments will be revised and updated, and dosimetry models will be refined to reflect actual trends as determined from the monitoring program.

Project personnel will provide a resource of expertise for establishment or independent review of radiation protection programs associated with cleanup and rehabilitation efforts in the northern Marshall Islands, and for related health physics interests of the Division of Operational Safety.

Field operations will be closely coupled with those of Brookhaven Medical Survey in the Marshall Islands, and Radiological Safety Program personnel will be of direct assistance to the Medical Survey whole body counting activities. Ancillary environmental radiological assessments will be made at Rongelap and Utirik atolls on an alternate year basis.

15. Relationship to Other Projects:

a) Surveys will be made in close conjunction with the BNL Medical Survey Team. Assistance will be given to their effort. The annual survey would be conducted during their visits to the Islands. b) Continued collaboration with the University of Washington, Laboratory for Radiation Ecology (LRE) is anticipated on Division of Operational Safety environmental programs in the Pacific basin. c) Extensive use will be made of prior survey data. Consultations will be held with other participating agencies in developing the bases for the survey requirements.

16. Technical Progress in FY 1976 and Transition Period:

A major survey was conducted at Bikini and Eneu Islands in February 1975 in response to Department of the Interior's request for guidance on the siting of the second increment of housing construction at Bikini. This survey revealed unacceptable radiation levels at most of the proposed sites, suggested alternate sites, and laid the groundwork for a larger multiagency survey in

(See Continuation Sheet)

16. Technical Progress in FY 1976 and Transition Period: (Cont'd.)

June-July 1975 in which BNL participated. Data from both these surveys are currently being used to refine dose and dose commitment predictions for returning Bikini residents.

BNL collaborated with the University of Washington LRE in a regional radiological background study in Micronesia, November-December 1975. Data from this study will be used as a reference base against which radiological data from the northern Marshall Islands can be compared.

The first routine followup study for Bikini and Eneu is scheduled for April 1976. This survey will include detailed radiological profiles of the Nam-Bokata complex of islands which are the next areas scheduled for agricultural development in the Bikini atoll master plan.

17. Expected Results in FY 1977:

Ground survey support will be provided for a planned interagency aerial radiological survey of all previously unsurveyed atolls in the northern Marshall Islands which may have received local fallout from the U.S. atmospheric nuclear tests.

Enewetak will be visited by the program principals in order to establish a routine environmental monitoring program for that atoll.

Continued technical support will be provided by BNL for the ERDA-funded Pacific Basin radiological program of the University of Washington LRE.

18. Expected Results in FY 1978:

Continuation of programs described in FY 1977.

19. Description and Explanation of Major Materials, Equipment and Subcontract Items:

Capital Equipment Fiscal Year 1977:

Additional memory and an x-y plotter ($9,000) for the Ge(Li) spectrometer system is needed to improve sample analyses and data processing capabilities on large numbers of environmental samples collected during field surveys.

Peripheral electronics ($6,000) for a thin intrinsic germanium detector array is needed to process soil samples for heavy elements.

Capital Equipment Fiscal Year 1978:

In FY 1978 a standard compatible magnetic tape unit ($7,000) will be needed for data storage, which will enable the scientific staff to transfer

(See Continuation Sheet)

19. Description and Explanation of Major Materials, Equipment and Subcontract Items: (Cont'd.)

Capital Equipment Fiscal Year 1978: (Cont'd.)

spectra data from present analyzer equipment to the Central Scientific Computing Facility.

20. Proposed Obligations for Related Construction Projects:

None

SCHEDULE 189

ADDITIONAL EXPLANATION FOR OPERATING COSTS

Brookhaven National Laboratory Laboratory	RK-Environmental Research and Development Program

1. Contractor: Associated Universities, Inc.
   Contract No.: EY-76-C-02-0016
   Task No.:

2. Project Title:
   Surveillance of Facilities and Sites
   Marshall Islands Radiological Safety Program
   189 No.:

3. Budget Activity No.: RK-01-05-02-3 (600003)

4. Date Prepared: May 1977

5. Method of Reporting: Annual Report to Division of Operational Safety, Standards and Compliance (SSC), Monthly Visits to SSC, Scientific Meetings and Journals

6. Working Location: Brookhaven National Laboratory

7. Person in Charge: C. B. Meinhold

   Principal Investigator: N. A. Greenhouse (664-4250)

8. Project Term: Continuing

   From: To:

9. Man-Years:

	FY 1977	Pres. Bud. FY 1978	Rev. Req. FY 1978	FY 1979
Sci.,Res.Assoc.(Ph.D or Equiv.)	1.0	2.0	2.0	1.0
Prof. (B.S. or Equiv.)	0.5	1.0	1.0	1.0
Sci. & Prof. - Total	1.5	3.0	3.0	2.0
Others	1.0	1.5	1.5	1.5
Guests & Research Collaborators	---	---	---	---
Total	2.5	4.5	4.5	3.5

10. Costs (In Thousands of Dollars):

	FY 1977	Pres. Bud. FY 1978	Rev. Req. FY 1978	FY 1979
Labor (including benefits)	63	79	87	83
Mats.,Trav.,Dev. Subcont.,Spec'l. Proc.	44	32	62	67
Reactor, Accel., and/or Computer Usage	0	0	0	0
Allocated Technical Services	2	1	1	1
Gen. & Adm. Overhead	31	38	42	60
Total Research Cost	140	150	192	211
Equipment Obligations	10	10	10	5

11. Reactor Concept:

12. Materials:

13. Publications:

Greenhouse, N. A., Levine, G. S., Kraner, H. W. and Naidu, J. R. A thin intrinsic germanium detector array for direct counting of soil samples. Presented at the 21st Annual Meeting of Health Physics Society, San Francisco, California, June 1976.

14. Scope:

(a) 200 Word Summary: Environmental and personnel monitoring programs for the Marshallese people living at Bikini, Rongelap and Utirik Atolls must continue indefinitely in order to assess dose contributions to these people from the residual radioactivity originally produced by U.S. nuclear weapons tests in the Pacific. Detailed assessments of the contributions of external gamma radiation have been made over the past two years, but the identification of internal exposure pathways and determination of their radiological significance are subject to many variables which will require environmental and diet monitoring and bioassay programs for many years. The focal points of the next year's efforts will be quantification of the average annual diet and its radionuclide content of each atoll; determination of the significance of the inhalation pathway for plutonium and other radionuclides resuspended from local soils, and establishment of urine excretion rates for plutonium, strontium 90 and cesium 137 for individuals if possible, and the averages for atoll populations.

From these data, assessments of both external and internal doses and dos commitments will be made. In addition, projections of future radiological co ditions will be postulated in order to provide appropriate guidance on projected land use and living patterns. Earlier dose assessments will be revised and updated, and dosimetry models will be refined to reflect actual trends as determined from the monitoring program.

Project personnel will provide a resource of expertise for establishment of independent review of radiation protection programs associated with cleanup and rehabilitation efforts in the northern Marshall Islands, and for related health physics interests of the Division of Safety, Standards and Compliance.

15. Relationship to Other Projects:

a. Field surveys will be made in close conjunction with those of the BNL Medical Survey Team, and assistance will be given to their efforts.

b. Continued collaboration with the University of Washington, Laboratory for Radiation Ecology is anticipated in SSC-sponsored environmental programs in the Pacific Basin.

16. Technical Progress in FY 1977:

During a field trip in September-October 1976, visits to Wotje, Ailuk, Utirik, Rongelap, and Bikini provided opportunities to collect urine samples

(See Continuation Sheet)

16. Technical Progress in FY 1977: (Cont'd)

representative of contaminated and uncontaminated locations in the region as part of a plutonium excretion study. Definitive measurements of external exposure rates were made at Utirik and Rongelap, and the incremental exposure rates from Bravo fallout were determined for the village islands and several others at these atolls.

Analyses of environmental samples collected from past surveys are nearly completed, and reports of the results are in progress.

17. Expected Results in FY 1978:

Installations of air sampling stations will be completed at Kwajalein, Bikini, Rongelap, and Utirik; and initial results of air monitoring and intensified urine bioassay programs are expected.

Group survey support will be provided for a planned interagency sponsored aerial radiological survey of all previously unsurveyed atolls in the northern Marshall Islands which may have received local fallout from U.S. atmospheric nuclear tests.

18. Expected Results in FY 1979:

Continuation of programs described for FY 1977 and 1978.

19. Description and Explanation of Major Materials, Equipment and Subcontract Items:

Capital Equipment, FY 1978:

Peripheral electronics ($10,000) for the Safety and Environmental Protection Division analytical laboratory is needed to process the increasing load of environmental samples collected on field surveys.

Major Subcontract Items, FY 1978:

A supplemental budget request was made for FY 1977 to initiate the air monitoring and expanded urine bioassay program for plutonium. It will be necessay to extend the contracted peak load analyses of these samples into FY 1978 because of the lengthy set up and processing times for amounts of radioactivity which are below conventional limits of detection. Anticipated cost is $10,000.

Capital Equipment, FY 1979:

Peripheral electronics equipment ($5,000) is needed to provide depth in the Safety and Environmental Protection Division analytical laboratory to handle peak loads of environmental samples which must otherwise be subcontracted to a commercial laboratory.

(See Continuation Sheet)

20. Proposed Oblizations for Related Construction Projects:

None

DEPARTMENT OF ENERGY

ENERGY - OPERATING EXPENSES AND CAPITAL ACQUISITION

SCHEDULE 189

ADDITIONAL EXPLANATION FOR OPERATING OBLIGATIONS

Brookhaven National Laboratory — GK-Multi-Resource

Laboratory — Mission Resource

1. Contractor: Associated Universities, Inc.

Contract No.: EY-76-C-02-0016

Task No.:

2. Project Title:

Surveillance of Facilities and Sites
Marshall Islands Radiological Safety Program

189 No.:

3. Budget Activity No.:

GK-01-01-52-3-(a)
(600003)

4. Date Prepared:

March 1978

5. Method of Reporting:

Annual Report to Division of Safety Standards and Compliance (SSC)
Monthly Visits to SSC
Scientific Journals and Meetings

6. Working Location:

Brookhaven National Laboratory

7. Person in Charge:

C. B. Meinhold

Principal Investigator:

N. A. Greenhouse (664-4250)

8. Project Term:

Continuing

From: To:

9. Person-Years:

	FY 1978	Pres.Bud. FY 1979	Rev.Req. FY 1979	FY 1980
Direct Person-Years				
Scientific & Professional	2.0	3.0	3.0	3.0
Others	2.5	2.0	4.0	4.0
Guests & Research Collaborators	---	---	---	---
Total	4.5	5.0	7.0	7.0

10. Costs (In Thousands of Dollars):

	FY 1978	Pres.Bud. FY 1979	Rev.Req. FY 1979	FY 1980
Research Costs	150	211	400	420
Total Research Obligations	198	218	369	427
Equipment Obligations	11	20	20	50

11. Reactor Concept:

12. Materials:

GK-115

13. Publications:

Greenhouse, N. A. and Miltenberger, R. P. Radiological analyses of Marshall Islands environmental samples from 1974 through 1976. BNL Report (in press).

Greenhouse, N. A. and Miltenberger, R. P. External radiation survey and dose predictions for Rongelap, Utirik, Rongerik, Ailuk, and Wotje Atolls. BNL Report (in press).

14. Scope:

(a) 200 Word Summary: A comprehensive radiological safety program will be maintained for the inhabitants of atolls in the northern Marshall Islands contaminated as a result of the U.S. Pacific Testing programs. The following items and services will be provided:

1. Environmental and personnel monitoring to provide data for BNL dose assessments and determination of radiological trends.

2. Individual and population dosimetry based on actual measurements. These data will be used to modify dose commitment predictive models so that they accurately reflect future trends.

3. Suggestions based on field experience to mitigate doses via the more critical pathways.

4. A flexible resource of radiological expertise to independently review radiation protection programs associated with rehabilitation efforts in the northern Marshalls, and for related health physics interests of OES in the Pacific Basin.

Program activities for the coming fiscal year will emphasize the following:

1. In vivo counting of Bikini and Enewetak residents. These efforts will define baseline body burdens of gamma-emitting nuclides for new residents at both atolls, and will periodically assess changes in body burdens over time which might result from various exposure pathways.

2. Urine bioassay to define radionuclide excretion patterns from individuals, and to estimate ^{90}Sr and transuranic nuclide burdens.

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(See Continuation Sheet)

14. Scope: (continued)

3. Definition of the annual contributions to dose via the inhalation pathway at Bikini, Rongelap, and Utirik. Special emphasis will be placed on continuous air sampling for wind-mediated resuspension of radionuclides in local soils; and on special measurements to define aerosol contributions resulting from human activity.

4. Development of radiological dose predictive models which involve both human and environmental monitoring data.

(b) Supplement to 200 Word Summary: The FY 1979 budget request contains a significant increase over the FY 1978 allocation. This increase reflects a realistic assessment of operating costs imposed by the *in vivo* counting, bioassay, and air monitoring activities begun in FY 1978. Additionally, field trip activities and analytical laboratory services have substantially exceeded original estimates for the basic radiological safety program, and these costs are expected to continue. Finally, there are a number of peripheral programs of mutual interest to BNL and OES which will be cost-effective if included with the basic efforts, manpower and budget permitting. These include in order of importance:

1. Definition of local diet patterns at all atolls of interest, and continuous monitoring of diets for seasonal changes and long-term trends which might impact on realistic dose predictions.

2. Incorporation of public information and education programs into the total BNL effort to minimize the adverse psychological and sociological impacts of local radiological conditions and of our efforts to understand them.

3. Retrospective assessment of the radiological picture in the northern Marshalls prior to the establishment of the BNL program in FY 1975.

4. Continued collaboration with UW/LRE on OES radiological programs.

15. Relationship to Other Projects:

This program will be logistically coupled wherever possible to the BNL Medical Program in the Marshall Islands. Technical collaboration will continue on matters of mutual interest. The radiological safety program will also bear directly on a retrospective reassessment of thyroid and whole body doses to the BRAVO fallout victims at Rongelap and Utirik, a new program for which funding is expected in FY 1978. The program will also interact cooperatively with related efforts at the University of Washington (LRE) and at Lawrence Livermore Laboratory.

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(See Continuation Sheet)

Surveillance of Facilities and Sites

Project Title: Marshall Islands Radiological Safety Program EK-01-01-02

16. Technical Progress in FY 1978:

Several reports are in press or in progress for publication in FY 1978. These reports will summarize all BNL radiological program activities to date and identify the technical issues to be addressed in FY 1979 and 1980. Two field trips were made in October 1977 to initiate the BNL air monitoring programs at Bikini, Rongelap, and Utirik; and to establish the in vivo counting program. Sufficient field monitoring data will become available to assess average radionuclide body burdens for residents of Bikini, Rongelap, and Utirik, and to make a preliminary analysis of the inhalation pathway at these atolls.

Personnel and analytical laboratory resources are being mobilized to provide technical program support for the "13 Atoll Survey" which is expected during FY 1978.

At least two additional field trips are planned for FY 1978 to continue environmental surveillance programs at Utirik, Rongelap, and Bikini, and the study of trends in ^{137}Cs body burdens at Bikini. Field trip scheduling continues to be hampered, however, by uncertainties over logistics support.

17. Expected Results in FY 1979:

At least three field trips will be made to Bikini, Rongelap, and Utirik Atolls to conduct routine environmental surveillance and personnel monitoring activities. In addition, two or more field trips will be made to Enewetak to continue baseline in vivo counting and bioassay activities begun in FY 1978, and to initiate a new environmental surveillance program consistent with the return of control of the atoll to the Marshallese.

Average baseline radionuclide body burdens will be established for typical residents of uncontaminated atolls. Additional contributions to body burdens from environmental pathways on contaminated atolls will be determined for individuals and populations at Bikini, Rongelap, and Utirik. Definition of the inhalation pathway at the aforementioned atolls will be completed, and a working predictive model will be developed which incorporates environmental and pathway analyses with actual human uptake experience.

18. Expected Results in FY 1980:

Continuation of programs described in FY 1979.

(See Continuation Sheet)

GK-1181

19. Description and Explanation of Major Materials, Equipment and Subcontract Items:

Capital Equipment - FY 1980:

Two phantoms ($10,000) are required to provide adequate calibrations for the Marshall Islands In Vivo Counting program. A computer-based pulse height analyzer ($40,000) is needed to maintain the division counting laboratory at state-of-the-art, and to provide independent analytical facilities for ultra-low-level sample counting.

20. Proposed Obligations for Related Construction Projects:

None.

DEPARTMENT OF ENERGY

ENERGY - OPERATING EXPENSES AND CAPITAL ACQUISITION

SCHEDULE 189

ADDITIONAL EXPLANATION FOR OPERATING OBLIGATIONS

Brookhaven National Laboratory — GK-Multi-Resource

Laboratory — Mission Resource

1. Contractor: Associated Universities, Inc.

Contract No.: EY-76-C-02-0016

Task No.:

2. Project Title: Surveillance of Facilities and Sites
Dose Reassessment for Populations on Rongelap and Utirik
Following Exposure to Fallout

189 No.:

3. Budget Activity No.: GK-01-01-52-3-(b)
(600160)

4. Date Prepared: March 1978

5. Method of Reporting: Annual Report to Division of
Biomedical & Environmental Research
Scientific Meetings and Journals

6. Working Location: Brookhaven National Laboratory

7. Person in Charge: C. B. Meinhold

Principal Investigator:

J. R. Naidu (664-4210)
N. A. Greenhouse (664-4250)

8. Project Term:

From: To:

Project to be initiated and terminated in FY 1979

9. Person-Years:

	FY 1978	Pres.Bud. FY 1979	Rev.Req. FY 1979	FY 1980
Direct Person-Years				
Scientific & Professional	---	---	0.5	---
Others	---	---	---	---
Guests & Research Collaborators	---	---	---	---
Total	---	---	0.5	---

10. Costs (In Thousands of Dollars):

	FY 1978	Pres.Bud. FY 1979	Rev.Req. FY 1979	FY 1980
Research Costs	0	0	25	0
Total Research Obligations	0	0	25	0
Equipment Obligations	0	0	0	0

11. Reactor Concept:

12. Materials:

GK-120

13. Publications:

None

14 Scope:

(a) 200 Word Summary: Incidences of thyroid nodules, benign and malignant, in the exposed populations of Utirik and Rongelap have indicated critical differences in correspondence between nodule incidence and thyroid dose for the two populations. The estimated external dose received from the time fallout began to the time of evacuation shows that the Rongelap population received an external dose (175 rads) which was about thirteen times that for the Utirik population (14 rads), and the thyroid dose was about ten times larger, whereas the incidence of thyroid nodules in the two populations were not signficantly different.

A preliminary study has indicated that the critical area of investigation that could shed light is the period during fallout and evacuation for both the islands. In addition, the fact that the Utirik population returned within 120 days following evacuation, whereas the Rongelap population returned only after three years, requires that we look closely at the Utirik population in terms of a longer exposure period, both internal and external. Further studies would, therefore, have to concentrate on the re-examination of all available data in reports issued by various agencies during that period, consultations with scientific personnel involved at that time, identifying the areas of uncertainty, and using appropriate computer programs to analyze the data. The end result will enable us to look for correlations between the incidence of thyroid nodules and the reassessed dose estimates.

15. Relationship to Other Projects:

(a) This study will help establish dose estimates from the time of the incident to the present, and will complement the aerial survey, for external radiation measurements, over these islands, which is scheduled soon. Together they should present a reliable picture of doses received by the populations and also enable dose estimates to be projected into the future.

(b) This study will be in close conjunction with the BNL Radiological Safety Program in the Marshall Islands and with related programs of the BNL Medical Department. Continued collaboration with the University of Washington, Laboratory of Radiation Ecology, in the area of environmental radioactivity will be maintained.

16. Technical Progress in FY 1978:

Preliminary literature search and consultations with Dr. C. A. Sondhaus, University of California, have been completed. This has resulted in defining areas of uncertainty in information and establishing the procedural steps that should be carried out towards elucidating this problem. Progress is being made

(See Continuation Sheet)

16. Technical Progress in FY 1978: (continued)

in the analysis of historical samples (dated March 1, 1954 from Rongelap and Utirik Islands). However, delay in funding for FY 1978 has caused the project to be set aside until such time that the funding is appropriated. Consequently, it is expected that studies will have to be continued into FY 1979.

17. Expected Results in FY 1979:

The literature search, consultations and the analysis of data will be completed, and will lead to comprehensive discussions and final dose assessments for both the islands. These results will be used to test the hypothesis that radiation effects can be translated into meaningful dose estimates. The prognosis of the FY 1978 study should also permit validation of the models used in arriving at the dose estimates in terms of present day exposures.

18. Expected Results in FY 1980:

Program completed.

19. Description and Explanation of Major Materials, Equipment and Subcontract Items:

None.

20. Proposed Obligations for Related Construction Projects:

None.

DEPARTMENT OF ENERGY

ENERGY - OPERATING EXPENSES AND CAPITAL ACQUISITION

SCHEDULE 189

ADDITIONAL EXPLANATION FOR OPERATING OBLIGATIONS

Brookhaven National Laboratory — GK-Multi-Resource

Laboratory — Mission Resource

1. Contractor: Associated Universities, Inc.
   Contract No.: EY-76-C-02-0016
   Task No.:

2. Project Title: Surveillance of Facilities and Sites--SUMMARY
   189 No.:

3. Budget Activity No.: GK-01-01-52-3

4. Date Prepared: March 1978

5. Method of Reporting: See sub-activities

6. Working Location: Brookhaven National Laboratory

7. Person in Charge: See sub-activities

   Principal Investigator: See sub-activities

8. Project Term: Continuing
   From: To:

9. Person-Years:

	FY 1978	Pres.Bud. FY 1979	Rev.Req. FY 1979	FY 1980
Sci.,Res.Assoc.(Ph.D. or Equiv.)	1.0	1.0	1.5	1.0
Prof. (B.S. or Equiv.)	1.0	2.0	2.0	2.0
Sci. & Prof. - Total	2.0	3.0	3.5	3.0
Others	2.5	2.0	4.0	4.0
Guests & Research Collaborators	---	---	---	---
Total	4.5	5.0	7.5	7.0

10. Costs (In Thousands of Dollars):

	FY 1978	Pres.Bud. FY 1979	Rev.Req. FY 1979	FY 1980
Labor (including benefits)	96	116	164	171
Mats., Trav., Dev. Subcont., Spec'l Proc.	6	32	135	126
Reactor, Accel., and/or Computer Usage	0	0	4	0
Allocated Technical Services	1	5	5	5
Gen. & Adm. Overhead	47	58	117	118
Total Research Cost	150	211	425	420
Total Research Obligations	198	218	394	427
Equipment Obligations	11	20	20	50

11. Reactor Concept:

12. Materials:

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SUMMARY

Sub-activity	Title
GK-01-01-52-3-(a)	Marshall Islands Radiological Safety Program
GK-01-01-52-3-(b)	Dose Reassessment for Populations on Rongelap and Utirik Following Exposure to Fallout

(See Continuation Sheet)

GK-114

DEPARTMENT OF ENERGY

ENERGY - OPERATING EXPENSES AND CAPITAL ACQUISITION

SCHEDULE 189

ADDITIONAL EXPLANATION FOR OPERATING OBLIGATIONS

Brookhaven National Laboratory
Laboratory

GK-Multi-Resource
Program

1. Contractor: Associated Universities, Inc.

Contract No.: EY-76-C-02-0016

Task No.:

2. Project Title:
External Radiation Measurements and "Ground Truth" for Northern Marshall Islands Regional Radiological Survey

189 No.:

3. Budget Activity No.:
GK-01-01-52-3

4. Date Prepared:
May 1978

5. Method of Reporting:
Written Report to D.O.E.S.

6. Working Location:
Brookhaven National Laboratory

7. Person in Charge:
C. B. Meinhold

Principal Investigator:
N. A. Greenhouse (664-4250)

8. Project Term:
From: 8/78
To: 12/31/78

9. Person-Years:

	FY 1978	Pres.Bud. FY 1979	Rev. Req. FY 1979	FY 1980
Sci.,Res.Assoc.(Ph.D. or Equiv.)	---	---	---	---
Prof. (B.S. or Equiv.)	0.5	---	0.5	---
Sci. & Prof. - Total	0.5	---	0.5	---
Others	---	---	---	---
Guests & Research Collaborators	---	---	---	---
Total	0.5	---	0.5	---

10. Costs (In Thousands of Dollars):

	FY 1978	Pres.Bud. FY 1979	Rev. Req. FY 1979	FY 1980
Labor (including benefits)	12	0	17	0
Mats., Trav., Dev. Subcont., Spec'l Proc.	7	0	12	0
Reactor, Accel., and/or Computer Usage	0	0	0	0
Allocated Technical Services	0	0	0	0
Gen. & Adm. Overhead	6	0	11	0
Total Research Cost	25	0	40	0
Total Research Obligations	33	0	45	0
Equipment Obligations	0	0	0	0

11. Reactor Concept:

12. Materials:

Project Title: External Radiation Measurements and "Ground Truth" for Northern Marshall Islands Regional Radiological Survey

13. Publications:

Greenhouse, N.A. and Miltenberger, R.P. Radiological analyses of Marshall Islands environmental samples from 1974 through 1976. BNL Report 50796 in press.

Greenhouse, N.A. and Miltenberger, R.P. External radiation survey and dose predictions for Rongelap, Utirik, Rongerik, Ailuk, and Wotje Atolls. BNL Report 50797 in press.

14. Scope:

(a) 200 Word Summary: A comprehensive external radiation survey program will be conducted on each of the approximately 13 atolls or islands in the Northern Marshall Islands which could have received tropospheric fallout from U.S. nuclear weapons tests in the Pacific. The surveys will provide "ground truth" data on ambient external gamma radiation levels on-island. This data will be used as the basis for calibration and normalization of aerial radiological monitoring by E.G.&G. Corporation. The program will include detailed external radiation measurements with pressurization chamber and scintillation survey instruments, and in situ gamma spectrometry on all islands of interest. Surface soil samples will be collected and analyzed for significant gamma emitters in order to make decay corrections for long-term dose predictions via the external radiation exposure pathway.

BNL field trip staff and analytical lab facilities will be available for other environmental sample collections and analyses as needed by the overall scientific program.

15. Relationship to Other Projects:

This program is directly related to our continuing environmental and personnel monitoring efforts under the BNL Marshall Islands Radiological Safety Program. It will also interact cooperatively with related efforts at the University of Washington (LRE) and Lawrence Livermore Laboratory.

16. Technical Progress in FY 1978:

Personnel and analytical laboratory resources will be mobilized in support of this program. If the regional survey begins on schedule, the first of the three survey legs should be completed by the end of FY 1978.

17. Expected Results in FY 1979:

The remaining two survey legs will be completed, data analyzed, and a

(See Continuation Sheet)

17. Expected Results in FY 1979: (Continued)

report of BNL activities in support of this effort will be written for inclusion in the overall project report.

18. Expected Results in FY 1980:

Project will be completed in FY 1979.

19. Description and Explanation of Major Materials, Equipment and Subcontract Items:

Capital Equipment, FY 1979:

None required.

Capital Equipment, FY 1980:

None required.

20. Proposed Obligations for Related Construction Projects:

None.

DEPARTMENT OF ENERGY

ENERGY - OPERATING EXPENSES AND CAPITAL ACQUISITION
SCHEDULE 189
ADDITIONAL EXPLANATION FOR OPERATING OBLIGATIONS

Brookhaven National Laboratory — GK-Multi Resource
Laboratory — Mission Resource

1. Contractor: Associated Universities, Inc.
Contract No.: EY-76-C-02-0016
Task No.:

2. Project Title: Special In-vivo Counting and Bioassay Program for the Bikini People. Supplement to the BNL Marshall Islands Radiological Safety Program.
189 No.:

3. Budget Activity No.: GK-01-01-52-3

4. Date Prepared: July 1978

5. Method of Reporting: Written report to D.O.E.S.

6. Working Location: Brookhaven National Laboratory and Marshall Islands

7. Person in Charge: C.B. Meinhold

Principal Investigator: N.A. Greenhouse

8. Project Term: Continuing

From: 8/01/78 To: 9/30/78

9. Person-Years:	FY 1978	Pres.Bud. FY 1979	Rev.Bud. FY 1979	FY 1980
Sci.,Res.Assoc.(Ph.D. or Equiv.)	---	---	---	---
Prof. (B.S. or Equiv.)	---	---	---	---
Sci. & Prof. - Total	---	---	---	---
Others	---	---	---	---
Guests & Research Collaborators	---	---	---	---
Total	---	---	---	---

10. Costs (In Thousands of Dollars):	FY 1978	Pres.Bud. FY 1979	Rev.Bud. FY 1979	FY 1980
Labor (including benefits)	0	0	0	0
Mats., Trav., Dev. Subcont., Spec'l Proc.	20	0	0	0
Reactor, Accel., and/or Computer Usage	0	0	0	0
Allocated Technical Services	0	0	0	0
Gen. & Adm. Overhead	0	0	0	0
Total Research Cost	20	0	0	0
Total Research Obligations	20	0	0	0
Equipment Obligations	0	0	0	0

11. Reactor Concept:

12. Materials:

13. Publications:

Greenhouse, N.A. and Miltenberger, R.P. Radiological analyses of Marshall Islands environmental samples from 1974 through 1976. BNL Report 50796.

Greenhouse, N.A. and Miltenberger, R.P. External radiation survey and dose predictions for Rongelap, Utirik, Rongerik, Ailuk, and Wotje Atolls. BNL Report 50797.

14. Scope:

(a) 200 Word Summary: A special field trip will be made in August 1978 to do in-vivo counting and urine bioassay at Kwajalein Atoll on 20 to 30 Bikini residents before their anticipated exodus from Bikini in late August. In addition, a separate field trip party will proceed to Bikini to collect 24 hr urine samples from those Bikini residents who cannot be accomodated on the charter flight which will bring the in-vivo counting subjects to Kwajalein.

The rationale for this effort is as follows:

(1) Accurate internal dosimetry for ^{137}Cs body burdens in the Bikinians requires an assessment of extant body burdens just prior to the departure of the people from Bikini.

(2) There is evidence that both the short-term and long-term compartment ^{137}Cs clearance rates from the Bikinians may differ significantly from those for the ICRP standard man. Determination of these parameters is essential to the accurate assessment of total dose commitments.

(3) During the past several years the Bikinians have become apprehensive about potential health effects which they feel might result from their having lived in the contaminated Bikini environment. The personal attention that they will receive in these personnel monitoring activities should help to alleviate some of their fears.

15. Relationship to other Projects:

This program is directly related to our on-going environmental and personnel monitoring efforts under the BNL Marshall Islands Radiological Safety Program.

16. Technical Progress in 1978:

Assessments of body burdens and clearance parameters and the determination

(See Continuation Sheet)

16. Technical Progress in 1978: (Cont'd)

of dose commitments for individuals living on Bikini Atoll will be completed by the end of the FY 1978.

17. Expected Results in FY 1979:

Project will be completed in FY 1978.

18. Expected Results in FY 1980:

N/A

19. Description and Explanation of Major Materials, Equipment and Subcontract Items:

The funding request includes $8,000 for two round trip charter flights between Bikini and Kwajalein to transport the Bikini people for in-vivo counting.

Capital Equipment, FY 1978:

N/A

20. Proposed Obligations for Related Construction Projects:

None.

DOE Form 5120.2 (12-78)

U.S. DEPARTMENT OF ENERGY

FIELD TASK PROPOSAL/AGREEMENT

1. WP BIN NUMBER	2. TASK NO.	3. REV. NO.	4. PROJECT NO.	5. DATE PREPARED (mm dd yy)	6. CONTRACTOR NUMBER
		0		04/02/79	

7. TASK TITLE	8. WORK PACKAGE TITLE
Marshall Islands Radiological Safety Program	

9. BUDGET AND REPORTING CODE	10. TASK TERM Begin: (mm dd yy)	End: (mm dd yy)	11. CONTRACTOR NAME	12. CODE (see instructions)
GK-01-01-08-4 (600003)	10/01/79	Open	Associated Universities, Inc.	BNL

13. CONTRACTOR TASK MANAGER (Name, FTS No.)	14. PRINCIPAL INVESTIGATORS
C.B. Meinhold 666-4209	N.A. Greenhouse

15. WORK LOCATION (See instructions): Name of facility, City, State, ZIP Code

16. Does this task include any management services efforts?
- [ ] YES
- [x] NO

17. TASK DESCRIPTION (Approach, relation to work package, in 200 words or less)

A comprehensive radiological safety program will be maintained for the inhabitants of atolls in the Northern Marshall Islands contaminated as a result of the U.S. Pacific Testing programs. The following items and services will be provided.

1. Personnel monitoring and environmental sampling to provide data for BNL dose assessments and determination of radiological trends.

2. Individual and population dosimetry based on actual measurements. The resulting data will be used to modify dose commitment predictive models so that they may more accurately reflect future trends.

3. Suggestions based on field experience to mitigate doses via the more critical pathways.

Program activities for the coming fiscal year will emphasize the following:

1. In vivo counting and urine bioassay of former Bikini residents to monitor the decline of environmentally derived body burdens of gamma emitters and ^{90}Sr, and to determine dose commitments to individuals from these radionuclides.

2. In vivo counting and urine bioassay of Rongelap and Utirik residents to determine dose commitments from environmentally-derived radionuclides at these atolls, and to better understand excretion kinetics among the Marshallese. The means and ranges of radionuclide loss rate constants will be determined to improve the accuracy of dose commitment estimates.

18. CONTRACTOR TASK MANAGER

Charles B. Meinhold (Division Head) for N. A. Greenhouse (Signature) — 04/05/79 (Date)

19. DETAIL ATTACHMENTS: (See instructions)

- [x] a. Facility Requirements
- [x] b. Publications
- [x] c. Purpose
- [x] d. Background
- [x] e. Approach
- [x] f. Technical progress
- [x] g. Future accomplishments
- [x] h. Relationships to other projects
- [x] i. Environmental assessment
- [ ] j. Explanation of milestones
- [ ] k. Other (specify)

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(12-78)

TASK REQUIREMENTS FOR OPERATING/EQUIPMENT COSTS AND OBLIGATIONS

CONTRACTOR NAME: Associated Universities, Inc.

BIN NUMBER	TASK NO./REV. NO.	DATE PREPARED	CONTRACTOR NUMBER
	0	04/02/79	

20. STAFFING (in staff years)	FY 1979 BY-2	FY 1980 - BY-1 PRESIDENTS	FY 1980 - BY-1 REVISED	AUTHORIZED	BY FY 1981
a. SCIENTIFIC	2.7	3.0	3.0		3.0
b. OTHER DIRECT	1.7	4.4	4.4		4.4
c. TOTAL DIRECT	4.4	7.4	7.4		7.4
21. OBLIGATIONS AND COSTS (in Thousands)					
a. TOTAL COSTS	211	420	420		465
b. TOTAL OBLIGATIONS	211	[illegible]	[illegible]		[illegible]
22. EQUIPMENT (in Thousands)					
a. EQUIPMENT COSTS	18	38	38		26
b. EQUIPMENT OBLIGATIONS	25	50	50		10
23. OTHER COSTS (specify)					
a.					
b.					
c.					
d.					

24. OPTIONAL FIVE YEAR PLAN (in Thousands, Constant BY dollars)	FY 82-BY+1	FY 83-BY+2	FY 84-BY+3	FY 85-BY+4
a. TOTAL OPERATING COSTS				
b. TOTAL OPERATING OBLIGATIONS				
c. TOTAL EQUIPMENT COSTS				
d. TOTAL EQUIPMENT OBLIGATIONS				

25. MILESTONE SCHEDULE	PROPOSED SCHEDULE	AUTHORIZED SCHEDULE

GK-37

TASK TITLE	BUDGET AND REPORTING CODE		DATE PREPARED
Marshall Islands Radiological Safety Program	GK-01-01-08-4 (600003)		04/02/79
CONTRACTOR NAME	CODE	BIN NUMBER	TASK NO.	REV. NO.
Associated Universities, Inc.	BNL			0

17. Task Description (Cont.)

3. Replicate determinations of ultra-low level Pu and Am urinary excretion rates among Northern Marshalls inhabitants and among Marshallese control groups who reside outside the fallout areas.

4. Establishment of ^{137}Cs and ^{90}Sr excretion rates among Marshallese control groups.

19a. Facility Requirements.

It is anticipated that work for this proposal will use existing Laboratory facilities and site utility services.

19b. Publications.

Fiscal Year 1978

Greenhouse, N. A., Miltenberger, R. P., and Cua, F. T. External Radiation Survey and Dose Predictions for Rongelap, Utirik, Rongerik, Ailuk and Wotje Atolls. BNL 50797, December 1977.

Greenhouse, N. A., Miltenberger, R. P., and Cua, R. T. Radiological Analyses of Marshall Islands Environmental Samples 1974-1976. BNL 50796, December 1977.

Fiscal Year 1979 - 1st Quarter

Miltenberger, R. P., Greenhouse, N. S., and Cua, F. T. Whole Body Counting Results for Inhabitants of the Northern Marshall Islands: 1974-1978. Health Physics Journal (submitted).

Miltenberger, R. P., Greenhouse, N. A., Cua, F. T., and Lessard, E. T. Dietary Radioactivity Intake from Bioassay Data: A Model Applied to ^{137}Cs Intake by Bikini Island Residents. Health Physics Journal (submitted).

Greenhouse, N. A. Follow-up Radiological Surveillance, Marshall Islands. Presented at the 1978 Annual Meeting of the Health Physics Society, Minneapolis, Minnesota, June 1978.

TASK TITLE	BUDGET AND REPORTING CODE	DATE PREPARED	
Marshall Islands Radiological Safety Program	GK-01-01-08-4 (600003)	04/02/79	
CONTRACTOR NAME Associated Universities, Inc.	CODE BNL , BIN NUMBER	TASK NO.	REV. NO. 0

19c. Purpose.

This program is operated to provide continuously updated data on ionizing radiation doses and dose commitments received by the residents of islands in the Northern Marshalls which have been contaiminated by U.S. atmospheric nuclear tests. These data will be used to develop predictive dose modelling, and to provide a basis for remedial actions when necessary.

19d. Background.

This work was begun in 1974 to provide radiation safety related information to the A.E.C. concerning the residents of Bikini, Rongelap, and Utirik Atolls, and the impending return of the Enewetak people.

19e. Approach.

Field trips to the Marshall Islands will be conducted two to three times per year to do *in vivo* counting and urine collections for radioassay and for environmental sampling. Samples and *in vivo* counting data will be analyzed primarily at BNL. Results will be incorporated into a computerized data base for manipulation, modelling studies, and incorporation into reports for publication.

19f. Technical Progress.

Three field trips were conducted during FY1978 for environmental sampling and personnel monitoring.

The Spring 1977 whole body counting trip to Bikini demonstrated dramatic and unexpected increases in ^{137}Cs body burdens among the residents. These findings led to a Department of the Interior decision to move the Bikini people off their home atoll. The decline in ^{137}Cs and ^{90}Sr body burdens among the Bikinians will be monitored during FY1979. A detailed diet and living pattern study of residents of the Northern Marshalls is expected to improve understanding of internal and external radiation exposure pathways. This study and estimates of radionuclide excretion rates derived from follow-up personnel monitoring on the Bikinians are expected to improve predictive modelling and reduce the probability of unexpected occurrences such as that at Bikini last year.

Emphasis on personnel monitoring is expected to continue through FY1980 and FY1981. Development at ultra-low level analytical capabilities for transuranic radionuclides and the establishment of corroborative bioassay programs in cooperation with other laboratories are expected to clarify and quantitate low level plutonium and americium body burdens among the Bikinians and Rongelapese. Similar determinations among a Marshallese control population are expected to demonstrate differences, if any, between the residents of contaminated atolls and regional background.

GK-89

TASK TITLE	BUDGET AND REPORTING CODE			DATE PREPARED
Marshall Islands Radiological Safety Program	GK-01-01-08-4 (600003)			04/02/79
CONTRACTOR NAME	CODE	BIN NUMBER	TASK NO.	REV. NO.
Associated Universities, Inc.	BNL			0

19f. Technical Progress (cont.)

Systematic personnel and environmental monitoring programs are expected to be initiated at Enewetak in FY 1980 and to be well established by FY 1981.

19g. Future Accomplishments.

These studies are expected to provide a better understanding of the radiological impact on man resulting from habitation in an environment contaminated with man-made radioactive materials. They are further expected to provide a basis for corrective actions where needed and to minimize through better understanding the fears of the people living in these areas.

19h. Relationship to Other Projects.

This program will function in cooperation with the BNL Medical Research Program in the Marshall Islands and will occasionally share the same logistical support resources for field trips. It will also function cooperatively with various Pacific research programs at the Lawrence Livermore Laboratory; and especially with programs to develop predictive dose estimates for present and future residents on contaminated islands. The BNL program will provide retrospective dose information to aid in the development of prospective dose models by LLL.

19i. Environmental Assessment.

Work done under this task proposal has either no environmental impact or has impacts similar to those described in and covered by BNL's Environmental Impact Statement (ERDA 1540).

19j. Explanation of Milestones.

None

19k. Other.

None

DOE Form 5120.3
(12-78)

U.S. DEPARTMENT OF ENERGY

FIELD TASK PROPOSAL/AGREEMENT

1. WP BIN NUMBER	2. TASK NO.	3. REV. NO.	4. PROJECT NO.	5. DATE PREPARED (mm dd yy)	6. CONTRACTOR NUMBER
		0		04/02/79	

7. TASK TITLE	8. WORK PACKAGE TITLE
Dose Reassessment for Rongelap and Utirik	

9. BUDGET AND REPORTING CODE	10. TASK TERM Begin: (mm dd yy)	End: (mm dd yy)	11. CONTRACTOR NAME	12. CODE (see instructions)
GK-01-02-01-1-(b) (003010)	10-01-79	Open	Associated Universities, Inc.	BNL

13. CONTRACTOR TASK MANAGER (Name, FTS No.)	14. PRINCIPAL INVESTIGATORS
C. B. Meinhold 666-4209	J. R. Naidu N. A. Greenhouse

15. WORK LOCATION (See instructions): Name of facility, City, State, ZIP Code

16. Does this task include any management services efforts?
☐ YES
☒ NO

17. TASK DESCRIPTION (Approach, relation to work package, in 200 words or less)

An in-depth study of all information pertaining to the BRAVO test fallout on Rongelap and Utirik will be made. In addition, using advanced analytical and computer techniques, a comprehensive fallout model will be developed. Using this model in conjunction with dietary and life style patterns prevalent at time of exposure, a reassessed dose estimate--internal and external--will be made for the populations of Rongelap and Utirik. The dose estimates will be evaluated in terms of the thyroid nodule incidences in these populations to test the hypothesis that radiation effects can be translated into meaningful dose estimates.

18. CONTRACTOR TASK MANAGER

[signature]

J. R. Naidu for J. R. Naidu (Signature) and N. A. Greenhouse — 03/05/79 (Date)

19. DETAIL ATTACHMENTS: (See instructions)

- ☐ a. Facility Requirements
- ☐ b. Publications
- ☐ c. Purpose
- ☐ d. Background
- ☐ e. Approach
- ☐ f. Technical progress
- ☐ g. Future accomplishments
- ☐ h. Relationships to other projects
- ☐ i. Environmental assessment
- ☐ j. Explanation of milestones
- ☐ k. Other (specify):

GK-101

DOE Form 3130-2 (Page 2)
(12-78)

TASK REQUIREMENTS FOR OPERATING/EQUIPMENT COSTS AND OBLIGATIONS

CONTRACTOR NAME: Associated Universities, Inc.

BIN NUMBER	TASK NO.	REV. NO.	DATE PREPARED	CONTRACTOR NUMBER
		0	04/02/79	

20. STAFFING (in staff years)	FY 1979 BY-2	FY 1980 - BY-1 PRESIDENT'S	FY 1980 - BY-1 REVISED	AUTHORIZED	BY-FY 1981
a. SCIENTIFIC	0.3	0.3	0.3		0.3
b. OTHER DIRECT	—	0.3	0.3		0.3
c. TOTAL DIRECT	[illegible]	[illegible]	[illegible]		[illegible]
21. OBLIGATIONS AND COSTS (in Thousands)					
a. TOTAL COSTS	50	50	50		53
b. TOTAL OBLIGATIONS	50	51	51		54
22. EQUIPMENT (in Thousands)					
a. EQUIPMENT COSTS	0	0	0		0
b. EQUIPMENT OBLIGATIONS	0	0	0		0
23. OTHER COSTS (specify)					
a.					
b.					
c.					
d.					

24. OPTIONAL FIVE-YEAR PLAN (in Thousands) Constant BY dollars	FY 82-BY+1	FY 83-BY+2	FY 84-BY+3	FY 85-BY+4
a. TOTAL OPERATING COSTS				
b. TOTAL OPERATING OBLIGATIONS				
c. TOTAL EQUIPMENT COSTS				
d. TOTAL EQUIPMENT OBLIGATIONS				

25. MILESTONE SCHEDULE	PROPOSED SCHEDULE	AUTHORIZED SCHEDULE

GK-102

TASK TITLE	BUDGET AND REPORTING CODE		DATE PREPARED	
Dose Reassessment for Rongelap and Utirik	GK-01-02-01-1-(b) (003010)		04/02/79	
CONTRACTOR NAME	CODE	BIN NUMBER	TASK NO.	REV. NO.
Associated Universities, Inc.	BNL			0

19a. Facility Requirements.

It is anticipated that work for this proposal will use existing Laboratory facilities and site utility services.

19b. Publications.

None

19c. Purpose.

To look for correlations between the incidence of thyroid nodules in the inhabitants of Rongelap and Utirik Islands (Marshall Islands) and the reassessed dose estimates.

This study will fuse together all available information on fallout from the BRAVO test and using advanced analytical techniques (now available) derive realistic dose estimates to the inhabitants of Rongelap and Utirik. The results should provide information towards elucidating the whole question of low-level effects of radiation.

19d. Background.

Incidence of thyroid nodules, benign and malignant, in the exposed populations of Utirik and Rongelap has indicated critical differences in correspondence between nodule incidence and thyroid dose for the populations. The estimated external dose received from the time fallout began to the time of evacuation shows that the Rongelap population received an external dose (175 rads) which was about 13 times that for the Utirik population (14 rads), and the thyroid dose was about 10 times larger, whereas the incidence of thyroid nodules in the two populations were not significantly different.

A preliminary study has indicated that the critical area of investigation that could shed light is the period during the fallout and evacuation for both the islands. In addition, the fact that the Utirik population returned within 120 days following evacuation, whereas the Rongelap population returned only after three years, requires that we look closely at the Utirik population in terms of a longer exposure period, both internal and external. Further studies would, therefore, have to concentrate on the re-examination of all available data in reports issued by various agencies during that period, consultations with scientific personnel involved at that time, identifying the areas of uncertainty, and using appropriate computer programs to analyze the data. The end result will enable us to look for correlations between the incidence of thyroid nodules and the reassessed dose estimates.

TASK TITLE	BUDGET AND REPORTING CODE			DATE PREPARED
Dose Reassessment for Rongelap and Utirik	GK-01-02-01-1-(b) (003010)			04/02/79
CONTRACTOR NAME Associated Universities, Inc.	CODE BNL	BIN NUMBER	TASK NO.	REV. NO. 0

19e. Approach.

Fiscal control will be exercised through the use of monthly comparisons between actual expenses incurred and corresponding line items in the budget.

The study will comprise:

a. Literature search for all available data concerning the BRAVO test, such as, meteorological conditions and radiation measurements. Discussions with scientific and technical personnel involved in the BRAVO test.

b. Use of historic samples and teeth samples to determine ^{129}I, ^{90}Sr, and $^{239,240}Pu$ concentrations to derive concentrations of other radionuclides.

c. Diet and life style studies to provide information for dose assessment.

d. Computer simulation to determine the transport and deposition of radioactive fallout following the BRAVO test.

19f. Technical Progress in BY-3 (FY 1978).

Preliminary literature search and consultations with Dr. C.A. Sondhaus, University of California, has been completed. This has resulted in defining areas of uncertainty in information available and establishing the procedural steps that should be carried out towards elucidating the problem. All available data on external radiation measurements, radionuclide concentrations in soil, water, vegetation, animal and food items have been collated. Historic samples collected from Rongelap and Utirik have been submitted for ^{129}I analysis. Pertinent meteorological information pertaining to the BRAVO test have been researched and the information provided to Lawrence Livermore Laboratory so that they can go ahead with the computer simulation of the transportation and deposition of fallout.

Technical Progress in BY-2 (FY 1979).

The ^{129}I determinations of the soil samples will be completed. These samples will also be analyzed for ^{129}I and ^{99}Tc if required. In addition, we are exploring the possibility of analyzing "Bikini-Ash" - the fallout that settled on the Japanese fishing vessel. This sample should provide the most accurate description of the fallout. The computer simulation of the transportation and deposition of fallout will also be completed. Final analysis of a recent diet and life style study will on completion provide an internal and external exposure estimate. All the data so gathered will be used to generate a model(s) for arriving at the dose estimate in terms of exposure at time of fallout. Discussions with scientists and technical people who were involved

TASK TITLE	BUDGET AND REPORTING CODE		DATE PREPARED
Dose Reassessment for Rongelap and Utirik	GK-01-02-01-1(b) (003010)		04/02/79

CONTRACTOR NAME	CODE	BIN NUMBER	TASK NO.	REV. NO.
Associated Universities, Inc.	BNL			0

19f. Technical Progress in BY-2 (FY 1979) (cont.)

with the BRAVO test will be continued.

Technical Progress in BY-1 (FY 1980).

Dose estimates derived for exposure during fallout, will be extrapolated to present times and the model(s) used will be tested for their validity based on current observed dose determinations.

19g. Future Accomplishments.

The techniques and expertise developed in the course of this study could be used to reassess doses to population in other areas subjected to exposure from fallout or even occupational situations in the past.

19h. Relationship to Other Projects.

a. This study will help establish dose estimates from the time of the incident to the present, and will complement the aerial survey for external radiaton measurements, over these islands, which has been completed. Together they should present a reliable picture of doses received by the populations and also enable dose estimates to be projected into the future.

b. This study will be in close conjunction with the BNL Radiological Safety Program in the Marshall Islands and with related programs of the BNL Medical Department. Continued collaboration with the University of Washington, Laboratory of Radiation Ecology, and the Battelle Pacific Northwest Laboratory will be maintained in the area of sample analysis and data interpretation.

19i. Environmental Assessment.

Work done under this task proposal has either no environmental impact or has impacts similar to those described in and covered by BNL's Environmental Impact Statement (ERDA 1540).

19j. Explanation of Milestones.

None

19k. Other.

None

DOE F 5120.2
(10-79)

U.S. DEPARTMENT OF ENERGY

FIELD TASK PROPOSAL/AGREEMENT

1. WORK PACKAGE NUMBER	2. TASK NO.	3. REV. NO.	4. PROJECT NO.	5. DATE PREPARED (mm dd yy)	6. CONTRACTOR NUMBER
		0		03/31/80	HP 0-10 (600003)

7. TASK TITLE	8. WORK PACKAGE TITLE
Marshall Islands Radiological Safety Program	

9. BUDGET AND REPORTING CODE	10. TASK TERM Begin: (mm dd yy)	End: (mm dd yy)	11. CONTRACTOR NAME	12. CODE (see instructions)
HA-02-01-02-0	Continuing	Open	Associated Universities, Inc.	BNL

13. CONTRACTOR TASK MANAGER (Name: Last, First, MI) (FTS No.)	14. PRINCIPAL INVESTIGATORS (Name: Last, First, MI)
C.B. Meinhold 666-4209	Greenhouse, N.A. 666-4250 or 4207

15. WORK LOCATION (See instructions): Name of facility, City, State, Zip Code	16. Is this task included in the Institutional Plan?	17. Does this task include any management services efforts?
	☒ YES ☐ NO	☐ YES ☒ NO

18. TASK DESCRIPTION (Approach, relation to work package, in 200 words or less)

A comprehensive radiological safety program will be maintained for the inhabitants of atolls in the Northern Marshall Islands contaminated as a result of the U.S. Pacific Testing programs. The following items and services will be provided.

a. Personnel monitoring and environmental sampling to provide data for BNL dose assessments and determination of radiological trends.

b. Individual and population dosimetry based on actual measurements. The resulting data will be used to modify dose commitment predictive models so that they may more accurately reflect future trends.

c. Continuation of diet and living pattern assessments to update relevant parameters in long range predictive dose efforts.

Program activities in the coming fiscal year will emphasize the following:

a. In vivo counting and urine bioassay of Rongelap and Utirik residents to determine dose commitments from environmentally-derived radionucldies at these atolls, and to better understand excretion kinetics among the Marshallese.

b. Followup personnel monitoring at Enewetak to evaluate any change in radionuclide body burden associated with ~1 year of residence on Enewetak Atoll.

c. A final determination of radionuclide body burdens among the former residents of Bikini Atoll.

d. Continuation of analyses of transuranic nuclide excretion rates among Northern Marshall Islands residents, and of transuranics and fission and activation products among Marshallese control groups who reside outside of the fallout area.

19. CONTRACTOR TASK MANAGER

Charles B. Meinhold — N.A. Greenhouse — 03/31/80

(Signature) (Date)

20. DETAIL ATTACHMENTS. (See instructions)

☐ a. Facility Requirements	☒ d. Background	☒ g. Future accomplishments	☐ j. Explanation of milestones
☐ b. Publications	☒ e. Approach	☐ h. Relationships to other projects	☐ k. ZBB Detail
☐ c. Purpose	☒ f. Technical progress	☐ i. Environmental assessment	☐ l. Other (Specify):

TITLE	BUDGET AND REPORTING CODE		DATE PREPARED	
Marshall Islands Radiological Safety Program	HA-02-01-02-0		03/31/80	
CONTRACTOR NAME Associated Universities, Inc.	CODE BNL	WP NUMBER	TASK NO.	REV. NO. 0

20a. Facility Requirements.

It is anticipated that work for this proposal will use existing Laboratory facilities and site utility services.

20b. Publications.

Greenhouse, N.A., Miltenberger, R.P., Lessard, E.T. External Exposure Measurements at Bikini Atoll, BNL 51003, January 1979.

Greenhouse, N.A. Dosimetry Methods and Results for the Former Residents of Bikini Atoll, BNL 26797, November 1979.

Miltenberger, R.P., Greenhouse, N.A., Lessard, E.T. Whole Body Counting Results for Inhabitants of the Northern Marshall Islands: 1974-1978, Health Physics, in press.

Miltenberger, R.P., Lessard, E.T., Greenhouse, N.A. Dietary Radioactivity Intake from Bioassay Data: A Model Applied to ^{137}Cs Intake by Bikini Island Residents, Health Physics, in press.

20c. Purpose.

The primary purpose of this program is to measure and evaluate the internal and external doses to people living on those islands in the Marshalls group which were impacted by tropospheric fallout from United States atmospheric nuclear tests in the Pacific. Its objectives are:

a. Direct or indirect measurement of radionuclide body burdens and resultant doses and dose commitments.

b. Measurement of external radiation environments and their contributions to the total doses to individuals and island populations.

c. Evaluation of dietary habits and living patterns insofar as they relate to the elucidation of exposure pathways and the determination of doses.

20d. Background.

This program was initiated in 1974 at the request of the AEC (DOS) in anticipation of potential radiation exposures to the returning Bikini population.

20e. Approach.

Internal and external doses will be measured and evaluted using accepted and up-to-date health physics practices.

TITLE	BUDGET AND REPORTING CODE	DATE PREPARED
Marshall Islands Radiological Safety Program	HA-02-01-02-0	03/31/80

CONTRACTOR NAME	CODE	WP NUMBER	TASK NO.	REV NO.
Associated Universities, Inc.	BNL			0

20e. Approach cont.

Dietary and living pattern information will be derived from direct observations of island residents, and from standardized interviews with island residents during programmatic field trips.

Management Controls

Fiscal control will be exercised in the form of monthly comparisons, over the task term, of actual costs incurred against corresponding line items of the budget. Technical results shall be monitored through a periodic review, by the Contractor Task Manager, of accomplishments by measuring actual performance as compared to expected progress. All work shall be conducted in conformance with generally accepted standards for R&D and other investigative or analytic procedures, as observed by universities and large independent research facilities including Brookhaven National Laboratory (BNL).

20f. Technical Progress.

Technical Progress in BY-3 (FY 1979).

External and internal dose equivalents received during residency on Bikini Island and internal dose equivalents to be received post residency were evaluated for former Bikini residents. Bioassay results from samples collected in January and May 1979 and prior bioassay results were used to construct individual $^{90}Sr-^{90}Y$ body burden histories. Whole body counting results during 1979 and results obtained in prior years were used to establish ^{137}Cs - ^{137m}Ba individual body burden histories. Daily activity ingestion rates were calculated from the body burden data. Uptake regimes which best fit the activity ingestion rate data were; constant continuous uptake for ^{90}Sr and stepwise increasing uptake for ^{137}Cs. Dosimetric models which described the uptake scenario were derived and individual dosimetric results for persons residing on Bikini Island sometime during the years 1969 and 1978 were determined. In addition, doses due to residual radioactivity in persons after departure from Bikini were calculated. Individual body burdens, urine activity concentrations and dose equivalents have been recorded or stored in a computer data base. Publications and reports describing dosimetric methods and results, whole body counting results and biological removal rate constants for Bikinians have been written.

Routine personnel monitoring was provided for Rongelap and Utirik residents. A statistical analysis was performed to determine the minimum sample size needed to establish the mean ^{137}Cs body burden at the 90% confidence level. Male and female adult, adolescent and child categories were counted at each atoll and many persons who participated in prior whole body counting visits were recounted. In addition, urine bioassay samples were collected from adult and adolescent population groups. Body burden histories and dosimetric results have been completed for half the resident populations for years following rehabitation of the atolls.

20f. Technical Progress cont.

Data collection on types and amounts of food consumed by the Marshallese was done by actually living with them. Simultaneous observations on their living patterns were also made. These studies were part of the Northern Marshallese Islands Radiological Survey (13-Atoll Survey)

Expected Progress in BY-2 (FY 1980).

Baseline radionuclide body burdens will be evaluated for the returning Enewetak population. Evaluation of the post residence decline of body burdens among former Bikini residents will continue. The data base on dietary habits and living patterns will be updated for all relevant atolls and/or islands.

Expected Progress in BY-1 (FY 1981).

Personnel monitoring and related demographic assessment activities will continue at Rongelap, Utirik, Enewetak and other areas of interest to DOE. Monitoring of former Bikini residents will be phased out unless circumstances dictate otherwise.

Expected Progress in BY (FY 1982).

Personnel monitoring and related demographic assessment activities will continue in all areas of interest in the Marshall Islands.

20g. Future Accomplishments.

A running account will be maintained of individual and population dosimetric information for the residents of islands affected by the Pacific Testing Programs. These data will provide an empirical basis for improving the accuracy and value of long-range predictive dose assessments from man-made radionuclides in the environment.

20h. Relationship to Other Projects.

This program operates and interacts directly with the Brookhaven Medical Program in the Marshall Islands, and provides contempory data to be factored into the Retrospective Dose Reassessments for Rongelap and Utirik (and other islands affected by weapons test fallout). It also provides empirical bases for upgrading long range predictive dose modelling activites such as those of the Lawrence Livermore Laboratory. Coordination of this program with related programs within DOE and its contractors will be accomplished through timely exchange of program findings and related information.

20i. Environmental Assessment.

Work done under this task proposal has either no environmental impact or has impacts similar to those described in and covered by BNL's Environmental Impact Statement (ERDA 1540).

DOE F 5120.2
(10-79)

U.S. DEPARTMENT OF ENERGY

FIELD TASK PROPOSAL/AGREEMENT

1. WORK PACKAGE NUMBER	2. TASK NO.	3. REV. NO.	4. PROJECT NO.	5. DATE PREPARED (mm dd yy)	6. CONTRACTOR NUMBER
		0		03/31/80	HP 0510 (003010)

7. TASK TITLE	8. WORK PACKAGE TITLE
Dose Reassessment for Rongelap and Utirik	

9. BUDGET AND REPORTING CODE	10. TASK TERM Begin: (mm dd yy)	End: (mm dd yy)	11. CONTRACTOR NAME	12. CODE (see instructions)
HA-02-01-01-0	Continuing	Open	Associated Universities, Inc.	BNL

13. CONTRACTOR TASK MANAGER (Name: Last, First, MI) (FTS No.)	14. PRINCIPAL INVESTIGATORS (Name: Last, First, MI)
C.B. Meinhold 666-4209	Naidu, J.R. (666-4263) Greenhouse, N.A. (666-4250)

15. WORK LOCATION (See instructions): Name of facility, City, State, Zip Code	16. Is this task included in the Institutional Plan?	17. Does this task include any management services efforts?
	☒ YES ☐ NO	☐ YES ☒ NO

18. TASK DESCRIPTION (Approach, relation to work package, in 200 words or less)

An in-depth study of all information pertaining to BRAVO test fallout on Rongelap and Utirik will be made. In addition, using advanced analytical and computer techniques, a comprehensive fallout model will be developed. Using this model in conjunction with dietary and life style patterns prevalent at time of exposure, a reassessed dose estimate--internal and external--will be made for the populations of Rongelap and Utirik. These dose estimates will be evaluated in terms of the thyroid nodule incidences in these populations, and the results obtained will provide information towards correlating doses and radiation effects.

19. CONTRACTOR TASK MANAGER

Charles B. Meinhold (Signature)

J.R. Naidu

N.A. Greenhouse

03/31/80 (Date)

20. DETAIL ATTACHMENTS (See instructions)

- ☐ a. Facility Requirements
- ☐ b. Publications
- ☐ c. Purpose
- ☐ d. Background
- ☐ e. Approach
- ☐ f. Technical progress
- ☐ g. Future accomplishments
- ☐ h. Relationships to other projects
- ☐ i. Environmental assessment
- ☐ j. Explanation of milestones
- ☐ k. ZBB Detail
- ☐ l. Other (Specify):

TITLE	BUDGET AND REPORTING CODE	DATE PREPARED
Dose Reassessment for Rongelap and Utirik	HA-02-01-01-0	02/31/80

CONTRACTOR NAME	CODE	WP NUMBER	TASK NO.	REV NO
Associated Universities Inc.	BNL			0

20a. Facility Requirements.

It is anticipated that work for this proposal will use existing Laboratory facilities and site utility services.

20b. Publications.

Data generated in this study has been used in other reports.

20c. Purpose.

To look for correlations between the incidence of thyroid nodules in the inhabitants of Rongelap and Utirik Islands (Marshall Islands) and the reassessed dose estimates.

This study will fuse together all available information on fallout from the BRAVO test and using advanced analytical techniques (now available) derive realistic dose estimates to the inhabitants of Rongelap and Utirik. The results should provide information towards assessment of the risk coefficients for radiation-induced thyroid disease.

20d. Background.

Incidence of thyroid nodules, benign and malignant, in the exposed populations of Utirik and Rongelap has indicated critical differences in correspondence between nodule incidence and thyroid dose for the populations. The estimated external dose received from the time fallout began to the time of evacuation shows that the Rongelap population received an external dose (175 rads) which was about 13 times that for the Utirik population (14 rads), and the thyroid dose was about 10 times larger, whereas the incidences of thyroid nodules in the two populations were not significantly different.

A preliminary study has indicated that the critical area of investigation is the period starting from the beginning of fallout to the completion of evacuation for both the islands. In addition, the fact that the Utirik population returned within 120 days following evacuation, whereas the Rongelap population returned only after three years, requires that we look closely at the Utirik population in terms of a longer exposure period, both internal and external. Further studies would, therefore, have to concentrate on the re-examination of all available data in reports issued by various agencies during that period, consultations with scientific personnel involved at that time, identifying the areas of uncertainty, and using appropriate computer programs to analyze the data. The end result will enable us to look for correlations between the incidence of thyroid nodules and the reassessed dose estimates.

TITLE	BUDGET AND REPORTING CODE			DATE PREPARED
Dose Reassessment for Rongelap and Utirik	HA-02-01-01-0			03/31/80
CONTRACTOR NAME Associated Universities, Inc.	CODE BNL	WP NUMBER	TASK NO.	REV. NO. 0

20e. Approach.

The study will comprise:

a. Literature search for all available data concerning the BRAVO test, such as, meteorological conditions and radiation measurements. Discussions with scientific and technical personnel involved in the BRAVO test.

b. Use of historic samples and teeth samples to determine ^{129}I, ^{90}Sr, and $^{239,240}Pu$ concentrations to derive concentrations of other radionucldies. In addition, excised thyroid glands from exposed Marshallese will be analyzed for ^{129}I and ^{99}Tc and data so generated will be used to estimate the concentrations of short lived iodine isotopes.

c. Diet and life style studies to provide information for dose assessment.

d. Computer simulation of the BRAVO test fallout to determine the transport and deposition of radionuclides.

Management Controls

Fiscal control will be exercised in the form of monthly comparisons, over the task term, of actual costs incurred against corresponding line items of the budget. Technical results shall be monitored through a periodic review, by the Contractor Task Manager, of accomplishments by measuring actual performance as compared to expected progress. All work shall be conducted in conformance with generally accepted standards for R&D and other investigative or analytic procedures, as observed by universities and large independent research facilities including Brookhaven National Laboratory (BNL).

20f. Technical Progress.

Technical Progress in BY-3 (FY 1979).

A preliminary literature search and consultations with Dr. C.A. Sondhaus, University of California, have been completed. This has resulted in defining areas of uncertainty in information available and establishing the procedural steps that should be carried out to reassess the dose estimates. All available data on external radiation measurements, radionuclide concentrations in soil, water, vegetation, animal and food items have been collated. Historic samples collected from Rongelap and Utirik have been submitted for ^{129}I analysis. Pertinent meteorological data pertaining to the BRAVO test has been researched and the information supplied to Lawrence Livermore Laboratory so that they can go ahead with the computer simulation of fallout transportation and deposition.

The ^{129}I determinations of the soil samples have been completed for those historic samples that were available. Some of these samples will also be analyzed for ^{99}Tc. In addition, we are exploring the possibility of analyzing "Bikini-

20f. Technical Progress cont.

ash" the fallout material that settled on the Japanese fishing vessel. These samples should provide the most accurate characterization of the fallout. Preliminary computer simulations of fallout transportation and deposition have been completed. Data analysis of the recent diet and life style study has been completed. Discussion with scientists and technical people who were involved with the BRAVO test is being continued. Analysis of the Marshallese teeth samples for Pu isotopes is in progress.

Expected Progress in BY-2 (FY 1980).

A final report on the diet and life style for the Marshallese will be completed. The computer simulation of fallout will also be completed. Thyroid glands from the exposed Marshallese will be analyzed for ^{99}Tc and ^{129}I. Analysis of the "Bikini-ash" will be done as soon as we get an aliquot of the sample. It is also expected that data on the exposed Japanese fishermen will be made available at that time. Preliminary analysis of the data generated so far will be made using existing models. The results will be extrapolated to present times so as to test the validity of the models used.

Expected Progress in BY-1 (1981).

Final dose estimates to the exposed inhabitants of Utirik and Rongelap should be completed. The methodology developed will be extended to Likiap and other islands which were on the "fringe" of the fallout pattern.

20g. Future Accomplishments.

The techniques and expertise developed in the course of this study could be used to reassess doses to population in other areas subjected to exposure from fallout or even those resulting from occupational situations in the past.

20h. Relationship to Other Projects.

a. This study will help establish dose estimates from the time of the incident to the present, and will complement the aerial survey for external radiation measurements, over these islands, which has been completed. Together they should present a reliable picture of doses received by the populations and also enable dose estimates to be projected into the future.

b. This study will be in close conjunction with the BNL Radiological Safety Program in the Marshall Islands (HA-02-01-02-0) and with related programs of the BNL Medical Department (HA-02-01-01-0). Continued collaboration with the University of Washington, Laboratory of Radiation Ecology, and the Battelle Pacific Northwest Laboratory will be maintained in the area of sample analysis and data interpretation.

TITLE	BUDGET AND REPORTING CODE			DATE PREPARED
Dose Reassessment for Rongelap and Utirik	HA-02-01-01-0			03/31/80
CONTRACTOR NAME	CODE	WP NUMBER	TASK NO.	REV NO
Associated Universities, Inc.	BNL			0

20i. Environmental Assessment.

Work done under this task proposal has either no environmental impact or has impacts similar to those described in and covered by BNL's Environmental Impact Statement (ERDA 1540).

20j. Explanation of Milestones.

None

20l. Other.

None

DOE - 5300.2

U.S. DEPARTMENT OF ENERGY
FIELD TASK PROPOSAL AGREEMENT

1. WORK PACKAGE NUMBER	2. TASK NO.	3. REV. NO.	4. PROJECT NO.	5. DATE PREPARED	6. CONTRACTOR NUMBER
		0		03/31/81	(600003)

7. TASK TITLE	8. WORK PACKAGE TITLE
Marshall Islands Radiological Safety Program	

9. BUDGET AND REPORTING CODE	10. TASK TERM Begin	End	11. CONTRACTOR NAME	12. CODE (see instructions)
HA-02-01-02	Continuing	Open	Associated Universities, Inc.	BNL

13. CONTRACTOR TASK MANAGER (Name: Last, First, MI) (FTS No.)	14. PRINCIPAL INVESTIGATORS (Name: Last, First, MI)
Meinhold, Charles B. 666--209	Lessard, Edward T. 666--250

15. WORK LOCATION (See instructions) Name of facility, City, State, Zip Code	16. Is this task included in the Institutional Plan?	17. Does this task include any management services efforts?
	☒ YES ☐ NO	☐ YES ☒ NO

18. TASK DESCRIPTION (Approach, relation to work package, in 200 words or less)

A comprehensive radiological safety program will be maintained for the inhabitants of atolls in the Northern Marshall Islands as a result of the U.S. Pacific Testing programs. The following items and services will be provided:

1. personnel monitoring and environmental sampling to provide data for dose assessments and determination of radiological trends,
2. individual and population dose-equivalent assessment based on measured body burdens, retention functions, and radioactivity uptake patterns. These data will be used to modify predictive dose-equivalent commitment models so they may more adequately reflect future trends, and
3. the collection of physiologic, anthropomorphic, diet and living pattern data to apply accurate parameters to contemporary and predictive dose assessments.

Program activities in the coming fiscal year will emphasize the following:

1. in vivo counting and radiochemical analysis of biological samples for Enewetak Atoll residents,
2. in vivo counting and radiochemical analysis of biological samples for former Bikini Island residents,
3. in vivo counting and radiochemical analysis of biological samples for Marshallese comparison groups who have not subsisted from food grown on Utirik, Rongelap, Bikini or Enewetak Atolls, and
4. sampling and analysis of coconuts and coconut tree food products obtained from Enewetak.

The nuclides of primary dosimetric interest are Cs-137, Sr-90 and Pu 239-240. Personnel monitoring programs will be aimed at measuring these in the Marshallese people.

19. CONTRACTOR TASK MANAGER

[signature] Charles B. Meinhold (Signature) — 03/31/81 (Date)

20. DETAIL ATTACHMENTS (See instructions)

- ☒ a. Facility Requirements
- ☒ b. Publications
- ☒ c. Purpose
- ☒ d. Background
- ☒ e. Approach
- ☒ f. Technical progress
- ☒ g. Future accomplishments
- ☒ h. Relationships to other projects
- ☒ i. Environmental assessment
- ☐ j. Explanation of milestones
- ☐ k. ZBB Detail
- ☒ l. Other (Specify)

Capital Equipment
HA-02-76

TASK REQUIREMENTS FOR OPERATING/EQUIPMENT OBLIGATIONS AND COSTS

CONTRACTOR NAME

Associated Universities, Inc.

WORK PACKAGE NUMBER	TASK NO.	REV. NO.	DATE PREPARED	CONTRACTOR NUMBER
		0	03 31 81	[illegible]

21. STAFFING (in staff years)	PRIOR YEARS	FY 1981 BY-2	FY 1982 – BY-1 PRESIDENT'S	FY 1982 – BY-1 REVISED	AUTHORIZED	BY-FY 1983
a. SCIENTIFIC		3.2	2.8	3.8		3.8
b. OTHER DIRECT		3.1	3.7	3.7		3.7
c. TOTAL DIRECT		6.3	6.5	7.5		7.5
22. OBLIGATIONS AND COSTS (in Thousands)						
a. TOTAL OBLIGATIONS		385	415	623		673
b. TOTAL COSTS		385	415	580		6[illegible]
23. EQUIPMENT (in Thousands)						
a. EQUIPMENT OBLIGATIONS		13	60	60		195
b. EQUIPMENT COSTS		51	54	54		133
24. OTHER COSTS (specify)						
a.						
b.						
c.						
d.						

25. OPTIONAL FIVE YEAR PLAN (in Thousands) Constant BY dollars	BY+1	BY+2	BY+3	BY+4	TOTAL TO COMPLETE
a. TOTAL OPERATING OBLIGATIONS					
b. TOTAL OPERATING COSTS					
c. TOTAL EQUIPMENT OBLIGATIONS					
d. TOTAL EQUIPMENT COSTS					

26. MILESTONE SCHEDULE	PROPOSED SCHEDULE	AUTHORIZED SCHEDULE

TITLE	BUDGET AND REPORTING CODE			DATE PREPARED
Marshall Islands Radiological Safety Program	HA-02-01-02			03/31/81
CONTRACTOR NAME Associated Universities, Inc.	CODE BNL	WP NUMBER	TASK NO	REV NO 0

10. Detail Attachments:

a. Facility Requirements.

It is anticipated that work for this proposal will use existing Laboratory facilities and site utility services.

b. Publications.

Lessard, E.T., Miltenberger, R.P., and Greenhouse, N.A. Dietary radioactivity intake from bioassay data: A model applied to Cs-137 intake by Bikini Island residents. Health Phys. 39, 177-183 (1980).

Miltenberger, R.P., Greenhouse, N.A., and Lessard, E.T. Whole body counting results from 1974 to 1979 for Bikini Island residents. Health Phys. 39, 395-407 (1980).

Miltenberger, R.P., Lessard, E.T., and Greenhouse, N.A. Co-60 and Cs-137 long term biological removal rate constants for the Marshallese population. Health Phys. (in press).

Lessard, E.T., Greenhouse, N.A., and Miltenberger, R.P. A reconstruction of chronic dose equivalents for Rongelap and Utirik residents - 1954 to 1980. BNL-51257, October 1980.

Lessard, E.T. Rate constants for biological elimination of Strontium and Cesium in the Marshallese population. Presented at the 25th Annual Conference on Bioassay, Analytical and Environmental Quality, Las Vegas, Nevada, October, 1979.

Lessard, E.T. Body burden measurements as determined from whole body counting and urine bioassay. Presented at the 25th Annual Conference on Bioassay, Analytical and Environmental Quality, Las Vegas, Nevada, October, 1979.

Lessard, E.T. Dose assessment for Rongelap and Utirik residents 1954 to Present. Presented at the 25th Annual Meeting of the Health Physics Society, Seattle, Washington, July, 1980.

c. Purpose.

The primary purpose of this program is to measure and evaluate the internal and external dose equivalents to persons living on those islands in the Marshalls group which were impacted by tropospheric fallout from United States atmospheric nuclear tests in the Pacific. Its objectives are:

1. direct or indirect measurement of radionuclide body burdens,

2. measurement of the external radiation environment,

TITLE	BUDGET AND REPORTING CODE	DATE PREPARED
Marshall Islands Radiological Safety Program	HA-02-01-02	03/31/81

CONTRACTOR NAME	CODE	WP NUMBER	TASK NO.	REV NO
Associated Universities, Inc.	BNL			0

10. Detail Attachments. cont.

c. Purpose cont.

3. evaluation of diet and living patterns insofar as they relate to the identification of exposure pathways and the determination of dose equivalents,

4. assess prospective dose equivalents for persons returning to atolls contaminated during the weapons testing period, and

5. maintain comparison data and personnel monitoring and dose equivalent data for individuals exposed to fission and activation products and transuranic nuclides in the Marshall Islands.

d. Background.

This program was initiated in 1974 at the request of the Atomic Energy Commission (DOS) in anticipation of potential radiation exposures to the returning Bikini population.

e. Approach.

Internal and external dose equivalents will be evaluated using accepted and up-to-date health physics practices.

Dietary and living pattern information will be derived from direct observation and interview with persons residing on atolls of interest. These interviews will be standardized and conducted during whole-body counting field trips.

Analysis of soil and food chain related plants will continue in order to relate radioactivity in food crops with body burdens. Coconuts, soil, sap from coconut trees and other diet items will be collected from residence or food source islands.

Management Controls.

Fiscal control will be exercised in the form of monthly comparisons, over the task term, of actual costs incurred against corresponding line items of the budget. Technical results shall be monitored through a periodic review, by the Contractor Task Manager, of accomplishments by measuring actual performance as compared to expected progress. All work shall be conducted in conformance with generally accepted standards for R&D and other investigative or analytic procedures, as observed by universities and large independent research facilities including Brookhaven National Laboratory (BNL).

HA-02-79

20. Detail Attachments. cont.

f. Technical Progress.

Technical Progress in FY 1980.

In February 1980, a field trip was undertaken to Japtan and Enewetak Islands, Enewetak Atoll and Ujelang Island, Ujelang Atoll to obtain baseline body-burden data on the Enewetak population prior to the repatriation of Enewetak Atoll in April 1980. Personnel monitoring was accomplished through whole-body counting and collection of one liter urine samples from all persons five years of age and older. At Ujelang, nonparticipants in the whole-body counting program were invited to provide urine samples. Approximately 400 urine samples were collected and are currently being spectrometrically analyzed for gamma emitters and radiochemically analyzed for Sr-90. Additionally, participants provided physical and demographic data.

Whole-body counting was conducted with two independent chair counting systems in which a sodium iodide detector was positioned in front of a shielded person. The solid angle of the detector permitted collection of photons emitted from the trunk of an adult body. This geometry allowed safe entry and egress with comparable sensitivity relative to the bed geometry used in prior field trips.

Approximately 400 spectra were obtained from individuals on Japtan, Enewetak and Ujelang Islands. These spectra were analyzed for Cs-137 and K-40 using calibration standards which best matched the sex, height and weight of the person. Additional analyses were performed to determine the frequency distribution statistics for various age and sex subgroupings of the body burdens. Quality assurance was obtained through duplicate whole-body counts and repetitive point source standard counts to determine the precision and accuracy of the system.

During the July and August 1980 field trip, whole-body counts and urine samples were collected at Majuro Atoll and Kili Island from former Bikini Atoll residents and from a comparison population. Approximately 200 spectra were obtained and 100 urine samples collected. Fifty percent of the spectra were from persons who were residents and whole-body counted on Bikini Atoll in April 1980, 10 percent were from former Bikini Atoll residents not counted before and the remaining spectra were from a comparison group who had never resided on Bikini Atoll.

A quality assurance program similar to that employed at Enewetak was used. Review of the historic Bikini whole-body counting data indicated no effects on body-burden assessment due to reconfiguration of the shielding and detector. Consecutive measurements of a former Bikini resident's body burden allowed computation of individual long-term biological removal rate constants. This data along with the methodology were written up and issued in a primary scientific publication.

At Kili Island there were former Bikini residents whose Cs-137 body burden remained unchanged or increased. Reasons for this nuclide being present in their current diet were investigated. This work showed that these burdens were within three standard deviations of the mean burden of the comparison population except in

20. Detail Attachments. cont.

f. Technical Progress cont.

Technical Progress in FY 1980 cont.

a few cases. Burdens elevated above this level could be attributed to recent ingestion of Bikini Atoll food which had been transported to Kili Island.

Human milk samples had been obtained from four lactating adult former Bikini females whose Cs-137 body burden had been defined by whole-body counting and radiochemical analysis of urine. Milk samples along with Bikini Island coconut tree sap and nuts were analyzed by gamma spectroscopy and atomic absorption to determine the presence of Cs-137 and K-40. Results were used to estimate the Cs-137 body burden for Marshallese infants whose primary food supply was human milk and coconut tree products.

Activity ingestion rates and future body burdens for Cs-137 were estimated for the population who may return to Enue Island, Bikini Atoll. This projection involved a determination of activity transfer factors calculated from Rongelap and Bikini whole-body counting data and from activity concentration analyses of coconut tree products. These factors were comparable for both atolls and dose-equivalent commitments were projected for adults.

Retrospective and contemporary external exposure rate data, whole-body counting data, and radiochemical analysis of urine and blood data were reviewed for the interval June 1954 to December 1980 for the Rongelapese and Utirikese. Dosimetric models which best described the uptake regime were constructed for the nuclides of interest. Daily activity ingestion rates, whole-body dose-equivalent rates and dose equivalent commitments to various organs were determined. Population dosimetry results and methods were written up and reported in a BNL publication. Individual dosimetric data records are maintained at the Laboratory.

Expected Progress in FY 1981.

Personnel monitoring and related demographic data will be obtained from residents of Rongelap, Utirik and Enewetak and other areas of interest to DOE. The data base on diet and living patterns will be updated for all relevant atolls and/or islands.

Expected Progress in FY 1982.

Evaluation of the decline of body burdens among former Bikini Island residents will continue for that portion of the population in residence on Majuro Atoll or Kili Island. Personnel monitoring will continue at Enewetak Atoll.

TITLE	BUDGET AND REPORTING CODE		DATE PREPARED	
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10. Detail Attachments. cont.

f. Technical Progress cont.

Expected Progress in FY 1983.

Radionuclide body burdens will be evaluated for the population in residence at Enue Island, Bikini Atoll. Personnel monitoring and related demographic assessment activities will continue in all areas of interest in the Marshall Islands.

g. Future Accomplishments.

A dosimetric history will be maintained for individual residents of the Marshall Islands affected by the Pacific Testing Programs. These data will provide information regarding the uptake, retention, and excretion of radioactive material and will improve the accuracy and value of long-range predictive dose assessments from man-made radionuclides in the environment.

h. Relationship to Other Projects.

This program operates and interacts directly with the Brookhaven Medical Program in the Marshall Islands, and provides contemporary data to be factored into the Retrospective Dose Reassessments for Rongelap and Utirik (and other islands affected by weapons test fallout). It also provides empirical bases for upgrading long range predictive dose modeling activites such as those of the Lawrence Livermore Laboratory. Coordination of this program with related programs within DOE and its contractors will be accomplished through timely exchange of program findings and related information.

i. Environmental Assessment.

Work done under this task proposal has either no environmental impact or has impacts similar to those described in and covered by BNL's Environmental Impact Statement (ERDA 1540).

l. Other.

Capital Equipment in FY 1983.

An intrinsic Ge(Li) whole body counting system is needed to provide more efficient and effective operation in the Marshall Islands Radiological Safety Program for counting low energy photons emitted from transuranic nuclides. This system ($150,000) and associated shielding and bed equipment ($25,000) will be used to measure body burdens of transuranic nuclides in persons at Enewetak Atoll at levels below the maximum allowable for members of the general public. Prospective dose equivalents for blood forming organs will be assessed based on these measurements.

HA-02-F2

TITLE	BUDGET AND REPORTING CODE	DATE PREPARED
Marshall Islands Radiological Safety Program	HA-02-01-02	03/31/81

CONTRACTOR NAME	CODE	WP NUMBER	TASK NO.	REV. NO.
Associated Universities, Inc.	BNL			0

20. Detail Attachments. cont.

1. Other cont.

Capital Equipment in FY 1983. cont.

A word processor ($20,000) for the Marshall Islands Radiological Safety Program to provide more efficient and effective operation will be needed to prepare primary scientific publications and to prepare, modify and store individual dosimetry, body burden, bioassay and demographic records on the inhabitants of the Marshall Islands included in our study. The processor will be used also in the preparation of trip reports, schedules and other administrative writing.

HA-02-83

DOE F 5120.2
(4-80)

U.S. DEPARTMENT OF ENERGY
FIELD TASK PROPOSAL/AGREEMENT

1. WORK PACKAGE NUMBER	2. TASK NO.	3. REV. NO.	4. PROJECT NO.	5. DATE PREPARED	6. CONTRACTOR NUMBER
		0		03 31 81	70030105

7. TASK TITLE	8. WORK PACKAGE TITLE
Dose Reassessment for Rongelap and Utirik	

9. BUDGET AND REPORTING CODE	10. TASK TERM Begin:	End:	11. CONTRACTOR NAME	12. CODE (see instructions)
HA-02-01-01	continuing	Open	Associated Universities, Inc.	BNL

13. CONTRACTOR TASK MANAGER (Name, Last, First, MI) FTS No.	14. PRINCIPAL INVESTIGATORS (Name, Last, First, MI)
Meinhold, Charles B. 666-4209	Naidu, Janakiram R. - 666-4263 Lessard, Edward T. - 666-4250

15. WORK LOCATION (See instructions) (Name of facility, City, State, Zip Code)	16. Is this task included in the Institutional Plan?	17. Does this task include any management services efforts?
	☒ YES ☐ NO	☐ YES ☒ NO

18. TASK DESCRIPTION (Approach, relation to work package, in 200 words or less)

An in-depth study of information pertaining to BRAVO test fallout on Rongelap and Utirik will be made. In addition, a comprehensive fallout model will be developed using advanced analytical and computer techniques. Using this model in conjunction with dietary and living patterns prevalent during and following the exposure of March 1954, internal and external thyroid absorbed dose estimates will be made for various age and sex groupings of the populations. Two other independent approaches involving calculation of thyroid absorbed dose based on the historical soil sample analysis and based on the radioiodine analysis of the single composited urine sample reported for the Rongelap population are to be undertaken. These results coupled with the Northern Marshall Islands Radiological Survey (NMIRS) and contemporary personnel monitoring activities will provide a technically sound basis for retrospective thyroid absorbed dose estimates for the atoll populations in the Northern Marshall Islands. These estimates will be evaluated in terms of thyroid nodule incidences in these populations, and the results obtained will provide information towards correlating absorbed dose and biological effects.

19. CONTRACTOR TASK MANAGER

[signature] Charles B. Meinhold (Signature) — 03 31 81 (Date)

20. DETAIL ATTACHMENTS (See instructions)

☐ a. Facility Requirements ☐ d. Background ☐ g. Future accomplishments ☐ j. Explanation of milestones
☐ b. Publications ☐ e. Approach ☐ h. Relationships to other projects ☐ k. 238 Detail
☐ c. Purpose ☐ f. Technical progress ☐ i. Environmental assessment ☐ l. Other (Specify):

HA-02-3

TASK REQUIREMENTS FOR OPERATING, EQUIPMENT
OBLIGATIONS AND COSTS

CONTRACTOR NAME

Associated Universities, Inc.

WORK PACKAGE NUMBER	TASK NO.	REV. NO.	DATE PREPARED	CONTRACTOR NUMBER
	0		03 31 81	[illegible]

21. STAFFING (in staff years)	PRIOR YEARS	FY 1981 BY-2	FY 1982 – BY-1 PRESIDENT'S	FY 1982 – BY-1 REVISED	AUTHORIZED	BY-FY 1983
a. SCIENTIFIC		0.2	1.2	1.2		1.2
b. OTHER DIRECT		---	---	---		---
c. TOTAL DIRECT		0.2	1.2	1.2		1.2
22. OBLIGATIONS AND COSTS (in Thousands)						
a. TOTAL OBLIGATIONS		53	90	97		156
b. TOTAL COSTS		53	90	90		140
23. EQUIPMENT (in Thousands)						
a. EQUIPMENT OBLIGATIONS		0	0	0		0
b. EQUIPMENT COSTS		0	0	0		0
24. OTHER COSTS (specify)						
a.						
b.						
c.						
d.						

25. OPTIONAL FIVE YEAR PLAN (in Thousands) Constant BY dollars	BY+1	BY+2	BY+3	BY+4	TOTAL TO COMPLETE
a. TOTAL OPERATING OBLIGATIONS					
b. TOTAL OPERATING COSTS					
c. TOTAL EQUIPMENT OBLIGATIONS					
d. TOTAL EQUIPMENT COSTS					

26. MILESTONE SCHEDULE	PROPOSED SCHEDULE	AUTHORIZED SCHEDULE

HA-02-7

TITLE	BUDGET AND REPORTING CODE			DATE PREPARED
Dose Reassessment for Rongelap and Utirik	HA-02-01-01			03/31/81
CONTRACTOR NAME	CODE	WP NUMBER	TASK NO	REV NO
Associated Universities, Inc.	BNL			0

10. Detail Attachments:

a. Facility Requirements.

It is anticipated that work for this proposal will use existing Laboratory facilities and site utility services.

b. Publications.

Naidu, J.R., Greenhouse, N.A., and Knight, J. Marshall Islands: A Study of Diet and Living Patterns. BNL 51313, July, 1980.

Lessard, E.T., Greenhouse, N.A., and Miltenberger, R.P. A Reconstruction of Chronic Dose Equivalents for Rongelap and Utirik Residents - 1954 to 1980, BNL 51257, October, 1980.

c. Purpose.

The purpose of this research is to refine the estimated thyroid absorbed doses received by members of the Rongelap and Utirik Atoll populations in the Marshall Islands. These doses will be compared to the thyroid nodule incidence to provide information towards assessment of the risk coefficients for radiation induced thyroid disease.

d. Background.

Incidence of thyroid nodules, benign and malignant, in the exposed populations of Utirik and Rongelap has indicated critical differences in correspondence between nodule incidence and thyroid absorbed dose for these populations relative to that reported by the Japanese Tumor Registry Life Span Study or the other populations under study as reported in BIER III. The estimated external dose received from the time fallout began to the time of evacuation shows that the adult Rongelap population received an external absorbed dose (175 rads) which was about 13 times that for the Utirik population (14 rads). The thyroid absorbed doses were estimated originally to be several times these external doses.

A preliminary study has indicated that the important dosimetric area of investigation is the period starting from the beginning of fallout to the completion of evacuation for both the islands. In addition, the fact that the Utirik population returned within 120 days following evacuation, whereas the Rongelap population returned after three years, requires that the Utirik population be examined dosimetrically in terms of a longer exposure period, both internal and external. Further studies would, therefore, have to concentrate on the reexamination of all available data in reports issued by various agencies during that period, consultations with scientific personnel involved at that time, identifying the areas of uncertainty, and using appropriate computer programs to analyze the data. The end result will enable comparisons between the incidence of thyroid nodules and the reassessed dose estimates.

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Dose Reassessment for Rongelap and Utirik	HA-02-01-01	03/31/81

CONTRACTOR NAME	CODE	WP NUMBER	TASK NO.	REV NO
Associated Universities, Inc.	BNL			0

20. Detail Attachments. cont.

e. Approach.

The study will comprise:

1. literature search for all available data concerning the BRAVO test, such as, meteorological conditions and radiation measurements, and discussions with exposed Marshallese and with scientific and technical personnel involved in the BRAVO test,

2. use of historic soil samples, food samples and teeth samples to determine I-129, Sr-90, and Pu-239, 240 concentrations to derive concentrations of other radionuclides. In addition, excised thyroid glands from exposed Marshallese will be analyzed for I-129 and Tc-99,

3. diet and life style studies to provide information for dose assessment,

4. computer simulation of the BRAVO test fallout to determine the transport and deposition of radionuclides,

5. use of historic BRAVO fallout radioactivity samples to determine the abundance of I-129 atoms per unit BRAVO activity.

Management Controls.

Fiscal control will be exercised in the form of monthly comparisons, over the task term, of actual costs incurred against corresponding line items of the budget. Technical results shall be monitored through a periodic review, by the Contractor Task Manager, of accomplishments by measuring actual performance as compared to expected progress. All work shall be conducted in conformance with generally accepted standards for R&D and other investigative or analytic procedures, as observed by universities and large independent research facilities including Brookhaven National Laboratory (BNL).

f. Technical Progress.

Technical Progress in FY 1980.

A report on the diet and living pattern of the Rongelapese and Utirikese has been completed. The computer simulation of fallout is being reformulated with additional data that has been acquired. Thyroid glands from the exposed Marshallese have been analyzed for Tc-99 and I-129. Approximately 50 historic soil samples have been analyzed for ^{129}I and other dosimetrically important nuclides. Preliminary dose assessment for the March 1954 exposed population has been performed by two independent methods (soil analysis and radiochemical analysis of urine) for residents of Rongelap Island, Rongelap Atoll. Additionally, a report has been completed on the dose equivalent following rehabitation of Rongelap and Utirik Atolls after the March 1954 evacuation. This work involved determination of post return thyroid and other organ dose equivalents for individuals and population groups based on historic and contemporary whole body counting and urine bioassay results.

TITLE	BUDGET AND REPORTING CODE			DATE PREPARED
Dose Reassessment for Rongelap and Utirik	HA-02-01-01			03/31/81
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20. Detail Attachments. cont.

f. Technical Progress cont.

Expected Progress in FY 1981.

Additional samples of soil, food and ash will be analyzed for I-129. Sr-90 and Pu-239, 240 analysis of teeth samples, especially that from exposed individuals, will be done. Data derived from the "Bikini Ash" studies will be factored into the refinement of the dose estimate. Diet and living pattern studies will be updated.

Expected Progress in FY 1982.

Factors such as solubility of iodine isotopes in fallout, the possible contribution from neutron induced activity, the impact of thyroid seekers other than iodine isotopes on dose, and confidence levels for values of derived quantities such as airborne activity concentrations during fallout will be investigated. Diet and living pattern studies will be updated.

Expected Progress in FY 1983.

Diet and living pattern studies and dose reassessment will continue until completed for all areas of interest in the Marshalls.

g. Future Accomplishments.

The techniques and expertise developed in the course of this study could be used to reassess doses to populations in other areas subjected to exposure from fallout or even those resulting from occupational situations in the past. Additionally, this study will provide a better estimate of the true value for thyroid nodule incidence per unit rad enabling technically sound risk factors to be associated with ionizing radiation exposure.

h. Relationship to Other Projects.

1. This study will help establish external and internal dose estimates from the time of the incident to the present, and will complement the aerial survey for external radiation measurements, over these islands, which has been completed. Together they should present a reliable picture of doses received by the populations and also enable dose estimates to be projected into the future.

2. This study will be in close conjunction with the BNL Marshall Islands Radiological Safety Program (HA-02-01-02). Continued collaboration with the University of Washington, Laboratory of Radiation Ecology, and the Battelle Pacific Northwest Laboratory will be maintained in the area of sample analysis and data interpretation.

TITLE	BUDGET AND REPORTING CODE			DATE PREPARED
Dose Reassessment for Rongelap and Utirik	HA-02-01-01			03/31/81
CONTRACTOR NAME Associated Universities, Inc.	CODE BNL	WP NUMBER	TASK NO.	REV. NO. 0

20. Detail Attachments. cont.

i. Environmental Assessment.

Work done under this task proposal has either no environmental impact or has impacts similar to those described in and covered by BNL's Environmental Impact Statement (ERDA 1540).

History

Marshall Islands Radiological Safety Program
and Rongelap/Utirik Dose Reassessment Project
- A Historical Synopsis

Preface

From the mid 1940's to 1958, the United States conducted its' high-yield nuclear weapons tests at Bikini and Enewetak Atolls in the tropical Pacific. These remote groups of small islands lie about 2,500 miles southwest of Hawaii, and are part of the Marshall Islands District of Micronesia. At that time, most of Micronesia was the political ward of the United States which acted as trustee under a United Nations mandate establishing the Trust Territory of the Pacific Islands (Micronesia) after World War II. Currently, this region, known as the Marshall Islands, intends to enter into a Compact of Free Association with the United States.

The largest of the nuclear tests was the "BRAVO" event which took place at Bikini Atoll on March 1, 1954. Radioactive fallout from this detonation was carried eastward by prevailing winds, and resulted in radiation exposures to Marshallese people living at Rongelap and Utirik Atolls a few hundred miles away. The exposed population of these atolls plus a comparison population are frequently examined by Brookhaven National Laboratory Medical personnel to detect and care for long-term health effects due to their exposure to radiation from the weapons testing program.

In addition to the high-level radiation exposures to the Rongelap and Utirik people, the nuclear tests also left a legacy of environmental radioactivity which, because of its lower level, is not expected to cause adverse health effects. However, residual radioactivity in the environment will contribute radiation exposures above natural background levels to people living in these areas.

In 1968, President Johnson authorized the return of Bikini Atoll to its original inhabitants, most of whom were living on Kili Island about 500 miles to the south of Bikini Atoll. A similar authorization was given for the Enewetak people who had been moved to Ujelang prior to th testing at their home atoll. Because of the residual radioactivity at Bikini and Enewetak, environmental monitoring programs were established to assure the people that the low-level radiation exposures (which residents would receive from living in these places) remain within acceptable limits. The dose-equivalent limits are those recommended by the International Commission on Radiological Protection (ICRP) for people not occupationally exposed to radiation.

The U.S. Department of Energy had assumed the old Atomic Energy Commission's commitment to provide continuing followup for the medical and environmental problems caused by the Pacific testing programs. Beginning in March 1954 to the present, the Brookhaven medical team has provided medical care and radiation protection guidance to the exposed population. They studied internal radioactivity levels through radiochemical analysis of urine and blood and through whole-body counting. Since the logistical support for Brookhaven medical team visits to Rongelap and Utirik had been established, it seemed reasonable to have the environmental and radiological safety assessments done by the Safety and Environmental Protection Division of Brookhaven National Laboratory as well.

The Safety and Environmental Protection Division undertook environmental measurements for radioactivity as early as 1974. In 1978, whole-body counting and radiochemical analysis of biological samples were transferred from the Medical Department to this division. At present, the program involves up to 3 field trips a year to the Northern Marshalls. Measurements are made of external and in vivo radiation levels. Samples are collected for laboratory analysis at Brookhaven National Laboratory to assess the radioactive content in soil, food products and humans. A major component of the field work involves having representative individuals monitored for radioactivity content in their bodies. The following is a brief description of the Safety and Environmental Protection Division's programs in the Marshall Islands starting from 1974 and covering current activities.

FY 1974

Negotiations between the Division of Operational Safety of the old Atomic Energy Commission (AECDOS) and the old Health Physics and Safety Division of Brookhaven National Laboratory (BNLHPS) resulted in a proposal submission to begin the Marshall Islands Radiological Safety Program (MIRSP). Lawrence Livermore Laboratory (LLL) had and still has a parallel program, Marshall Islands Radioecology, which concentrates on Enewetak and Bikini Atolls.

An orientation field trip was arranged for Greenhouse and Ash of BNLHPS. They accompanied the BNL Medical Department's spring medical survey to Utirik, Rongelap and Bikini, in April 1974. Nelson, of the University of Washington's Laboratory of Radiation Ecology (UWLRE) also participated in this field trip. Plans were made to collaborate with UWLRE in the future. This field trip included physical examinations, in-vivo whole-body counting and urine bioassay sampling of all three atoll populations by the BNL medical team. External radiation measurements and sampling of groundwater, soil, plants, fish and coconut crabs were performed by Greenhouse and Nelson.

FY 1975

The Marshall Islands Radiological Safety Program was formally initiated. Funding levels were $125,000 for operating and $20,000 for capital equipment. Staffing levels were 1.5 man years scientific and professional and 1.0 man year technical support. Greenhouse directed the program. Arrangements were made to upgrade the BNLHPS analytical lab with the additions of a computer based multi-channel analyzer and a high efficiency GeLi detector.

Greenhouse and Nelson, in a joint UWLRE/BNLHPS field trip to the Northern Marshalls in December 1974, collected environmental samples and made external radiation measurements at Rongelap, Utirik, Rongerik and Bikini Atolls. Greenhouse, Williams, and Kuehner of BNLHPS, Reilly of the State of Pennsylvania, Davis of Pacific Gas and Electric, and Nelson of UWLRE participated in an April 1975 field trip to Bikini Atoll. They collected samples and defined the external radiation environments of Bikini and Enue Islands. Limited soil and vegetation sampling were done at Bikini and comparison environmental samples were collected at Wotho and Kwajalein Atolls. This field trip established the groundwork for a major interagency survey of Bikini and Enue Islands in June in which Greenhouse participated. This survey included soil, groundwater and some vegetation sampling. It was performed jointly by LLL, UWLRE, the Environmental Protection Agency, and BNLHPS. Their primary objective was selection of locations for the second increment of house construction on Bikini and Enue Islands by the Department of the Interior.

FY 1976

Funding levels were $172,000 operating and $20,000 capital equipment. Staffing levels were 2.0 man years scientific and professional and 1.0 man years technical support. Major equipment purchases included a Lawrence Livermore Laboratory Portable Gamma Spectrometer and two Reuter Stokes Environmental Radiation Monitors. Naidu (BNLHPS) joined Greenhouse to form the program's principle staff.

Nelson and Greenhouse collaborated on a field trip to Majuro, Ponape, Truk, Guam, and Palau, as part of the UWLRE Pacific Basin Study. Greenhouse, Naidu, and Kuehner of BNLHPS, Haughey of Rutgers University, Terpilak of the Department of Health, Education and Welfare, Bureau of Radiological Health and Kastens of University of New York at Stony Brook, Marine Science Center participated in a March-April field trip to Bikini Atoll. Their primary objectives were beta and gamma dose rate measurements on Bikini Island and a general radiological survey of Nam Island in the northwestern sector of the atoll. This survey included limited soil and vegetation sampling. A joint BNLHPS and UWLRE survey with the BNL Medical Department was undertaken in September. The BNLHPS objective was to perform an environmental radiation survey at Wotje, Ailuk, Utirik, Rongelap and Bikini Atolls. Special efforts focussed on several northern islands at Rongelap.

PUBLICATION: Marshall Islands Radiological Followup, N. A. Greenhouse and T. F. McCraw, BNL #20767.

PRESENTATIONS: Marshall Islands Radiological Followup, N. A. Greenhouse, Presented at the Ninth Midyear Topical Symposium, Operational Health Physics, Denver, Colorado, February 1976.

FY 1977

Funding levels were $207,000 for operating and $80,000 for capital equipment. Staffing levels were 2.0 man years scientific and professional and 1.25 man years technical. An additional 0.25 man years for technical support was obtained from the new Safety and Environmental Protection Division (BNLSEP formerly BNLHPS). Miltenberger (BNLSEP) replaced Naidu and joined Greenhouse as principle staff. A request from the Energy Research and Development Administration, Division of Safety, Standards and Compliance (ERDADSSC formerly AECDOS) to add air sampling equipment to the radiological surveillance program at Bikini was received. ERDADSSC also requested in vivo counting of the Bikini and Enewetak people. Major equipment purchases included four wind-powered electrical generators, three multichannel analyzers and two sodium iodide (NaI) detectors.

During a September 1976 BNL medical survey to Rongelap, Knudsen, a Medical Department physician, was requested by the residents of Rongelap to have Naidu of BNLSEP stay on Rongelap Island and instruct the people in radiation sciences. Naidu was funded by the Energy Research and Development Administration's Division of Biomedicine and Environmental Research (ERDADBER) and spent six weeks during January and February 1977 educating the Rongelap people on matters pertaining to the effects of radiation on man.

During April and May of 1977, BNLSEP's Greenhouse, Miltenberger and Levine went to Utirik, Rongelap and Bikini to do site planning for wind-powered electrical generators and air sampling stations. Together with a conventionally powered comparison air sampling station, which they installed at Kwajalein Island, Kwajalein Atoll, these stations initiated the long-term sampling program for air activity concentrations of plutonium. Fossil-fueled generators were judged incapable of supplying continuous year round power on outer atolls. Wind-powered generators were thought to be capable of supplying power for a 12 month period without needing repairs. In addition, wind-powered electrical generators were virtually noiseless compared to gasoline powered electrical generators. They offered the possibility of collecting a large volume air sample without disruption of quiescent village living patterns on outer atolls. A plutonium excretion study was also undertaken by collecting pooled large-volume urine samples from three to five families at each atoll except Kwajalein.

Early in 1977, the question of the past dose equivalent to the Marshallese who have lived on Rongelap and Utirik, had become an important scientific and health related question with considerable political overtones. Bond, Borg, Conard, Cronkite, Greenhouse, Naidu and Meinhold, all members of BNL, and Sondhaus of the University of California, College of Medicine (UCCM) initiated technical evaluation of the issue.

FY 1978

MIRSP funding levels were $207,000 for operating and $10,000 for capital equipment. Staffing levels were 2.0 man years scientific and professional and 2.5 man years technical support. Greenhouse and Miltenberger made up the program's principle staff, Cua and Knight joined the program staff part time. Major equipment purchases consisted of peripheral alpha spectroscopy equipment for plutonium analyses of environmental and biological samples. As a result of earlier discussions by Bond, Meinhold, Naidu and others of BNL, a proposal for Rongelap and Utirik Dose Reassessment (RUDR) had been forwarded to the Department of Energy's Division of Biological and Environmental Research (DOEDBER formerly ERDADBER) and the program was funded with an operational budget of $50,000. Staffing levels were 0.5 man years scientific and professional, Naidu and Greenhouse were the RUDR program's primary staff.

In October 1977, three wind-powered electrical generators and long term air sampling stations were installed at Utirik, Rongelap and Bikini Islands by members of BNLSEP and the owner/operator of Enertech Corporation, the seller of the wind-powered systems. A second comparison station was installed at Roi-Namur Island, Kwajalein Atoll. In addition, large volume urine samples were collected under controlled conditions from five to seven Marshallese males at Utirik, Rongelap and Bikini. All of this work was performed by Greenhouse, Levine, Dillingham, DeAngelis and Cua of BNLSEP and by Sherwin of Enertech Corporation. Also in October 1977 Miltenberger of BNLSEP and Cohn, Rothman and Clareus of BNL medical attempted to whole-body count the Marshallese population residing at Japtan Island, Enewetak Atoll. Due to an uncertain political and social atmosphere, it was decided by the new Department of Energy's Division of Safety, Standards and Compliance (DOEDSSC formerly ERDADSSC) that BNL refrain from involvement with the Marshallese on Japtan Island. At that time, the focus of the field work was switched to counting 35 Holmes and Narver employees who were residents of Enewetak Island.

In January 1978 Balsamo and Sherwin returned to Bikini, Rongelap and Utirik to complete wind-powered electrical generator installation and repair. In April 1978 Miltenberger, Lessard and Naidu of BNLSEP participated in a joint field trip with BNL Medical on Rongelap, Utirik and Bikini Atolls. At Utirik, the BNLSEP team collected urine, soil, vegetation and fish samples for radiochemical analysis. They also collected 5 day high-volume air samples and Anderson cascade impactor air samples. The wind-powered electrical generator at Utirik was not working and could not be repaired. Naidu remained behind on Utirik for several weeks to teach the biological effects of radiation, a program similar to the one given on Rongelap in 1977. Lessard and Miltenberger proceeded to Rongelap to collect additional urine and environmental samples and conducted an external exposure study at the northern islands of Rongelap Atoll. The wind-powered electric generator had malfunctioned here too. An attempt to repair the wind-powered generator also was made, however, no long term successful operation of the system could be achieved. Greenhouse and Kuehner of BNLSEP joined the field team at Bikini. Of the 143 persons residing on Bikini, 99 were whole-body counted. Additionally, urine samples and environmental soil, air and vegetation samples were collected. Samples of locally prepared indigenous food items such as jekaro (coconut sap), jekami (coconut syrup) and powdered taro flour (a starchy tuber based flour) were obtained. The wind-powered generator on Bikini was not working nor could it be repaired. The Bikinians were made aware of the fact that their prior body burdens had increased to new levels and many of them knew they exceeded the internationally accepted annual guidelines for dose-equivalent commitment.

In June 1978, the RUDR program contracted the meteorological group at LLL, headed up Gudiksen, to provide a computer simulation of the dispersion, transport and deposition of fallout from the 1954 atmospheric nuclear test, BRAVO. Also, a contract to provide neutron activation analyses of environmental samples for I-127 and I-129 resulting from the deposition of fallout on Rongelap and Utirik Atolls was given to the Radiological Sciences Department, Battelle-Pacific Northwest Laboratory (BPNL) under the guidance of Brauer and Ballou. Historic soil samples from Rongelap and Utirik Atolls were provided by Seymour, the director of UWLRE. In August, Sondhaus of UCCM was asked to collaborate on the dose reassessment project (RUDR).

In September 1978, Naidu, Craighead and Greenhouse of BNLSEP began a diet and living pattern study of Rongelap, Utirik, Likiep and Ailuk Atolls. Initial observations had been performed by Naidu during prior visits (Rongelap 6 weeks, January-February 1977 and Utirik 2 weeks, April 1978) and by Knight during FY 78. Basic data was gathered on age distribution, family size, seasonal variations of locally grown food, food from other islands, individual diet patterns and individual daily activity patterns. Greenhouse also performed ground level exposure rate measurements and surface soil sampling. This work was performed in support of the Northern Marshall Islands Radiological Survey and expenses totalling $37,000 were reimbursed through Robison of LLL and Liverman of DOE.

PUBLICATIONS: External Radiation Survey and Dose Predictions for Rongelap, Utirik, Rongerik, Ailuk and Wotje Atolls, N. A. Greenhouse and R. P. Miltenberger, BNL #50797, December 1977.

Radiological Analyses of Marshall Islands Environmental Samples 1974-1976, N. A. Greenhouse, R. P. Miltenberger and F. T. Cua, BNL #50796, December 1977.

FY 1979

MIRSP was funded with $281,000 operating and $25,000 capital. RUDR was funded with $50,000 operating. Total staffing levels were 3.4 man years scientific and professional and 1.6 man years technical support. Lessard, a prior collaborator on MIRSP joined with Greenhouse, Miltenberger and Naidu as principle staff for MIRSP and RUDR. Major equipment purchases included a portable Davidson multi-channel analyzer and tower extentions for the wind-powered electrical generators.

Twelve two week Marshallese comparison urine samples were collected in October 1978 by Shoniber, Department of Health Services, Trust Territory of the Pacific Islands and forwarded to BNL for analyses. Each sample was to have been analyzed for Sr-90, Cs-137, Pu-239 and Pu-240 from world-wide fallout and for natural K-40. The results were to be used to establish the baseline excretion rates for these radionuclides so that a reference against which urine samples from the atolls contaminated with troposheric fallout could be compared.

During November 1978, Marshall Island's whole-body counting, environmental, demographic, physiologic and bioassay data bases were initiated by Miltenberger. Preliminary diet and living pattern reports were submitted to Robison (LLL) by Naidu. Under the RUDR program, 62 teeth samples from Bikini, Rongelap and Utirik were collected by BNL Medical for future analyses of Sr-90, Pu-239 and Pu-240. Naidu invited The Institute of Physical and Chemical Research of Japan to contribute some Bikini ash to RUDR research.

During January and February 1979, Lessard constructed appropriate dosimetric models and determined retrospective and prospective dose equivalents to various body organs for all former Bikini residents. This work also compared urine bioassay derived body burdens to whole-body counting measured body burdens for Cs-137.

In January, a whole body counting field trip to Majuro to examine the former Bikini Island residents was undertaken by Miltenberger, Greenhouse and Craighead. They whole-body counted 101 persons and collected 49 urine samples, 64 whole-body counts were from the relocated former Bikini residents. Miltenberger and Greenhouse continued to cross the Trust Territory to finish the Pacific Basin Study, a collaborative effort with Nelson of UWLRE which had commenced in 1975. During May, another field trip to Majuro and Kili was completed by Miltenberger and Lessard. They whole-body counted 129 persons, 79 of which had been relocated from Bikini Island in August of 1978. The whole-body counts on Marshallese persons other than the former Bikinians provided baseline body burden and urine radionuclide excretion rate data for comparison purposes.

During August and September 1979, Miltenberger, Lessard, Balsamo, Hunt and Dillingham of BNLSEP, Sherwin of Enertech Corporation, and Rademacher of St. Mary's College, participated in a field trip. They re-established the air sampling programs at Kwajalein, Rongelap and Utirik, continued the routine environmental monitoring program at Rongelap and Utirik and continued the whole-body counting programs formerly performed by BNL medical. At Utirik and Rongelap, Brown of DOE Pacific Area Support Office (PASO) restated a former BNL promise. He said that the electric generating windmill apparatus would be given to the people in working order following collection of air sampling data for one year. During this trip, 150 whole-body counts and 146 urine samples had been collected. In addition, the windmills were left generating electricity. Coconut, pandanus and breadfruit had been obtained from traditional selection sites. Brown of DOEPASO, Otterman of US Oceanography, and Miltenberger and Lessard of BNLSEP prepared sketches and plans for a new whole-body counting trailer. The new design incorporated two chair type counters. Their design maximized the use of available equipment and space, minimized the discomfort of the Marshallese and eliminated many of the previous trailer design deficiencies.

By August 1979, members of the RUDR program completed a draft of the diet and living pattern study. Also, results of the soil analyses for I-129 on samples collected during the 1950's indicated samples from recent times could be analyzed. In addition, soil samples from Likiep were submitted for analyses. Efforts were initiated to procure excised thyroid glands taken from the Marshallese who were resident on Rongelap and Utirik. These samples were to be analyzed for Tc-99 and I-129. The computer simulation of fallout data was expected to be completed by September. McInroy of Los Alamos Scientific Laboratory had begun analyses of Marshallese teeth samples for Pu, U, Th and Sr radionuclides.

A September 1979 visit to Rongelap and Utirik was performed by US Oceanography. They reported the wind-powered electrical generators were not working and according to the run time indicators, they had failed shortly after their repair in August. It was becoming apparent that to keep the wind-powered generators operational, routine maintenance by a trained individual equipped with spare parts and proper tools was required.

PUBLICATION: External Exposure Measurements at Bikini Atoll, N. A. Greenhouse, R. P. Miltenberger and E. T. Lessard, BNL #51003, January 1979.

PRESENTATIONS: 137 Cs Body Burdens at Bikini: To Move or Not to Move, N. A. Greenhouse, Presented at the Chemical Physics Section, Health and Safety Research Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee, January 1979.

The Anatomy, Physiology, and Radiobiology of The Gastrointestinal Tract, E.T. Lessard, Presented at the Twenty-Fourth Annual Meeting of the Health Physics Society, Philadelphia, Pennsylvania, July 1979.

FY 1980

Funding levels were $351,000 operating and $50,000 capital equipment for MIRSP. An operating budget of $50,000 was provided for RUDR. Staffing levels were 3.8 man years scientific and professional and 2.2 man years technical support. Major equipment purchased was a computer based multi-channel pulse height analyzer to replace and upgrade the existing BNLSEP analytical laboratory equipment. By September 1980, Greenhouse, Cua and Knight had left the program and Miltenberger, Naidu and Lessard performed as primary staff with Lessard as program director.

During October 1979, Miltenberger and Lessard finalized plans for the new whole-body counting trailer with Dillingham, Otterman and Brown. Chair construction began at BNL. Enertech was informed in October of the failure of the wind-generators supplied and repaired by them. During the next few months, the whole-body counting chairs were built, disassembled, packed and forwarded to Kwajalein along with the new trailer. Naidu and Greenhouse, of BNLSEP and Pratt of BNL Medical prepared an educational program on the effects of fallout from nuclear tests for the inhabitants of Bikini, Enewetak, Rongelap and Utirik Atolls. This effort documented the original training presented to the Rongelapese and Utirikese by Naidu during 1977 and 1978.

In February 1980, a personnel monitoring field trip was undertaken to Japtan and Enewetak Islands, Enewetak Atoll and Ujelang Island, Ujelang Atoll to obtain baseline body-burden data on the Enewetak population prior to the repatriation of Enewetak Atoll in April 1980. Miltenberger, Levine and Greenhouse of BNLSEP and Manalastas, a Phillipine national and a fellow of the International Atomic Energy Agency performed whole-body counting and collected urine samples from persons 5 years of age and older. At Ujelang, non-participants of the whole-body counting program were invited to provide urine samples. Approximately 400 urine samples were collected and are curently being spectrometrically analyzed for gamma emitters and radiochemically analyzed for Sr-90. Additionally, participants provided physical and demographic data.

As previously mentioned, whole-body counting was conducted with two independent chair counting systems in which a sodium iodide detector was positioned in front of a sitting person. This geometry allowed safe entry and egress with comparable sensitivity relative to the bed geometry used in prior field trips. Approximately 400 spectra were obtained in this way and analyzed for Cs-137 and K-40 using calibration standards which best matched the sex, height and weight of the individual. Additional analyses were performed to determine frequency distribution statistics for various age and sex groupings of the data. Quality assurance was obtained by duplicate whole-body counts and repetitive point-source standard counts.

During January and February 1980, Lessard undertook retrospective assessment of chronic external and internal dose equivalents to the residents of Rongelap and Utirik. The dose interval assessed was after they returned home following the BRAVO test and evacuation and prior to January 1, 1980. Lessard, Miltenberger and Greenhouse also completed the Sr-90 and Cs-137 dose equivalent-commitment estimates for former residents of Bikini Atoll. Additionally they determined dietary radioactivity intake for Cs-137 in the Bikini population and compiled whole-body counting results for the years 1974 to 1979. These Bikini related works were prepared as 3 primary scientific publications.

In January 1980, Naidu, Greenhouse, Craighead and Knight summarized information on diet and living patterns for the Marshallese. The data was derived from literature, from personnel observations through living with the Marshallese for periods extending from months to years, from answers to questionnaires and from direct participation in their activities. It was recognized at that time that the study needed to be extended in order to identify trends in local food consumption and living patterns.

During March 1980, at the request of McCraw of the Department of Energy's Division of Health and Environmental Research, Lessard and Miltenberger identified individual Bikinians who exceeded the recommended 500 mRem per year limit to the whole body and red bone marrow. They also explained the discontinuity which appeared in the Sr-90 estimated body burden between residence and post residence periods for Bikini adult females and Bikini youths. Additionally, they evaluated LLL's calculations relating body burden, dose equivalent and activity ingestion rate.

In March, Public Law 96-205 was enacted which authorized the Secretary of the Interior to provide for certain people medical care and treatment and environmental research and monitoring for any injury, illness or condition which may be the result directly or indirectly of the Pacific Nuclear Weapon Testing Program. The Secretary of Energy was authorized to assume all costs associated with the development and implementation of the program. Later that year, at the request of Robison of LLL, Lessard and Greenhouse related to him an outline of MIRSP and RUDR program history and costs. Robison would draw upon this information in order to set forth a general plan for the periodic comprehensive survey and analyses of the radiological status of the atolls, the development of an updated radiation dose assessment and an estimate of the risks associated with the predicted human exposure.

In April, Greenhouse began to summarize external exposure rate data for the Micronesian islands outside of the Northern Marshalls. Much of this data was collected in collaboration with Nelson of UWLRE during 1975 and 1976.

During the summer months Kaplan, an undergraduate student from Yale University, and Lessard performed the initial analysis relating I-129 activity in soil to acute thyroid dose equivalents in persons on Rongelap and Utirik Atolls in March 1954. The analysis accounted for I-129 atom distribution with depth of soil and the kinetic relationships between the iodine isotopes, time post detonation and fission neutron energy. The dosimetry accounted for differences in uptake, excretion and retention of iodine as a function of age of the individual. Preliminary estimates of thyroid dose from the March 1, 1954 exposure were determined for Rongelap and Utirik residents.

During July and August 1980, whole-body counts and urine samples were obtained at Majuro Atoll and Kili Island by Greenhouse, Moorthy, Watts and Rivera of BNLSEP. Former Bikini Island residents and a comparison population contributed approximately 200 spectra and 100 urine samples. Fifty percent of the April 1978 population at Bikini were recounted. Consecutive measurements of a Bikini residents body burden post departure allowed for computation of individual long-term biological removal rate constants. This data was reviewed and written up by Miltenberger, Lessard and Greenhouse and submitted to a scientific journal.

In September, a meeting of RUDR was held between Bond, Borg, Conard, Cronkite, Hull, Lessard, Meinhold, Miltenberger and Naidu of BNL, and Sondhaus of UCCM. The meeting centered on dose reassessment and was conducted in two parts aimed at reviewing past accomplishments and assigning future tasks. A review of the circumstances that led to the study was presented by Naidu who also discussed the status of the Sr and Pu in teeth samples. Lessard presented a draft of the chronic phase dose-equivalent estimates for Rongelap and Utirik residents and reviewed the acute phase dosimetric methods and dose-equivalent estimates based on the I-129 soil analysis. The second stage of the meeting led to detailed discussions on the chronic and acute dosimetry. The outcome was to define specific tasks in order to further substantiate the dose estimates to the thyroid.

During September, as part of the ongoing quality assurance program for MIRSP, an interlaboratory analysis for Sr-90 in urine samples from the Marshall Islands was initiated.

PUBLICATIONS:

Dosimetric Results for the Bikini Population, N.A. Greenhouse, R.P. Miltenberger and E.T. Lessard, Health Physics, Vol 38, pp. 846-851, May 1980.

Marshall Islands: A Study of Diet and Living Patterns, J. Naidu, N.A. Greenhouse, J. Knight, BNL#51313, July 1980.

Dietary Radioactivity Intake from Bioassay Data: A Model Applied to Cs-137 Intake By Bikini Island Residents, E.T. Lessard, R.P. Miltenberger, and N.A. Greenhouse, Health Physics Vol. 39, pp.177-183, August 1980.

Whole Body Counting Results from 1974 to 1979 for Bikini Island Residents, R.P. Miltenberger, N.A. Greenhouse and E.T. Lessard, Health Physics, Vol. 39, pp. 395-407, August 1980.

Co-60 and Cs-137 Long Term Biological Removal Rate Constants for the Marshallese Population, R.P. Miltenberger, E.T. Lessard and N.A. Greenhouse, Health Physics (In press).

PRESENTATIONS:

Rate Constants for Biological Elimination of Strontium and Cesium in the Marshallese Population, E.T. Lessard. Presented at the Twenty-Fifth Annual Bioassay Conference, Las Vegas, Nevada, October 31-November 2, 1979.

Body Burden Measurements as Determined from Whole-Body Counting and Urine Bioassay, E.T. Lessard, Presented at the Twenty-Fifth Annual Bioassay Conference, Las Vegas, Nevada, October 31-November 2, 1979.

Dosimetry Methods and Results for the Former Residents of Bikini Atoll, N.A. Greenhouse, Presented at the IRPA Congress, Manilla, Phillipines, November 5-9, 1979.

An Educational Program on the Effects of Fallout from Nuclear Tests for the Inhabitants of Bikini, Enewetak, Rongelap and Utirik (Marshall Islands), J. Naidu, Presented at the Thirteenth Midyear Symposium of the Health Physics Society, Honolulu, Hawaii, December 10-13, 1979.

Dose Assessment for Rongelap and Utirik Residents 1954 to Present, E.T. Lessard, Presented at the Twenty Fifth Annual Meeting of the Health Physics Society, Seattle, Washington, July 21-25, 1980.

FY 1981 (Progress to Date)

Funding levels were $415,000 operating and $5,000 capital equipment for MIRSP. In November, $30,000 operating were withheld by DOE, thus reducing the MIRSP operating dollars to $385,000. An operating budget of $53,000 was directed to RUDR. Lessard, Miltenberger and Naidu form the primary staff.

During October Lessard completed the reconstruction of chronic dose equivalents for Rongelap and Utirik residents for the time interval 1954 to 1980. Retrospective and contemporary external exposure rate data, whole-body counting data, and radiochemical analysis of urine and blood data were reviewed. Dosimetric models which best described the uptake regime were constructed for the nuclides of interest. Daily activity ingestion rates, whole-body dose-equivalent rates and dose-equivalent commitments to various organs were determined. Population dosimetry results and methods were written up and reported in a BNL publication. Individual dosimetric records are maintained at the Laboratory.

At the request of McCraw (DOEDHER), Lessard and Miltenberger analyzed former Bikini and Rongelap personnel monitoring data in order to estimate Cs-137 body burdens for the population who may return to Enue Island, Bikini Atoll. This projection involved a determination of activity transfer factors calculated from Rongelap and Bikini whole-body counting data and from activity concentration analyses of coconut tree products. These factors were comparable for both atolls and dose-equivalent commitments were projected for adults.

In December, Naidu contacted Dr. Shinji Okano of Japan regarding analyses of the "Bikini Ash of Daigo-Fukuryumara". Lessard, Miltenberger and Moorthy outlined a radiochemical separation/neutron fission radioassay technique to be used on urine collected from Marshallese exposed to tropospheric weapons-test plutonium. Sondhaus (UCCM) visited Lessard to discuss his work related to acute phase dose reassessment for Rongelap and Utirik residents. Thiessen, the new Director of the Human Health and Assessments Division of the Department of Energy was appraised of the RUDR program's activities. Also in

December, Lessard, Naidu, Miltenberger, Baum and Olmer began preparations for site review scheduled for May 1981.

During October through March, Miltenberger, Lessard and Steimers of BNLSEP summarized the data regarding human milk samples which had been obtained from four lactating adult former Bikini females whose Cs-137 body burden had been defined by whole-body counting. Also, coconut tree sap and nuts were analyzed by gamma spectroscopy to determine the presence of Cs-137 and K-40. Results were used to estimate the Cs-137 body burden for Marshallese infants whose primary food supply was human milk and coconut tree products. Dose estimates for a hypothetical infant resident on Bikini Island during August 1977 to August 1978 were derived from the Cs-137 body burden [illegible]timate.

During January, Miltenberger and Roesler of BNLSEP and [illegible] of BNL Medical conducted a personnel monitoring field trip to Enewetak Atoll and performed a health physics survey of the x-ray machine located aboard the Liktanur II. Analysis of the [illegible]tak [illegible]cated [illegible]207 [illegible] out of several hundred [illegible]ly [illegible] [illegible]ody [illegible] Cs-137, noted in all individuals examined the year before, had declined during this first year in residence on Enewetak Atoll. The survey of the x-ray machine provided an estimate of the operator and patient dose equivalent.

During January and February, McCraw (DOEDHER) requested a review and response to questions posed by Johnson of the Micronesia Support committee regarding repatriation of Rongelap and Utirik Atolls. Additionally, McCraw requested a reanalysis of dose equivalent due to ingestion of coconut crab from the northern islands of Rongelap Atoll. Conard and Cronkite of BNL Medical and Hull, Naidu, Miltenberger and Lessard of BNLSEP prepared the formal responses.

A whole-body counting protocol by Miltenberger and radiochemical analyses protocol by Olmer were prepared in March. A review of quality assurance data for the Marshall Islands was also prepared by Miltenberger, Naidu and Lessard. Brauer of BPNL and Naidu prepared radiochemical analysis and analytical procedures for determination of I-129 in soil. Lessard prepared a historical synopsis, a summary of MIRSP and RUDR highlights and a collection of publications and protocols.

PUBLICATIONS FY 81 to date:

Reconstruction of Chronic Dose Equivalents for Rongelap and Utirik Residents-1954 to 1980, E.T. Lessard, N.A. Greenhouse and R.P. Miltenberger, BNL #51257, October 1980.

Thyr[illegible] Absorbed Dose [illegible]r Rongelap and Utirik Re[illegible]ts, E.T. Lessard, J.R. Naidu, R.P. Miltenb[illegible] N.A. Greenh[illegible]and L.V. Kaplan, BNL #28939, Draft.

Body Burden [illegible] Re[illegible]s-1969 to 1980. Editors [illegible] J. Balsamo, S. Cohn, E. Craighead, F. Cua, N.A. Greenhouse, A. Hunt, S. Johnson, A. Kuehner, E.T. Lessard, G. Levine, R.P. Miltenberger, A. Moorthy, J. Naidu, N. Rivera, J. Steimers and K. Watts, BNL Report, Draft.

Cs-137 in Human Milk and Dose Equivalent Assessment, R.P. Miltenberger, E.T. Lessard, J. Steimers, and N.A. Greenhouse, BNL Report, Draft.

Whole-Body Counting Operations Manual, R.P. Miltenberger, BNL Protocol, Draft.

Standard Procedure for Air Sampling, F. Cua, BNL Protocol, Draft.

Protocol for Radiochemical Analysis of Urine Teeth and Milk, Editor: L.L. Olmer, Contributors: D.M. Henze and J.R. Steimers, BNL Protocol, Draft.

An Evaluation of Physiological Parameters and Their Influence on Doses Calculated from Two Alternative Dosimetric Models for the Gastrointestinal Tract, E.T. Lessard and K.W. Skrable, Proceedings of the Third International Radiopharmaceutical Dosimetry Symposium, Oak Ridge, Tennessee, October 1980 (In Press).

An Inter[illegible] of Natural and Technologically Enhanced Background Radiation Levels in Micronesia, Y.A. Greenhouse, and R.P. Miltenberger, LBL Report, Draft.

Review of [illegible] Data-Marshall Islands Radiological Safety Program, E.T. L[illegible], R.P[illegible] J. Naidu, BNL Report, Draft.

I-129 Ana[illegible] Marshall Islands [illegible]onmen[illegible]les, Analytical and Quality Assu[illegible]rocedures, F.P. [illegible]auer and [illegible]

PRESENTATIONS FY [illegible] to da[illegible]

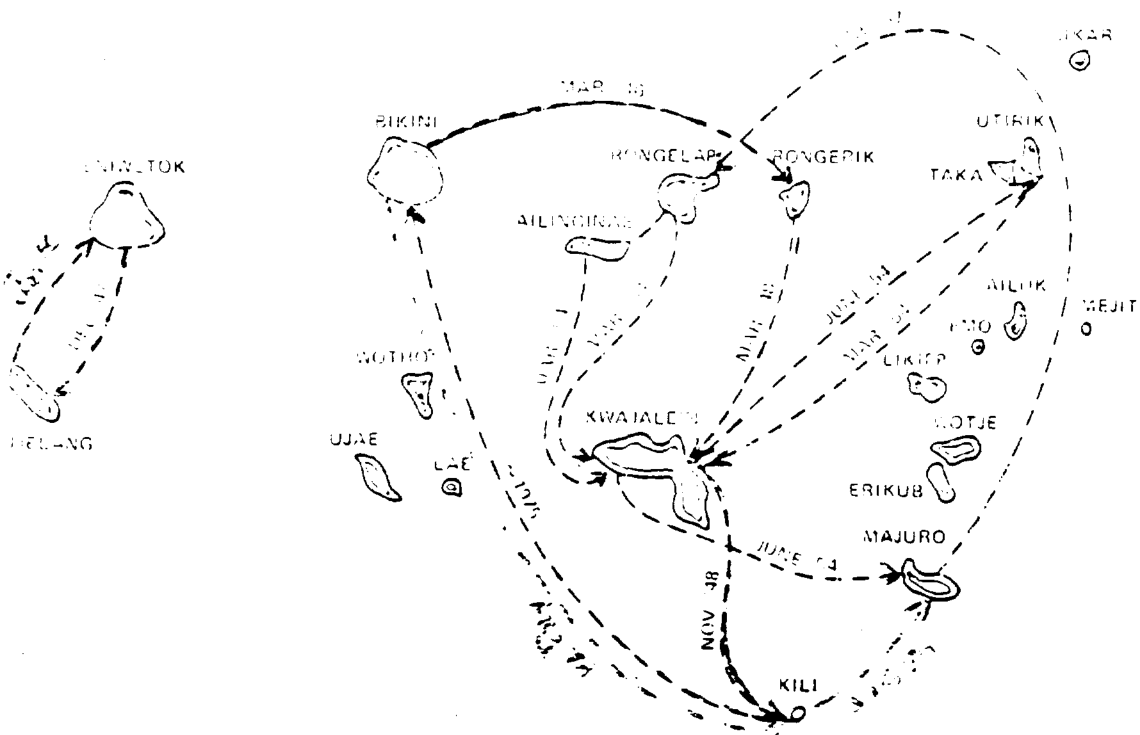
Cs-137 In [illegible] Milk, [illegible] Miltenberger. [illegible] the 26th Annual Bioassay C[illegible] October 14-15, 198[illegible]

An Evaluation of Physiological Parameters and Two Alternative Dosimetric Models for the Gastrointestinal Tract, E.T. Lessard. Presented at the Third International Radiopharmaceutical Dosimetry Symposium, Oak Ridge, Tennessee, October 6-10, 1980.

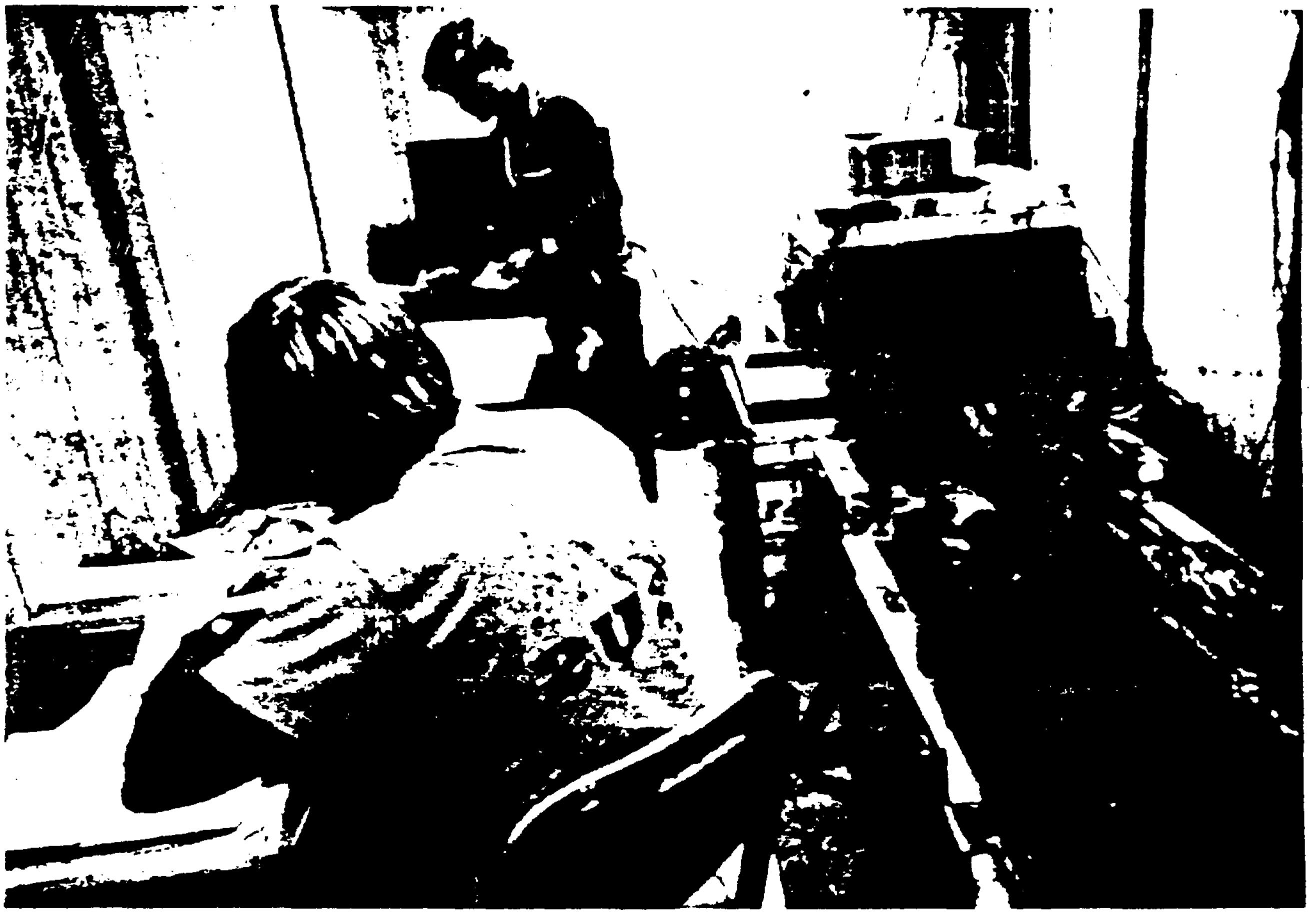
Expected Man Made Radionuclides to be Encountered in the Marshall Islands

Source	Nuclide	Origin	Source	Nuclide	Origin
Soil	^{3}H	Unfused fuel	Animals	^{3}H	Unfused fuel
Soil	^{14}C	Activation	Animals	^{55}Fe	Activation
Soil	^{55}Fe	Activation	Animals	^{60}Co	Activation
Soil	^{60}Co	Activation	Animals	^{90}Sr	Fission
Soil	^{63}Ni	Activation	Animals	^{137}Cs	Fission
Soil	^{90}Sr	Fission	Animals	^{207}Bi	Activation
Soil	^{102}Rh	Activation	Animals	^{239}Pu	Unfissioned fuel
Soil	^{125}Sb	Fission	Animals	^{240}Pu	Unfissioned fuel
Soil	^{147}Pm	Fission	Fish	^{3}H	Unfused fuel
Soil	^{151}Sm	Fission	Fish	^{55}Fe	Activation
Soil	^{152}Eu	Activation	Fish	^{60}Co	Activation
Soil	^{154}Eu	Fission	Fish	^{90}Sr	Fission
Soil	^{155}Eu	Fission	Fish	^{137}Cs	Fission
Soil	^{207}Bi	Activation	Fish	^{207}Bi	Activation
Soil	^{235}U	Unfissioned fuel	Fish	^{239}Pu	Unfissioned fuel
Soil	^{238}U	Unfissioned fuel	Fish	^{240}Pu	Unfissioned fuel
Soil	^{238}Pu	Unfissioned fuel			
Soil	^{239}Pu	Unfissioned fuel			
Soil	^{240}Pu	Unfissioned fuel			
Soil	^{241}Am	Unfissioned fuel			
Plants	^{3}H	Unfused fuel			
Plants	^{60}Co	Activation			
Plants	^{90}Sr	Fission			
Plants	^{102}Rh	Activation			
Plants	^{137}Cs	Fission			
Plants	^{239}Pu	Unfissioned fuel			
Plants	^{240}Pu	Unfissioned fuel			

MOVEMENT OF PEOPLE PACIFIC TESTING



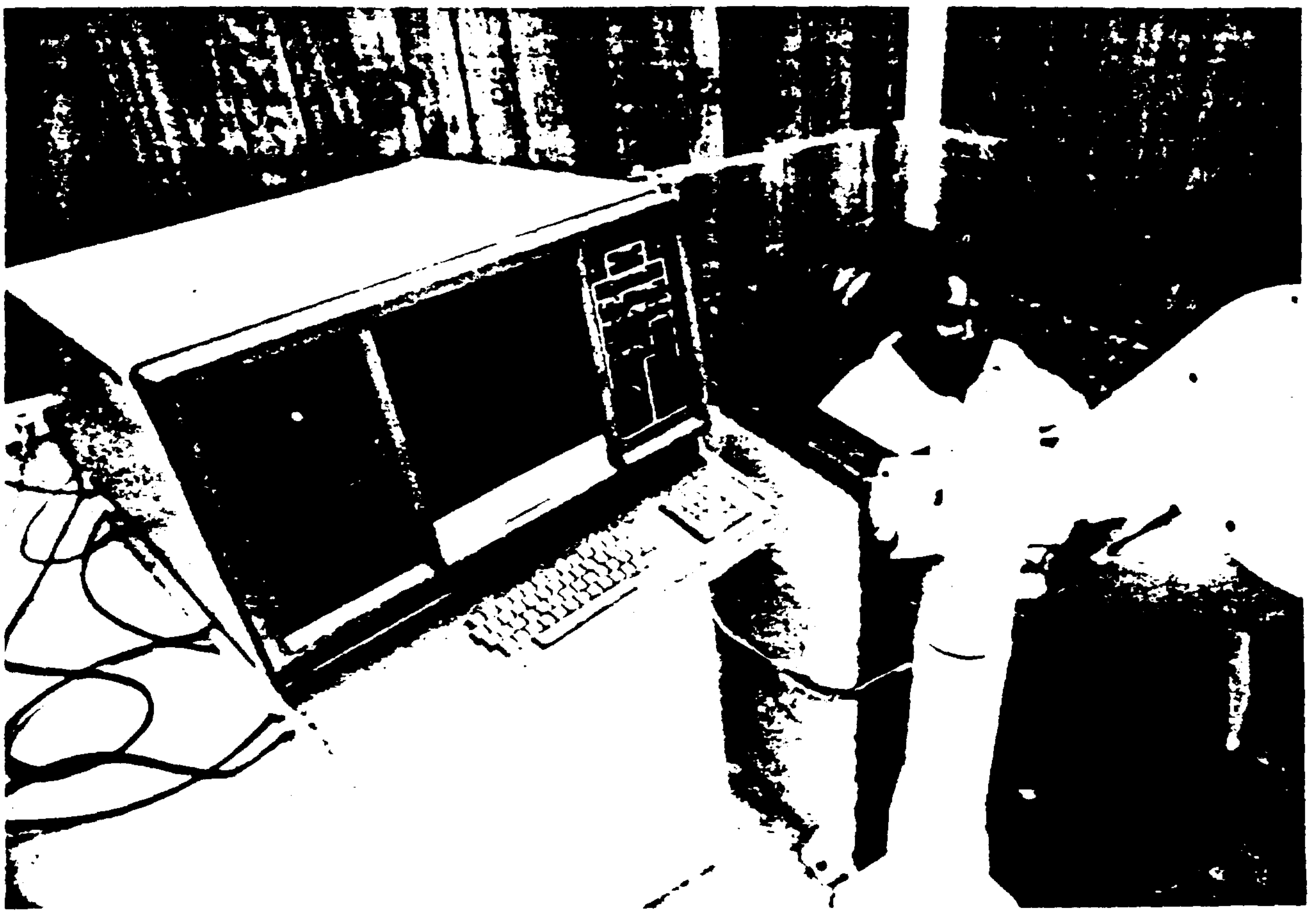
Movement of the Marshallese People
Following the Weapons Testing Programs
at Bikini and Enewetak Atoll



Bed Geometry Whole-Body Counting
at Bikini Atoll

External Radiation Measurements
at Bikini Atoll

Collection of Demographic, Anthropometric
and Physiologic Data and Selection of
Individuals for the Bioassay Programs



Whole-Body Counting in One of the
New Chair Geometry Systems. Two Independent
Systems are Used Throughout a Field Study

BNL REPORTS

BNL REPORTS

Marshall Islands Radiological Followup

Radiological Analyses of Marshall Islands Environmental Samples 1974-1976

External Radiation Survey and Dose Prediction for Rongelap, Utirik, Ailuk and Wotje Atolls

External Exposure Measurements at Bikini Atoll

A Reconstruction of Chronic Dose Equivalents for Rongelap and Utirik Residents - 1954 to 1980

Marshall Islands: A Study of Diet and Living Patterns

Thyroid Dose Assessment for Rongelap and Utirik Residents-Draft

Body Burdens and Dose Assessment for Bikini Island Residents-Draft

Review of Quality Assurance Data - Marshall Islands Radiological Safety Program-Draft

M.I. Radiological Follow-up

MARSHALL ISLANDS RADIOLOGICAL FOLLOWUP*

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and
Division of Operational Safety, U.S. Energy Research and Development Administration, Washington, D.C. 20545

Abstract

In August, 1968, President Johnson announced that the people of Bikini Atoll would be able to return to their homeland. Thereafter, similar approval was given for the return of the peoples of Enewetak. These two regions, which comprised the Pacific Nuclear Testing Areas from 1946 to 1958, will probably be repopulated by the original inhabitants and their families within the next year. As part of its continuing responsibility to insure the public health and safety in connection with the nuclear programs under its sponsorship, ERDA (formerly AEC) has contracted Brookhaven National Laboratory to establish radiological safety and environmental monitoring programs for the returning Bikini and Enewetak peoples. These programs are described in the following paper. They are designed to define the external radiation environment, assess radiation doses from internal emitters in the human food chain, make long range predictions of total doses and dose commitments to individuals and to each population group, and to suggest actions which will minimize doses via the more significant pathways.

Introduction

The U.S. nuclear testing programs of the 1940s and 1950s had significant local environmental impacts on the coral atolls of Bikini and Enewetak in the Marshall Islands. The high level close-in fallout made these atolls uninhabitable for many years. Fallout from the BRAVO event, which took place at Bikini in 1954, was inadvertently deposited on the nearby atolls of Rongelap, Rongerik and Utirik. In all, some thirteen atolls in the northern Marshalls were probably affected to a greater or lesser extent by fallout from these nuclear tests. Of these, however, the most significant long term radiological impact was on the test atolls, Bikini and Enewetak, and on Rongelap Atoll.

In 1957, Rongelap was reoccupied by its original inhabitants who had been evacuated two days after BRAVO. During the past several years, definitive plans have been made to repatriate the original inhabitants of Bikini and Enewetak Atolls, and their families. It is hoped that their return can take place soon.

In order to identify radiological problems from residual radioactivity in the environment, and to provide a data base for dose predictions applicable to the returning populace, ERDA (and its predecessor, the AEC), has sponsored many radiological surveys in the Marshall Islands. These surveys began during test operations and have been conducted periodically up to the present time. Results of the surveys have been published in numerous reports and scientific journals. References 1 through 12 are published reports of AEC/ERDA supported surveys of these atolls. References 13 through 29 are a portion of the published reports on work with collected environmental samples supported by AEC/ERDA.

Evaluation of survey results for Bikini Atoll, the consideration of predicted exposures compared with applicable radiation standards, and the acknowledgement of the many benefits to the people if they could return, led to the decision to clean up and rehabilitate that atoll. The Department of Defense, Department of the Interior (DOI), and AEC (now ERDA) participated in a joint effort of clean up and rehabilitation of Bikini Atoll starting in February, 1969. Clean up was completed in the fall of that year. Agricultural rehabilitation and housing construction is being conducted by DOI.

The decision to return the Enewetakese to their atoll led to a comprehensive survey conducted at Enewetak in 1972-1973.[(10)] A regional survey planned for 1976 will provide baseline radiological data for future dose assessments throughout nearly all of the northern Marshall Islands which may have been affected by the testing program. Environmental evaluations at Rongelap and Utirik Atolls have been undertaken periodically in association with ERDA's medical evaluations program there over the past 20 years.[(30-32)]

From all of these earlier surveys, it became apparent that periodic environmental monitoring and dose assessments must be made for Bikini, Enewetak, Rongelap and perhaps other atolls in the northern Marshalls to maintain a current radiological data base and to provide current information on individual and population doses. This followup monitoring is being performed by Brookhaven National Laboratory at the request of the Division of Operational Safety, U.S. Energy Research and Development Administration.

*Research carried out at Brookhaven National Laboratory under the auspices of the U. S. Energy Research and Development Administration.

Radiological Concerns

The primary radiological problems are the result of residual fission and activation products in the terrestrial environment. They have been identified by previous environmental surveys as follows: 1) External radiation levels significantly higher on some islands in an atoll compared to levels on lightly contaminated islands. 2) Fission and activation product radioactivity in certain terrestrial food items now growing on islands of these atolls and the possibility that unacceptable levels of these radionuclides may appear in foods, plants and animals newly introduced into these atolls. 3) Radioactivity in the ground water, a possible source of drinking water and water for irrigation. 4) Plutonium and americium isotopes in the surface soil. These factors are illustrated by data in Tables 1 through 4 taken from previous radiological survey reports.

Table 1. Gamma Radiation Rates in Bikini Atoll*
(mR/hr)

Island	Exposure rate Range	Major contributors
Bikini	.010-.120	^{137}Cs
Weathered areas	.010-.030	
Close to shore	.020-.040	
Island center	.050-.080	
Hot spots	.080-.120+	
Eneu	.002-.010	^{137}Cs
Nam	.010-.330	^{60}Co, ^{137}Cs
Outer edge	.010-.030	
Island center	.015-.150	
N.E. corner	.110-.330	
Bokantuak, Iomelan, Rojkere, Eonjebi	.003-.010	**
Aerokoj-Emenman complex:		
Aerokoj, Aerokojlol	.001-.010	**
Bikdrin, Lele	.006-.010	**
Eneman	.001-.570	^{60}Co, ^{125}Sb, ^{102m}Rh
East Eneman	.001-.010	
West Eneman	.020-.570	
Enidrik	.003-.235	^{60}Co, ^{125}Sb, ^{102m}Rh
East Enidrik	.003-.030	
West Enidrik	.010-.235	
Lukoj	.060-.200	^{60}Co, ^{125}Sb, ^{102m}Rh
Jelete	.060-.130	**
Oroken	.015-.045	**
Bokaetoktok	.010-.035	**
Bokdrolul	.020-.050	
Bokbata	.01[illegible]-.030	^{60}Co, ^{137}Cs
Aomen-Iroij complex:		
Aomen	.005-.020	**
Lomilik	.020-.330	^{60}Co, ^{125}Sb
Odrik, Iroij	.010-.040	**

*See ref. 9.

**No soil sample or field spectra measurements.

In some cases, the predicted doses and dose commitments derived from survey information for Bikini and Enewetak Atolls approach or even exceed national and international radiation protection standards for certain living and dietary patterns. Corrective actions or restrictions must be placed on use of these atolls and their resources to assure that the applicable radiation standards are not exceeded. Herein lies the primary justification for the continuing environmental followup surveys sponsored by ERDA.

Environmental Monitoring

The most important sources of exposure to people living on Rongelap and to future residents of Bikini and Enewetak Atolls are from internal deposition of radioisotopes from certain elements in the human diet, and from the long term occupancy of islands having external radiation dose rates higher than natural background. Aside from periodic re-evaluations to establish trends in external dose rate reduction, external radiation monitoring will assume less significance, compared to monitoring of the food chain, as time passes. At present, annual visits are being made to identify and collect representative samples of local diets for laboratory analysis and dose commitment updates. New locally grown food items are becoming available in small quantities on Bikini Island as a result of the experimental agricultural practices of a small group of caretaker families living there. Neither Bikini Atoll, where radiological cleanup has been completed, nor Enewetak Atoll where clean up has not yet begun, have a subsistence agriculture resource in being which is sufficient to support the anticipated populations which will one day live there (though such crops are currently being developed or planned).

Table 2. Concentrations of ^{40}K, ^{60}Co, ^{90}Sr, and ^{137}Cs in Food Plants Collected on Bikini Island in November 1971 and March 1972*

Plant type	Tissue	Collection date	pCi/g, dry†			
			^{40}K	^{60}Co	^{137}Cs	^{90}Sr
Lettuce	Entire	March 1972	7.1±0.1	NS‡	360±10	320 ±25
Papaya #1	Seeds	March 1972	17 ±2	0.13±0.12	140± 1	NA§
"	Fruit	March 1972	31 ±3	NS	160± 1	72 ± 3
Papaya #2	Seeds	March 1972	14 ±4	NS	270± 2	NA
"	Fruit	March 1972	23 ±3	NS	190± 1	69 ± 4
Pandanus	Fruit (edible)	November 1971	7.5±0.6	0.05±0.03	32± 0.4	56 ± 0.6
"	Fruit (fibrous)	November 1971	12 ±2	NS	200± 1	220 ± 2.2
"	Leaves	November 1971	3.4±1.5	NS	71± 0.4	190 ± 1.9
Coconut #1	Meat	November 1971	1.6±1.3	NS	93± 0.5	NA
"	Milk	November 1971	3.9±1.9	NS	110± 0.7	NA
Coconut #2	Meat	November 1971	4.4±2.1	NS	110± 1	0.38± 0.04
"	Milk	November 1971	4.3±2.5	NS	100± 1	< .22
Coconut #3	Meat	November 1971	11 ±4	NS	147± 1	NA
Coconut #4	Meat	November 1971	2.5±2.0	NS	100± 0.8	NA
"	Milk	November 1971	3.0±1.3	NS	77± 0.6	NA
Coconut #5	Meat	November 1971	15 ±6	NS	270± 2	NA
"	Milk	November 1971	2.1±1.3	NS	33± 0.3	NA
Coconut	Fronds (old)	November 1971	7.0±5.0	NS	310± 3	NA
	Fronds (new)	November 1971	14 ±5	NS	220± 2	NA

*See ref. 11.

†The error terms for ^{40}K, ^{60}Co, and ^{137}Cs are two-sigma, propagated, counting errors. The errors for ^{90}Sr are one-sigma, propagated, counting errors.

‡NS = not significant. The net sample count is less than the two-sigma, propagated, counting error.

§NA = not analyzed.

Table 3. Some Radionuclides in Water Samples Collected with a Large Volume Filter Sorption Bed from Bikini Atoll, May 1972*

Collection location	Fraction	Liters Sampled	Radionuclide concentration in pCi/m³†				
			^{60}Co	^{137}Cs	^{155}Eu	^{207}Bi	^{241}Am
Bravo Crater (bottom)	Particulate‡	3785	51 ±3	12 ±1	97 ±4	27 ± 2	70 ±5
	Soluble§	3785	28 ±8	<14 ±	<20	160 ±11	<30
Bravo Crater (surface)	Particulate	3785	6.5±1.4	NSΔ	9.6±1.3	0.5± 0.3	9.2±1.4
	Soluble	3785	<10	< 6	<16	<12	<22
Bokdrolul Pass (ebb tide)	Particulate	4088	6.0±7.3	NS	6.4±1.2	NS	5.4±1.1
	Soluble	4088	1.4±0.6	<1.0	<2.3	3.0± 0.5	<2.9
Bokdrolul Pass (flood tide)	Particulate	4921	2.1±0.7	NS	1.5±0.8	NS	1.8±0.9
	Soluble	4921	NS	NS	NS	2.5± 1.7	NS
Bikini Island (seaward reef)	Particulate	1620	1.5±1.5	NS	NS	2.0± 0.3	NS
	Soluble	1620	6.2±5.4	NS	NS	NS	NS
Bikini Island (lagoon)	Particulate	2271	5.6±1.0	NS	NS	0.76± 0.38	1.1±1.1
	Soluble	2271	9.2±6.6	NS	NS	NS	NS
Ocean between Bikini and Enewetak⁰	Particulate	4898	NS	7.7±1.0	NS	NS	NS
	Soluble	4898	NS	NS	NS	NS	NS
Bikini Island (freshwater well)	Particulate	1893	21 ±3	21 ±1	14 ±3.7	NS	NS
	Soluble	1893	54 ±9	990 ±60	<2	<7	34 ±0

*See ref. 11.

†Errors are two-sigma, propagated, counting errors.

‡Particulate—that portion retained by the 0.3 μ filter.

§Soluble—that portion which passes through the 0.3 μ filter and is sorbed by the Al_2O_3 beds.

ΔNS—not significant. The net sample count is less than the two-sigma, propagated counting error.

⁰This sample was collected over a 6 hr period between the following positions: 11°29'5" by 164°53'0" E to 11°24'5" N by 164°18'0" E.

Table 4. $^{239,240}Pu$, ^{238}Pu and ^{241}Am in Surface Soil Samples Collected at Bikini Atoll in 1972, activities in pCi/g ± 1σ.*

Location	$^{239,240}Pu$	^{238}Pu	^{241}Am	$^{239,240}Pu/^{238}Pu$	$^{239,240}Pu/^{241}Am$
Isl-29, Jurukaen	16.3 ±0.5	5.7 ±0.2	3.6 ±0.3	2.86	4.53
Isl-30, Bokoatokutoku	15.1 ±0.7	3.9 ±0.3	4.3 ±0.42	3.87	3.51
Isl-30, Bokoaetokutoku Pisonia Grove	22.2 ±0.5	6.7 ±0.2	7.0 ±0.20	3.31	3.17
Boro Bokororyruru, Isl-31 down center of island	36.4 ±2.3	7.2 ±0.8	13.0 ±1.1	5.05	2.75
Namu, west end - 150 yds	24.0 ±0.1	00.28±0.02	14.0 ±0.4	85.7	1.68
Namu, 200 yds SW of bunker 300 yds E of west tip	20.1 ±0.3	0.24±0.02	11.0 ±0.7	83.8	1.76
Namu, top of bunker center of island	22.9 ±0.7	0.31±0.04	15.0 ±0.05	73.9	1.57
Namu, 200 yds E of bunker, center of island	17.4 ±0.6	0.57±0.11	10.0 ±0.5	30.5	1.68
Bikini, Row 24 center BL to 1st BLN	3.3 ±0.1	0.45±0.04	2.2 ±0.3	7.33	1.50
Bikini, N corner of ctr. BL and Lagoon Beach Rd.	3.41±0.36	N.R.†	.85±0.12	--	4.01
Bikini, Row 34 center BL to 1st BL	3.0 ±0.2	0.06±0.04	2.1 ±0.2	50.0	1.42
Bikini, Row 38 2nd BLN to Lagoon Beach Rd.	2.5 ±0.2	0.07±0.04	1.2 ±0.2	35.7	2.08
Bikini, Row 25 or 26 sand-pile sample, 100 yds S of 2nd BLN	0.50±0.05	N.S.‡	--	--	--
Bikini, Row 34 ctr BL to 1st BLS	10.8 ±0.04	N.R.	3.3 ±0.3	--	3.27
Bikini, Row 24 ctr BL to 1st BLS	13.2 ±0.3	N.R.	8.4 ±0.55	--	1.58
Bikini, Row 24, 1st BLN to Lagoon Beach Rd.	9.3 ±0.4	0.39±0.07	4.1 ±0.2	23.8	2.27
Bikini, Row 34, 1st BLS to 2nd BLS	11.6 ±0.4	0.09±0.02	5.3 ±0.4	128.0	2.18
Bikini, Row 24, 1st BLN to 2nd BLN	7.8 ±0.2	0.20±0.03	3.5 ±0.3	39.0	2.23
Eneman, NW end of island 500-700 mR/hr area	209.2 ±9.0	97.6 ±4.3	24.0 ±1.5	2.14	8.57
Eneman, 500-700 mR/hr area	360.9 ±5.9	174.3 ±2.3	45.0 ±1.0	2.07	8.05

*Single sample error values are one-sigma, propagated, counting errors. See ref. 29.
†N.R. Not resolved by alpha spectroscopy.
‡N.S. Not significant.

As a result, some of the dietary items likely to have the higher radionuclides content, e.g. pandanus and breadfruit, are not actual problems to date. They may or may not be of concern in the future as the plantings mature and the fruit becomes available in quantity. Thus, the diets of people living in these two atolls are expected to change over the coming years reflecting the relative influences of imported and locally grown food items. Allowance has been made for this in development of radiation dose estimates. Experimental studies at Enewetak may yield techniques to interrupt or break the recycling of radionuclides through the vegetation, soil, and ground water systems, and thereby reduce the radioactivity content of some important dietary items. All of the aforementioned factors will necessitate continuing monitoring of the diet for many years. Periodic sampling and analysis of soil and ground water will be necessary in order to establish trends in the changes of radioactivity content of these media.

In the northern Marshalls, drinking water is obtained primarily from rain water catchments. While the radionuclide content of collected rain water will not be zero, this source is not expected to contribute significantly to the radiation exposure picture for future Bikini, Enewetak, and Rongelap Atoll residents. However, rain water which drains from the windward side of building rooftops may provide useful data on resuspension of radioactivity in the soil. The collection of rain water by future Bikini and Enewetak residents is being facilitated by including gutters and water storage tanks in plans for houses and community structures. Some of the larger islands have fresh ground water located only a few feet below the surface. Analysis of this water for its radionuclide content has been limited to date and the capacity of this resource to serve the needs of island residents is not well defined. More study of this water is being supported by ERDA.

Personnel Monitoring

Dose predictions for Bikini and Enewetak Atoll residents derived from environmental data have been deliberately conservative, and establish probable upper limits on doses to be expected for individuals.

Reliable assessments of actual doses must be determined through personnel monitoring. External radiation dosimeters do not appear to be a practical means of personnel monitoring for individual external dose measurements, although certain individuals within given populations may be relied upon to wear them. A "lifestyle model" which includes estimates of occupancy factors for various locations in a given atoll has been coupled with environmental monitoring data to estimate average external radiation doses to individuals. This model will be revised as needed so that it closely approximates the actual lifestyle of the people.

The more important internal pathway can be monitored directly by conventional techniques of bioassay and whole body counting of individuals. A portable shadow shield whole body counter has been constructed and mounted in a shipboard trailer for use in the Marshall Islands. It is capable of quantitative detection of very small quantities of certain radionuclides in the body such as ^{137}Cs and ^{60}Co, the primary environmental gamma emitters at Bikini, Enewetak and Rongelap Atolls. The system clearly identifies individuals in the Rongelap population who are not following the recommended dietary restrictions on eating coconut crabs from certain locations.(42,43) Body burdens of $^{90}Sr/^{90}Y$, $^{239,240}Pu$ and ^{241}Am are estimated by the radiochemical analysis of urine samples. Urine sample collections and whole body counting will be performed every one to two years at Bikini and Enewetak Atolls when the people return, and every two to three years at Rongelap Atoll until the results warrant less frequent measurement intervals.

Summary

Marshall Islands Radiological Followup has consisted of intensive environmental studies at Bikini, Enewetak, and Rongelap Atolls to gather radiological data on the external radiation environment and on radioactivity in food chains. Radiation and radioactivity levels in these atolls are being reduced with time. These changes are monitored in annual or biannual environmental surveys. Updated information is used to make conservative estimates of population doses and dose commitments. When people have returned, actual internal doses to individuals are determined for whole body counting and bioassay data. These results are combined with environmental data on the external radiation environment to complete the total dose assessment picture.

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Radiological Analyses of M.I. Environmental Samples 1974-1976

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RADIOLOGICAL ANALYSES OF MARSHALL ISLANDS ENVIRONMENTAL SAMPLES 1974 - 1976

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Introduction

Brookhaven National Laboratory commenced environmental monitoring of the Marshall Islands for radioactivity in April 1974. Since then, members of the BNL staff have made a total of six field trips to the Marshall Islands to collect a representative cross-section of vegetation, animals, fruits, soil and water found on the islands for the purpose of assessing the radiological effects of the U. S. Pacific Testing Programs.

The surveys covered Kwajalein, Wotho, Bikini, Rongelap and Utirik Atolls. A total of 1200 analyses were performed on 400 samples. In general, all samples were analyzed for Sr-90, Pu-238, Pu-239/240 and any gamma emitters which may have been present at the time of analyses.

Most of the field sampling work was done in conjunction with and in cooperation with a related environmental monitoring program operated by the Laboratory for Radiation Ecology (LRE) of the University of Washington. The results of both programs will be published in a series of joint and separate reports, with emphasis on the terrestrial environment from BNL, and emphasis on the marine food chain from LRE.

Sampling Procedures

The majority of the sampling was done on Bikini, Rongelap and Utirik Atolls. Data obtained from Wotho and Kwajalein provide baseline information concerning the radioactive content of soil, flora and fauna indigenous to the Northern Marshall Islands.

The sampling procedures at Wotho, Kwajalein, Rongelap and Utirik atolls were essentially similar. Samples were obtained in the areas which were inhabited by the Marshallese or in locations which were actual or potential food gathering resources.

Because the Bikinians were only beginning to return to their atoll, the initial monitoring of Bikini Island required a program with a wider scope. At the time BNL started its surveys of Bikini Atoll, two questions required further elucidation. The first was in reference to the external dose that one would receive while living on Bikini Island. The second question dealt with the prediction of internal dose commitments due to ingestion of food products grown on the atoll. Consequently, the monitoring program was designed to thoroughly examine Bikini Island and several other islands in the atoll. Sampling on Bikini Island was conducted in a grid pattern which corresponds to future areas of habitation and food production. Other islands in the atoll were examined in a similarly thorough way to verify initial assumptions regarding the radiological concerns at these locations.

The Bikini Atoll section of the Marshall Islands environmental monitoring program provides the predominant bulk of data presented in this report. Various islands within this atoll were sampled and surveyed in relative proportion to the projected development according to the Bikini Atoll Master Plan (1).

This report concentrates on the results of the environmental monitoring program. The external dose measurements with the use of ion chamber and field gamma spectroscopy will be reported separately as will dose commitment estimates via various internal exposure pathways.

Bikini Atoll

Environmental surveillance of Bikini Atoll was achieved by sampling vegetation, soil, fish, catchment water and sediment. Eneu Island was surveyed for external radiation and sampled for marine fauna, soil and vegetation consisting of Scaveola leaves, Messerschmidia leaves, coconuts and pandanus. Eneu had previously been identified as a potential village island, since it received the least amount of radioactive fallout during the atomic bomb testing. Eneu has also been suggested as the main source of food production for those individuals living on Bikini Island (2,1). Consequently, thorough sampling of this island was essential to establish radionuclide quantities within the food chain.

The island of Nam was considered to be heavily contaminated because of its proximity to the 1954 BRAVO event. Environmental monitoring to date on this island includes samples of mullet and snapper fish, six inch soil cores and soil profiles, scaveola and messerschmidia leaves.

Several food items grown on Bikini Island have been suggested for exclusion from the local diet (3,2). Samples of coconuts, pandanus, breadfruit, arrowroot, scaveola leaves, messerschmidia leaves, pumpkins, squash, bananas and papaya, soil samples in the form of 15 cm cores and 0-100 cm soil profiles, mackerel (fish) and tridacna (clams), plus catchment sediment and water have been collected in an effort to determine their radiological impacts as local marine and terrestrial food items.

Rongelap Atoll

Most of the people living on Rongelap Island have been there since their return three years after the BRAVO incident. They have well established dietary patterns based on availability of various vegetation. The monitoring program for Rongelap attempts to reflect the main constituents of the Rongelap diet. As such, samples were collected from areas where the local inhabitants collected their food.

The three islands of initial interest in Rongelap Atoll were Rongelap, Kabelle and Eniaitok. Samples of Scaveola Leaves were taken from all three islands. Other samples at Eniaitok include breadfruit, pandanus and Messerschmidia leaves. On Rongelap Island, samples consisted of parrot fish, pandanus, Guettarda, breadfruit, arrowroot and coconuts. Soil samples in the form of shallow cores and vertical profiles were also collected.

Utirik Atoll

Previous studies have concluded that Utirik Atoll has received the least amount of radioactive contamination following the BRAVO incident (4, 2, 5) The BNL monitoring program reflected the results of these studies. Consequently, Utirik Island was the only location within the atoll where the food chain was sampled. Samples collected at Utirik consisted of pandanus, breadfruit, arrowroot, coconut, copra and messerschmidia leaves.

Kwajalein and Wotho Atolls

Kwajalein and Wotho Atolls were not involved with close-in radioactive fallout as were other atolls of the Marshall Islands. Consequently, samples from these atolls served as controls. Soil, pandanus, coconut, breadfruit and coconut crabs were collected from Wotho and Kwajalein for purposes of comparison with similar samples collected at Bikini, Rongelap and Utirik Atolls.

Sample Preparation and Analysis

Soil samples were dried at 110°C for a period of 1-2 days. The dried material was then pulverized in a ball mill for approximately 2½ days, and then sieved through an 80 mesh screen. The material which passed through the sieve was used for analysis. An aliquot was packaged in an aluminum can and analyzed for gamma emitters by Ge(Li) or NaI (Tl) gamma spectrometry. Plutonium and $^{90}Sr/^{90}Y$ analyses were performed on aliquots of pulverized soil ashed at 900°C for 12 hours. The ash was dissolved in HNO_3 and the solution evaporated to near dryness (several times, if necessary, to produce a clear solution). The residue was redissolve in HNO_3 and this solution used for the radiochemical isolation of Pu and Sr.

Vegetation was first weighed, dried at 110°C for 1-3 days (depending on sample size and type). The dried material was weighed and pulverized in a blender. After the sample was reduced to a powder, aliquots were packaged for gamma pulse-height analysis. Vegetation samples destined for radiochemical analysis were dry ashed at 485°C. The temperature of the oven was raised slowly over a three day period to 485°C in order to prevent burning of the sample. The ash was dissolved in HNO_3 and evaporated to dryness. The residue was redissolved in HNO_3 and put aside for Pu and Sr analyses. Plutonium was separated from an acid solution of the sample by two ion exchange separation procedures followed by electrodeposition on stainless steel discs. The Pu isotopes are determined by alpha pulse-height analysis and recoveries measured by the use of ^{242}Pu tracer added to the samples prior to analysis.

Strontium-90 content was determined by diethylhexyl phosphoric acid extraction of ^{90}Y from an acid solution of the samples. The ^{90}Y was stripped from the organic phase, separated as the oxalate and counted in a low background beta counter. Yields are determined gravimetrically through the use of yttrium carrier added at the start of the analysis.

Gamma Spectroscopy

Once dried, soil samples were placed in a plastic petri dish and counted on either a NaI(Tl) or Ge(Li) detector. Vegetation, water and animal samples were placed in an aluminum tuna can and counted. Counting time was 4000 seconds for most samples. Both systems were originally calibrated for the tuna can geometry. Correction factors were developed to normalize all petri dish results to the standard tuna can counting geometry. All counting standards are traceable to NBS sources.

Samples counted prior to the middle of 1976 were counted on the NaI(Tl) detector. Samples counted after these dates were counted on the Ge(Li) system. This accounts for the capability to identify the presence of radionuclides such as Am-241, Sb-125, BaLa-140 and Ce-144 in samples where previously only Co-60, Cs-137 and K-40 were positively identified.

Quality Control

BNL operates its own QC program consisting of blind duplicates. BNL also participates in interlaboratory comparisons with HASL, the University of Washington and the IAEA. Results from our program are listed in Table 17.

The first part of this table illustrates all the data from the BNL blind duplicate studies. These data appear to be in reasonable agreement with each other. The second section presents data from a split sample project with the Health and Safety Laboratory (HASL) in New York. These results compare less favorably, but are also in most cases, in reasonable agreement.

Discussion of Results

Reported results of the analyses performed on the Marshall Island samples are presented in Tables 2 through 9 with associated 2-sigma error. The tables have been divided into two sections: results of gamma spectral analyses and ^{90}Sr plus transuranic elements by radiochemistry. Tables 2 through 5 present data on gamma emitting radionuclides found in vegetation, soil, water and animals, while values for ^{90}Sr and the detectable transuranic elements for the same samples are reported in Tables 6 through 8. The data have been ordered so that like samples from the same island are reported together. The results are not arranged by date of sample collection.

In general, there is a wide range of results for each radionuclide within a given sample type. The variation is due to spatial differences in sample site selection and to biological variability between individual organisms sampled. Because the exact sampling sites varied from year to year, there is no correlation between radionuclide concentration and date of sampling. The results in this report provide an aereal evaluation of the islands surveyed. For Bikini Island, vegetation results indicate a radionuclide concentration distribution similar to that reported by Lawrence Livermore Laboratory in their survey reports (3,6,7,8,9).

Soil profile samples confirm the erratic nature of the radionuclide concentrations in soil at the Bikini Atoll. Figures 1 through 14 provide a depth profile for the soil samples taken at Bikini, Nam and Eneu Islands. Soil take from pits F, H, J and K at Bikini, stations W-1 and W-2 at Nam and stations 2 and 3 at Eneu indicate some degree of mechanical turnover in the soil (tilling, plowing, building, etc.) as indicated by the nonexponential distribution of activity within the soil, differences in the depth profile and depth of maximum concentration. Normally, the top layers contain the greatest amount of radioactivity due to initial deposition, otherwise, the strata containing maximum organic matter tend to be the most significant sources.

Soil collected at pits B, G, L and M at Bikini, station #2 at Nam and pit 11 at Eneu display characteristics of typical radionuclide distribution in soil.

There is apparently a decrease in activity in near-surface strata due to migration into lower soil levels and soil erosion. Peak concentrations occur several centimeters below the surface, while the lowest soil strata display an exponential decline of radionuclide concentration similar to patterns examined in the USA at the Hanford Laboratory and the Nevada testing grounds. Figure 15 is a map of Bikini designating the soil sampling locations.

Tables 9 through 16 correlate results from samples common to several locations. The data reported in these tables are average concentrations for all similar samples on an island. No error is reported due to the wide range of values encountered within the values selected and due to the relatively few values available for averaging.

Examination of the comparison data reveals that the ratio of averages between one island and another varies relative to the nuclide selected for a specific sample type. The range of ratios does tend to converge around a single value. For example, if the average results for Bikini Island are used as the numerator of the ratio, and the denominator is chosen to be the results from Rongelap, Eneu and Utirik, the following ratios are observed:

Islands	Ratio
Bikini/Rongelap	4
Bikini/Eneu	10
Bikini/Utirik	20

These ratios correspond to relative concentration differences between Bikini and other islands in the Marshall Islands previously reported by other laboratories.

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Table 1

Sample Description	Wotho Island	Bigej Island	Kwajalein Island	Utirik Island	Eniaitok Island	Kabelle Island	Rongelap Island	Eneu Island	Nam Island	Enidrik Island	Bikini Island
Parrot Fish							X				
Convict Surgeon										X	
Mackerel											X
Tridacna											X
Mullet									X		
Snapper									X		
Coconut Crab			X								
Catchment Sediment											X
Catchment Water											X
Soil-core							X		X		X
Soil-profile								X	X		X
Scaveola leaves					X	X	X	X	X		X
Messerschmidia leaves					X			X	X		X
Guettarda							X				
Coconut	X	X		X			X				X
Pandanus	X			X	X		X	X			X
Breadfruit	X			X	X		X				X
Arrowroot				X			X				X
Pumpkins											X
Bananas											X
Papaya											X
Unidentified Fish								X			
	Wotho Atoll	Kwajalein Atoll		Utirik Atoll	Rongelap Atoll			Bikini Atoll			

Table 2

Location by Island-Atoll

Description	Sample ID	Date	K-40 pCi/g	Cs-137 pCi/g	Co-60 pCi/g
Soil; Bikini-Bikini					
Sample series A, Pit M		4/17/75			
26-35	A-6		<11.64	2.980±0.320	
36-70	A-7		18.26±09.97	2.000±0.320	
71-100	A-8		13.91±07.28	3.400±0.330	
Sample series E, Pit K, 0-2.5 cm	E-1		22.20±12.40	102.900±1.740	1.12±0.61
2.6-5	E-2		20.90±13.79	112.000±1.850	1.59±0.68
6-10	E-3		25.70±17.17	158.000±2.690	2.65±0.87
11-15	E-4			120.000±1.920	
16-25	E-5			91.900±3.130	
26-50	E-6			1.520±0.440	<0.884
51-75	E-7			1.880±0.340	
Sample series F, Pit L, 0-2.5 cm	F-1			146.000±2.480	3.95±0.84
2.6-5	F-2			135.000±2.420	4.54±0.84
6-10	F-3			139.000±2.440	7.24±0.93
11-15	F-4		<24.38	104.000±1.930	4.95±0.79
16-25	F-5		46.74±22.37	85.100±3.380	3.53±1.39
26-50	F-6		<12.65	8.310±0.410	
51-75	F-7			0.934±0.324	
76-100	F-8				0.44±0.41
Sample series G; Grab samples	G-1		26.37±08.88	38.600±0.690	
Sample series H; Pit F, 0-2.5 cm	H-1	4/16/75	74.55±36.94	255.000±4.800	5.49±1.75
2.6-5	H-2			271.000±4.120	6.95±1.35
6-10	H-3			290.000±4.520	8.12±1.49
11-15	H-4		<28.56	225.000±3.700	7.25±1.26
16-30	H-5			183.000±2.850	4.16±1.01
6" core between houses 14 & 15	S-5	4/5/76	8.42±00.13	54.300±0.770	0.84±0.13
6" core 30 yds N. of house #24	S-6			38.800±0.620	0.72±0.17
6" core N. of hot area	S-7		1.18±00.59	169.000±1.590	2.19±0.23
House #40 Dust	D-1			19.700±0.630	

Table 2 (Cont'd.)

Location by Island-Atoll

Description	Sample ID	Date	K-40 pCi/g	Cs-137 pCi/g	Co-60 pCi/g
Soil: Bikini; Bikini					
House #35, Dust	D-2	4/5/76		89.60±2.01	
House #35, Dust	D-2A			90.60±1.44	
House #30, Dust	D-3			79.40±3.39	
House #25, Dust	D-4			59.80±1.65	
House #20, Dust	D-5			53.10±5.71	
House #15, Dust	D-6			92.60±3.90	
House #10, Dust	D-7			141.00±2.57	
Sample series I, Pit B 0-2.5 cm	B-1	4/6/76		263.00±3.72	6.52±1.210
2.6-5	B-2			419.00±6.66	10.70±2.160
6-10	B-3			371.00±6.08	9.41±1.800
11-15	B-4			369.00±5.45	4.11±1.400
16-25	B-5		78.07±14.58	42.80±0.83	
26-35	B-6			3.30±0.32	
Sample series J, Pit G 0-2.5 cm	J-1		24.54±10.14	66.10±0.92	0.95±0.442
2.6-5.0	J-2		10.14±05.56	46.30±0.66	0.99±0.308
6-10	J-3		18.68±07.70	45.10±0.70	0.99±0.361
11-15	J-4		32.08±09.38	25.00±0.54	
16-30	J-5		29.07±09.97	4.68±0.35	
31-50	J-6			8.00±0.20	
51-75	J-7			<0.55	
Sample series K, Pit H 0-2.5 cm	K-1	4/17/75	<49.76	240.00±4.49	
2.6-5	K-2		<31.25	198.00±3.15	2.18±0.990
6-10	K-3		<34.51	197.00±2.97	2.39±0.960
11-15	K-4		<22.95	186.00±2.63	3.27±0.830
16-25	K-5		38.53±15.66	123.00±1.96	2.05±0.740
26-35	K-6		62.99±22.45	154.00±2.51	2.32±1.000
36-60	K-7		41.88±17.42	132.00±2.09	1.84±0.820
61-75	K-8		26.89±13.74	120.89±1.98	2.64±0.760
Sample series L, Pit J 0-2.5 cm	L-1		37.41±15.50	86.40±1.66	
2.6-5	L-2		42.97±15.66	80.20±1.59	
6-10	L-3		21.78±13.99	45.90±0.73	0.98±0.400
11-15	L-4		<16.50	94.00±1.33	2.16±0.520
16-25	L-5		45.90±24.96	276.00±40.5	4.76±1.260

Table 2 (Cont'd.)

Location by Island-Atoll

Description	Sample ID	Date	K-40 pCi/gm	Cs-137 pCi/gm	Co-60 pCi/gm
Soil; Bikini-Bikini (Cont)					
Sample Series L, Pit J (Cont) 26-35cm	L-6	4/17/75	32.67±11.48	60.30±1.300	
36-50	L-7	↓	44.56±12.13	27.20±0.780	
51-70	L-8			12.00±0.520	
Soil; Eneu-Bikini					
Sample series B; Pit. #3		4/14/75			
2.6-5.0	B-6			1.51±0.265	
5.1-7.5	B-4			1.55±0.241	0.53±0.29
7.6-10	B-5			2.00±0.250	
Sample series C; Pit #2 2.6-5cm	C-1	4/14/75		5.30±0.340	
5.1-7.5	C-2			4.51±0.340	
50-55	C-3			3.97±0.360	
61-66	C-5			2.26±3.210	
66-71	C-6			2.14±0.350	
Sample series D; Pit #1					
0-2.5	D-11			5.34±0.360	
5.1-7.5 cm	D-14			7.25±0.380	
7.6-10	D-7			4.25±0.330	
11-15	D-1			1.99±0.270	
16-20	D-6			1.52±0.310	
21-25	D-5			0.84±0.280	
44-48	D-12			1.26±0.320	
49-53	D-4			<0.33	

Table 2 (Cont'd.)

Location by Island-Atoll

Description	Sample ID	Date	K-40 pCi/g	Cs-137 pCi/g	Co-60 pCi/g
Soil: Non-Bikini (Cont)					
6" Core near W-2	S-8	4/7/76			
6" Core near W-1	S-9	↓		10.00±0.340	2.700±0.220
0-40 cm profile; Soil Pit W-1 0-5cm	S-10			12.00±0.450	3.060±0.290
6-10	S-11			03.30±0.220	3.370±0.250
11-15	S-12			04.14±0.290	5.730±0.390
16-25	S-13				
26-40	S-14				
0-50 cm profile; Soil Pit W-2					
11-20	S-17			17.10±0.470	4.820±0.314
21-25	S-18			2.41±0.180	0.670±0.119
35-50	S-19			0.69±0.095	0.219±0.075
6" core, end of east transit	S-20			79.00±1.020	157.000±0.564
6" core, Station E-1	S-21		5.210±1.140	9.38±0.350	7.400±0.380
0-50 cm Composite station E-1	S-22			9.92±0.380	3.890±0.290
6" core between station 1 and 2	S-23			9.49±0.340	3.940±0.280
5 cm composite-3 samples bet. St. 1&2	S-24			23.40±0.520	6.710±0.350
6" core, Station #2	S-25			10.10±0.390	1.390±0.190
5 cm composite-3 samples at St. #2	S-26			13.80±0.420	2.910±0.240
		4/8/76		26.70±0.700	5.730±0.410
0-5	S-27	↓			
6-10	S-28		0.927±0.679	9.74±0.380	1.310±0.180
11-20	S-29			4.52±0.240	0.768±0.135
21-35	S-30			3.58±0.220	0.677±0.121
36-45	S-31			1.63±0.149	0.161±0.064
46-50	S-32			1.54±0.150	
51-60	S-33			0.96±0.106	0.135±0.056
61-70	S-34			0.94±0.107	<0.0807
6" core between shore & St. #W-1	S-35			5.87±0.260	1.380±0.160
6" core between St. #W-1 & W-2	S-36			17.90±0.440	3.360±0.240
5 cm composite-3 samples St. #1 and shore	S-37			11.30±0.340	1.430±0.155
6" core between St. #1 and shoreline	S-38	↓		8.17±0.311	1.420±0.162

Table 2 (Cont'd.)

Location by Island-Atoll

Description	Sample ID	Date	K-40 pCi/g	Cs-137 pCi/g	Co-60 pCi/g
Soil; Rongelap-Rongelap					
9-10 profile (150-200 yds)	S-1	4/3/76		16.50±0.380	0.470±0.085
12" profile last house east end	S-2	↓		10.50±0.462	0.647±0.165
12" profile behind Jabwe's house	S-3			13.40±0.403	0.378±0.090
12" profile last house	S-4			7.08±0.334	0.110±0.065

Table 3

Location by Island-Atoll

Description	Sample ID	Date	K-40 pCi/g	Cs-137 pCi/g	Co-60 pCi/g
Veg. Bikini; Bikini					
Coconut Tree-leaves/North-2nd BL	V-66	4/11/74		321.000±02.780	
Coconut Tree-leaves/South-1st BL	V-72	↓	154.00±060.50	301.000±02.080	
Coconut Tree-leaves/South-2nd BL	V-73		<11.00	318.000±01.320	
Coconut Tree-leaves/Center-Row 34	V-74		411.00±122.00	838.000±05.110	
Coconut Frond North-1st BL	V-82	4/1/74	178.00±045.40	343.000±02.120	
Coconut Frond-North of House #37	V-38	4/16/75	< 9.47	28.200±00.484	
Coconut-Frond Pit C	V-40	↓		55.500±00.783	
Coconut-Frond Pit H	V-42			424.000±18.100	204.0±12.50
Coconut Meat V-120-A	V-120A		3.33±001.31	10.800±00.455	
Coconut Meat V-120-B	V-120B		26.30±005.91	177.000±03.120	
Coconut Milk V-121	V-121		1.17±000.61	0.593±00.082	
Pandanus-leaves North 3rd BL	V-67	4/12/74	18.51±001.47	46.600±00.519	
Pandanus-leaves Pit 4	V-90	↓	16.60±009.42	196.000±01.370	
Pandanus frond lagoon road-Houses 35 & 36	V-31	4/14/75		159.000±02.130	
Pandanus frond 3rd BL - Sea	V-32	4/18/75	52.27±011.73	46.700±00.837	
Pandanus frond house #30	V-34	↓	10.55±001.07	115.700±01.600	
Pandanus fruit-northeast					
Edible	V-89A	4/12/74		327.000±02.340	21.2± 3.43
Inedible	V-89B	↓		284.000±02.460	11.1± 3.62
Core	V-89C		76.80± 12.80	549.000±05.690	
Pandanus fruit-Pit #4					
Edible	V-91A	4/12/74		425.000±02.330	12.0± 3.31
Pandanus fruit-lagoon Rd bet. Houses #35 & 36	V-30	4/14/75	14.91± 2.24	945.000±11.800	
Pandanus fruit-house #30	V-35	4/18/75		422.000±05.210	
Pandanus fruit-lagoon road behind house #30	V-36	4/16/75		434.000±05.070	

Table 3 (Cont'd.)

Location by Island-Atoll

Description	Sample ID	Date	K-40 pCi/g	Cs-137 pCi/g	Co-60 pCi/g
Veg. Bikini-Bikini (Cont)					
Scaveola leaves-North	V-68	4/12/74		110.0 ±01.030	
Scaveola leaves House #30	V-71	4/16/75		111.00±02.840	
Scaveola leaves Pit A	V-1	4/18/75	<12.82	137.00±02.070	
Scaveola leaves Pit B	V-2	↓		1460.00±21.800	
Scaveola leaves Pit C	V-3	↓		483.00±06.860	
Scaveola leaves Pit D	V-4	↓		418.00±05.790	
Scaveola leaves Pit E	V-5	↓		352.00±04.980	
Scaveola leaves Pit F	V-6	↓		243.00±03.370	
Scaveola leaves Pit G - Row 14	V-7	↓		393.00±05.740	
Scaveola leaves Pit H - 3rd b/1-N	V-8	↓		1103.00±16.300	
Scaveola leaves Pit L	V-9	↓	25.97±13.99	179.00±02.430	
Scaveola leaves Pit M	V-10	↓	27.48±10.89	098.20±01.440	
Scaveola leaves Pit N	V-11	↓	16.75±06.76	092.30±01.290	
Scaveola leaves near Palm Tree	V-12	4/16/75	13.99±07.84	130.00±01.770	
Scaveola leaves near USGS Well	V-13	↓	14.41±09.52	172.00±02.350	
Immature Pandanus-House #35					
Fruit	V-3A	4/5/76		649.00±05.790	17.40±5.50
Core	V-3B	↓		1120.00±10.700	
Stem	V-3C	↓	<48.50	706.00±08.280	
Inedible	V-3D	↓		648.00±06.170	11.70±6.35
Pumpkin-House #40					
Flesh	V-2A	4/5/76	25.70±07.94	326.00±02.510	11.50±2.61
Seed	V-2B	↓		126.00±01.070	
Skin	V-2C	↓	20.90±05.87	228.00±01.740	4.32±2.13
Squash-House #29	V-51	4/14/75	37.28±10.81	232.00±03.510	
Arrow Root Tubers E of House #4	V-52	4/17/75		1250.00±19.800	
Banana Fruit behind House #24	V-53	↓	11.73±02.24	30.20±00.330	
Banana Skin behind House #24	V-54	↓	32.08±05.44	56.90±00.973	
Breadfruit leaves Pit I	V-55	4/18/75	65.84±13.24	29.70±00.985	
Immature breadfruit behind House #34	V-4	4/5/76	17.60±05.27	159.00±01.370	
Immature breadfruit bet. H.16&17	V-6	↓	13.60±02.85	85.30±00.730	
Breadfruit-composite of samples between Houses #8 & 9	V-7	4/6/76		191.00±01.860	

Table 3 (Cont'd.)

Location by Island-Atoll

Description	Sample ID	Date	K-40 pCi/g	Cs-137 pCi/g	Co-60 pCi/g
Messerschmidia leaves- 3 BL N.	V-75	4/12/74	543.00±23.00	132.0±0.905	
Messerschmidia leaves Pit H	V-76	3/18/75		713.0±6.100	25.8±6.10
Messerschmidia leaves Pit A	V-17	4/18/75	9.80±03.90	27.1±0.480	<0.622
Messerschmidia leaves Pit C	V-18	↓		544.0±7.980	
Messerschmidia leaves Pit G	V-19	↓		227.0±3.370	
Messerschmidia leaves Pit I	V-20	↓		448.0±6.540	
Messerschmidia leaves Pit M	V-21	↓	<71.04	493.0±6.880	
Messerschmidia leaves Pit N	V-22	↓		535.0±6.650	
Messerschmidia leaves South road NW of Bunke	V-23			715.0±9.540	
Messerschmidia leaves - USGS well	V-24	4/16/75	33.80±10.30	204.0±2.570	
Papaya Meat	V-102	4/4/74		155.0±1.610	
Papaya (Immature) N of House #25					
Fruit	V-5A	4/5/76	32.40±06.32	98.7±1.020	
Skin	V-5B	↓		87.6±1.520	
Papaya Skin & Seeds	V-103	4/4/74	<25.00	153.0±1.670	
Papaya Seeds - behind House #24	V-48	4/14/75		447.0±6.030	
Papaya Seeds - behind House #24	V-50	↓	<22.87	308.0±4.520	
Papaya Fruit - behind House #24	V-47	↓	<31.08	762.0±12.10	
Papaya Fruit - behind House #24	V-49	↓	<27.64	677.0±9.570	

Table 3 (Cont'd)

Location by Island-Atoll

Description	Sample	Date	K-40 pCi/g	Cs-137 pCi/g	Co-60 pCi/g
Vegetation: Eneu-Bikini					
Scaveola leaves Pit #1	V-14	4/14/75	16.92±6.53	41.40±0.614	<0.489
Scaveola leaves Pit #2	V-15		13.24±4.89	16.30±0.450	<0.529
Scaveola leaves Pit #3	V-16		< 5.78	9.15±0.302	<0.446
Messerschmidia leaves Pit #1	V-25		9.88±4.47	48.70±0.670	6.672±0.331
Messerschmidia leaves Pit #2	V-26		17.42±9.39	78.30±1.140	
Messerschmidia leaves Pit #3	V-27		18.09±8.45	57.40±0.854	
Messerschmidia fruit Pit #1	V-28		16.92±4.60	54.80±0.819	
Messerschmidia fruit Pit #3	V-29		24.54±8.48	85.10±1.390	<1.000
Pandanus-frond: Camp Blardy, lagoon road	V-56	4/15/75	<15.33	29.00±0.711	
Vegetation: Nam-Bikini					
Scaveola near soil pit at St #W-2	V-8	4/7/76		332.00±2.970	7.370±3.440
Scaveola between St. #W-1 & W-2	V-10			213.00±2.000	5.180±2.530
Scaveola near soil pit at St. #W-1	V-14			501.00±5.170	22.900±4.980
Scaveola midway between beach & St. #W-1	V-15		10.30±2.39	35.60±0.474	
Scaveola beyond E-2-end of east t/a	V-17		12.00±5.65	140.00±1.560	6.300±2.020
Scaveola near E-2; east transect	V-19		11.90±3.72	83.10±0.721	
Scaveola between E-1 & E-2	V-20			54.30±0.740	5.040±1.070
Scaveola near E-1 (East transect)	V-23		7.95±3.96	56.60±0.876	5.080±1.270
Scaveola between shore & E-1	V-24	4/8/76	11.20±2.79	54.40±0.645	<1.040
Messerschmida at St. #W-2	V-9	4/7/76		262.00±2.970	8.900±3.500
Messerschmida between W-1 & W-2	V-11		15.40±9.48	334.00±3.290	
Messerschmida near St. #W-1	V-12			572.00±3.640	12.700±3.660
Messerschmida near soil pit, W-1	V-13			585.00±4.580	
Messerschmida midway between beach & W-1	V-16		11.00±4.85	24.60±1.160	<2.040
Messerschmida East transect near E-2	V-18		12.50±6.70	112.00±1.780	6.740±2.320
Messerschmida " between E-1&E-2	V-21		8.64±4.20	95.70±1.060	
Messerschmida " near E-1	V-22		15.20±5.37	93.40±1.130	
Messerschmida " between shore & E-1	V-25	4/8/76	8.39±3.52	60.20±0.768	<1.930

Table 3 (Cont'd)

Location by Island-Atoll

Description	Sample ID	Date	K-40 pCi/g	Cs-137 pCi/g
Vegetation: Bigej-Kwajalein				
Coconut Milk	V-109	4/12/75	2.56±0.734	<0.048
Coconut Meat	V-110	↓	10.70±1.950	0.134±0.072
Vegetation: Rongelap-Rongelap				
Scaveola leaves sea side, church	V-77	4/4/74	9.45±1.720	9.130±0.210
Guettarda leaves sea side, church	V-63	↓	12.15±2.370	7.810±0.227
Breadfruit leaves, Tree #2, cntrofvil	V-64		13.07±3.040	42.600±0.500
Breadfruit leaves westend	V-65	4/5/74		10.800±0.265
Breadfruit leaves eastend	V-79	4/4/74	8.09±1.830	23.900±0.300
Breadfruit skin & core westend	V-95	↓		19.200±1.030
Breadfruit skin & core eastend	V-97		10.20±2.480	23.500±0.350
Breadfruit skin, core: Tree #2	V-99		10.80±2.040	47.800±0.431
Breadfruit Meat: Tree #2	V-100		6.54±2.300	41.700±0.459
Breadfruit Meat: eastend	V-98		6.86±1.820	19.800±0.265
Breadfruit Meat: westend	V-96	4/5/74	20.50±4.510	22.900±0.541
Breadfruit	V-27	4/3/76	10.40±1.860	35.300±0.372
Arrowroot	V-101A	4/4/74		19.900±0.470
Arrowroot	V-101B	↓		41.600±1.410
Coconut copra	V-70		04.89±1.520	15.900±0.200
Coconut frond; Tree #1 eastend	V-83			10.700±0.220
Coconut Meat	V-114	4/12/75	14.60±4.540	08.750±0.781
Coconut Meat	V-116	↓	37.30±9.660	36.800±2.120
Coconut Meat	V-122		12.70±2.480	12.000±0.540
Coconut Milk	V-115		2.19±0.750	1.000±0.110
Coconut Milk	V-116		3.14±0.890	1.790±0.163
Pandanus leaves; Tree #1 eastend	V-62	4/4/74	14.24±2.840	65.300±0.570
Pandanus Fruit	V-26D1	4/3/76	19.90±5.760	08.000±0.930
Core	V-26D2	↓	7.44±1.930	21.000±2.050
Inedible	V-26D3			61.900±0.430

Table 3 (Cont'd.)

Location by Island-Atoll

Description	Sample ID	Date	K-40 pCi/g	Cs-137 pCi/g	Co-60 pCi/g
<u>Veg. Rongelap-Rongelap (Cont)</u>					
Pandanus Fruit	V-26C1	4/3/76		117.00±1.270	6.23±1.65
Stem	V-26C2	↓		120.00±1.170	
Core	V-26C3	↓	33.60±09.04	235.00±2.060	
Inedible	V-26C4	↓	11.10±05.04	89.30±1.040	
Pandanus Fruit	V-26B1	↓	15.00±01.84	69.90±0.430	
Stem	V-26B2	↓	31.90±05.90	56.20±0.820	
Core	V-26B3	↓	63.40±17.00	96.60±1.540	
Inedible	V-26B4	↓	12.10±02.26	39.20±0.400	
Pandanus Fruit	V-26A1	↓	3.17±01.18	18.70±0.200	
Stem	V-26A2	↓		35.30±1.650	
Core	V-26A3	↓		50.70±1.290	
Inedible	V-26A4	↓	6.09±02.50	10.80±0.200	
Pandanus Fruit - edible Tree #2	V-86A	4/4/74	9.65±01.25	23.50±0.240	<0.87
Inedible - Tree #2	V-86B	↓	7.54±01.88	12.30±0.240	
Pandanus Fruit Edible	V-85A	4/5/74	6.63±01.37	38.20±0.300	
Inedible	V-85B	↓	11.00±02.29	25.60±0.340	
Pandanus Fruit Edible Tree #1 E	V-84	4/4/74	<4.13	72.40±0.640	
Inedible	V-84A	↓		58.50±0.600	
Pandanus Fruit Edible	V-26E1	4/3/76	10.80±03.30	72.30±0.670	
Core	V-26E2	↓	29.80±09.80	112.00±1.230	
Inedible	V-26E3	↓	11.00±02.60	50.60±0.440	
<u>Vegetation Enialtok-Rongelap</u>					
Scaveola leaves; oceanside	V-69	4/6/74	9.30±01.69	3.73±0.174	
M.ascrschmidia leaves; oceanside	V-78	↓	7.48±02.36	22.60±0.310	
Bread Fruit leaves	V-80	↓	8.23±01.81	14.90±0.243	
Pandanus Fruit-Edible	V-88A	↓		191.00±1.410	13.7±2.03
Coconut Meat	V-118	4/12/75	6.65±01.60	5.26±0.320	
Coconut Milk	V-119	↓		1.01±0.143	
<u>Vegetation Kabelle-Rongelap</u>					
Scaveola leaves	V-81	4/6/74	17.80±01.72	15.70±0.240	
<u>Vegetation Utirik-Utirik</u>					
Pandanus Fruit-Edible	V-87	4/1/74	1.58±01.32	20.20±0.214	<0.89
Inedible	V-87A	↓	7.69±02.53	21.20±0.310	

Table 3 (Cont'd.)

Location by Island-Atoll

Description	Sample ID	Date	K-40 pCi/g	Cs-137 pCi/g
Veg. Utirik-Utirik (Cont)				
Breadfruit skin & core: Jakas House	V-92	4/5/74	17.70±2.26	11.90±0.265
Breadfruit Edible: Jakas House	V-93	4/5/74	13.00±1.06	9.37±0.144
Arrowroot - skin east end island	V-94A	4/1/74		16.20±3.840
		↓		
Coconut Copra	V-104			6.71±0.210
Vegetation Wotho: Wotho				
Pandanus Fruit - edible	V-106A		7.88±2.80	3.46±0.262
Breadfruit skin & core	V-107	4/19/75		
Breadfruit meat	V-108	↓	9.55±1.92	1.04±0.143
Coconut milk	V-111			1.36±0.260
Coconut meat	V-112		3.74±1.04	1.10±0.120

Table 4

Location by Island-Atoll

Description	Sample ID	Date	K-40 pCi/g	Cs-137 pCi/g
Catchment Sediment-Bikini				
House #35	Sediment #1	4/5/76		19.20 ±2.04
House #30	Sediment #2			63.00 ±1.93
House #25	Sediment #3			38.40 ±3.09
House #15	Sediment #5A			42.80 ±1.09
House #15-1	Sediment #2B			36.30 ±1.21
House #20	Sediment #4			18.00 ±0.72
House #10	Sediment #6			20.50 ±1.20
WATER - Bikini				pCi/l
W-4	W-4	4/6/76		1.920±0.346
W-5	W-5			0.681±0.315
W-1	W-1	4/4/76		$1.06 \times 10^{-4} \pm 9.71 \times 10^{-5}$

Table 4 (Cont'd)

Location by Island-Atoll

Description	Sample ID	Date	Co-60
<u>Catchment Sediment - Bikini</u>			
House #35	Sediment #1	4/5/76	Not detectable
House #30	Sediment #2	↓	↓
House #15	Sediment #5A	↓	↓
House #10	Sediment #6	↓	↓
House #20	Sediment #4	↓	↓
House #15-1	Sediment #5B	↓	↓
<u>Bikini at Eneu</u>			↓
Water W-1	W-1	4/4/76	↓
<u>Soil: Bikini at Bikini</u>	E-4	4/17/75	↓
Sample Series E, Pit K	E-5	↓	↓
	E-6		↓
<u>Animal: Bikini-Bikini</u>			↓
Mullet (Viscera)	F-1C	12/8/74	↓

Table 5

Location by Island-Atoll

Description	Sample ID	Date	K-40 pCi/g	Cs-137 pCi/g	Co-60 pCi/g
Animal, Bikini - Bikini					
Mackerel (Scales) Lagoon	F-6A	12/8/74	10.60±3.02		1.610±0.461
Mackerel (Flesh) Lagoon	F-6B	↓	19.40±3.47	0.608±0.126	2.570±0.337
Mackerel (Viscera) Lagoon	F-6C	↓	11.90±3.95		5.070±0.933
Mackerel (bones, gills, head) Lagoon	F-6D	↓	5.49±2.21		1.580±0.452
Tridacna Lagoon	F-7	4/16/75	11.40±2.49		1.210±2.210
Animal, Bikini-Eneu					
Fish (Scales)	F-3A	4/14/75	11.90±2.35		1.420±0.288
			11.50±2.17		1.320±0.266
Animal, Bikini-Nam					
Mullet (Flesh)	F-1A	12/8/74	9.34±1.97		2.390±0.349
			10.10±2.14		2.610±0.381
Mullet (Bone)	F-1B	↓			1.650±0.456
Mullet (Viscera)	F-1C	↓	7.00±3.00		8.870±1.120
Mullet (Fin, Scaler)	F-1D	↓	4.05±1.62	0.433±0.161	3.320±0.480
		12/8/74	4.38±1.76	0.481±0.170	3.060±0.440
Snapper (Scales)	F-4A	↓	8.05±1.48		1.630±0.241
Snapper (Flesh)	F-4B	↓	16.90±2.22		1.120±0.233
Snapper (Viscera)	F-4C	↓	7.22±1.68		4.520±0.445
			6.67±1.55		4.170±0.411
Snapper (Bone)	F-4D		3.54±1.14		0.901±0.174
Animal, Bikini-Endjrik					
Conv. Surg (Scales) West End Reef	F-5A	12/9/74	4.38±1.23		1.980±0.264
Conv. Surg (Flesh) "	F-5B	↓	15.00±2.04		1.770±0.254
Conv. Surg (Viscera) "	F-5C	↓	5.78±1.44		3.330±0.350
Conv. Surg (Bones) "	F-5D	↓	3.03±1.29		1.650±0.263
Animal, Kwajalein, Kwaj					
Coconut Crab (Shell)	F-8A	12/9/74			
Coconut Crab (Meat)	F-8B	↓	13.40±2.56	0.674±0.139	
Coconut Crab (Viscera)	F-8C	↓	8.34±1.96	0.481±0.112	
Animal, Rongelap-Rongelap					
Parrot Fish (Flesh)	F-2A	12/8/74	17.70±2.58		
Parrot Fish (Scales)	F-2B	↓	9.36±2.33		
Parrot Fish (Bone)	F-2C	↓	5.29±1.72		
Parrot Fish (Viscera)	F-2D	↓	4.60±1.42		

Table 6

Location by Island-Atoll

Description	Sample ID	Date	Sr-90 pCi/g	Pu-238 pCi/g	Pu-239/240 pCi/g	Am-241 pCi/g
Soil; Bikini-Bikini						
Sample series A, Pit M 0-2.5 cm	A-1	4/17/75	81.34±0.81		16.09±2.20	
2.6-5.0	A-2		67.16±0.74		09.04±1.80	
6-10	A-3		39.76±0.40		04.18±0.80	
11-15	A-4		37.62±0.38		02.29±0.46	
15-25	A-5		30.32±0.30		0.52±0.15	
26-35	A-6		21.14±0.27		0.32±0.10	
36-70	A-7		21.72±0.22		0.10±0.03	
71-100	A-8		8.54±0.12		0.04±0.04	
Sample series E, Pit K 0-2.5 cm	E-1		94.01±0.94		10.23±0.07	
2.6-5	E-2		120.36±1.21		1.18±0.24	
6-10	E-3		150.99±1.51		14.94±2.98	
11-15	E-4		101.53±1.02		4.75±0.96	
16-25	E-5		131.62±1.32		4.88±0.98	
26-50	E-6		54.05±0.54		0.198±0.06	
51-75	E-7		1.61±0.07		0.092±0.09	
76-100	E-8		0.16±0.01		0.014±0.01	
Sample series F, Pit L 0-2.5 cm	F-1		162.66±1.63		22.56±2.52	
2.6-5	F-2		216.85±2.19		29.03±2.80	
6-10	F-3		323.11±3.23		42.32±2.40	
11-15	F-4		257.25±2.57		27.50±1.50	
16-25	F-5		159.28±1.59		6.89±1.38	
26-50	F-6		21.35±0.36		0.102±0.03	
51-75	F-7		6.05±0.15		0.025±0.02	
76-100	F-8		1.88±0.09		0.014±0.01	
Sample series G; Grab samples	G-1		14.39±0.17		2.020±0.40	
Sample series H; Pit F 0-2.5 cm	H-1	4/16/75	520.27±5.28		44.92±2.01	
2.6-5	H-2		527.52±5.73		48.24±2.60	
6-10	H-3		573.42±5.73		46.94±2.40	
11-15	H-4		562.61±5.63		40.69±4.00	
16-30	H-5		394.59±3.95		23.01±2.22	
31-50	H-6		10.67±0.17		0.042±0.40	
51-70	H-7		4.66±0.12		0.018±0.20	
6" core between houses 14 & 15	S-5	4/5/76	45.06±0.49			
6" core 30 yds N. of house #24	S-6		77.00±0.63			
6" core N. of hot area	S-7		123.68±0.74			7.41±0.96
House #40 Dust	D-1		7.16±0.15	0.106±0.021	1.829±0.082	

Table 6 (Cont'd.)

Location by Island-Atoll

Description	Sample ID	Date	Sr-90 pCi/g	Pu-238 pCi/g	Pu-239 Pu-240 pCi/g
Soil: Bikini; Bikini					
House #30, Dust	D-3	4/5/76	26.41±1.08		
House #25, Dust	D-4				
House #20, Dust	D-5		29.11±1.69	.283±0.066	1.720±0.20
House #15, Dust	D-6				
House #10, Dust	D-7		43.04±0.67	.027±0.020	3.569±0.41
Sample series I, Pit B 0-2.5 cm	B-1	4/6/76	578.83±5.79		39.810±2.90
2.6-5	B-2		535.14±5.35		53.600±2.71
6-10	B-3		869.34±8.69		60.180±2.33
11-15	B-4		565.32±5.65		21.730±2.15
16-25	B-5		242.72±2.43		1.320±0.50
26-35	B-6		22.10±0.22		0.220±0.20
36-50	B-7		0.46± -		0.009 -
51-75	B-8		0.36± -		0.014 -
Sample series J, Pit G 0-2.5 cm	J-1		38.84±0.39		6.530±0.53
2.6-5.0	J-2		45.50±0.46		7.140±1.14
6-10	J-3		35.54±0.36		6.030±0.72
11-15	J-4		42.18±1.01		4.760±0.50
16-30	J-5		37.36±0.41		5.920±0.66
31-50	J-6		14.82±0.34		-
51-75	J-7		1.80± -		0.023±0.03
Sample series K, Pit H 0-2.5 cm	K-1	4/17/75	198.33±1.98		16.250±1.25
2.6-5	K-2		191.85±1.92		17.300±1.55
6-10	K-3		175.32±1.75		15.730±0.98
11-15	K-4		193.87±1.94		19.100±0.81
16-25	K-5		180.36±1.80		14.620±1.15
26-35	K-6		206.44±2.06		15.280±1.00
36-60	K-7		205.14±2.05		12.910±0.83
61-75	K-8		191.58±1.92		12.140±2.02
76-100	K-9		24.15±0.24		0.135 -
Sample series L, Pit J 0-2.5 cm	L-1		135.54±1.36		7.890±0.77
2.6-5	L-2		88.42±0.89		7.830±0.94
6-10	L-3		60.45±0.61		5.120±0.68
11-15	L-4		108.65±1.09		13.060±1.52
16-25	L-5		373.69±3.74		24.970±1.09

Table 6 (Cont'd.)

Location by Island-Atoll

Description	Sample ID	Date	Sr-90 pCi/g	Pu-238 pCi/g	Pu-239 Pu-240 pCi/g
Soil; Bikini-Bikini (Cont)					
Sample Series L, Pit J (Can) 26-35cm	L-6	4/17/75	251.94±2.520		2.000±0.03
36-50	L-7	↓	149.00±1.490		0.068± -
51-70	L-8		28.80±0.290		0.012± -
71-100	L-9		0.36±0.020		
			0.57±0.040		0.004± -
101-120	L-10		0.90± -		0.009± -
Soil; Eneu-Bikini					
Sample series B; Pit. #3 30-35cm	B-1	4/14/75	0.41± -		0.004± -
0-2.5	B-2	↓	1.24±0.074		0.160±0.10
61-66	B-3		0.45± -		0.005± -
5.1-7.5	B-4		1.08±0.060		0.270±0.25
7.6-10	B-5		1.61±0.070		0.250±0.20
2.6-5.0	B-6		1.16±0.080		0.180±0.10
Sample series C; Pit #2 2.6-5cm	C-1	4/14/75	3.18±0.110		0.670±0.55
5.1-7.5	C-2	↓	3.16±0.100		0.560±0.25
50-55	C-3		3.82±0.070		0.840±0.24
			3.84±0.130		
7.6-10	C-4		3.00±0.080		0.640±0.30
			4.12±0.140		
61-66	C-5		3.91±0.070		0.090± -
			4.30±0.160		
66-71	C-6		10.44±0.120		0.050± -
			9.78±0.180		
86-91	C-7		8.38±0.150		0.009± -
			5.38±0.120		0.008± -
0-2.5	C-8		4.13±0.080		0.710±0.60
			4.46±0.130		
35-40	C-9		6.21±0.110		1.280±0.33
			5.37±0.130		

Table 6 (Cont'd.)

Location by Island-Atoll

Description	Sample ID	Date	Sr-90 pCi/g	Pu-238 pCi/g	Pu-239 Pu-240 pCi/g
Soil: Bikini-Bikini (Cont)					
Sample series D; Pit #1 11-15cm	D-1				0.345±0.27
			3.92±0.070		0.210±0.15
86-91	D-2		0.45± -		0.004± -
59-63	D-3		1.34±0.060		0.014± -
49-53	D-4		2.64±0.090		0.045± -
21-25	D-5		5.41±0.010		0.354±0.33
16-20	D-6		5.32±0.010		0.302±0.30
7.6-10	D-7		10.51±0.170		1.670±0.80
			6.34±0.150		
2.6-5.6	D-8		7.42±0.150		0.562±0.39
54-58	D-9		1.90±0.100		0.023± -
38-43	D-10		4.78±0.110		0.116±0.12
0-2.5	D-11		7.65±0.150		0.923±0.44
44-48	D-12		3.36±0.100		0.080± -
Not Present	D-13		-		-
5.1-7.5 cm	D-14		11.80±0.390		1.900±0.67

Table 6 (Cont'd.)

Location by Island-Atoll

Description	Sample ID	Date	Sr-90 pCi/g	Pu-238 pCi/g	Pu-239/240 pCi/g	Am-241 pCi/g
Soil: Nam-Bikini (Cont)						
6" Core near W-2	S-8	4/7/76	53.89±0.53			
			55.57±0.79			
6" Core near W-1	S-9		35.25±0.42			11.90±0.58
0-40 cm profile; Soil Pit W-1 0-5cm	S-10		22.74±0.50			10.80±0.69
6-10	S-11		27.17±0.54			11.30±0.56
11-15	S-12		56.47±0.76			21.90±0.921
16-25	S-13		261.59±1.17			
26-40	S-14		57.19±0.54			
0-50 cm profile; Soil Pit W-2 0-5cm	S-15		51.74±0.79			
			49.52±0.50			
			48.63±0.50			
6-10	S-16		69.43±0.60			
11-20	S-17		68.04±0.57			
21-25	S-18		47.51±0.50			
35-50	S-19		37.45±0.44			
6" core, end of east transit	S-20		183.80±1.00			50.10±1.35
6" core, end of east transit	S-20		186.74±1.45			NA
6" core, Station E-1	S-21		58.59±0.56			11.20±0.62
0-50 cm Composite station E-1	S-22		67.74±0.61			11.00±0.71
6" core between station 1 and 2	S-23		54.10±0.51			15.70±0.70
5 cm composite-3 samples bet.St.1&2	S-24		105.57±0.74			19.70±0.87
6" core, Station #2	S-25		75.30±0.64			01.62±0.45
6" core, Station #2	S-25		84.22±1.02			NA
5 cm composite-3 samples at St. #2	S-26		98.70±0.71			
0-70 cm profile; St. #2 soil pit	S-27	4/8/76	75.30±0.62			
0-5 cm			77.01±0.64			
0-5	S-27		83.80±1.41			
6-10	S-28		14.62±0.39			2.74±0.48
11-20	S-29		14.69±0.39			
21-35	S-30		9.93±0.33			
36-45	S-31		4.54±0.22			
46-50	S-32		3.33±0.19			
51-60	S-33		3.00±0.17			
61-70	S-34		2.72±0.16			
6" core between shore & St. #W-1	S-35		24.46±0.51			10.60±0.56
6" core between St. #W-1 & W-2	S-36		25.88±0.50			9.33±0.55
5 cm composite-3 samples St.#1 and shore	S-37		15.10±0.41			6.32±0.45
6" core between St. #1 and shoreline	S-38		14.22±0.36			.15±0.37

Table 6 (Cont'd.)

Location by Island-Atoll

Description	Sample ID	Date	Sr-90 pCi/g	Pu-238 pCi/g	Pu-239/240 pCi/g	Am-241 pCi/g
Soil; Bigej-Kwajalein						
Sample series M	M-1	4/12/75	0.41± -		0.002± -	
Soil; Rongelap-Rongelap						
9-10 profile (150-200 yds)	S-1	4/3/76	20.89±0.34			
			21.26±0.59			
12" profile last house east end	S-2	↓	20.09±0.33			1.82±0.443
12" profile behind Jabwe's house	S-3	↓	12.96±0.26			
12" profile last house	S-4	↓	6.27±0.18			

Table 7

Location by Island-Atoll

Description	Sample ID	Date	Sr-90 pCi/g	Pu-238 pCi/g	Pu-239/240 pCi/g
Veg. Bikini; Bikini					
Coconut Frond-North of House #37.	V-38	4/16/75	34.21±0.620		0.125±0.10
Coconut-Frond Pit C	V-40	↓	13.85±0.300		0.097± -
Coconut-Frond Pit H	V-42		34.73±0.450		0.029± -
Pandanus frond lagoon road-Houses 35 & 36	V-31	4/14/75	402.16±4.020		0.044± -
Pandanus frond 3rd BL - Sea	V-32	4/18/75	260.27±2.600		0.031± -
Pandanus frond house #30	V-34	↓	41.46±0.456		0.074± -
Pandanus fruit-lagoon Rd bet. Houses #35 & 36	V-30	4/14/75	199.32±1.990		0.010± -
Pandanus fruit 3rd-baseline	V-33	4/18/75	193.60±1.936		0.001± -
Pandanus fruit-house #30	V-35	↓	38.32±0.380		0.002± -
Pandanus fruit-lagoon road behind house #30	V-36	4/16/75	34.17±0.342		0.010± -
Messerschmidia leaves Pit A	V-17	4/18/75	14.62±0.16		0.070± -
Messerschmidia leaves Pit C	V-18	↓	113.60±1.14		0.182±0.12
Messerschmidia leaves Pit G	V-19		35.20±0.35		0.417±0.29
Messerschmidia leaves Pit I	V-20		97.75±0.98		0.459±0.21
Messerschmidia leaves Pit M	V-21		384.05±3.84		0.853±0.38
Messerschmidia leaves Pit N	V-22		104.19±1.04		0.671±0.31
Messerschmidia leaves South road NW of Bunker	V-23		56.67±0.57		0.181±0.11
Messerschmidia leaves - USGS well	V-24	4/16/75	110.54±1.11		0.985±0.60
Papaya (immature) N of House #25 Fruit	V-5A	4/5/76	7.09±0.20		
Papaya Fruit - behind House #24	V-47	4/14/75	79.19±0.87		0.001± -
Papaya Fruit - behind House #24	V-49	↓	74.28±0.74		0.009± -

Table 7 (Cont'd.)

Location by Island-Atoll

Description	Sample ID	Date	Sr-90 pCi/g	Pu-238 pCi/g	Pu-239 Pu-240 pCi/g
Veg. Bikini-Bikini (Cont)					
Scaveola leaves Pit A	V-1	4/18/75	47.07±0.47		0.115±0.12
Scaveola leaves Pit B	V-2	↓	168.56±1.69		0.180±0.18
Scaveola leaves Pit C	V-3	↓	162.93±1.63		0.156±0.16
Scaveola leaves Pit D	V-4	↓	127.39±1.27		0.070± -
Scaveola leaves Pit E	V-5	↓	80.90±0.81		0.522±0.53
Scaveola leaves Pit F	V-6	↓	37.64±0.38		0.366±0.40
Scaveola leaves Pit G - Row 14	V-7	↓	50.54±0.51		0.248±0.25
Scaveola leaves Pit H - 3rd b/1-N	V-8	↓	166.89±1.67		0.358±0.39
Scaveola leaves Pit L	V-9	↓	124.60±1.25		0.148±0.15
Scaveola leaves Pit I	V-9-1	↓	155.05±1.55		0.145±0.15
Scaveola leaves Pit M	V-10	↓	49.23±0.49		0.931±0.58
Scaveola leaves Pit N	V-11	↓	38.64±0.39		0.014± -
Scaveola leaves near Palm Tree	V-12	4/16/75	31.35±0.31		0.080± -
Scaveola leaves near USGS Well	V-13	↓	39.66±0.40		0.205±0.20
Immature Pandanus-House #35					
Fruit	V-3A	4/5/76	172.36±1.09		
Inedible	V-3B	↓	64.08±0.64		
Pumpkin-House #40					
Flesh	V-2A	4/5/76	9.62±0.22		
Squash-House #29	V-51	4/14/75	5.31±0.14		0.003± -
Arrow Root Tubers E of House #4	V-52	4/17/75	9.69±0.85		0.239±0.15
Banana Fruit behind House #24	V-53	↓	9.33±0.23		0.002± -
Banana Skin behind House #24	V-54	↓	90.00±0.90		0.018± -
Breadfruit leaves Pit I	V-55	4/18/75	377.88±3.78		0.148±0.12
Immature breadfruit behind House #34	V-4	4/5/76	80.97±0.65		
Immature breadfruit bet. H.16&17	V-6	↓	41.31±0.35		
Breadfruit-composite of samples between Houses #8 & 9	V-7	4/6/76	48.09±0.58		

Table 7 (Cont'd.)

Location by Island-Atoll

Description	Sample	Date	Sr-90 pCi/g	Pu-239/Pu-240 pCi/g
Vegetation: Eneu-Bikini				
Scaveola leaves Pit #1	V-14	4/14/75	14.69±0.210	0.007±
Scaveola leaves Pit #2	V-15		6.11±0.150	0.009± -
Scaveola leaves Pit #3	V-16		1.82±0.075	0.023± -
Messerschmidia leaves Pit #1	V-25		19.42±0.290	0.001± -
Messerschmidia leaves Pit #2	V-26		50.81±0.510	-
Messerschmidia leaves Pit #3	V-27		37.24±0.370	0.010± -
Messerschmidia fruit Pit #1	V-28		4.38±0.350	0.004± -
Messerschmidia fruit Pit #3	V-29		16.78±0.500	0.018± -
Pandanus-frond; Camp Blardy, lagoon road	V-56	4/15/75	6.10±0.210	0.005±
Vegetation: Nam-Bikini				
Scaveola near soil pit at St #W-2	V-8	4/7/76	104.29±0.830	-
Scaveola between St. #W-1 & W-2	V-10		198.09±1.450	
Scaveola near soil pit at St. #W-1	V-14		89.38±0.980	
Scaveola midway between beach & St. #W-1	V-15		98.23±1.040	
Scaveola beyond E-2-end of east t/s	V-17		175.21±1.320	
Scaveola near E-2; east transect	V-19		103.19±1.040	
Scaveola between E-1 & E-2	V-20		93.53±0.960	
Scaveola near E-1 (East transect)	V-23		111.96±1.130	
Scaveola between shore & E-1	V-24	4/8/76	62.12±0.840	
Messerschmida at St. #W-2	V-9	4/7/76	321.81±1.520	
Messerschmida between W-1 & W-2	V-11		258.32±1.800	
Messerschmida near St. #W-1	V-12		74.83±0.820	
Messerschmida near soil pit, W-1	V-13		167.93±1.410	
Messerschmida midway between beach & W-1	V-16		191.65±1.500	
Messerschmida East transect near E-2	V-18		301.50±1.900	
Messerschmida " between E-1&E-2	V-21			
Messerschmida " near E-1	V-22			
Messerschmida " between shore & E-1	V-25	4/8/76	133.62±1.240	

Table 7 (Cont'd.)

Location by Island-Atoll

Description		Sample ID	Date	Sr-90 pCi/g
Vegetation: Rongelap-Rongelap				
Breadfruit		V-27	4/3/76	1.56±0.14
Pandanus Fruit	Inedible	V-26D3	4/3/76	2.17±0.16
Pandanus Fruit		V-26C1	4/3/76	3.44±0.20
Stem	Unedible	V-26C2		
Core	Unedible	V-26C3		1.97±0.15
Inedible	Unedible	V-26C4		
Pandanus Fruit		V-26B1		6.05±0.26
Stem		V-26B2		
Core		V-26B3		2.51±0.18
Inedible		V-26B4		
Pandanus Fruit		V-26A1		0.98±0.12
Stem		V-26A2		
Core		V-26A3		1.45±0.13
Inedible		V-26A4		
Pandanus Fruit Edible		V-26E1	4/3/76	
Core		V-26E2		
Inedible		V-26E3		2.05±0.16

Table 8

Location by Island-Atoll

Description	Sample ID	Date	Sr-90 pCi/g	Pu-238 pCi/g	Pu-239 Pu-240 pCi/g
Bikini					
House #30	Sediment #2	4/5/76	3.34±0.26	0.039±0.016	4.440±0.90
House #15-1	Sediment #5B	↓	7.84±0.31	0.099±0.018	4.390±1.53
House #20	Sediment #4	↓	6.04±0.21	<0.012	1.250±0.80
House #10	Sediment #6	↓	2.79±0.20	0.039±0.016	1.783±0.87
Water - Bikini			pCi/l	pCi/l	pCi/l
House #35	Sediment #1	4/5/76	3.49±0.98	<0.073	<0.004
House #30	Sediment #2	↓	5.79±1.04	<0.156	<0.037
House #25	Sediment #3	↓	5.34±1.05	<0.066	<0.011
House #15	Sediment #5A	↓	19.33±1.60	<0.007	<0.012
House #20	Sediment #4	↓	2.72±0.95	<0.003	ND
House #10	Sediment #6	↓	6.50±1.11	<0.016	<0.012
WATER, Filtered Sediment - Bikini					
W-3	W-3	4/5/76	<0.039	<0.077	<0.015
W-4	W-4	4/6/76	<0.390	<0.013	0.043± –
W-5	W-5	↓	<0.390	<0.033	<0.006
Water, Filtered Sediment - Enen					
W-1	W-1	4/4/76	<0.390	<0.008	
W-1A	W-1A	↓	<0.390	0.547±0.123	0.710±0.71
W-2	W-2	↓	<0.390	<0.034	0.206±0.21
					<0.023

Table 9

Soil Cores

ISLAND	Average Concentration in pCi/g Dry Weight					
	Sr-90	Pu-239/240	Am-241	K-40	Cs-137	Co-60
Bikini	53.5	1.4	7.4	12	77.2	1.3
Nam	71.2	-	14.0	3.1	17.4	16.1
Rongelap	16.3	-	1.82	-	11.9	0.4

Table 10

Soil Profile

ISLAND	Highest Concentration in pCi/g Dry Weight					
	Sr-90	Pu-239/240	Am-241	K-40	Cs-137	Co-60
Bikini	328	32.3	-	45.3	228	5.4
Nam	138	-	-	0.93	18.6	3.9
Eneu	7.9	0.93	-	-	4.9	0.5

Table 11

Messerschmidia

ISLAND	Average Concentration in pCi/g Dry Weight					
	Sr-90	Pu-239/240	Am-241	K-40	Cs-137	Co-60
Bikini	114.6	0.5	-	-	426	25.8
Nam	207	-	-	11.9	238	9.5
Eneu	25.7	0.01	-	17.4	64.9	6.7
Eniaitok	-	-	-	7.5	22.6	-

Table 12

Pandanus - Edible

ISLAND	Average Concentration in pCi/g Dry Weight					
	Sr-90	Pu-239/240	Am-241	K-40	Cs-137	Co-60
Bikini	235	0.50	-	14.9	402	16.6
Rongelap	2.51	-	-	10.4	65	6.2
Eniaitok	-	-	-	-	191	13.7
Utirik	-	-	-	1.6	20	0.9
Wotho	-	-	-	7.9	3.5	-

Table 13

Scaveola Leaves

ISLAND	Average Concentration in pCi/g Dry Weight					
	Sr-90	Pu-239/240	Am-241	K-40	Cs-137	Co-60
Bikini	91.5	0.25	-	19.7	365.4	-
Nam	115	-	-	10.5	77.7	10.4
Eneu	7.5	0.01	-	15.1	22.3	-
Rongelap	-	-	-	9.1	9.1	-
Kabelle	-	-	-	17.8	15.7	-
Eniaitok	-	-	-	9.3	3.7	-

Table 14

Coconut Meat

ISLAND	Average Concentration in pCi/g Dry Weight					
	Sr-90	Pu-239/240	Am-241	K-40	Cs-137	Co-60
Bikini	-	-	-	14.8	94	-
Eniaitok	-	-	-	6.7	5.3	-
Rongelap	-	-	-	21.5	19.2	-
Utirik	-	-	-	-	6.7	-
Bigej	-	-	-	10.7	0.13	-
Wotho	-	-	-	3.7	1.1	-

Table 15

Breadfruit

ISLAND	Average Concentration in pCi/g Dry Weight					
	Sr-90	Pu-239/240	Am-241	K-40	Cs-137	Co-60
Bikini	56.8	-	-	15.6	116	-
Rongelap	1.6	-	-	10.8	28.8	-
Eniaitok	-	-	-	8.2	14.9	-
Utirik	-	-	-	15.4	10.6	-
Wotho	-	-	-	9.6	1.2	-

Table 16

Arrowroot

ISLAND	Average Concentration in pCi/g Dry Weight					
	Sr-90	Pu-239/240	Am-241	K-40	Cs-137	Co-60
Bikini	9.7	0.24	-	-	1250	-
Rongelap	-	-	-	-	20.8	-
Utirik	-	-	-	-	16.2	-

Table 17

Summary of Quality Control Data for Marshall Island Project

Location by Island-Atoll Sample Type-Description	Sample ID	Date	K-40 pCi/g	Sr-90 pCi/g	Cs-137 pCi/g	Pu-239 Pu-240 pCi/g	Pu-238 pCi/g	Others pCi/gm
Sludge: Bikini-Bikini from House 15	Sludge 5A	4/5/76			42.8±1.09			
	Sludge 5B	"		07.84±0.31	36.3±1.21	4.390± 1.19	0.099±0.10	–
Soil: Bikini-Bikini, Series L, Pit J	L-9	4/17/75		00.36±0.02	–	–	–	
	L-9	"		00.57±0.04	–	–	–	–
Soil: Eneu-Bikini, Series C, Pit 2	C-3	4/14/75		03.82±0.07	–	–	–	–
	C-3	"		03.84±0.13	–	–	–	–
	C-4	"		03.00±0.08	–	–	–	–
	C-4	"		04.12±0.14				–
	C-5	"		03.91±0.07	–	–	–	–
	C-5	"		04.30±0.16	–	–	–	–
	C-6	"		10.44±0.12				–
	C-6	"		09.78±0.18	–	–	–	–
	C-7	"		08.38±0.15	–	0.009± –	–	–
	C-7	"		05.38±0.12		0.008± –		–
	C-8	"		04.12±0.08	–		–	–
	C-8	"		04.46±0.13	–	–	–	–
	C-9	"		06.21±0.11	–	–	–	–
	C-9	"		05.37±0.13	–	–	–	–
Soil Eneu: Bikini, Series D, Pit #1	D-1	"				0.345± 0.30		–
	D-1	"		–	–	0.210± –	–	–
	D-7	4/14/75		10.51±0.17				
	D-7	"		06.39±0.15	–	–	–	–
Soil: Nam-Bikini, 6" Core near W-2	S-8	4/7/76		53.89±0.53	–	–	–	–
	S-8	"		55.57±0.79	–	–	–	
0-50cm Profile at Pit W-1	S-15	"		48.63±0.79				–
				51.74±0.79	–	–	–	–
	S-15	"		49.52±0.50	–	–	–	–
6" Core East Transect-Soil Nam	S-20	"		183.80±1.00	–	–	–	–
				186.74±1.45	–	–	–	
Soil: Nam-Bikini, 0-70cm Profile at St. #2	S-27	4/8/76		83.80±1.41	–	–	–	–
				77.01±0.64	–	–	–	–
	S-27			75.32±0.62	–	–	–	
6" Core Station #2	S-25			75.30±0.64				–
				84.22±1.02	–	–	–	–
Soil: Rongelap-Rongelap, 12" Profile	S-1	4/3/76		46.38±0.75	–	–	–	–
	S-1	"		47.20±1.32	–	–	–	
Animal: Eneu-Bikini-Fish Scales	F-3A	4/14/75	11.90±2.35	–	–	–	–	1.43±0.288(Co-60)
	F-3A	"	11.50±2.17	–				1.32±0.266(Co-60)
Animal: Nam-Bikini-Mullet Fish	F-1A	12/8/74	09.34±1.97	–	–	–	–	2.39±0.349(Co-60)
	F-1A	"	10.10±2.14	–	–	–	–	2.61±0.381(Co-60)

Location by Island-Atoll

Table 17 (Cont)

Summary of Quality Control Data for Marshall Island Project

Sample Type-Description	Sample ID	Date	K-40 pCi/g	Sr-90 pCi/g	Cs 137 pCi/g	Pu-239 Pu-240 pCi/g	Pu-238 pCi/g	Others pCi/gm
Animal: Nam-Bikini-Mullet Skin	F-1D	12/8/74	4.05±1.62		0.433±0.161			3.32±0.480(Co-60)
	F-1D	"	4.38±1.76		0.481±0.170			3.06±0.440(Co-60)
Animal: Nam-Bikini, Snapper Viscera	F-4C	"	7.22±1.68					4.52±0.445(Co-60)
	F-4C	"	6.67±1.55					4.17±0.411(Co-60)
	HASL No.		nCi/Kg	nCi/Kg	nCi/Kg	nCi/Kg	nCi/Kg	nCi/Kg
Pig Skin - Bikini	X2405 *	4/76		0.38±0.05	116.000±2.000			
	X2405			0.48±0.05	128.000±6.000	19.0±4.0		
Pig Meat - Bikini	X2406 *			0.44±0.06	226.000±3.000			
	X2406			0.39±0.05	224.000±9.000	4.0±3.0		
Pig Bone - Bikini	X2407 *			24.99±0.34	63.000±1.000			
	X2407			65.00±2.00	69.000±3.000	26.0±4.0		
Pig Nose, Tongue, etc. - Bikini	X2408 *			1.33±0.09	209.000±4.000			
	X2408			2.10±0.20	173.000±9.000	11.0±2.0		
Pig Brains and Eyes - Bikini	X2409 *			2.10±0.14	184.000±5.000			
	X2409			2.60±0.20	141.000±7.000	2.0±2.0		
Pig Head Muscles - Bikini	X2410 *			0.45±0.06	66.000±2.000			
	X2410			0.86±0.10	154.000±8.000	3.0±3.0		
Coconut Crab Shell - Wotje	X2411 *			1.10±0.11	0.400±0.200			
	X2411			1.10±0.10	0.800±0.200	2.0±2.0		
Coconut Crab Meat - Wotje	X2412 *			0.10±0.06	2.750±0.290			
	X2412			0.08±0.01	1.500±0.100	1.0±1.0		
Coconut Crab Viscera - Wotje	X2413 *			0.03±0.06	0.250±0.070			
	X2413			0.11±0.01	0.700±0.100	1.0±1.0		
Coconut Crab Shell - Kabelle	X2414 *			212.26±2.96	17.000±1.000			
	X2414			136.00±14.00	18.000±1.000	8.0±1.0		
Coconut Crab Meat - Kabelle	X2415 *			7.35±0.31	66.000±1.200			
	X2415			6.70±0.50	74.000±4.000	20.0±3.0		
Coconut Crab Viscera - Kabelle	X2416 *			10.40±0.23	44.000±1.000			
	X2416			11.40±0.50	47.000±2.000	92.0±4.0		
Coconut Crab Shell - Arbor	X2417 *			92.29±1.43	4.700±0.100			
	X2417			58.00±3.00	6.000±0.500	4.0±1.0		
Coconut Crab Meat - Arbor	X2418 *			3.03±0.15	24.900±0.700			
	X2418			2.80±0.30	16.000±1.000	11.0±2.0		
Coconut Crab Viscera - Arbor	X2419 *			8.57±0.78	11.100±0.500			
	X2419			7.40±0.70	29.000±1.000	45.0±5.0		

* Indicates a result string from Brookhaven National Laboratory
Non starred result strings indicates results from the Health and Safety Laboratory (HASL)

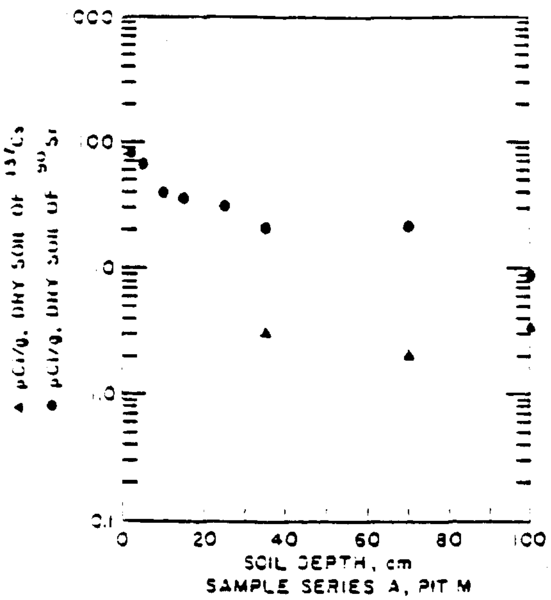

Figure 1. Bikini Island soil samples.

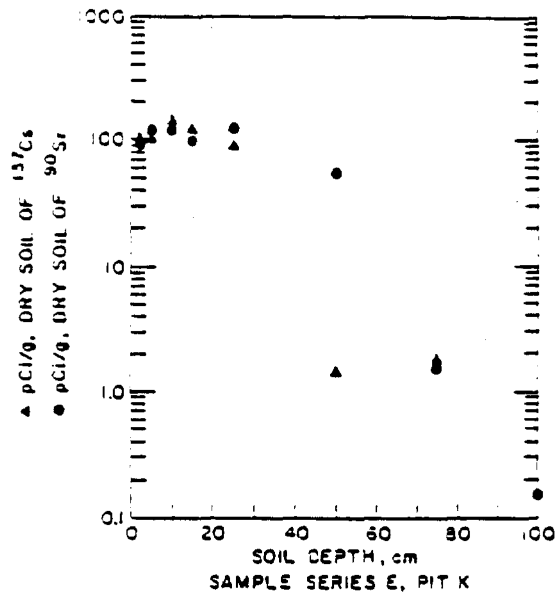

Figure 2. Bikini Island soil samples.

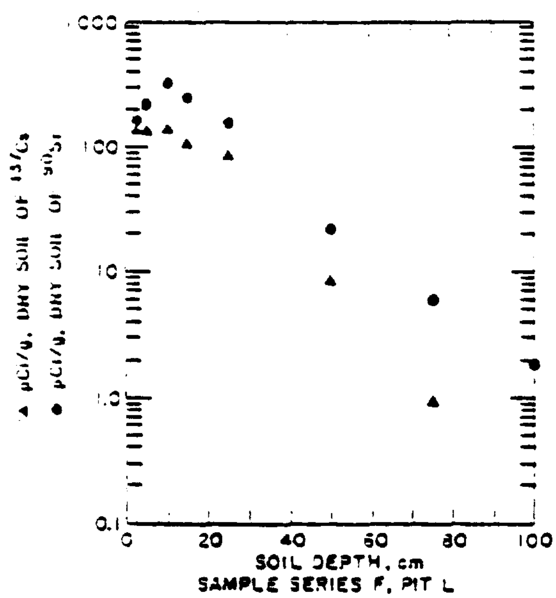

Figure 3. Bikini Island soil samples.

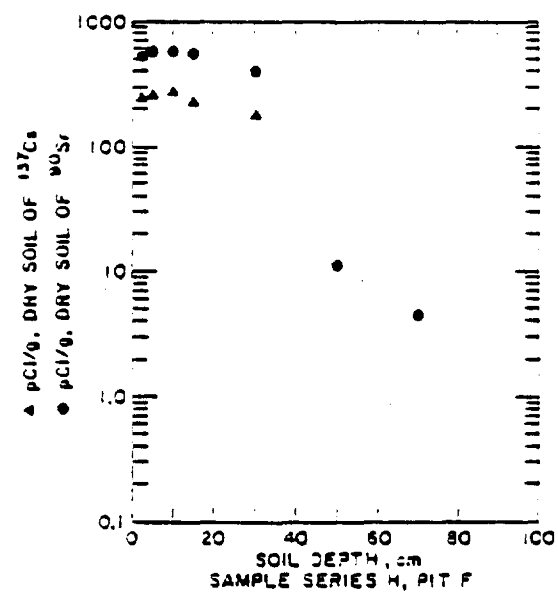

Figure 4. Bikini Island soil samples.

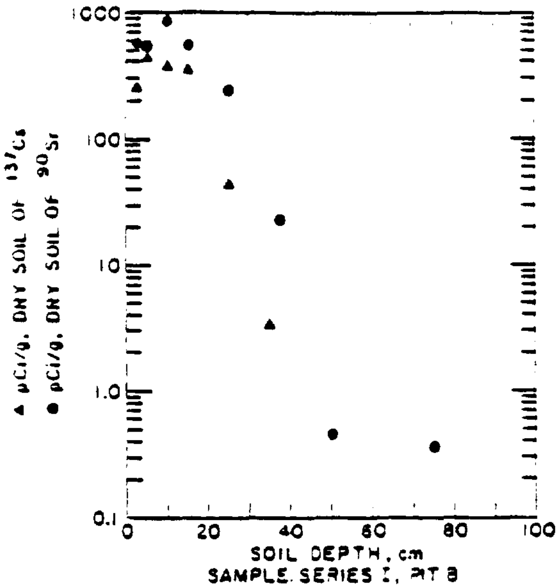

Figure 5. Bikini Island soil samples.

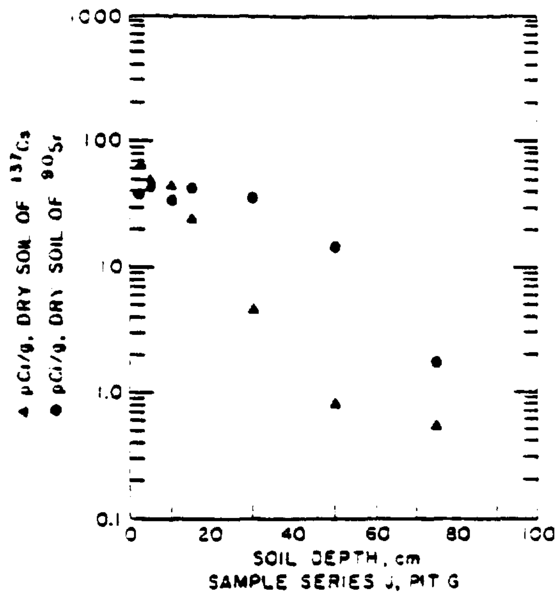

Figure 6. Bikini Island soil samples.

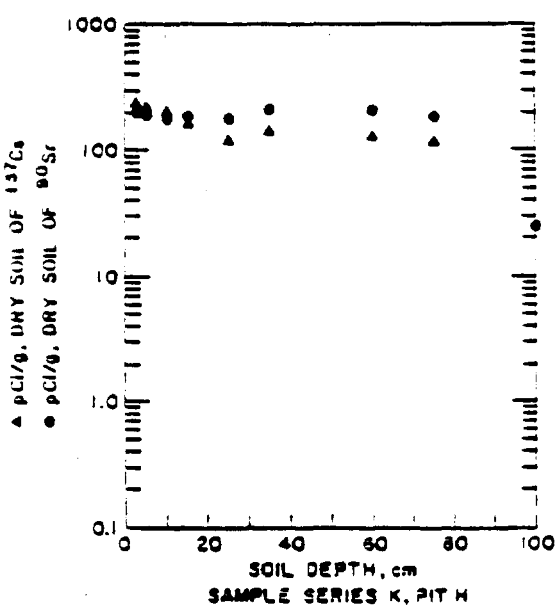

Figure 7. Bikini Island soil samples.

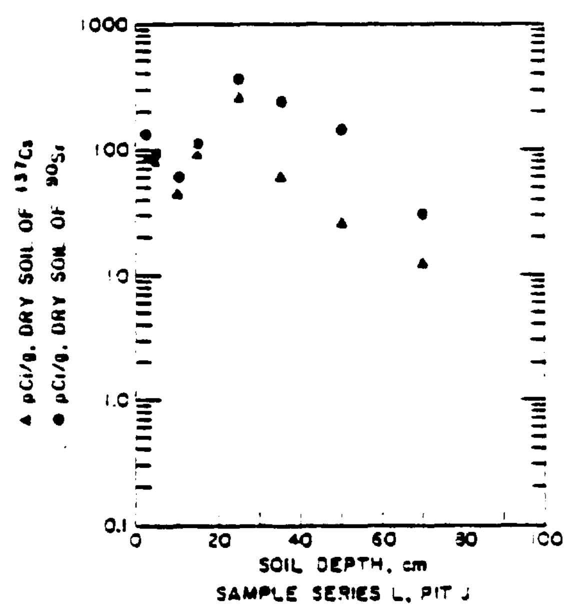

Figure 8. Bikini Island soil samples.

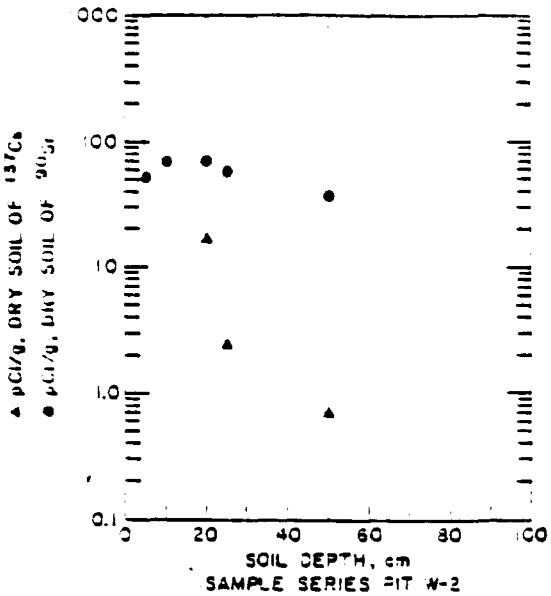

Figure 9. Nam Island soil samples.

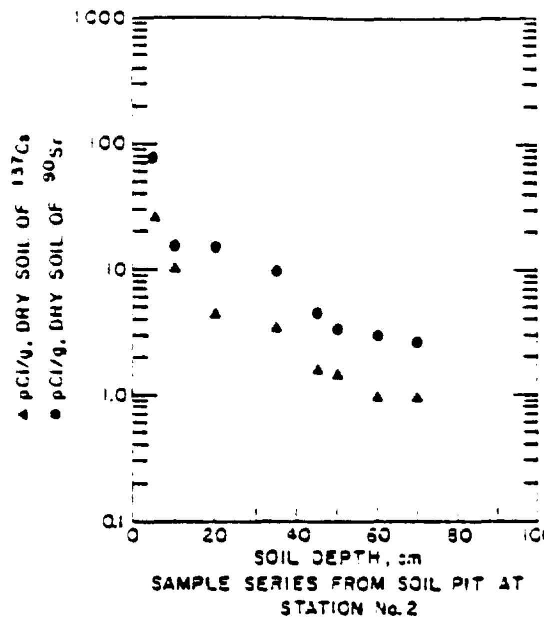

Figure 10. Nam Island soil samples.

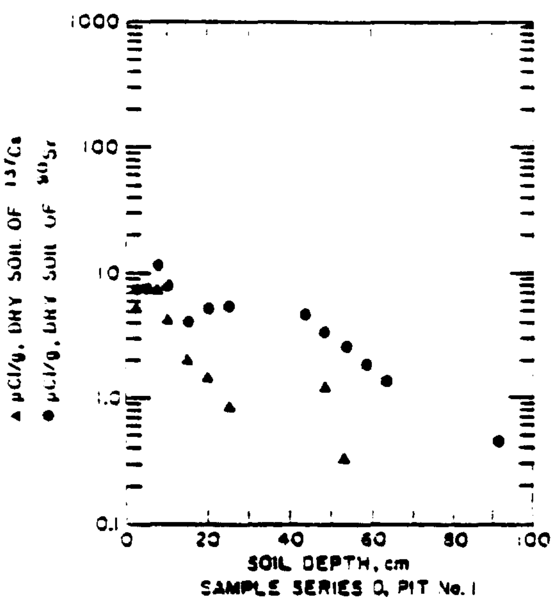

Figure 11. Eneu Island soil sample.

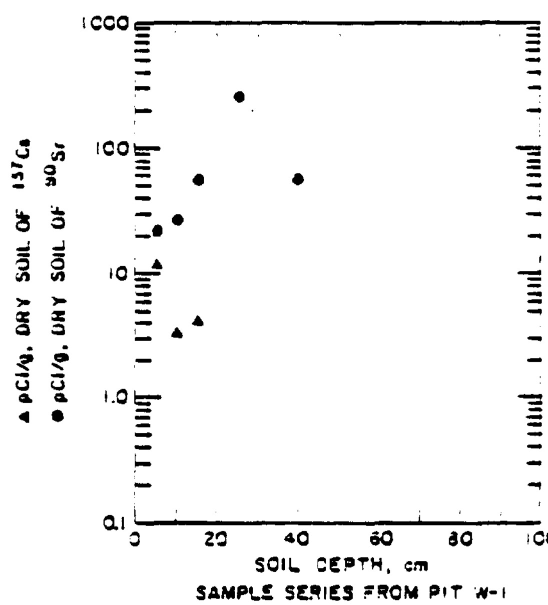

Figure 12. Nam Island soil sample.

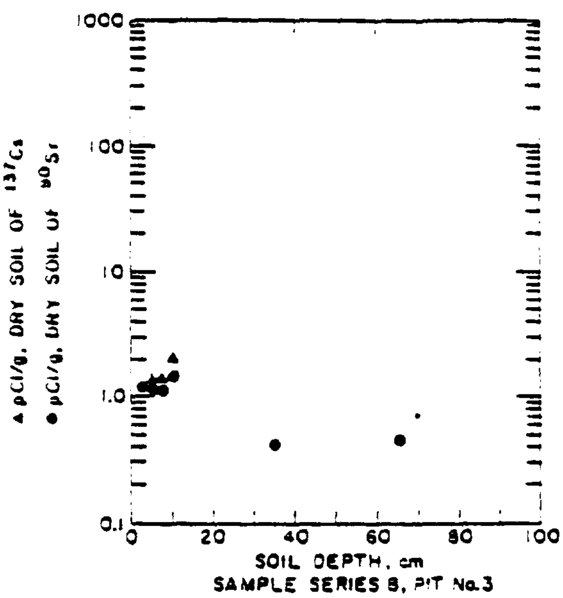

Figure 13. Eneu Island soil sample.

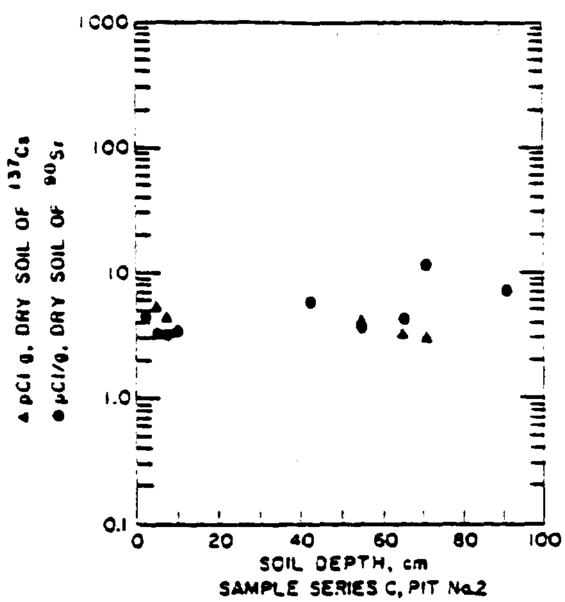

Figure 14. Eneu Island soil sample.

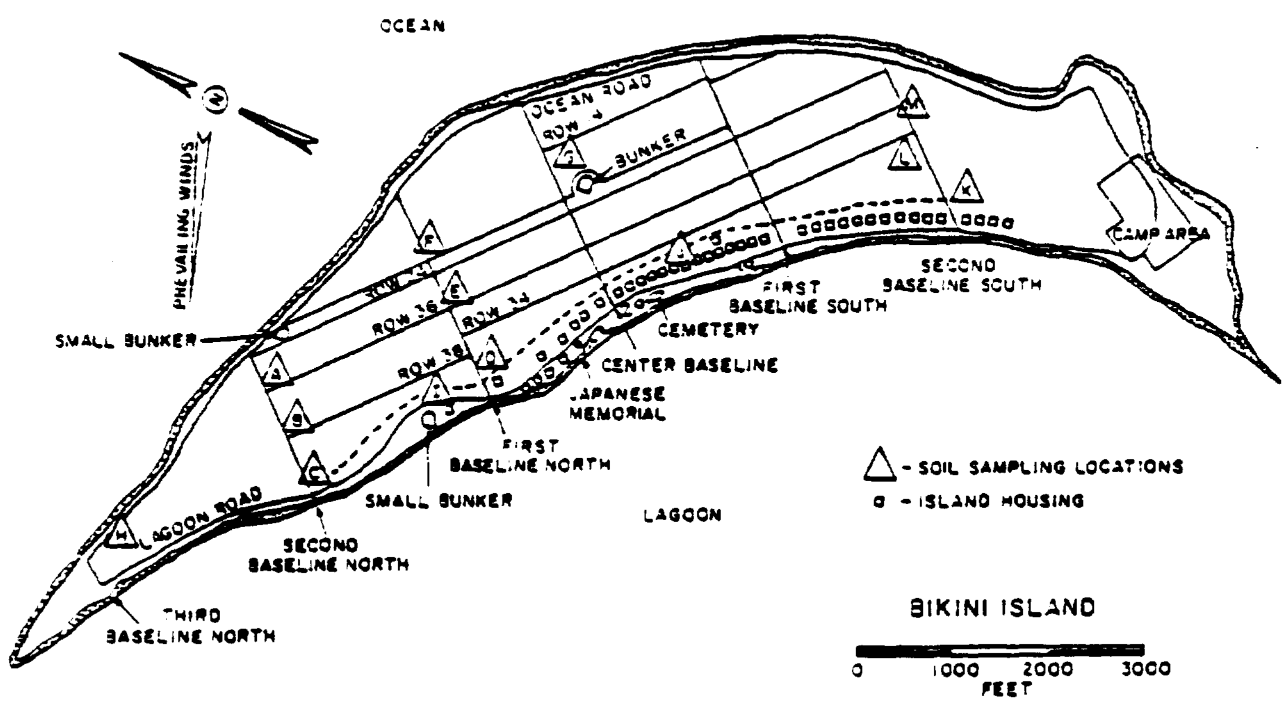

Figure 15. Soil sampling points on Bikini Island.

* U.S. GOVERNMENT PRINTING OFFICE:1978—3-714-079/13

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N.A. Greenhouse and R.P. Miltenberger

December 13, 1977

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ABSTRACT

External radiation measurements were made at several atolls in the northern Marshall Islands, which are known or suspected to have been the recipients of tropospheric fallout during the Pacific Testing Programs. Sufficient data were available to ascertain realistic dose predictions for the inhabitants of Rongelap and Utirik Atolls where the 30 year integral doses from external sources exclusive of background radiation were 0.65 and 0.06 rem respectively. These estimates are based on realistic life-style models based on observations of each atoll community. Ailuk and Wotje Atolls were found to be representatives of regional background radiation levels.

Introduction

In 1976, Brookhaven National Laboratory initiated a program of external radiation survey for the Rongelap, Rongerik, Ailuk, Wotje and Utirik Atolls. The purpose of these surveys was to provide sufficient information concerning the ambient radiation levels resulting from the mid 1950's weapons testing program to make external dose calculations for the individuals living in the surveyed areas. During the last two years, sufficient measurements were made to provide external dose information for most of the populations in the region.

The data from Rongerik, Ailuk, Wotje, Rongelap and Utirik Atolls were acquired during trips in September 1976, May 1977 and October 1977. All the exposure rate information gathered from these atolls was obtained with a pressurized ion chamber.

The equipment used in these studies consisted of a Reuter Stokes Environmental Radiation Monitor, Model RSS-111 and a gamma spectroscopy system consisting of a sodium iodide detector coupled to a portable multichannel analyzer. Environmental exposure levels were assessed via the RSS-111, and the NaI gamma spectrometer was used to determine the energy dependence correction factors for the RSS-111 instrument.

The field trips were staffed by BNL personnel and guest scientists from other institutions. Participants are listed later in the report.

This report represents all of the external exposure data collected to date by BNL from these atolls. From these data, we have made external exposure estimates for the people living on Rongelap, Ailuk, Wotje and Utirik Atolls.

Instrumentation and Methods

A) Ion Chamber Measurements

All environmental exposure rate measurements were obtained using a Reuter Stokes environmental radiation monitor model RSS-111. The instrument is designed to measure environmental radiation as low as 100 μRad/year. The RSS-111 consists of a spherical high pressure ion chamber filled to 25 atmospheres of argon. Incident radiation produces ion pairs within the active volume of the chamber which result in a current flow. The current flow is measured by an electrometer and is directly related to the free air exposure rate (1).

The active volume of the stainless steel ionization chamber is known to ±01%. The current produced in the chamber is a function of incident radiation from an external field, cosmic ray-response and contamination found in the stainless steel. The equation relating instrument response to energy of the incident radiation is:

$$Rj = Kj\ Ij + R\alpha + Kc\ Ic$$

where

Rj = current produced in the chamber by the incident gamma field

Kj = proportionality constant stating the variability of instrument response to the energy of the incident gamma field

Ij = intensity of the gamma field in μR/hr

$R\alpha$ = current produced by activity in the stainless steel

Kc = proportionality constant for cosmic rays

Ic = intensity of cosmic rays

For a given area, the values of Kc and Ic will be constant along with R_α. Since we measure R_T, the only unknown are Kj and Ij. The value of Kj can be determined once the ambient gamma spectrum is known. Data from the manufacturer indicates an error of as much as 6 to 10% could result if energy corrections are not made to the gross readings.

The RSS-111s used in this study were calibrated at the factory using radium sources whose calibration is traceable to the National Bureau of Standards. Calibration of the instruments were also checked by EML (formerly HASL) prior to field use.

Energy Dependence Corrections

In the 1977 surveys, BNL used a sodium iodide detector, whose output was coupled to a multichannel analyzer. The purpose was to enable the BNL team to acquire spectra of the terrestrial background radiation at one meter above the surface. This was done at the same height and in the same areas where the RSS-111 measurements were taken. Consequently, energy dependence factors could be calculated by examining the environmental gamma scan for the energies of those nuclides most predominant in the terrestrial environment.

The equipment used to accomplish this part of the work was a computing Gamma Spectrometer, Model LEA 74-008 #11 built by Lawrence Livermore Laboratory (2). The system uses a Harshaw 5.08 cm diameter x 5.08 cm thick NaI(Tl) scintillation detector. The spectrometer can be operated from AC power or on internal batteries. Spectra are visually displayed on a CRT, and transferred to magnetic tape for storage. Using the math package with the system, each spectrum was examined in 100 KeV increments, and folded into the RSS-111 energy response curve to determine the energy dependence factors.

The range of factors needed to compensate the RSS-111 response due to energy dependence was 1.01 to 1.05. The mean correction was approximately 1.02. Consequently, we felt no need to correct the remaining 1976 or 1977 data for the minor energy dependence encountered.

Results

A total of 112 RSS-111 measurements were taken on five atolls. Each data point is the average of at least 20 individual readings. This assures the precision of the value while the initial calibration guarantees accuracy. The one sigma error is on the mean exposure rate. All exposure rate values include natural background except where otherwise noted. Figure 1 graphically presents the data obtained at Eniwetak Island, Rongerik Atoll. On this island, random measurements were taken along a central northsouth transect. Table 1 presents the raw data collected with one sigma error. The average exposure rate for this island is 6.3 μR/hr. This is about 1.5 times higher than the cosmic/terrestrial date rate found on uncontaminated coral islands. Eniwetak was the island surveyed in the Rongerik Atoll due to presence of U. S. servicemen at the weather station there at the time of the BRAVO fallout incident.

Tables 2, 3, 4, 5 and 6 present the raw data from Rongelap Atoll. The islands surveyed were Kabelle, Naen, Eniaetok and Rongelap. Naen is located at the northwest corner of the atoll, and Kabelle at the northeast corner. Kabelle is a significant copra resource; and both of these islands may be used for brief visits, but neither of them is permanently inhabited. These islands received a significant amount of fallout debris and consequently, are still substantially more contaminated than the islands of Rongelap and Eniaetok, located in the southeast and eastern parts of the atoll. The current values for external exposure rates on these islands are listed below and in Table 14. The entire population presently

Island	Average Exposure Rate in μR/hr
Naen	43.1
Kabelle	21.7
Eniaetok	9.9
Rongelap	7.3

lives on Rongelap Island. The people obtain most of their food from Rongelap with occasional supplemental trips to Eniaetok and to other southern islands in the atoll. Little or no activities currently takes place on Naen or Kabelle, or other islands in the north.

Figure 2 is a graphic presentation of the measurement points and exposure rates along the main road of Rongelap Island. The exposure rate is fairly uniform averaging 7.3 μR/hr over the island. This is about twice the background radiation level of uncontaminated atolls in the Marshall Islands.

Tables 7, 8 and 9 present the data for the islands surveyed in the Utirik Atoll. These islands, Aon, Eorukku and Utirik, represent the major islands within the atoll. Aon, located in the southwest corner and Utirik located in the southeast corner of the atoll, are the major areas for living and food production. The external exposure rate for all these islands is about 4 μR/hr, i.e., very near the regional background level.

Tables 10, 11, 12 and 13 present the RSS-111 survey results for Wormej and Wotje Islands of Wotje Atoll and for Bigen and Ailuk Islands of Ailuk Atoll. These islands were surveyed to determine whether they were representative of baseline external exposure rates for the Marshall Islands. The individual island averages are found in Table 14, but range from 3.7 μR/hr to 3.9 μR/hr. These exposure rates are about the same as that for Kwajalein and other areas not exposed to gross contamination from fallout; we assumed them to be representative of ambient background radiation levels for the region.

Discussion of Results

The average exposure rate as measured for each island is listed in Table 14. In all areas, except for Rongelap Atoll and Rongerik Atoll where only Eniwetak Island was visited, there is essentially an uniform exposure rate within the islands of a given atoll. For hypothetical inhabitants of Eniwetak Island at Rongerik Atoll, and for the people living at Utirik Atoll, external dose estimates were made, and the results are presented in Table 15. These dose estimates were made based upon the following assumptions or observations:

1) The exposure rate was relatively uniform throughout the atoll.
2) The average exposure rate represents the average for all islands within the atoll.
3) Wotje and Ailuk Atolls are representative of the natural background in the Northern Marshall Islands.

It is difficult to estimate an external dose for the inhabitants of Rongelap Atoll apart from typical residents who spend most of their time on Rongelap Island. The reason lies in the nonuniform distribution of radioactive material from island to island within the atoll. While the southern islands of Rongelap were determined to have uniform exposure rates on a per island basis, there were significant differences in the exposure rates between islands and substantial heterogeneity in exposure rates on any given island in the northern sector.

In UCRL 51879 Rev. 1 (3,4), this problem was approached by estimating the fraction of the time that an individual spends on various activities. This estimate is reprinted here as Table 16. Using this as a basic assumption, we have constructed external exposure rate estimates for the various living activities based upon our measurements reported in Tables 1-13. The value for the lagoon exposure rate was assumed to be the same as that for uncontaminated atolls in the region (~3.7 μR/hr). The value for "other islands" was obtained by assuming that the Marshallese would spend an equal amount of time on each of the other islands which we surveyed. All other estimates are made by taking the average of all measurements made within the area of interest.

Table 17 represents the exposure rate at each pattern of activity as listed in Table 16 calculated assuming 100% occupancy for Rongelap Atoll. Table 18 presents an estimate of the exposure rate for each age group, weighted by the percent of time spent in each area for inhabitants of Rongelap Atoll based on the Lawrence Livermore lifestyle Model (3,4). Summation of the exposure rates in each area provides the average exposure rates to the Rongelapese.

Using the average hourly exposure rates, the long term external dose was calculated. These data, presented in Table 9 for Rongelap Atoll, have been corrected for background (terrestrial and cosmic) radiation by using the average exposure rate of Wotje and Ailuk Atolls as a representative sample of the normal (unexposed) Marshall Island environment.

We feel that this is a very conservative estimate for Rongelap Atoll since the people rarely visit the more heavily contaminated islands in the north, and tend to restrict their "other islands" visits to the southern sector where exposure rates are similar to that on Rongelap Island itself. This observation was supported by an independent living pattern assessment from which data became available in the fall of 1977 (5).

Specific living pattern information for Rongelap was obtained on a field trip in October 1977 (5). This information is presented in Table 20. It should be noted that as previously mentioned, the Rongelap "lifestyle" involves very little time away from Rongelap Island where a constant exposure rate of 7.3 μR/hr is assumed. Revised external dose predictions based on the observed Rongelap living pattern are given in Tables 21, 22 and 23. These doses include corrections for physical decay for ^{137}Cs and ^{60}Co which are responsible for >99% of the total external exposure rate above background. The cesium and cobalt ratios were obtained using the averages of soil sample activities from analyses by BNL (6) and the University of Washington (LRE) (7). It was assumed for this assessment that no radionuclide loss mechanisms are operative other than physical decay.

ICRP #9 suggests that in 30 years, the general public should receive a dose of less than 5.0 rem from total body sources other than medical or natural background (8). In all cases examined here, this requirement is met. The problem arises that the external gamma radiation is only one source of exposure to the Marshallese. The dietary pathway could contribute a substantial increment as an internal dose commitment.

Reviewing all atoll dose commitments in this light, we feel that inhabitants of Rongelap Atoll may have difficulty meeting the ICRP #9 criterion of 5 rem in 30 years, but should be within the 0.5 rem/year standard for individuals. The interal dose assessment for the people of Rongelap will be the subject of a separate report. At this time, we do not recommend any remedial action until a complete dose commitment can be determined by means of examining the external, dietary and whole body counting data available to date.

The other islands and atolls surveyed are well within the ICRP recommended levels. As such, little more than minimal followup should be done on these atolls. The main task of the environmental programs should be one of detecting significant changes in the environment or lifestyle which might warrant a reassessment of these dose predictions.

Acknowledgments

The field portion of the radiological survey of the Marshall Islands was accomplished by a very intense and thorough effort by people representing different organizations. The number of samples collected and the amount of information obtained during the survey was a direct result of the cooperation and diligent effort of the following individuals:

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G. Hughes

L. Phillips

F. Stepnoski

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The outstanding cooperation of personnel from the Trust Territory of the Pacific Islands and from the Office of the District Administrator of the Marshall Islands, as well as that of the Bikini people, played on important part in the successful completion of the survey.

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Table 1

ENIWETAK ISLAND - RONGERIK ATOLL
RSS-111
EXPOSURE SURVEY
May 1977

Location	Exposure Rate in μR/HR
Cross Island transect, 100 m from the ocean in a sandy open area	5.26±0.28
Cross Island transect, 120 m from the ocean in a wooded grove	6.47±0.22
Cross Island transect, 170 m from the ocean in a sandy area	6.85±0.22
Cross Island transect, near center of the island near the lone standing pole	8.33±0.36
Cross Island transect, 50 m from lagoon on top of organic debris	8.42±0.25
Cross Island transect, 20 m from lagoon in clearing	4.8 ±0.25
Cross Island transect, 20 m from lagoon under shrubbery	5.11±0.42

Table 2

KABELLE ISLAND - RONGELAP ATOLL
RSS-111
EXPOSURE SURVEY
September 1976

Location	Exposure Rate in μR/hr
Cross Island transect beginning at the water catchment	
Innermost penetration along this transect 220 m from lagoon	13.0±0.3
30 m west of innermost penetration	16.3±0.3
65 m west of innermost penetration	18.1±0.3
90 m west of innermost penetration	12.9±0.4
115 m west of innermost penetration by water catchment	22.1±0.3
125 m west of innermost penetration in area of sand and scaveola scrub	34.0±0.3
20 m south of water catchment	29.7±0.4
170 m west of innermost penetration	31.3±0.3
Second transect 275 m south of Cross Island transect	
First level messerschmidia canopy	18.2±0.2
Scaveola clearing	20.3±0.3
Scaveola clearing ~30 m to the lagoon beach	26.9±0.4

Table 3

ENIAETOK ISLAND - RONGELAP ATOLL
RSS-111
EXPOSURE SURVEY

September 1976

Location	Exposure Rate in μR/hr
Eastwest cross island transect - Middle Island	
50 m due west of Ocean Beach	5.6±0.4
85 m due west of Ocean Beach - clearing south of path	11.4±0.3
85 m due west of Ocean Beach - clearing north of path	12.4±0.2
135 m due west of Ocean Beach	11.7±0.5
175 m due west of Ocean Beach	11.5±0.3
215 m due west of Ocean Beach near cluster of three houses. Area has patchy coral gravel.	8.6±0.2
265 m west of Ocean Beach: 40 m from Lagoon Beach	5.8±0.4
Second transect: 250 m due north of Middle Island transect	
70 m due east of lagoon	11.5±0.3
Adjacent clearing returning toward Lagoon Beach	12.0±0.4
Third transect near south end of the island	
80 m due east of the lagoon	12.0±0.3
30 m from Lagoon Beach near a house: some gravel present	6.7±0.4

Table 4

NAEN ISLAND - RONGELAP ATOLL
RSS-111
EXPOSURE SURVEY

September 1976

Location	Exposure Rate in μR/hr
First transect due west to northwest from near southeast corner of the island	
clearing 40 m in from the beach	22.5±0.4
150 m inland due west to northwest	55.3±0.6
returning to beach due southeast, 25 m to next clearing	42.1±0.5
southeast ~40 m to next clearing	40.6±0.5
Midisland second transect due north from the lagoon center of island	62.2±0.7
25 m south of center island towards the lagoon	45.5±0.7
60 m south of center island towards the lagoon	44.7±0.5
90 m south of center island towards the lagoon	59.0±0.6
120 m south of center island towards the lagoon	33.1±0.5
150 m south of center island towards the lagoon	70.7±3.4
sandy head land on southeast corner of the island	6.0±0.6

Table 5

RONGELAP ISLAND - RONGELAP ATOLL
RSS-111
EXPOSURE SURVEY

September 1976

Location	Exposure Rate in μR/hr
Cross Island transect on path near church	
70 m from Ocean Beach	6.8±0.6
140 m north from Ocean Beach	7.0±0.3
200 m north from Ocean Beach	8.5±0.3
270 m north from Ocean Beach	8.5±0.2
350 m north from Ocean Beach	9.1±0.5
420 m north from Ocean Beach	7.7±0.4
500 m north from Ocean Beach	7.5±0.3
570 m north from Ocean Beach	4.9±0.4
Village road transect starting at western end of the village	
100 m west of first house in the village	8.2±0.3
front of first house: lagoon site of the road	7.8±0.4
100 m due east of first house	7.3±0.4
200 m due east of first house: past houses 3, 4 and 5	8.9±0.3
300 m due east of first house: near houses 6, 7, 8 and 9 (area covered with crushed coral)	5.9±0.4
100 m part church	7.1±0.3
200 m past church near co-op	6.7±0.3
in front of Jerry Knight's house	6.0±0.3
in front of 2 houses near the dock	5.8±0.4
100 m east of the bock	6.5±0.4
170 m east of the dock	6.6±0.7
Observation tower at west end of the island in open field	5.1±0.3
0.5 km east near main road in clearing	9.6±0.3
1.0 km east near main road about 50 m from the lagoon	8.5±0.3
1.5 km east near main road in the middle of the road	5.8±0.3
in coconut grove about 1.2 km east of observation tower	8.1±0.2
1.9 km east near main road on lagoon side of the road	7.8±0.2
2.4 km east near main road, lagoon side on grass covered coral	6.3±0.3
2.9 km east near main road, lagoon side of grassy area	7.1±0.2
3.4 km east near main road, grassy area on the ocean side	8.8±0.4
3.8 km east near main road, grassy area on the ocean side	8.3±0.4
4.3 km east near main road, grassy near trees lagoon side	7.1±0.3
4.8 km east near main road, grassy area on ocean side	6.1±0.4
5.3 km east near main road, grassy area on lagoon side	7.4±0.2
5.8 km east near main road, a grassy area with Pandanus at edge of village	6.6±0.3
6.3 km east near main road in the village by the school and cemetery	5.0±0.2
along side church in mil village	8.9±0.4
6.7 km east near main road, east of village in grassy area beneath coconut trees, ocean side of the road	6.6±0.2
8.3 km east near main road near Japanese cistern	7.9±0.2
8.8 km northeast beneath Guettarda grove, ocean side	7.5±0.2
9.3 km northeast approaching north end of island	9.5±0.4
9.8 km northeast on main road, ocean side in a coconut grove	9.5±0.5
10.2 km northeast near end of island in grassy area and scaveola trees	6.0±0.4

Table 6

RONGELAP ISLAND - RONGELAP ATOLL
RSS-111
EXPOSURE SURVEY

October 1977

Location	Exposure Rate in μR/hr
Cross Island transect on path behind Tarbud's (Jerry Knight's) house	
shrub line, ocean side	3.9±0.3
39 m lagoonward (scaveola grove)	4.6±0.2
80 m lagoonward (edge of coconut grove)	4.9±0.3
118 m lagoonward	5.8±0.2
158 m lagoonward	5.8±0.4
197 m lagoonward	5.9±0.3
237 m lagoonward	6.1±0.2
276 m lagoonward	6.4±0.1
316 m lagoonward	7.0±0.1
355 m lagoonward	6.2±0.3
395 m lagoonward	7.3±0.4
434 m lagoonward	7.8±0.3
474 m lagoonward	7.5±0.4
513 m lagoonward (near rear of Tarbud's house)	5.9±0.3
Main island road, front of Tarbud's house	5.5±0.3
Lagoon Beach near Boas' house	4.2±0.2

Table 7

AON ISLAND - UTIRIK ATOLL
RSS-111
ESPOSURE SURVEY

September 1976

Location	Exposure Rate in μR/hr
100 m from the Ocean Beach	4.1±0.3
200 m from the Ocean Beach	4.2±0.3
30 m from Lagoon Beach near middle of the island	4.1±0.3

Table 8

EORUKKU ISLAND - UTIRIK ATOLL
RSS-111
EXPOSURE SURVEY

September 1976

Location	Exposure Rate in μR/hr
Middle Island	4.3±0.5
Southwest	4.1±0.4

Table 9

UTIRIK ISLAND - UTIRIK ATOLL
RSS-111
EXPOSURE SURVEY

September 1976

Location	Exposure Rate in μR/hr
Eastwest transect across island near south end of village	
60 m west of Ocean Beach	3.7±0.3
150 m west of Ocean Beach	4.3±0.3
10 m east of village road	4.1±0.8
100 m west of ocean near the middle of the village	4.1±0.2
200 m west of ocean near the middle of the village	4.2±0.2
300 m west of ocean near large hollow and taro patch	4.5±0.9
100 m from large hollow and taro patch	4.5±0.4
200 m from large hollow and taro patch near the middle of village	3.9±0.7
village road by the cemetery	4.0±0.2

Table 10

WORMEJ ISLAND - WOTJE ATOLL
RSS-111
EXPOSURE SURVEY

September 1976

Location	Exposure Rate in μR/hr
Middle of the village	3.9±0.3
transect due north ~150 m north of the church	3.7±0.3
transect due north ~250 m north of village	3.6±0.3
transect due north ~350 m north of village	3.8±0.3
transect due north ~450 m north of village	3.7±0.2
transect due north ~550 m north of village and ~30 m south of of Ocean Beach	3.9±0.2

Table 11

WOTJE ISLAND - WOTJE ATOLL
RSS-111
EXPOSURE SURVEY

September 1976

Location	Exposure Rate in μR/hr
northsouth air strip, 2/3 of the distance from the lagoon to the ocean	3.7±0.2
100 m west of air strip	3.7±0.2
200 m west of air strip	3.8±0.3
300 m west of air strip	3.8±0.3

Table 12

BIGEN ISLAND - AILUK ATOLL
RSS-111
EXPOSURE SURVEY

April 1976

Location	Exposure Rate in μR/hr
150 m from the Lagoon Beach, north end of the island North end Lagoon Beach	4.2±0.3

Table 13

AILUK ISLAND - AILUK ATOLL
RSS-111
EXPOSURE SURVEY

September 1976

Location	Exposure Rate in μR/hr
50 m from Ocean Beach	4.0±0.4
150 m due west of Ocean Beach	3.7±0.3
350 m due west of Ocean Beach	3.9±0.5
450 m due west of Ocean Beach, ~100 m from village	3.7±0.4
Ailuk village near intersection of village road and Cross Island road	3.7±0.4

Table 14

Average Exposure Rates (May 1977)

Island	Atoll	n	Average Exposure Rate ±1σ error*
Kabelle	Rongelap	11	21.7 μR/hr ± 7.3 μR/hr
Naen	Rongelap	11	43.1 μR/hr ±18.6 μR/hr
Eniaetok	Rongelap	11	9.9 μR/hr ± 2.7 μR/hr
Rongelap	Rongelap	57	7.3 μR/hr ± 1.5 μR/hr
Aon	Utirik	3	4.0 μR/hr ± 0.3 μR/hr
Eorukku	Utirik	2	4.1 μR/hr ± 0.1 μR/hr
Utirik	Utirik	9	4.1 μR/hr ± 0.3 μR/hr
Bigen	Ailuk	2	3.9 μR/hr ± 0.3 μR/hr
Ailuk	Ailuk	5	3.7 μR/hr ± 0.1 μR/hr
Wormej	Wotje	6	3.7 μR/hr ± 0.1 μR/hr
Wotje	Wotje	4	3.7 μR/hr ± 0.1 μR/hr
Eniwetak	Rongerik	7	6.3 μR/hr ± 1.7 μR/hr

*Corrected for energy dependence of RSS-111. (Typical spectral correction factor was 1.05).

Table 15

External Exposure Rates and Dose Predictions
Persons Living on Surveyed Atolls [1,2]
(Exclusive of Rongelap Atoll)

Atoll	Ave. Gross Exposure Rate April 1977	Net Exposure Rate[3] April 1977	10 yr. Integral[3] Dose in Rem	30 yr. Integral[3] Dose in Rem	50 yr. Integral[3] Dose in Rem
Utirik[4]	4.07 μR/hr	0.32 μR/hr	0.024	0.056	0.077
Ailuk	3.80 μR/hr	-	-	-	-
Wotje	3.70 μR/hr	-	-	-	-
Rongerik[5]	6.30 μR/hr	2.55 μR/hr	0.199	0.484	0.663
ICRP 9 Population Dose Limit		-	1.700	5.000	8.300

1. Doses were calculated from average exposure rates for each atoll.
2. Multiple year dose calculations were made on the background substracted exposure rate. Background was assumed to be the average of exposure rates detected at Ailuk and Wotje Atolls.
3. Dose represents increase over background.
4. Conservatively assumes 100 percent of time spent on Utirik Island.
5. Based on a superficial survey of Eniwetak Island only.

Table 16

Population Breakdown by Age and Geographical Living Patterns
(Ref. 6)

	Infants and small children	Children and adolescents	Men	Women
Age Bracket (years)	0-4	5-19	20+	20+
Fraction of population (%)	16	41	22	21
Fraction of time spent in respective areas (%):				
Inside Home	50	30	30	30
Within 10 m of home	15	10	5	10
Elsewhere in village	5	10	5	10
Beach	5	5	5	5
Interior of island	5	15	20	15
Lagoon	0	10	10	5
Other Islands	20	20	25	25

Table 17

Assumed Exposure Rate for
Each Living Pattern*

Pattern	Rongelap Atoll μR/hr
Inside home	7.3
Within 10 m of home	7.3
Elsewhere in village	7.3
Beach	7.3
Interior Island	7.3
Lagoon**	3.7
Other Islands***	24.9

*Values listed are mean exposure rates.

**Lagoon value is assumed to be the same as regional background at uncontaminated atolls.

***Values used for other islands assumed equal distribution of time spent on other islands within the atoll.

Table 18

Rongelap Exposure Rates Based on Living Pattern Assumed for Bikini (3,4)

Description	Infants 0-4 yrs	Children 5-19 yrs	Men 20+ yrs	Women 20+ yrs
Fraction of population	16%	41%	22%	21%
Dose rate due to Time spent within these areas (μR/hr)				
Inside Home	3.65	2.19	2.19	2.19
Within 10 m of home	1.10	0.73	0.37	0.73
Elsewhere in village	0.37	0.73	0.37	0.73
Beach	0.37	0.37	0.37	0.37
Interior Island	0.37	1.10	1.46	1.10
Lagoon	0.00	0.37	0.37	0.19
Other Islands	4.98	4.98	6.23	6.23
Total (μR/hr) (incl bkgd)	10.84	10.47	11.36	11.54

Table 19

Exposure Rates and Dose Predictions for Persons Living on Rongelap Atoll Based on Assumed Bikini Living Pattern

Age Group	Net Weighted Rate in μR/hr May 1977	External Integral Dose in Rem (Bkgd Subt) 10 yr.	30 yr.	50 yr.
Infants (0-4 yrs)	7.09	0.56	1.35	1.84
Children (5-19 yrs)	6.72	0.52	1.27	1.75
Men (20 yrs+)	7.61	0.60	1.44	1.97
Women (20 yrs+)	7.79	0.62	1.49	2.03

Table 20

Living Pattern Model for Rongelap
(October 1977)

	Infants & Small Children	Children & Adolescents	Men	Women	Old People
Age Bracket (yrs)	0-4	5-19	20-59	20-59	60+
Fraction of time spent in respective areas(%)					
In village (including inside home)	100	84	77	94	100
Interior of island	-	8	13	4	-
Beach	-	8		2	-
Lagoon	-	-	4	-	-
Other islands	-	-	6	-	-

Table 21

Rongelap Exposure Rates Based on Observed Living Pattern (5)

Description	Infants 0-4 yrs	Children 5-19 yrs	Men 20-59 yrs	Women 20-59 yrs	Old People >60 yrs
Dose rate due to time spent within these areas (μR/hr)					
In village (including home)	7.3	6.13	5.62	6.86	7.3
Beach	-	0.58	-	0.15	-
Interior Island	-	0.58	0.95	0.29	-
Lagoon	-	-	0.15	-	-
Other islands	-	-	1.49	-	-
Total μR/hr (incl bkgd)	7.3	7.3	8.21	7.3	7.3

Table 22

Average Exposure Rates and Dose Predictions for Persons Living on Rongelap Atoll Based on Rongelap Living Pattern (1977)

Age Group	Weighted Net Exposure Rate in μR/hr	Net Integral External Dose in Rem 10 yr	30 yr	50 yr
Infants (0-9)	3.6	0.27	0.65	0.90
Children (5-19)	3.6	"	"	"
Men (20-59)	4.5	0.34	0.82	1.12
Women (20-59)	3.6	0.27	0.65	0.90
Old People (60+)	3.6	"	"	"
Additional Contribution From Background Radiation	3.7	0.32	0.97	1.62

Table 23

Total Doses Including Background Based on Rongelap Living Pattern (1977)

Group	Weighted Total Exposure Rate μR/hr	Total Integral Dose in Rem 10 yr	30 yr	50 yr
Rongelap Men (ages 20-34)	8.3	0.66	1.79	2.74
All others (Rongelap)	7.3	0.59	1.62	2.54
Utirik, all residents*	4.1	0.34	1.03	1.70

*Assumes (conservatively) 100% occupancy on-island.

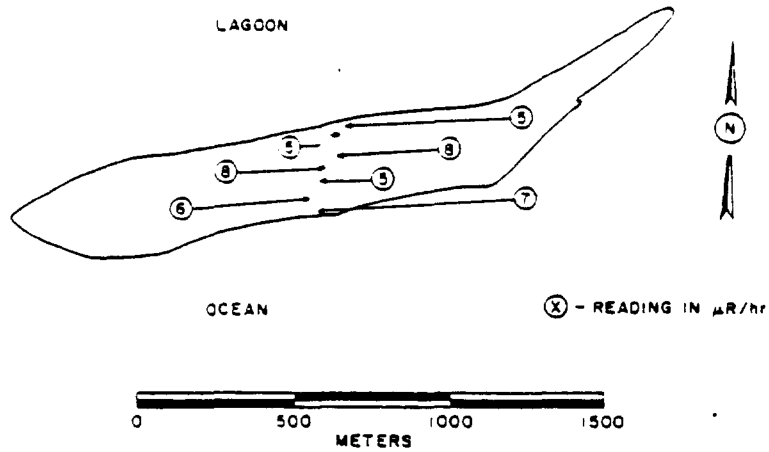

Figure 1. Eniwetak Island Rongerik Atoll.

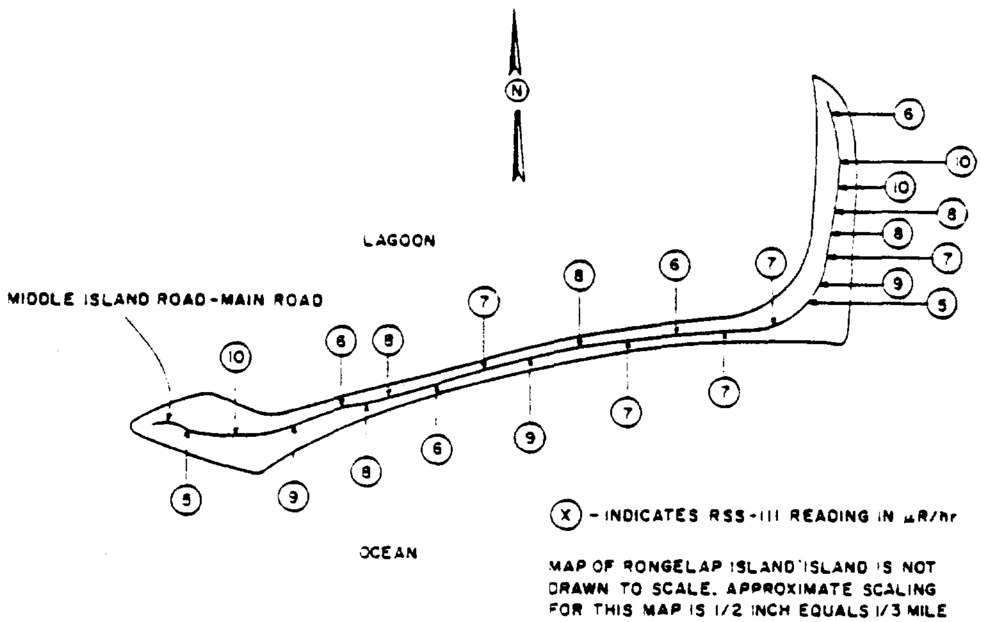

Figure 2. Rongelap Island.

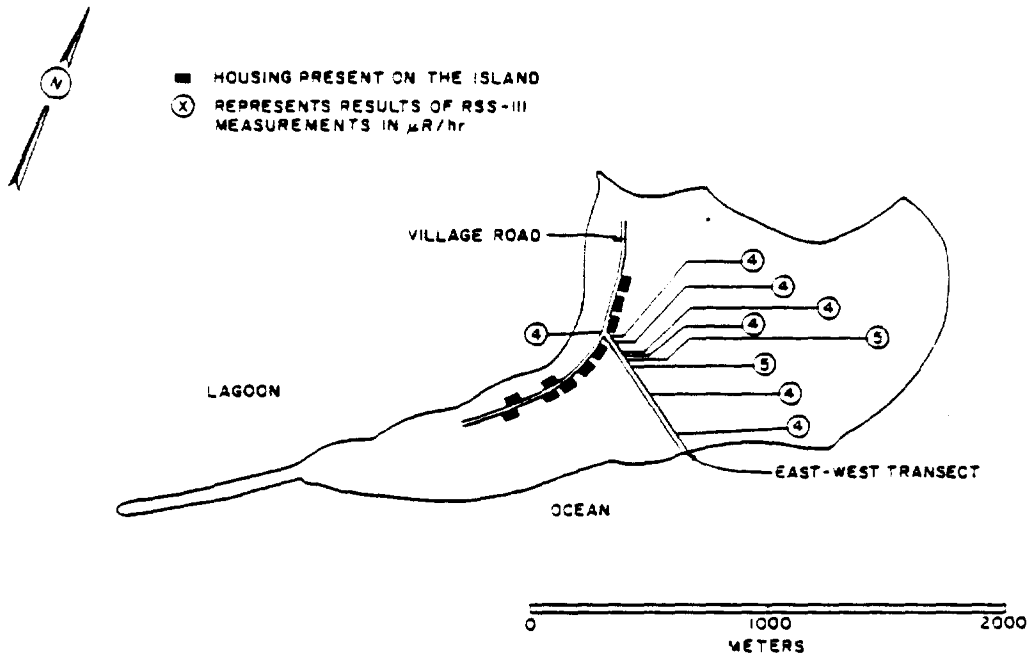

Figure 3. Utirik Island.

External Exposure Measurements at Bikini Atoll

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EXTERNAL EXPOSURE MEASUREMENTS AT BIKINI ATOLL

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ABSTRACT

External exposure rate surveys from 1975 to 1977 on the islands Nam, Eneu and Bikini of Bikini Atoll gave average external exposure rates of 24, 5.7 and 32 μR/hr respectively. The exposure rate on Eneu Island is uniform, whereas those on Bikini and Nam range from 7.0 to 80. μR/hr. Based on an assumed living pattern at Bikini Island, the adult male Bikinian is estimated to be in the presence of an external radiation field corresponding to 16 μR/hr due to debris and fallout from the 1954 BRAVO incident. This corresponds to a 30 year dose equivalent of 2.8 rem.

INTRODUCTION

In April 1975, Brookhaven National Laboratory initiated an external survey of Bikini Atoll in order to obtain information concerning the ambient external radiation levels resulting from the mid 1950's weapons testing program and to make dose equivalent commitment determinations for the individuals living in the surveyed area. From 1975 to 1977, measurements were made to provide sufficient information on the external exposure received by the Marshallese people.

Most of the information concerning Bikini and Eneu Islands was obtained in April 1975, when environmental ionization chamber measurements were made. In addition, thermoluminescent dosimecers (TLDs) were placed in the field and exposed for six months at Bikini Island to verify the uniformity of the exposure. Other groups assisted in these surveys. The team from Lawrence Livermore Laboratory (UCRL) made a detailed survey of Bikini and Eneu Islands in June 1975[4,9], and they refer to the information presented in this report as BNL unpublished data. In general, their results are substantiated by the exposure and dose equivalent commitments calculated here.

The equipment used in 1975 consisted of a Reuter Stokes environmental radiation monitor model RSS-111 and a Baird-Atomic scintillation detector consisting of a sodium iodide detector (2.5 cm in diameter by 3.9 cm in length) connected to a ratemeter readout. Portable survey meters were used to help locate gross changes in the external exposure rate. Lithium fluoride thermoluminescent dosimeters were left on Bikini Island and retrieved in December 1975.

Environmental exposure levels were assessed via the RSS-111 and a NaI gamma spectrometer whose purpose was to determine the photon energy distribution and to compensate for the nonlinearity in the RSS-111 instrument response.

This report presents all of the external exposure data collected to date for Bikini Atoll by BNL. These data have been used to make external exposure estimates for the people living on Bikini Island, and the BNL data have been compared with UCRL data[9] for Bikini Atoll.

INSTRUMENTATION AND METHODS

A) Ion Chamber Measurements

All environmental exposure rate measurements were obtained with a Reuter Stokes environmental radiation monitor model RSS-111, which is designed to measure environmental radiation as low as 100 μR/yr. The RSS-111 consists of a spherical high pressure ion chamber filled with argon to a pressure of 25 atm. Incident radiation produces ion pairs within the active volume of the chamber which result in an ionization current. The current flow is measured by an electrometer and is directly related to the free air ionization rate[8].

The active volume of the stainless steel ionization chamber is known to ±1%. The ionization current produced in the chamber is a function of incident radiation from an external field, cosmic-ray response, and contamination present in the stainless steel. The instrument response is energy dependent, and data from the manufacturer indicate an error of as much as 6 to 10% could result if energy corrections are not made to the gross readings[8].

The RSS-111s used in this study were calibrated at the factory against radium sources whose calibration is traceable to the National Bureau of Standards. The calibration of the instruments was also checked at the Environmental Monitoring Laboratory (formerly Health and Safety Laboratory) before and after field use.

In the report on external exposure for all other atolls surveyed by BNL[3], energy dependence corrections were calculated for data from Rongelap and Rongerik Atolls. The factors needed to compensate the RSS-111 response for energy dependence ranged from 1.01 to 1.05. The mean correction was approximately 1.02.

B) Thermoluminescent Survey

Lithium fluoride (LiF) thermoluminescent dosimeter chips 1/4-inch square were used[5], for several reasons. LiF is approximately a tissue equivalent material, and its response is essentially energy independent for photon energies greater than 20 keV up to several MeV. The system is precise to ±2% and has a long term retention of 5% loss at room temperature for one year. These qualities made the LiF ideal for use in the Marshall Islands.

All TLDs were cleaned with analytical grade methanol before departure for the Marshall Islands and prior to analysis. Prior to irradiation, the TLDs were annealed at 400°C for one hour and them at 100°C for 2 hr. After field exposure and before reading, the TLDs were annealed at 100°C for 10 min.

In addition to the TLDs exposed in the field at Bikini and Eneu, several sets of TLDs were assembled for use in correcting field measurements for background, fading and air transportation contributions. Several TLDs were annealed and then immediately stored in a lead pig in the BNL analytical counting area. An equal number of TLDs were irradiated to 100 mR and stored with the background TLDs to determine fading losses. Four other TLDs were sent to Kwajalein and stored there in a lead pig to determine in-transit contributions to the response. All TLD results have been corrected for these parameters.

The TLDs were calibrated at BNL with ^{137}Cs gamma and $^{90}Sr/^{90}Y$ betas. Results are directly related to the external exposure and beta absorbed dose that would be received by individuals living on Bikini and Eneu Islands.

Because the total response must be differentiated into beta and gamma components, a TLD holder was developed that would eliminate nearly 100% of the ^{90}Y beta of 2.27 MeV (Figure 1). Four TLDs are used per holder. Two are covered by 1100 mg/cm^2 of aluminum and Mylar which is of sufficient mass density thickness to eliminate beta response; these provide the gamma response. The two other TLDs are shielded by $\sim$ 15 mg/cm^2 Mylar to respond to the total gamma-beta contribution at one meter above the earth's surface. The difference between the responses of the two TLD sets gives the beta response. TLDs placed in the field were positioned with the open windows facing the soil.

Because shielding part of the dosimeter may bias the data, an attempt was made to predict the resulting error by randomly placing four of the dosimeters (16 TLDs) together, open windows facing the soil, in a series of tests using ^{90}Sr-^{90}Y as a source, placed 30 cm from the TLDs. The open and closed windows were varied to cover all combinations of field positioning. The error using a point source and a source-to-detector distance of 30 cm was <2.5%. Because the field situation represents a distributed plane source, and the source-to-dosimeter distance was between 50 and 100 cm, the field situation should have a minimal positioning error associated with the results (Figure 2).

RESULTS

A total of 203 RSS-111 measurements were made on Bikini Atoll. Each data point is the average of at least 20 individual readings. This assures the precision of the value, and the initial calibration guarantees accuracy. The mean exposure rate is reported with one standard deviation calculated by assuming that the data obtained from a specific site follow a Gaussian distribution.

Tables 1 through 5 represent all data taken on Bikini Atoll. Table 2 lists the data from Nam Island, located at the northwest corner of the atoll, closest to ground zero of the BRAVO device. The average external exposure rate over the land areas monitored is $\sim$ 24 μR/hr. This is six times higher than the background levels at Wotje, Ailuk or Utirik Atolls[3]. This average value should not be interpreted as a true value for the Nam island average, since dense vegetation prevented a representative sample of readings over the whole island. Nam is uninhabited at present and is not used for food production. The exposure rate is non-uniform and varies significantly as a function of location.

Table 3 presents the data from Eneu Island, located south and west of Bikini Island. Eneu received the least fallout contamination as evinced from the average external radiation exposure rate of 5.7 μR/hr. This value is 1.5 times the natural background and is the lowest external exposure rate on any of the islands surveyed. Figure 3 shows the sample sites and the exposure rate measured at each site. These data demonstrate the uniformity of exposure rate on this island.

The external exposure rate on Bikini Island is a strong function of location (Figure 4A-E). It is the lowest in the areas closest to the lagoon and current housing*, highest in the center of the island and intermediate in other areas. The average exposure rate for the island, based on an average of all the data is 32.1 μR/hr. Table 4 lists exposure rate measurements made in the living areas of the available housing. Table 5 lists all other exposure rate measurements made at Bikini Island.

---

*In 1978, the Department of Interior made the decision to relocate the inhabitants of Bikini Atoll to either Ejit Island, Majuro Atoll, or Kili Island. The relocation took place in August 1978.

The TLD data for Bikini Island (Table 1) agree with the RSS-111 measurements, but no constant relationship is seen between beta dose and gamma exposure. Non-uniform deposition of fallout material in the areas surveyed and translocation of material are major factors governing this result.

DISCUSSION OF RESULTS

The average exposure rate as measured for each island is listed in Table 6. Estimation of the dose equivalent for the inhabitants of Bikini Atoll is debatable due to the nonuniform distribution of radioactive material within given areas of the atoll. The exposure rates measured on Eneu Island are fairly uniform, but those on Bikini Island showed significant differences between areas (Table 5 along with Figure 4A - 4E). In the UCRL work[4], this problem was approached and a solution derived by estimating the fractions of an individual's time spent in various areas. These estimates[4] are used here (Table 7) to construct external exposure rate estimates for the various activities based on the measurements reported in Tables 2 through 5. The exposure rate for the lagoon was obtained by assuming that it would be less than or equal to that in the areas of continual habitation. The values for other islands were obtained by assuming that the Marshallese would spend an equal amount of time on each of the other islands surveyed. All other estimates were made by taking the average of all measurements made within the area of interest.

Table 8 shows the estimated exposure rate for each pattern of activity in Table 7 based on continuous occupancy of Bikini Atoll. Table 9 shows the estimated exposure rate for each age group as weighted by the percent of time spent in each area, for inhabitants of Bikini Atoll. Summation of the exposure rates in all the areas provides the average total-body exposure rate for each age group.

Using the average hourly exposure rate, the long term external dose equivalent was calculated (Table 10). The data were corrected for background (terrestrial and cosmic radiation) by using the average exposure rate on Wotje and Ailuk as representative samples of the normal Marshall Island environment[3]. These data for Bikini residents are lower than UCRL data[9] for living patterns 2 and 3, which give the estimated integral external gamma dose equivalent for 30 years as 4 rem, because the present estimates include the measured exposure rate for habitation of the newly constructed housing. These indoor values are 39% lower than those previously reported and their use reduces the total estimated reduction in the 30 year dose equivalent commitment by 32%.

The ICRP suggests[6] that population groups should not receive a 30-year dose equivalent of more than 5.0 rem to the whole body from sources other than medical equipment or natural background. For the external radiation component at Bikini Atoll, this requirement is met; the problem is that external radiation is not the sole source of radiation exposure to the Marshallese. The dietary pathway, based on UCRL data[9], could increase the 30-year total body dose equivalent commitment by a factor of 4.

Whole-body counting data taken in 1974[1], 1977[2] and 1978[7] indicate that the dietary pathway became the prime source of radiation exposure after January

1977. Current *in vivo* data indicate that the equilibrium body burdens for ^{137}Cs will range from 3 μCi to 30 μCi in the Bikini population. This corresponds to a 30-year internal dose equivalent that falls in the range of 11 to 110 rem. Bioassay data obtained from Bikinians during 1978 indicate that bone marrow dose equivalents for 30 years of habitation would be between 0.4 and 1.0 rem from ^{90}Sr-^{90}Y[10].

Reviewing the Bikini dose commitment in this light, one immediately realizes that the inhabitants would receive a total body dose equivalent exceeding the ICRP criteria[6]. Thus, for Bikini Atoll, we concur with the UCRL recommendation[9] that more must be done to lower the total body and bone marrow radiation exposures so that the Marshallese can live within the population dose equivalent recommendations.

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Table 1

Bikini Island TLD Exposure Survey (129 days), Dec. 7, 1974, to Apr. 15, 1975

Location	Total γ Exposure μR	Total β Dose, μrad
House 4 - inside	28400*	-
House 4 - outside 20 in. above ground	36200*	-
House 20 - inside	29900*	-
House 20 - outside mid backyard	27800*	-
House 38 - inside	48600*	-
House 38 - outside mid backyard	41000*	-
Big twin coconut trees, west side of tree near USGS well	194300*	-
Behind house 40, cookhouse at 18 in. off ground	26800	1500
Behind house 35, behind living area at 22 in. off ground	45300	25800
Behind house 30, behind living area at 20 in. off ground	32800	10300
East/west road by house 30 about 30 yd. north of bunker	35600	11000
Behind house 25 near banana and papaya patch, 22 in. off ground	54000	29800
Behind house 21, 20 in. off ground	26300	14700
Behind house 15	29900	4700
Behind house 10	73000	62800
Behind house 6	36200	8400
By USGS well and twin coconut trees	79100	85100
Control 1	2900	2400
Control 2	5100	0
Control 3	6300	0

*Total unshielded response.

Table 2

Nam Island, Bikini Atoll, RSS-111 Exposure Survey, April 1976

Location	μR/hr
West Transect - 200 meters from soil pit	33.4 ± 0.6
West Transect - 100 meters from soil pit	16.7 ± 0.4
East Transect - 200 meters from soil pit	17.6 ± 0.5
East Transect - 100 meters from soil pit	15.2 ± 0.4
East Transect - 245 meters north of lagoon beach	44.9 ± 0.7
East Transect - 150 meters north of lagoon beach	23.1 ± 0.5

Table 3

ENEU ISLAND RSS-111 EXPOSURE SURVEY APRIL 1975

Location	μR/hr
South road to ocean near middle of island	7.2 ± 0.62
2nd coconut row, ocean side of runway adjacent to marker 4	5.6 ± 0.25
2nd coconut row, ocean side of runway adjacent to marker 1	4.2 ± 0.17
2nd coconut row, ocean side of runway adjacent to marker 2	4.9 ± 0.37
2nd coconut row, ocean side of runway adjacent to marker 3	8.2 ± 0.10
1st coconut row, ocean side of runway adjacent to marker 1	5.3 ± 0.16
Midway north of runway apron and coconut row	6.1 ± 0.32
5th coconut row up the road from north corner of runway apron	8.7 ± 0.23
16th coconut row by 2nd large nature tour	6.1 ± 0.14
Group of old buildings, south of church, ocean side of road	6.9 ± 0.12
West bend in road just north of old church, ocean side	8.1 ± 0.31
North 1/3 way up road to Camp Blandy, ocean side	4.9 ± 0.30
North 2/3 way up road to Camp Blandy, ocean side	6.5 ± 0.20
Blandy area just south of soil pit 3, 100 yd from lagoon beach	6.1 ± 0.15
Blandy area just south of soil pit 3, 100 yd from ocean beach	5.6 ± 0.31
North end of Camp Blandy near middle of the island	5.9 ± 0.29
North end of Camp Blandy near lagoon road, ocean side	6.0 ± 0.21
Lagoon road south of Camp Blandy, 100 yd west of church	5.7 ± 0.15
Lagoon road about 150 yd north of Camp Blandy	5.0 ± 0.35
Bunker near dock	5.0 ± 0.22
Old bldg. frame work due west of runway marker 1	6.1 ± 0.27

Table 4

Measured Exposure Rates Within Permanent Housing Constructed on Bikini Island

Location	Exposure rate μR/hr	Location	Exposure rate μR/hr
House 21	6.6 ± 0.13	House 4	7.5 ± 0.15
House 22	7.3 ± 0.37	House 6	7.8 ± 0.28
House 23	7.2 ± 0.10	House 7	10.5 ± 0.28
House 25	7.3 ± 0.28	Outside house 7	
House 26	7.3 ± 0.25	north side on gravel	12.9 ± 0.20
School		House 9	10.7 ± 0.16
middle of the room	7.2 ± 0.10	House 10	11.1 ± 0.25
House 30	8.4 ± 0.14	House 11	9.3 ± 0.23
House 31	8.9 ± 0.10	House 12	9.7 ± 0.49
House 32	10.0 ± 0.37	House 13	13.3 ± 0.19
House 33	9.6 ± 0.45	House 15	11.6 ± 0.23
House 35	15.8 ± 0.19	House 16	11.5 ± 0.60
House 36	13.1 ± 0.17	House 18	8.2 ± 0.17
House 37	11.9 ± 0.30	House 19	7.8 ± 0.26
House 40	11.1 ± 0.15	House 20	7.2 ± 0.13

Table 5

Bikini Island RSS-111 Exposure Survey, April 1975

Location	μR/hr
Column 1, due east of house 30	57.3 ± 0.2
Column 10, due west of bunker	31.8 ± 0.4
Column 20	50.0 ± 0.4
Column 30	46.6 ± 0.4
Column 40	26.4 ± 0.1
Column 50, due west of twin coconut trees	36.6 ± 0.2
Column 58-59, intersection with 1st baseline south	44.5 ± 0.3
North/south transect between 1st baseline south and 2nd baseline south	
Column 1	59.5 ± 0.3
Column 10	78.4 ± 0.5
Column 20	64.7 ± 0.2
Column 30	49.2 ± 0.3
Column 40	45.0 ± 0.2
Column 50	53.8 ± 0.1
Column 60	48.0 ± 0.1
Column 70	48.9 ± 0.4
North/south transect from 2nd to 1st baseline north	
Column 2, 10 yd due south of soil pit A	47.7 ± 0.2
Column 10	54.2 ± 0.6
Column 20	41.2 ± 0.3
Column 30	39.1 ± 0.2
Column 40	55.1 ± 0.2
Column 50	41.3 ± 0.7
Column 60	53.4 ± 0.4
Column 70	82.1 ± 0.5
Column 77, 2 rows due east of soil pit E	31.6 ± 0.3
South/north transect north from 1st baseline north (continuation of USGS-bunker rd.)	
Column 1	52.7 ± 0.1
Column 10	43.2 ± 0.1
Column 20	44.0 ± 0.3
Column 30	58.2 ± 0.2
Column 40	46.6 ± 0.2
Column 50	34.3 ± 0.3
Column 60, due west of small bunker on ocean rd.	31.6 ± 0.3
Column 70	31.2 ± 0.3
Column 77, and intersection of 2nd baseline north	26.6 ± 0.2
40 yards north of 1st baseline north	22.3 ± 1.4
Across lagoon road from house 37	20.0 ± 0.7
Across lagoon road from house 38	24.0 ± 1.1

Table 5 (Cont'd)

Bikini Island RSS-111 Exposure Survey, April 1975

Location	μR/hr
Across lagoon road from house 39	22.9 ± 0.6
10 columns north of house 40	28.5 ± 0.6
South on ocean beach road from 2nd baseline north	
Column 1	23.6 ± 1.0
Column 10	38.3 ± 1.3
Column 20, 3 columns south of small bunker	25.9 ± 0.4
Column 30, 3 rows east of ocean beach road	22.4 ± 1.1
Column 40, 6 rows east of ocean beach road	49.4 ± 0.8
Column 50, 1 row in from ocean beach road	33.4 ± 0.4
Column 60, 3 rows in from ocean beach road	33.4 ± 0.3
Column 70, 1 row in from ocean beach road	37.0 ± 0.7
Column 78, at intersection of ocean beach road and 1st baseline north	33.2 ± 0.5
North/south transect along road separating (1972 designation of rows) rows 24 & 25 from center baseline to 1st baseline north	
Column 1	22.6 ± 0.3
Column 10	62.0 ± 0.2
Column 20	26.7 ± 0.4
Column 30	52.9 ± 1.1
Column 40	42.6 ± 0.3
Column 49 and the intersection of 1st baseline north	48.0 ± 0.3
North/south transect along breadfruit row starting at 2nd baseline north	
Column 4 of older plantings behind house 40	49.2 ± 0.9
Breadfruit planting east of house 39	59.0 ± 0.4
Breadfruit planting east of house 38	40.9 ± 0.5
Breadfruit planting near small bunker between houses 37 & 38	29.9 ± 0.5
Breadfruit east of house 37	28.0 ± 0.8
2 columns of coconut trees north of 1st baseline north	23.0 ± 0.3
1st breadfruit south of 1st baseline north by soil pit D	42.0 ± 0.7
5th breadfruit east of house 36	33.1 ± 0.6
9th breadfruit near banana garden, house 35	34.1 ± 0.6
12th breadfruit east of Japanese memorial and house 34	38.8 ± 0.3
15th breadfruit north of center baseline and east of house 31	22.4 ± 0.2
North/south transect along breadfruit row from center baseline	
Due east and house 30	18.4 ± 0.2
Breadfruit near house 26 and 30 yards east of papaya patch	26.2 ± 0.3
Breadfruit 8 near house 4 and main garden	48.4 ± 0.5
Due east of houses 20 and 21	19.2 ± 0.3
Due east of house 17	25.6 ± 0.5
Due east of house 16 just north of center baseline and soil pit	30.3 ± 0.2

Table 5 (Cont'd)

Bikini Island RSS-111 Exposure Survey, April 1975

Location	μR/hr
Due east of house 14	32.4 ± 0.2
Due east between houses 12 & 13	40.3 ± 0.6
Due east and between house 10 and breadfruit row	24.7 ± 0.3
Due east of house 8 next to breadfruit row	46.4 ± 0.4
Due east of houses 7 & 8 near vegetation depression	16.3 ± 0.2
Due east of houses 5 & 6	34.5 ± 0.5
Due east of houses 3 & 4	7.7 ± 0.4
North/south transect between 2nd baseline north (pit B) and 1st baseline north (pit D)	
Column 2, 15 yd due south of soil pit B	44.5 ± 0.4
Column 10	52.3 ± 0.3
Column 20 due east of house 39	56.9 ± 0.4
Column 30	66.8 ± 0.2
Column 40	41.5 ± 0.4
Column 50	33.2 ± 0.4
Column 60 due east of house 36	42.5 ± 0.3
Column 70	32.8 ± 0.4
Column 77	45.1 ± 0.4
North/south transect between 1st baseline north and center baseline, sample locations proceed due south	
Column 1	28.5 ± 0.2
Column 10	41.0 ± 0.3
Column 20	41.8 ± 0.4
Column 30	56.6 ± 0.2
Column 40	61.5 ± 0.2
Column 48 (last column before crossing center baseline)	15.2 ± 0.2
Row 20	50.9 ± 2.1
Row 30	60.1 ± 1.4
Row 40	46.7 ± 2.2
Row 50	55.1 ± 2.4
Ocean road just behind row 59	34.4 ± 2.0
South on ocean beach road from 2nd baseline south, measurements taken on lagoon side of road	
Column 10	36.9 ± 0.6
Column 20	38.0 ± 0.4
Column 30	29.2 ± 0.5
Column 40	19.6 ± 0.6
Column 50, about 100 yd from ocean	27.7 ± 0.6
Column 60, about 150 yd from ocean	27.8 ± 0.7
Column 67	16.2 ± 0.4

Table 5 (Cont'd)

Bikini Island RSS-111 Exposure Survey, April 1975

Location	µR/hr
Camp area	
Bldg. 1	12.2 ± 0.2
Bldg. 3	13.8 ± 1.0
Near church on northward bend of road halfway between	17.3 ± 0.3
equipment shed and house 1 (ocean side of road)	26.3 ± 0.5
Lagoon road north, measurements taken on ocean side of road	
Open area between houses 3 and 4	16.0 ± 0.1
Open area between houses 5 and 6	18.5 ± 0.4
Open area between houses 7 and 8	28.4 ± 0.6
Open area between houses 9 and 10	23.9 ± 0.3
Open area between houses 12 and 13	24.9 ± 0.3
Open area between houses 14 and 15	37.8 ± 1.8
Open area between houses 16 and 17	28.1 ± 1.6
Open area between houses 34 and 35	13.9 ± 0.9
Open area between houses 35 and 36	14.0 ± 0.3
75 yd north of house 36	23.0 ± 2.0
3rd baseline north starting at the lagoon road	
Row 1	30.9 ± 0.1
Row 5	40.4 ± 0.3
Row 10	44.7 ± 0.4
Lagoon road	
100 yd south of north beach	19.6 ± 0.3
Near house 40 - ocean side of road	13.5 ± 0.5
Near house 38 - lagoon side of road	17.0 ± 0.3
50 yd south of house 37	20.4 ± 0.4
Near house 35 - lagoon side	31.6 ± 0.4
Village center - near intersection of lagoon road and center baseline	9.4 ± 0.4
Soil pit G	22.5 ± 0.4
Near house 25 - lagoon side	18.5 ± 0.1
Near house 20 - lagoon side	18.2 ± 0.2
Near house 15 - lagoon side	24.7 ± 0.2
Near intersection of 1st baseline and lagoon road	
Near house 10 - lagoon side	17.5 ± 0.2
Near house 5 - lagoon side	26.0 ± 0.3
Near house 1 - lagoon side	11.8 ± 0.1
Second baseline south starting behind house 7	
Behind house 7, breadfruit row ~10 yd to row 1	27.0 ± 0.9
Row 10	54.9 ± 1.7
Row 20	50.5 ± 1.4
Row 30	54.0 ± 1.8

Table 5 (Cont'd)

Bikini Island RSS-111 Exposure Survey, April 1975

Location	μR/hr
Row 40	47.3 ± 0.2
Soil pit between rows 42 & 43	40.8 ± 1.4
Row 50, 100 yds from ocean beach	50.8 ± 5.1
Row 60, 30 yds from ocean beach	25.0 ± 0.3
Pandanus 118 behind house 15	27.4 ± 1.4
Behind agriculture area	
Row 1	44.5 ± 1.9
Row 10	51.5 ± 1.9
North face of bunker	21.5 ± 0.5
North-south road midway between bunker and USGS well	66.5 ± 0.2
North-south road, column 5 from 1st baseline south	56.8 ± 1.1
North-south road, column 15 from 1st baseline south	43.4 ± 0.3
North-south road, column 25 from 1st baseline south	32.7 ± 0.6
North-south road, column 35 from 1st baseline south	58.0 ± 1.1
North-south road, column 45 from 1st baseline south	27.2 ± 0.3
Lagoon road, end of center baseline behind house 30	18.7 ± 0.3
Row 10, south side of baseline	25.0 ± 0.2
Row 20, 30 yd from fork to bunker	20.4 ± 0.8
Row 30, 50 yd north of bunker	20.1 ± 0.4
Row 40	12.3 ± 0.2
Row 50	30.8 ± 0.6
Row 60	29.5 ± 0.3
Row 69-70	18.4 ± 0.4
East-west transect	
Lagoon road and 1st baseline north	44.4 ± 0.2
Soil Pit D	40.3 ± 0.3
Row 10, east from lagoon road	36.3 ± 0.5
Row 20	38.3 ± 0.4
Row 30	35.7 ± 0.2
Row 40	42.3 ± 0.4
Row 50	58.1 ± 0.6
Row 60	41.8 ± 0.1
North side of 2nd baseline north (near house 40)	
Row 1	17.5 ± 0.2
Row 10	30.6 ± 0.3
Row 20, near soil pit B	[illegible]5.9 ± 0.3
Row 30	[illegible]3.9 ± 0.3
Row 36-37, near soil pit A	23.3 ± 0.3
Row 40	29.6 ± 0.2
Row 50	30.6 ± 0.2

Table 6

Average Exposure Rate Corrected for Decay to May 1977

Island	No. of Observations	Av. exposure rate μR/hr
Nam	6	23.5 ± 11.0
Eneu	21	5.7 ± 1.1
Bikini	203	32.1 ± 16.3

Table 7

Population Breakdown by Age and Geographical Living Patterns[5]

	Infants and small children	Children and adolescents	Men	Women
Age, yr	0-4	5-19	20+	20+
Percent of population	16	41	22	21
Percent of time spent in following areas:				
Inside home	50	30	30	30
Within 10 m of home	15	10	5	10
Elsewhere in village	5	10	5	10
Beach	5	5	5	5
Interior of island	5	15	20	15
Lagoon	0	10	10	5
Other islands	20	20	25	25

Table 8

Assumed Mean Exposure Rate for Each Activity Area

Pattern	Bikini Atoll μR/hr
Inside home	9.7
Within 10 m of home	15.8
Elsewhere in village	25.3
Beach	15.8
Interior island	44.9
Lagoon	15.8*
Other islands	15.5**

*Value assumed to be less than or equal to value for beach.
**Based on assumption that equal amounts of time are spent on other islands within the Atoll.

Table 9

Exposure Rate Estimates for Bikini Atoll Inhabitants

	Infants 0-4 yr	Children 5-19 yr	Men 20+ yr	Women 20+ yr
Percent of population	16%	41%	22%	21%
Exposure rate (μR/hr) during time within following areas:				
Inside home	4.85	2.91	2.91	2.91
Within 10 m of home	2.37	1.58	0.79	1.58
Elsewhere in village	1.27	2.53	1.27	2.53
Beach	0.79	0.79	0.79	0.79
Interior island	2.25	6.74	8.98	6.74
Lagoon	0.00	1.58	1.58	0.79
Other islands	3.10	3.10	3.88	3.88
Total	14.63	19.23	20.20	19.22

Table 10

External Dose Equivalent to Inhabitants of Bikini Atoll

Age Group	Net ext. exposure rate, μR/hr, May '77	Ext. integrated dose equiv., rem (background subtracted)		
		10 yr	30 yr	50 yr
Infants (0-4)	10.27	0.80	1.90	2.59
Children (5-19)	14.60	1.12	2.69	3.66
Men (20+)	15.52	1.20	2.85	3.88
Women (20+)	14.60	1.12	2.69	3.66

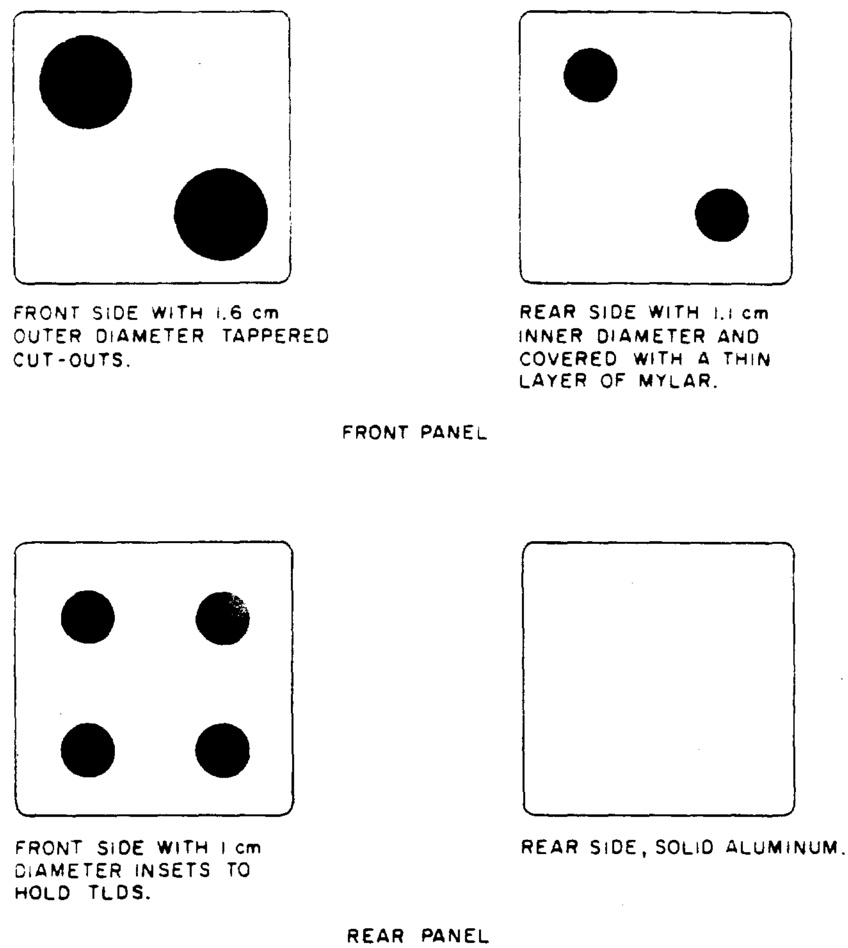
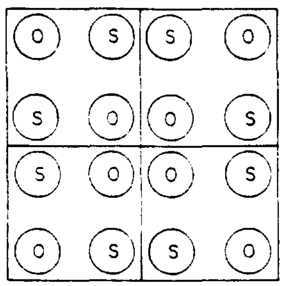


Figure 1. Aluminum TLD holder.

CONFIGURATION #1



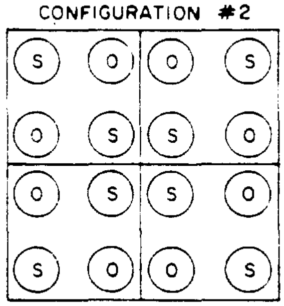
$^{90}Sr/^{90}Y$ SOURCE PLACED 12 INCHES FROM THE MIDLINE OF THE TLD HOLDER.

S — INDICATES TLD LOCATED BENEATH 3.48 mm OF ALUMINUM

O — INDICATES TLD WASN'T SHIELDED

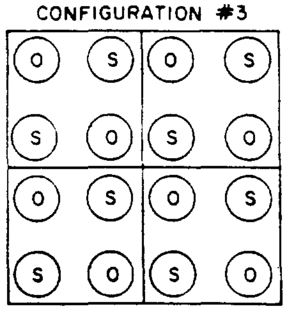
CALIBRATION FACTOR = 0.1458 RADS/NANOCOULOMB

CONFIGURATION #2



CALIBRATION FACTOR = 0.1414 RADS/NANOCOULOMB

CONFIGURATION #3



CALIBRATION FACTOR = 0.1464 RADS/NANOCOULOMB

AVERAGE CALIBRATION FACTOR = 0.1445 ± 0.00273 RADS/NANOCOULOMB

Figure 2. Determination of Beta calibration factor.

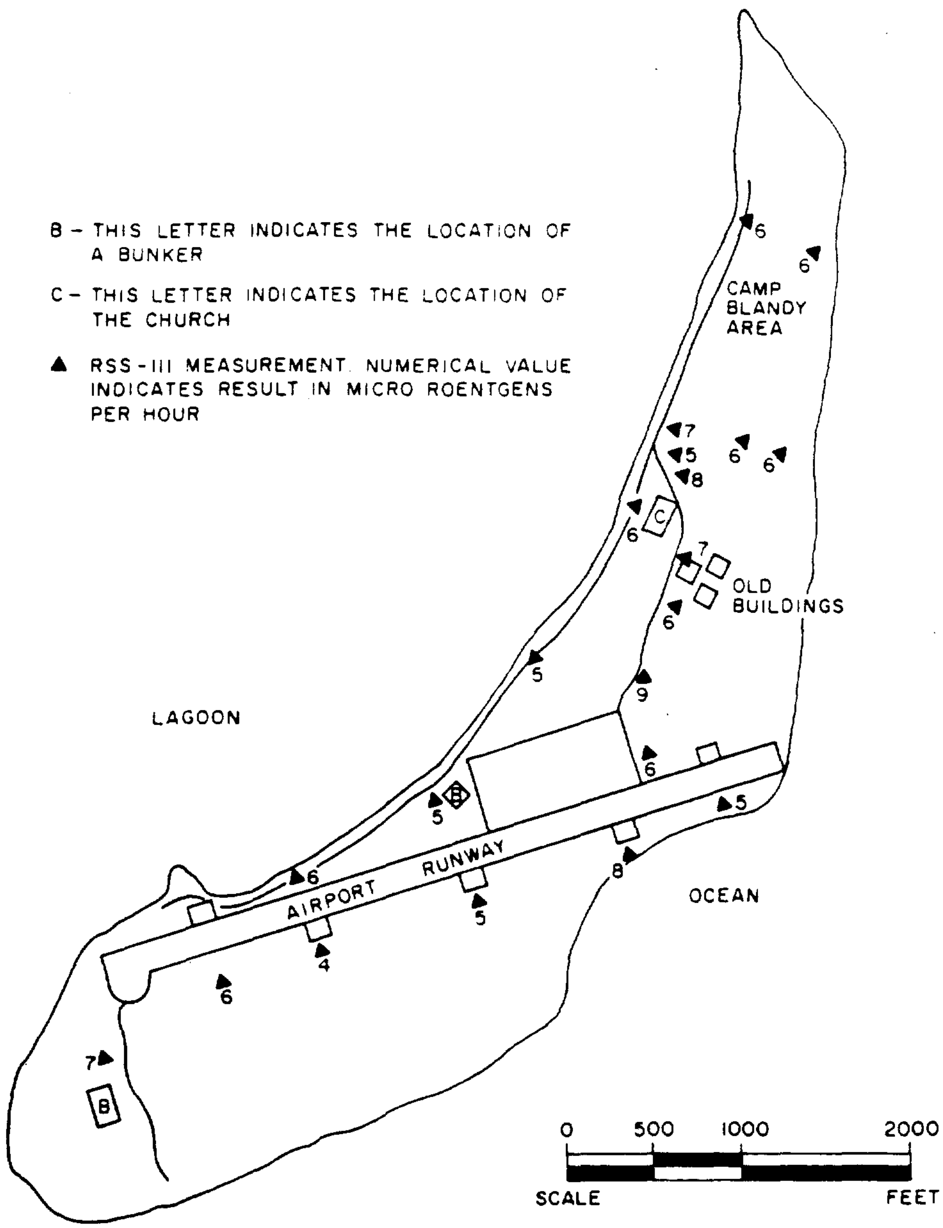


Figure 3. Eneu Island external exposure survey, April 1975.

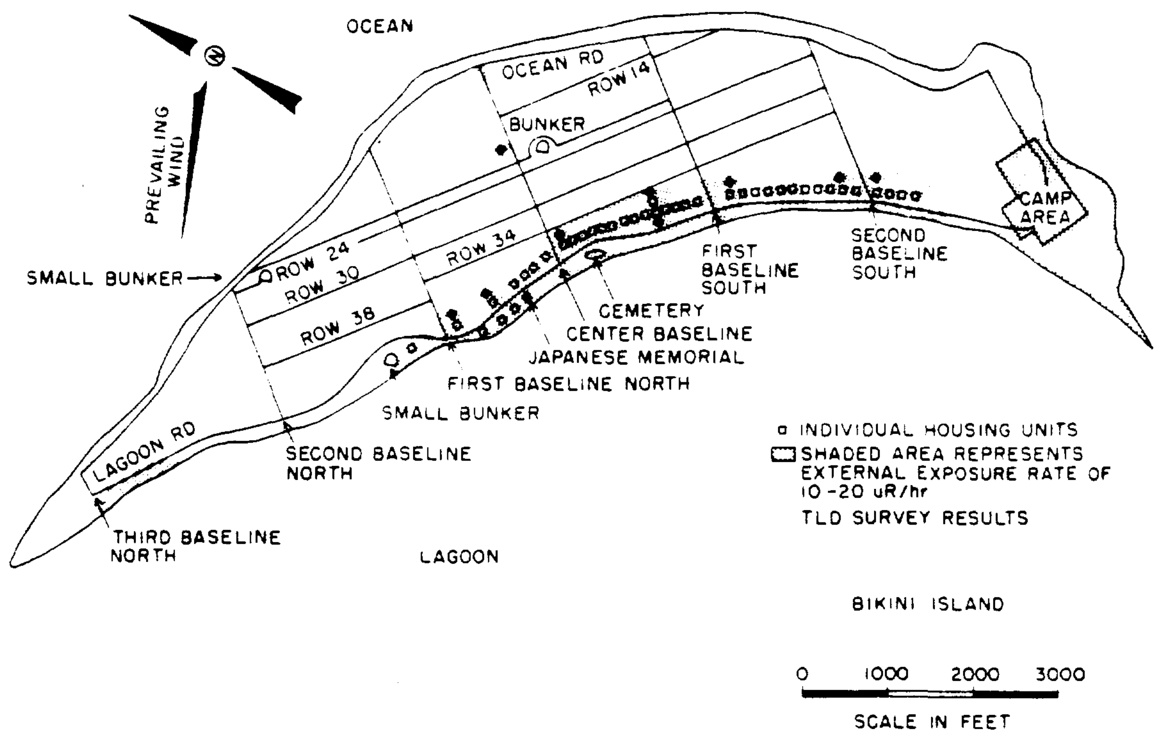


Figure 4A.

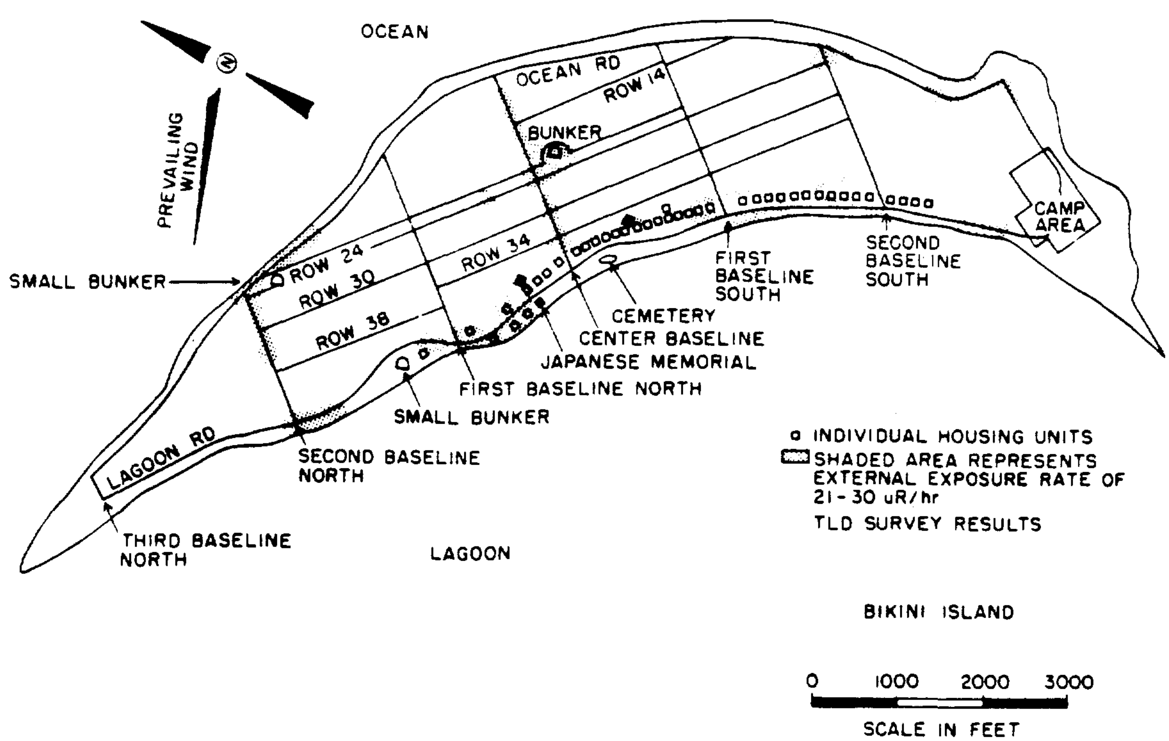


Figure 4B.

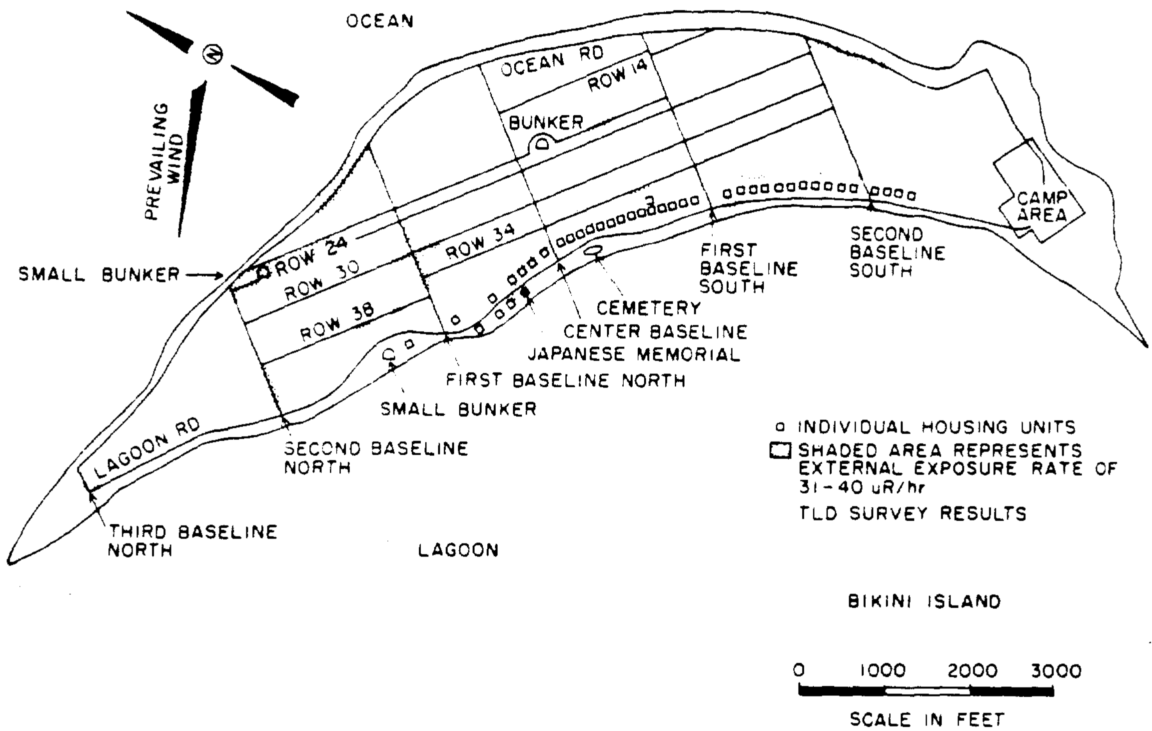


Figure 4C.

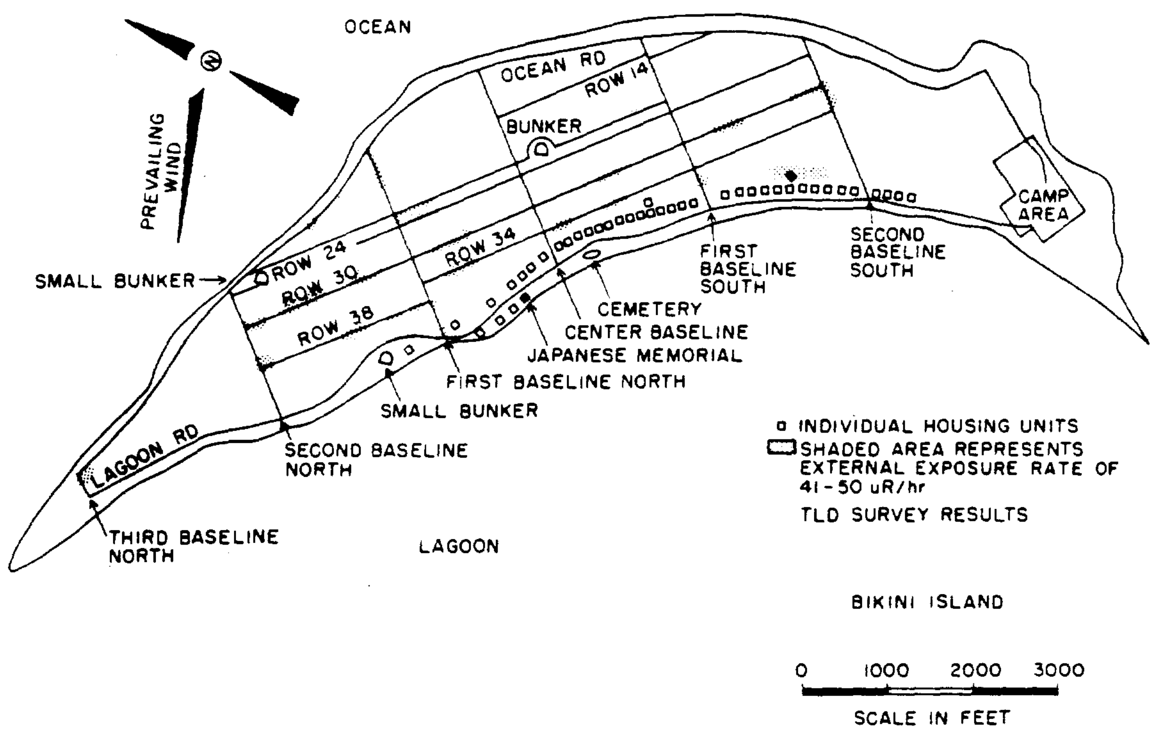


Figure 4D.

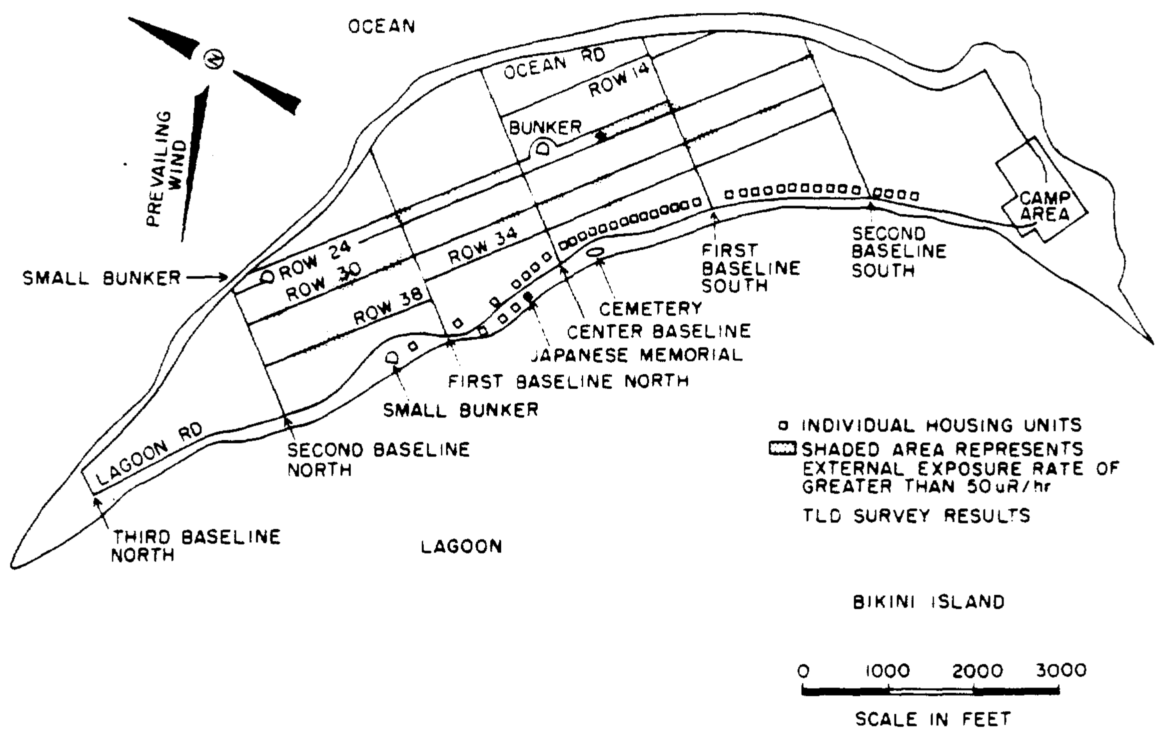

OCEAN
OCEAN RD
ROW 14
BUNKER
PREVAILING WIND
SMALL BUNKER
ROW 24
ROW 30
ROW 34
ROW 38
FIRST BASELINE SOUTH
SECOND BASELINE SOUTH
CAMP AREA
CEMETERY
CENTER BASELINE
JAPANESE MEMORIAL
FIRST BASELINE NORTH
SMALL BUNKER
LAGOON RD
SECOND BASELINE NORTH
THIRD BASELINE NORTH
LAGOON
INDIVIDUAL HOUSING UNITS
SHADED AREA REPRESENTS EXTERNAL EXPOSURE RATE OF GREATER THAN 50uR/hr
TLD SURVEY RESULTS
BIKINI ISLAND
0 1000 2000 3000
SCALE IN FEET

Figure 4E.

Reconst'n of Chron. Dose Equiv. for Rongelap & Utirik Resid. '54-'80

BNL 51257

A RECONSTRUCTION OF CHRONIC DOSE EQUIVALENTS FOR RONGELAP AND UTIRIK RESIDENTS - 1954 TO 1980

E.T. LESSARD, N.A. GREENHOUSE, AND R.P. MILTENBERGER

October 1980

SAFETY AND ENVIRONMENTAL PROTECTION DIVISION

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E. T. Lessard, N. A. Greenhouse, R. P. Miltenberger

ABSTRACT

From June 1946 to August 1958, the U.S. Department of Defense and Atomic Energy Commission conducted nuclear weapons tests in the Northern Marshall Islands. BRAVO, an aboveground test in the Castle series, resulted in radioactive fallout contaminating Rongelap and Utirik Atolls. On March 3, 1954, the inhabitants of these atolls were relocated until radiation exposure rates declined to acceptable levels. Environmental and personnel radiological monitoring programs were begun in the mid 1950's by Brookhaven National Laboratory to ensure that dose equivalents received or committed remained within U.S. Federal Radiation Council Guidelines for members of the general public. Body burden and dose equivalent histories along with activity ingestion patterns post return are presented. Dosimetric methods, results, and internal dose equivalent distributions for subgroups of the population are also described.

INTRODUCTION

On March 1, 1954, at Bikini Atoll, BRAVO, the first of six nuclear weapons tests in the Castle series, was detonated. The BRAVO device caused substantial surface contamination on inhabited atolls within a 2,000 square mile area. The contaminated region was cigar shaped and included Ailinginae, Rongelap, Rongerik, and Utirik Atolls which lay east of ground zero at distances from 60 to 300 miles. The fallout on Rongelap, initially visible at H+6 hours, had thinned out to the extent that it was no longer seen at H+10 hours (G162).

On March 3, 1954, the 64 residents of Rongelap Atoll and 18 residents of Sifo Island, Ailinginae Atoll, were evacuated. On March 3 and 4, evacuation of 157 Utirik Atoll residents also took place. During the first few weeks and at least once every year from 1957 to the present, a Brookhaven National Laboratory medical team, organized by the Department of Defense and by the Atomic Energy Commission and its successor organizations, has provided medical examinations to monitor the health of the persons initially affected by the fallout from the nuclear testing program, plus a comparison population. Reports of their findings are given in Cr56, Co58, Co59, Co60, Co62, Co63, Co65, Co67, Co70, Co75, and Co80.

The Utirikese and Rongelapese returned to their home atolls in June 1954 and in June 1957 respectively. The earlier repatriation of Utirik Atoll was based on the low level of external radiation exposure measured after the initial 3 month observation period (March to June 1954). The Utirik population was not examined by a Brookhaven medical team until March, 1957, when 144 people received comprehensive physical examinations. Following the 1957, medical survey, two men, removed from Utirik for medical reasons, were whole body counted at Argonne National Laboratory and provided urine samples for radiochemical analysis of ^{137}Cs. Four persons visited Argonne from Rongelap and, in addition, pooled urine samples from both atolls were analyzed radiochemically for ^{137}Cs and ^{90}Sr. Subsequent Brookhaven National Laboratory expeditions by members of the Medical Department and Safety and Environmental Protection Division utilized whole body counting and radiochemical analysis of urine and blood samples to identify and quantify the radionuclides that were present in the body. The results of these radiological measurements are given in terms of body burden in Tables 1 and 2. Throughout this paper the units of quantities are SI derived and those which are accepted for use with the SI for the time being. Thus both the Curie and the Becquerel may be used as units for the quantity activity.

The aforementioned body burden tables illustrate adult mean values for Rongelap and Utirik. An adult, as classified here, was a person over 16 years of age. The mean body mass in this age interval was 60 kilograms. The observed body mass versus age distribution is shown in Figure 1 for Rongelap residents. The same body mass versus age distribution was observed at Utirik.

Because of the paucity of measurements at Utirik, information on ^{60}Co, ^{65}Zn, and ^{55}Fe was in some instances derived from the ratio of adult mean body burdens between Rongelap and Utirik. A mean ratio of 2.6 was observed in body burdens for ^{65}Zn, ^{90}Sr, and ^{137}Cs after they reached their maximum values. The standard deviation of this ratio was 15%.

In the following analysis, personal body burden histories and residence intervals, in conjunction with contemporary dosimetric models, are used to estimate internal dose. Dosimetric distributions were constructed from the results and a summary of the derived activity ingestion rates and dose equivalents was provided for various subgroups of the population. Additionally, exposure rate history curves were constructed for each atoll for the period following the

Table 1

Rongelap Body Burdens

	Adult Males		Adult Females		Adults		
	Body Burden μCi	Number of Persons	Body Burden μCi	Number of Persons	Body Burden μCi	Number of Persons	Days Post Return Days
^{60}Co	2.9×10^{-5}	NA	1.7×10^{-5}	NA	2.3×10^{-5}	NA	1
	1.0×10^{-2}	37	7.8×10^{-3}	37	9.0×10^{-3}	74	1370
	2.5×10^{-3}	45	2.0×10^{-3}	45	2.2×10^{-3}	90	2831
^{65}Zn	4.3×10^{-2}	NA	3.8×10^{-2}	NA	4.1×10^{-2}	NA	1
	4.3×10^{-1}	30	3.8×10^{-1}	12	4.1×10^{-1}	42	304
	6.2×10^{-1}	32	5.0×10^{-1}	27	5.6×10^{-1}	59	639
	9.5×10^{-2}	38	8.5×10^{-2}	23	9.0×10^{-2}	61	1370
^{55}Fe	4.3×10^{-1}	28	4.0×10^{-1}	32	4.1×10^{-1}	60	4626
^{90}Sr	1.9×10^{-4}	NA	1.4×10^{-4}	NA	1.7×10^{-4}	NA	1
	3.7×10^{-3}	11	2.8×10^{-3}	4	3.4×10^{-3}	15	304
	5.7×10^{-3}	24	3.5×10^{-3}	16	4.8×10^{-3}	40	639
	3.7×10^{-3}	9	1.6×10^{-3}	4	3.0×10^{-3}	13	1370
	8.8×10^{-3}	12	7.9×10^{-3}	13	8.4×10^{-3}	25	2100
	7.9×10^{-3}	11	7.4×10^{-3}	7	7.7×10^{-3}	18	2466
	2.8×10^{-3}	12	4.6×10^{-3}	12	3.7×10^{-3}	24	3561
	3.9×10^{-3}	11	3.1×10^{-3}	11	3.5×10^{-3}	22	3927
	4.1×10^{-3}	11	3.3×10^{-3}	13	3.6×10^{-3}	24	4292
	1.3×10^{-3}	8	3.3×10^{-3}	11	2.5×10^{-3}	19	4657
	3.1×10^{-3}	8	2.8×10^{-3}	7	3.0×10^{-3}	15	5022
	2.0×10^{-3}	5	1.4×10^{-3}	7	1.6×10^{-3}	12	5388
	6.6×10^{-3}	4	4.2×10^{-3}	7	4.3×10^{-3}	13	5753
	3.3×10^{-3}	10	1.7×10^{-3}	4	2.8×10^{-3}	14	6118
	4.4×10^{-3}	23	NA	0	NA	NA	7579
	6.3×10^{-4}	24	4.6×10^{-4}	19	5.5×10^{-4}	43	8097
^{137}Cs	1.4×10^{-2}	NA	8.4×10^{-3}	NA	1.1×10^{-2}	NA	1
	8.7×10^{-1}	NA	5.2×10^{-1}	NA	6.8×10^{-1}	NA	304
	7.9×10^{-1}	47	4.1×10^{-1}	49	5.7×10^{-1}	96	639
	9.5×10^{-1}	37	4.7×10^{-1}	37	6.7×10^{-1}	74	1370
	9.4×10^{-1}	44	4.9×10^{-1}	45	6.8×10^{-1}	89	2831
	4.8×10^{-1}	22	3.0×10^{-1}	24	3.9×10^{-1}	46	6118
	3.0×10^{-1}	30	1.9×10^{-1}	21	2.5×10^{-1}	51	7213
	1.8×10^{-1}	19	1.5×10^{-1}	18	1.7×10^{-1}	37	8097

NA = Not available

Table 2

Utirik Body Burdens

	Adult Males		Adult Females		Adults		
	Body Burden µCi	Number of Persons	Body Burden µCi	Number of Persons	Body Burden µCi	Number of Persons	Days Post Return Days
^{60}Co							
D	4.0×10^{-3}		3.1×10^{-3}		3.5×10^{-3}		2464
D	9.7×10^{-4}		7.6×10^{-4}		8.7×10^{-4}		3924
^{65}Zn	3.5×10^{-1}*	2	-		-		
	2.7×10^{-1}	14	1.6×10^{-1}	15	2.1×10^{-1}	29	1734
D	3.7×10^{-2}		3.3×10^{-2}		3.5×10^{-2}		2464
^{55}Fe							
D	1.7×10^{-1}		1.6×10^{-1}		1.6×10^{-1}		6114
^{90}Sr							
	1.4×10^{-3}	5	2.4×10^{-3}	2	1.7×10^{-3}	7	1734
	1.2×10^{-3}	5	1.3×10^{-3}	6	1.3×10^{-3}	11	7213
	NA	12	NA	12	NA	24	8669
	1.5×10^{-4}	14	1.5×10^{-4}	17	1.5×10^{-4}	31	9225
^{137}Cs							
	4.1×10^{-1}	NA	2.7×10^{-1}	NA	3.3×10^{-1}	NA	1004
	2.9×10^{-1}	15	2.0×10^{-1}	15	2.5×10^{-1}	30	1734
	2.6×10^{-1}	9	1.3×10^{-1}	13	1.8×10^{-1}	22	7213
	1.2×10^{-1}	27	7.8×10^{-2}	21	1.0×10^{-1}	48	8309
	6.2×10^{-2}	19	4.3×10^{-2}	17	5.3×10^{-2}	36	9225

D = Ratio derived body burden
NA = Not available
* = Measured at Argonne National Laboratory

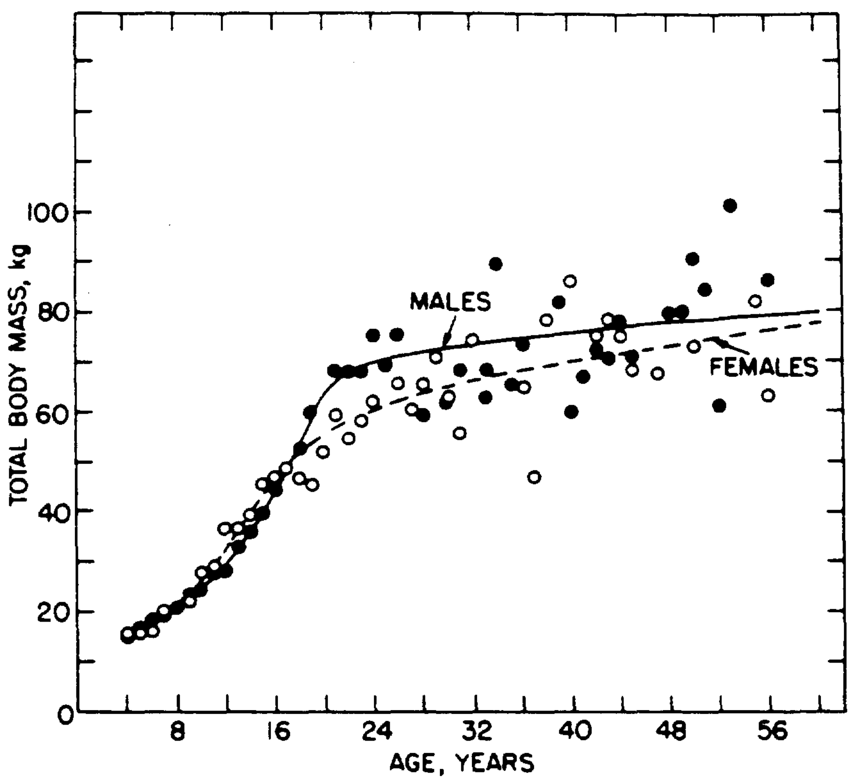

Fig. 1 Body Mass as a Function of Age for Residents of Rongelap Atoll

BRAVO test. These data, together with appropriate conversion factors and living pattern models, provided an estimate of external dose equivalent.

METHODS

Exponentially declining activity concentrations have been observed in surface soil for ^{137}Cs, ^{129}I, and ^{90}Sr from 1954 to the present on Rongelap and Utirik Atolls. Declining activity concentrations have also been observed in vegetation at a rate greater than that predicted by radioactive decay. Thus exponential decline in dietary activity was assumed and the following general equations were derived.

$$\lambda P^{\circ} = \frac{U\, U_s/f_u - q^{\circ}\left(\Sigma_i\, K_i \chi_i' \, e^{-(\lambda+K_i)t}\right)}{f_1 \left(\Sigma_i \frac{\chi_i K_i}{K_i - K_E}\left(e^{-(\lambda+K_E)t} - e^{-(\lambda+K_i)t}\right)\right)}, \qquad (1)$$

or

$$\lambda P^{\circ} = \frac{q - q^{\circ}\left(\Sigma_i\, \chi_i' \, e^{-(\lambda+K_i)t}\right)}{f_1 \left(\Sigma_i \frac{\chi_i}{K_i - K_E}\left(e^{-(\lambda+K_E)t} - e^{-(\lambda+K_i)t}\right)\right)}, \qquad (2)$$

and

$$D = f_1 \lambda P^{\circ}\, \Sigma_i \frac{\chi_i}{K_i - K_E}\left(\frac{K_i - K_E - (\lambda+K_i)\, e^{-(\lambda+K_E)t} + (\lambda+K_E)\, e^{-(K_i+\lambda)t}}{(K_E+\lambda)\,(K_i+\lambda)}\right)$$

$$+ q^{\circ}\, \Sigma_i \frac{\chi_i'}{\lambda+K_i}\left(1 - e^{-(\lambda+K_i)t}\right), \qquad (3)$$

where

t ≡ time post onset of uptake, days,

λ ≡ instantaneous fraction of atoms decaying per unit time, day^{-1}

P° ≡ initial atom ingestion rate, atoms day^{-1},

K_i ≡ instantaneous fraction of atoms removed from compartment i by physiological mechanisms, day^{-1},

χ_i ≡ compartment i deposition fraction,

χ_i' ≡ the number of atoms in compartment i relative to the number in all compartments at the onset of declining continuous uptake, (t=0),

U ≡ instantaneous urine activity concentration, Bq ℓ^{-1},

U_s ≡ subject urine excretion rate, ℓ day^{-1},

f_1 ≡ fraction from GI tract to blood,

f_u ≡ fraction excreted by the urine pathway,

K_E ≡ instantaneous fraction of atoms removed or added to the atom uptake per unit time, day^{-1}, due to factors other than radioactive decay,

q ≡ instantaneous body burden, Bq,

q° ≡ body burden at the onset of uptake, Bq,

D ≡ the number of disintegrations in all compartments occurring during the uptake interval, Bq days.

The development of Eqs. (1), (2), and (3) was based on the following convolution integral. At some variable time, τ, defined during a fixed uptake interval, T, the daily activity ingestion rate crossing the gastrointestinal tract to blood is given by

$$\lambda f_1 P^{\circ} e^{-(k_E+\lambda)\tau} \ .$$

The whole body retention at any time $t-\tau$ of the fraction of initial radioactivity inputed at time τ is

$$\Sigma_i \chi_i e^{-(\lambda+K_i)(t-\tau)} .$$

Thus, the instantaneous activity at time $t-\tau$ that remains following input during $d\tau$ is

$$\lambda f_1 P^\circ e^{-(K_E+\lambda)\tau} \Sigma_i \chi_i e^{-(\lambda+K_i)(t-\tau)} d\tau .$$

It follows that the instantaneous activity at time $t-\tau$ that remains following input during T is

$$\int_o^T \lambda f_1 P^\circ e^{-(K_E+\lambda)\tau} \Sigma_i \chi_i e^{-(\lambda+K_i)(t-\tau)} d\tau .$$

The solution of the integral yields a general expression that depends on the user defining t. For example, if t is the fixed uptake interval, T, plus an additional fixed post uptake interval, $\emptyset$, then the body burden at T + $\emptyset$ is given by

$$\sum_i \frac{\lambda P^\circ f_1 \quad \chi_i \left(e^{-(\lambda+K_E)T} - e^{-(\lambda+K_i)T}\right) e^{-(\lambda+K_i)\emptyset}}{K_i - K_E} .$$

As previously stated, Eq. (2) applied at Rongelap and Utirik, it was for the situation that variable time t was the uptake interval. Additionally, persons who returned to the atolls in June 1954 and June 1957 did so with an initial body burden, q°. The behavior of this contribution to body burden, q, was embodied in the q° term of Eq. (2). A similar model was used to relate urine activity concentration to body burden. Equation 3 was obtained by integrating Eq. (2).

Equations (1) and (2) were used to determine the instantaneous fraction of atoms removed or added to the atom uptake per unit time, K_E, and then the initial daily activity ingestion rate required to produce the measured or derived body burden. Equation (3) was used to determine the number of disintegrations that occurred in the body during the residence interval of an individual living on Rongelap or Utirik Atoll.

If the mean residence time in the diet is much much longer than the residence interval, then constant continuous uptake is achieved. Equations (1) and (2) can be converted to the constant continuous equations by replacing K_E with $-\lambda$. Single uptake expressions are obtained by setting P^o equal to zero. In some cases only radioactive decay may remove the nuclide from dietary items; for these cases K_E would equal zero. In the case of the former Bikini residents, the maturing of coconut trees during residence on Bikini Atoll caused a continuously increasing dietary uptake of ^{137}Cs. Thus, K_E was found to have a negative value. In the case of Rongelap and Utirik, K_E was found to have a positive value for ^{137}Cs, ^{65}Zn, ^{60}Co, and ^{90}Sr. This indicated that in addition to radioactive decay, some other removal mechanism decreased the radioactivity in dietary items during the residence interval. For the nuclide ^{55}Fe, only one measurement was published by the BNL Medical Program (Be72); thus an estimate of K_E was not possible.

K_E was determined by using Eq. (1) or (2) and the population subgroup mean body burden or urine activity concentration. Portions of these bioassay data are illustrated for adult males and females in Figures 2 to 6. Two consecutive urine or body burden data points were used to eliminate the unknown ingestion

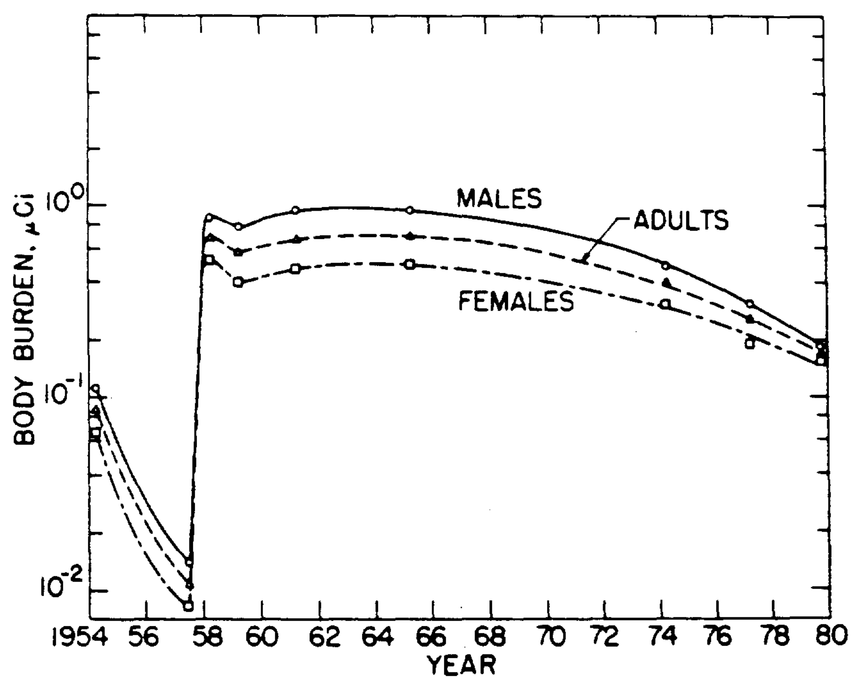

Fig. 2 Mean Adult ^{137}Cs Body Burden History at Rongelap Atoll

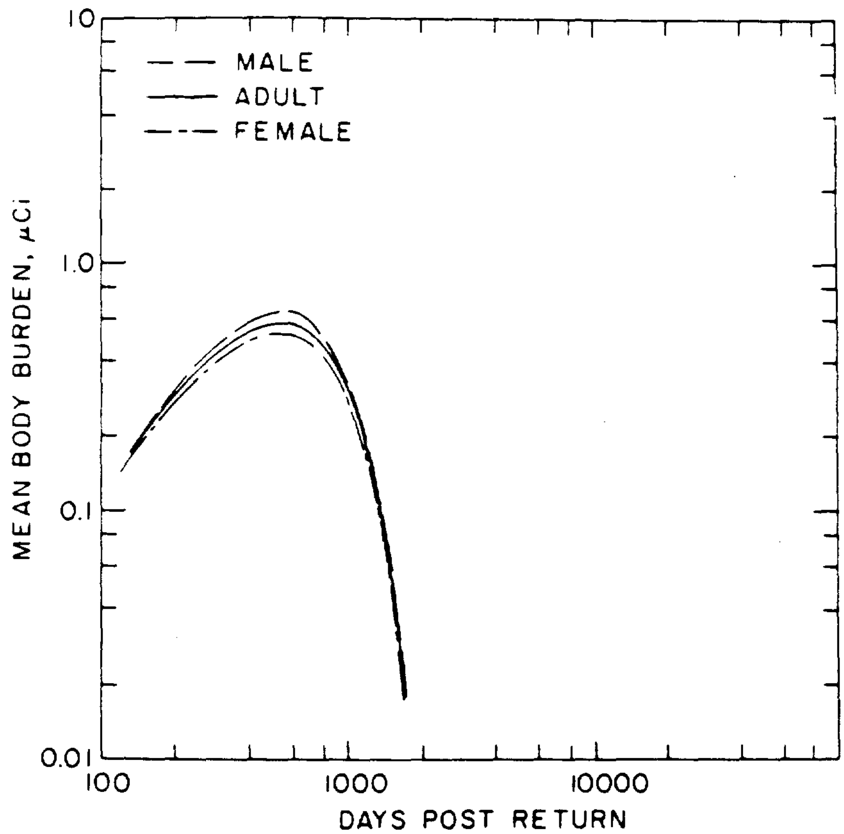

Fig. 3 Mean Adult ^{65}Zn Body Burden History at Rongelap Atoll

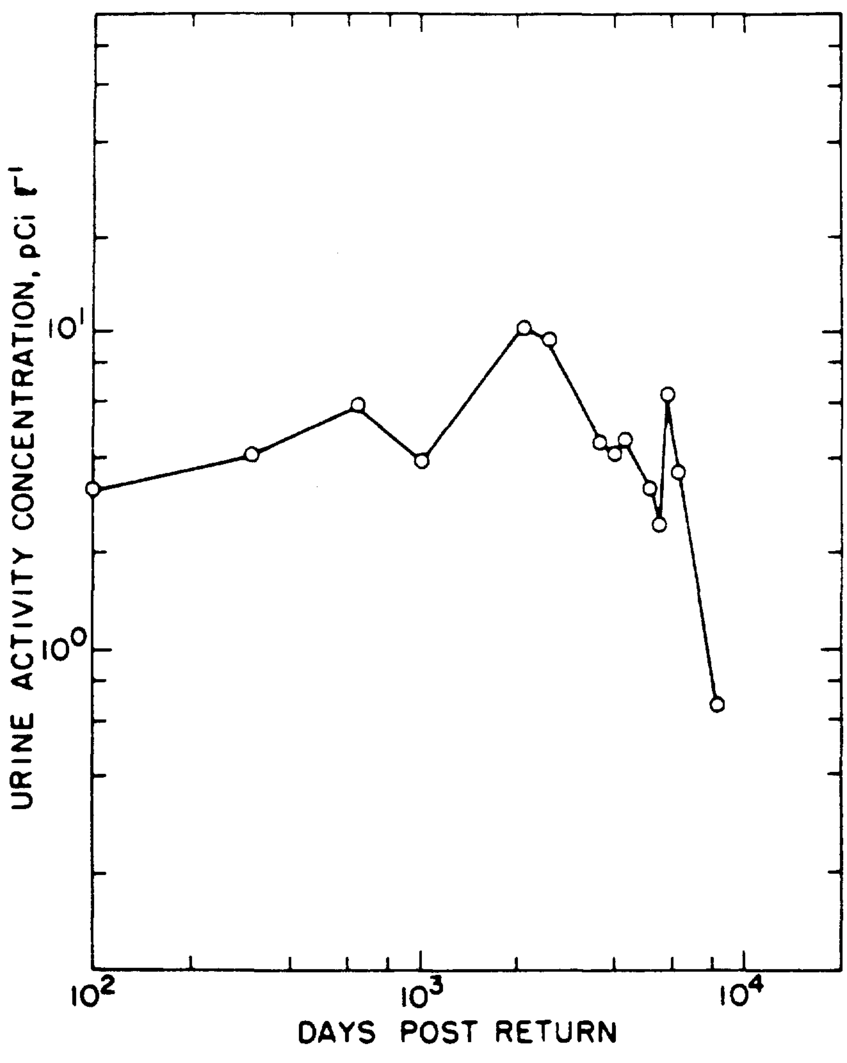

Fig. 4 Mean Adult ^{90}Sr Urine Activity Concentration History at Rongelap Atoll

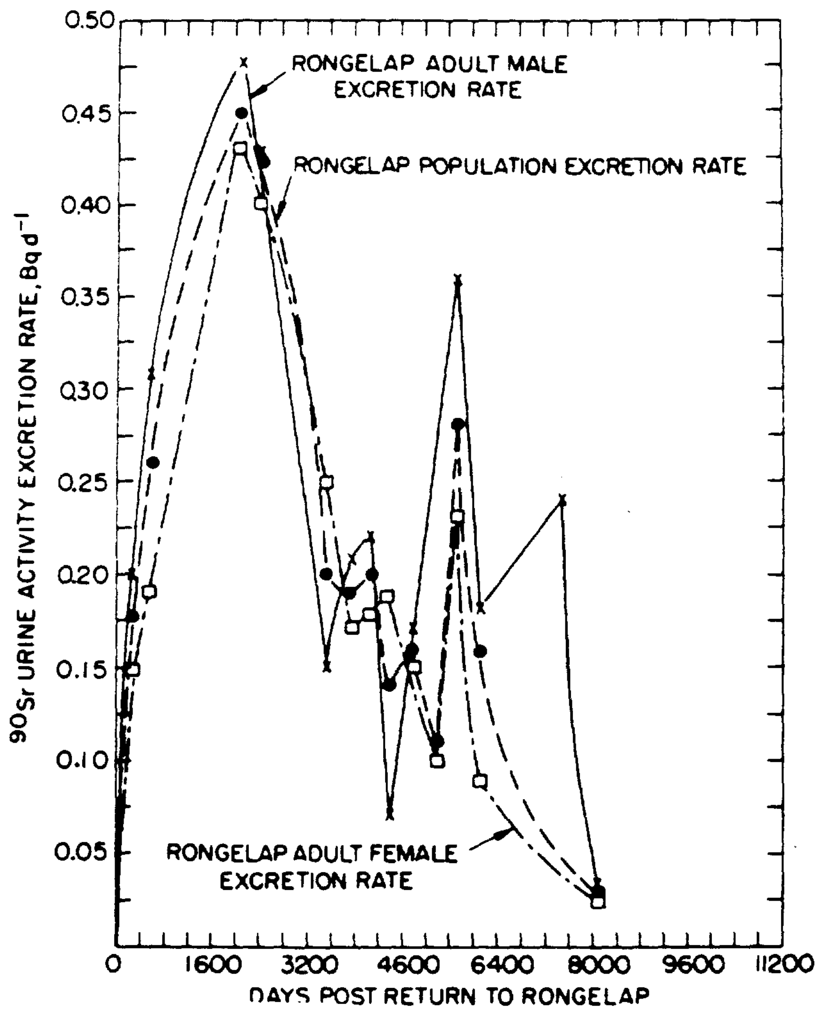

Fig. 5 Mean Adult ^{90}Sr Urine Activity Excretion Rate at Rongelap Atoll

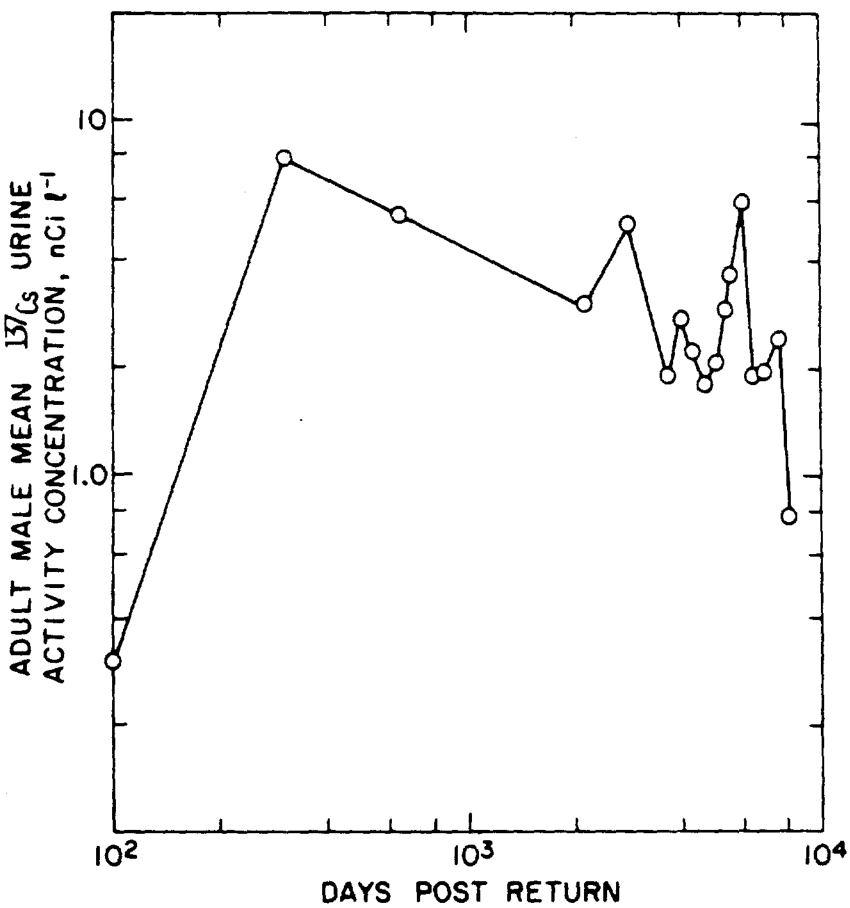

Fig. 6 Mean Adult Male ^{137}Cs Urine Activity Concentration History at Rongelap Atoll

rate from the equation. This method yields n-1 estimates of K_E where n was the number of data points. An average value of K_E was assigned for each nuclide, and the results for the Rongelap and Utirik populations are given in Table 3. For the evaluation of K_E from Eq. 1 and 2, radiological and physiological parameters were obtained from the open literature (ICRP59, ICRP68, ICRP69, ICRP79, Ki78). A representative sample of these parameters is presented in Table 4.

Table 3

Summary of Dietary Rate Constants (K_E, d^{-1})

	^{60}Co	^{90}Sr	^{65}Zn	^{137}Cs
Rongelap Adults				
Males	1.5×10^{-3}	1.8×10^{-4}	3.1×10^{-3}	1.4×10^{-4}
Females	1.6×10^{-3}	4.1×10^{-4}	3.5×10^{-3}	1.4×10^{-4}
Adults	1.5×10^{-3}	1.9×10^{-4}	3.1×10^{-3}	1.4×10^{-4}
Utirik Adults				
Males	N.D.	4.6×10^{-4}	N.D.	1.4×10^{-4}
Females	N.D.	4.0×10^{-4}	N.D.	1.4×10^{-4}
Adults	N.D.	4.2×10^{-4}	N.D.	1.4×10^{-4}

N.D. ≡ No data sufficient for analysis.

The values of K_E were similar for males and females and for residents of Rongelap and Utirik. For ^{90}Sr on Rongelap a factor of 2 difference between K_E values was observed for males and females. The female parameter for Rongelap Atoll compares with that obtained from the Utirik data. A paired t-test of the Rongelap male and female data indicates that the male/female difference was highly probable and therefore not significant. This difference leads to a

Table 4

Total Body Dosimetric and Physiologic Data

Nuclide $^{A}_{Z}X$	Compartment Deposition Fraction x_i	Compartment Removal Rate Constant K_i d^{-1}	GI Tract to Blood Transfer f_1	Fraction Excreted in Urine f_u	Decay Constant λ d^{-1}	Significant Progeny $^{A}_{Z}X$	Branching Ratio
$^{137}_{55}Cs$	0.13 0.87	0.50 0.0051	1.0	0.90	$6.3x10^{-5}$	$^{137m}_{56}Ba$	0.946
$^{65}_{30}Zn$	0.25 0.75	0.058 0.0022	0.35	0.25	$2.8x10^{-3}$	$^{65*}_{29}Cu$	0.49
$^{90}_{38}Sr$	0.89 0.059 0.051	0.21 $7.1x10^{-4}$ $1.0x10^{-4}$	0.20	0.85	$6.5x10^{-5}$	$^{90}_{39}Y$ $^{90*}_{40}Zr$	1.0 0.0002
$^{60}_{27}Co$	0.5 0.3 0.1 0.1	1.4 0.12 0.012 $8.7x10^{-4}$	0.05	0.70	$3.6x10^{-4}$	$^{60*}_{28}Ni$	1.0
$^{55}_{26}Fe$	1.0	$3.5x10^{-4}$	0.1	0.0	$7.0x10^{-3}$		

bimodal activity ingestion rate distribution for ^{90}Sr in the Rongelap population.

Data for ^{60}Co and ^{65}Zn were not sufficient for analysis for the Utirik Atoll residents. Values for K_E observed at Rongelap were assigned to Utirik males and females and body burden histories for population subgroups were reconstructed using Eq. 1 or 2. Figures 7 and 8 illustrate the derived mean adult body burdens for all significant nuclides studied on Rongelap and Utirik. This method provides a best fit of the data shown in Figures 2 through 6, and provides a body burden history during the early years post return at Utirik, a time when body burden measurements were not made. Actual data points are also plotted to demonstrate the fit.

The curves shown for ^{55}Fe in Figures 7 and 8 were obtained by setting K_E equal to zero. This underestimated the initial body burdens and overestimated future ones. Since ^{55}Fe contributed less than 1.0% to the total dose equivalent, an arbitrary assignment of K_E based on observed values for the other nuclides was not attempted. During 1974, another series of blood samples was obtained from Rongelap and Utirik (Co75). Analysis for ^{55}Fe has yet to be reported. A recalculation of ^{55}Fe body burden and its impact on early dose equivalent rates will be conducted when the data is made available. A substantial change in dose equivalent is not to be expected.

Figure 4 and Figure 6 illustrate the observed adult histories of ^{90}Sr and ^{137}Cs mean urine activity concentrations. Mean values for adult males or all adults were plotted. Measured values for ^{137}Cs body burdens were also shown in Figure 7. A much smoother curve was plotted in Figure 7 and it was determined that the collection and analysis technique for urine samples introduced the additional variations. On the basis of this observation for ^{137}Cs, a smooth body

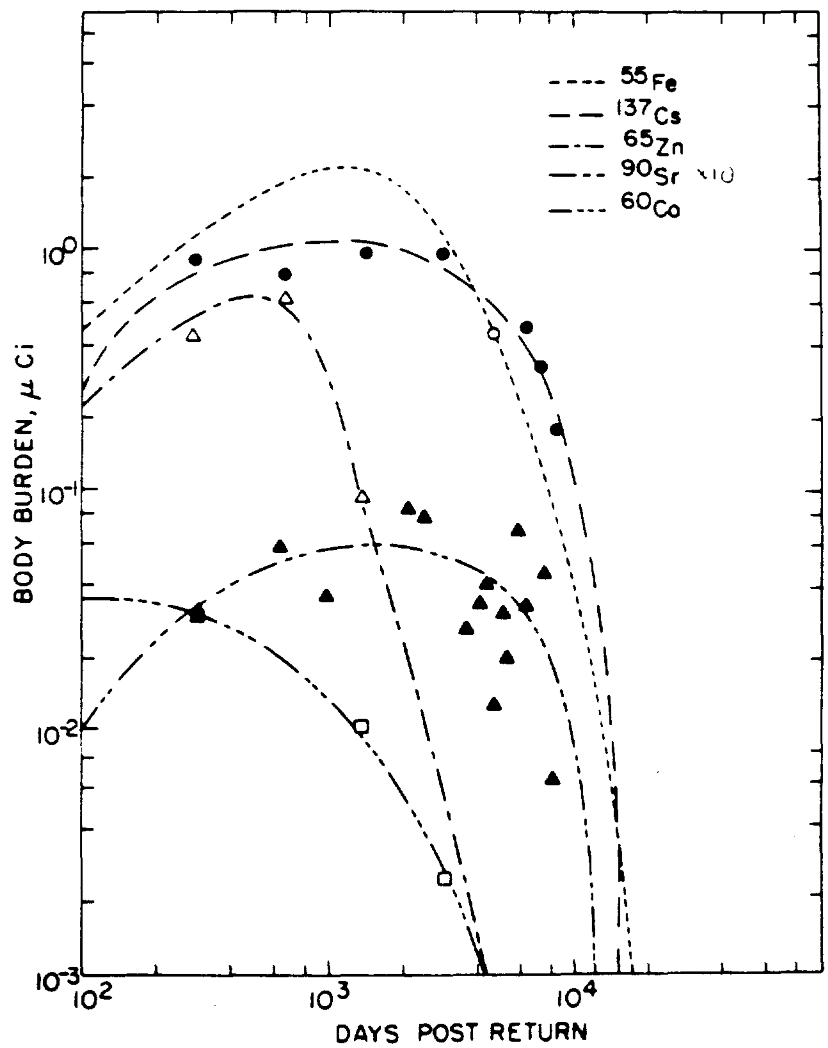

Fig. 7 Composite Nuclide Body Burden History For Adults at Rongelap Atoll

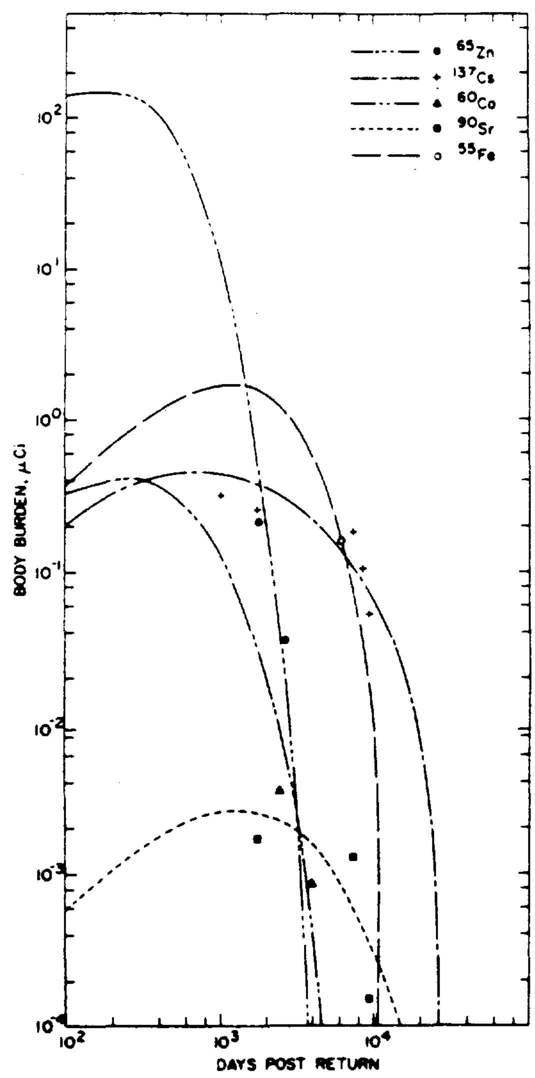

Fig. 8 Composite Nuclide Body Burden History For Adults at Utirik Atoll

burden curve for ^{90}Sr, reconstructed from raw data and Eq. 1, was considered a more accurate history. A detailed presentation of the greater variation in radiochemical analysis of urine versus direct body burden measurements can be found in Mi81.

Figure 9 illustrates the variation exhibited in the body burden of 5 randomly chosen subjects over the 25 year monitoring period. These individual variations may have had a dramatic impact on the mean data. In Figure 2, which illustrates the adult male, adult female, and adult population mean ^{137}Cs body burden for the 25 year exposure period, a decrease followed by an increase was seen during the years 1958 through 1963. Although the Castle BRAVO test initially contaminated Rongelap in March 1954, it had been proposed that the Hardtack Phase I series added to this an amount of contamination equal to that responsible for the Figure 2 body burden pattern (Co63). Figure 9 suggests that most individuals counted in those years had body burdens which remained the same or declined; however, one individual's burden (#881 M) rose and fell quite differently from the others. Several factors could have contributed to this variation from the mean such as departure and return to the atoll, sickness, the dietary contribution of imported foods, etc. Since the mean values are based on small numbers of persons who were chosen at random, it is conceivable that individuals like 881 M influenced the mean body burdens to a greater degree than recontamination of the inhabited atolls. The impact of the individual body burden pattern on the true mean value is moot since body burdens of all individuals were not monitored consistently throughout their residence intervals except in the few cases exhibited in Figure 9.

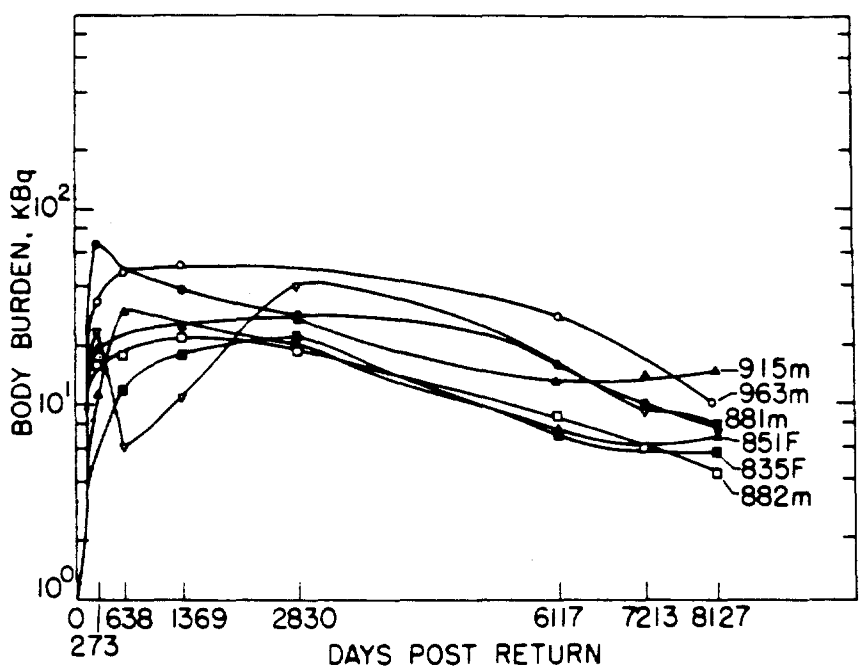

Fig 9 Individual Male and Female Body Burden Histories Randomly Chosen From The Rongelap Atoll Population

RESULTS AND DISCUSSION

Daily Activity Ingestion Rates

Daily activity ingestion rates were calculated for dosimetrically significant nuclides post return. An exponential decline was proposed for the ingestion rate within a population subgroup and initial reference values are given in Figures 10 through 14 (June 1, 1957, was assigned as a return date to Rongelap). Figure 10 demonstrates the differences in ingestion of ^{137}Cs for various population subgroups. This undulating pattern was exhibited by ^{137}Cs, ^{90}Sr, and ^{65}Zn, nuclides for which sufficient data existed for analysis.

Differences in ingestion rates of the stable element at the same geographic location have been shown to occur among members of a population (ICRP 23). Age dependent diet studies for ingestion of Cs for urban Japan have values varying from 11 $\mu g\ d^{-1}$ for adults to 8.6 $\mu g\ d^{-1}$ for children. Sr in a western type diet rose from 600 $\mu g\ d^{-1}$ for infants to 690 $\mu g\ d^{-1}$ for 5 year olds to 3,600 $\mu g\ d^{-1}$ for 13 year olds and fell to a mean of 1,900 $\mu g\ d^{-1}$ for adults. Zn in the United Kingdom rose from 2 to 40 $mg\ d^{-1}$, the higher value of Zn being observed in adult tea drinkers. Fe ingestion in a western type diet has a minimum at age 3 and maxima at ages 1 and 20 years. Co is ingested at a rate of 20 $\mu g\ d^{-1}$ for Japanese adults and half this amount for children. The Marshallese population also exhibits dietary changes as a function of age. The authors of the Marshall Islands Diet and Living Pattern Study (Na80) observed coconut sap being used as a major food supplement for infants, and later in adult life as a major source of daily fluid intake. Since coconuts and coconut tree sap provided the major source of ^{137}Cs on Bikini Atoll (Le80, Mi80), the shape of Figure 10 was in agreement with the observed diet pattern.

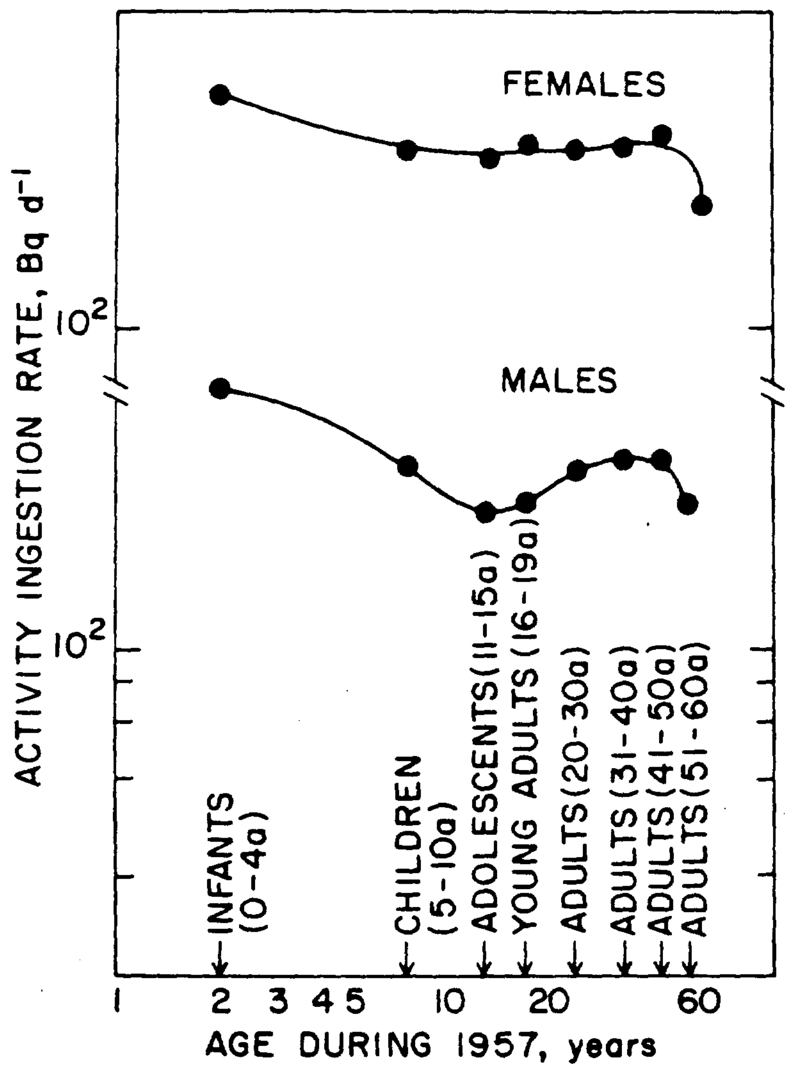

Fig. 10 Age and Sex Group Mean Values For ^{137}Cs Activity Ingestion Rate Referenced To Mid 1957 for Rongelap Atoll

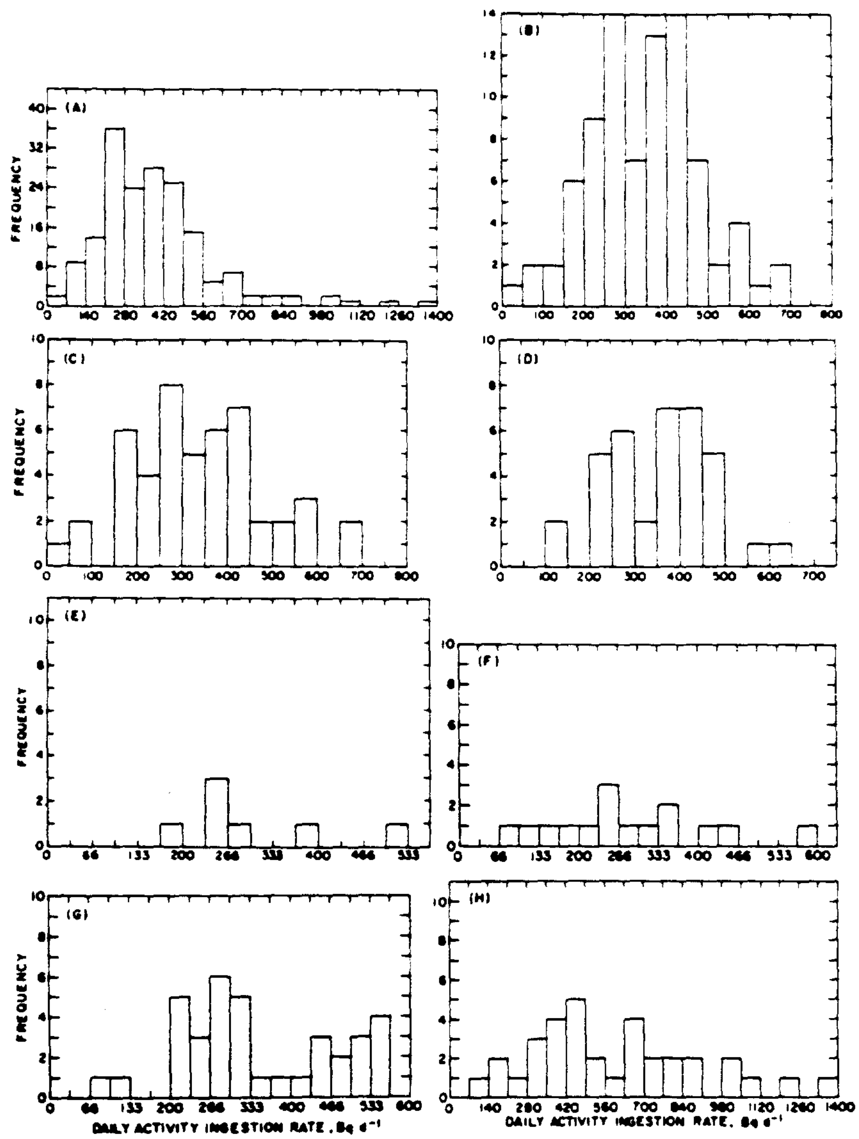

Fig. 11 ^{137}Cs Daily Activity Ingestion Rate For (A) All Residents (B) Adults (C) Adult Males (D) Adult Females (E) Young Adults (F) Adolescents (G) Children and (H) Infants on Rongelap - Referenced to June 1957

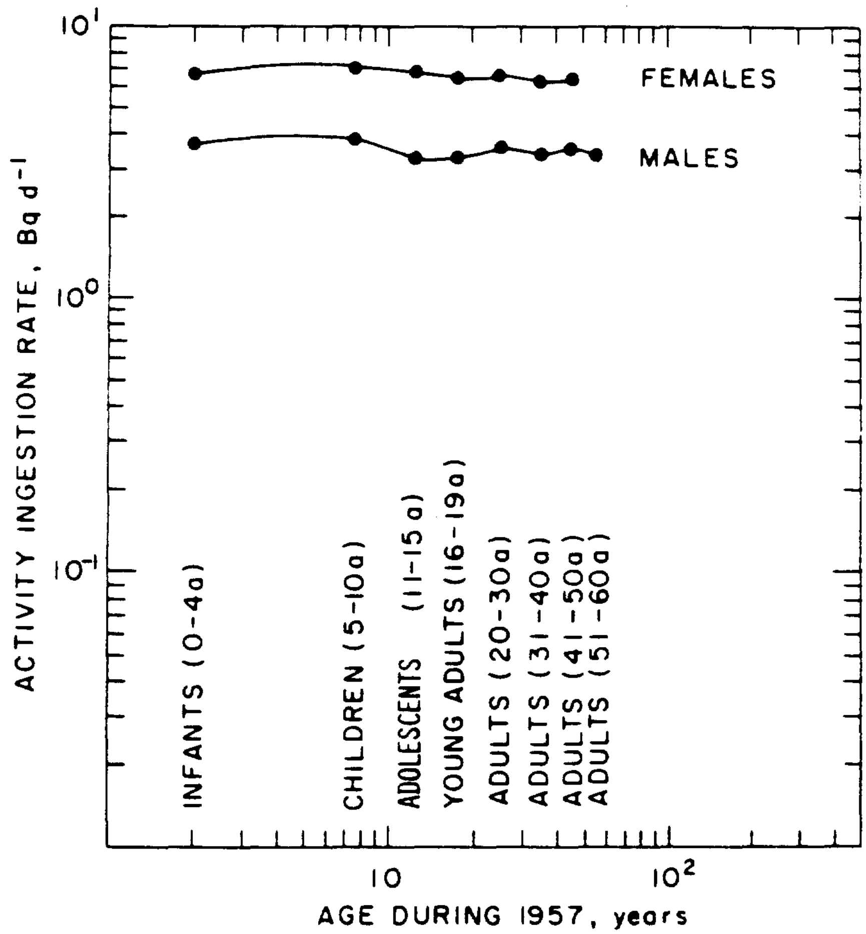

Fig. 12 Age and Sex Group Mean Values For ^{90}Sr Activity Ingestion Rate Referenced To Mid 1957 For Rongelap Atoll

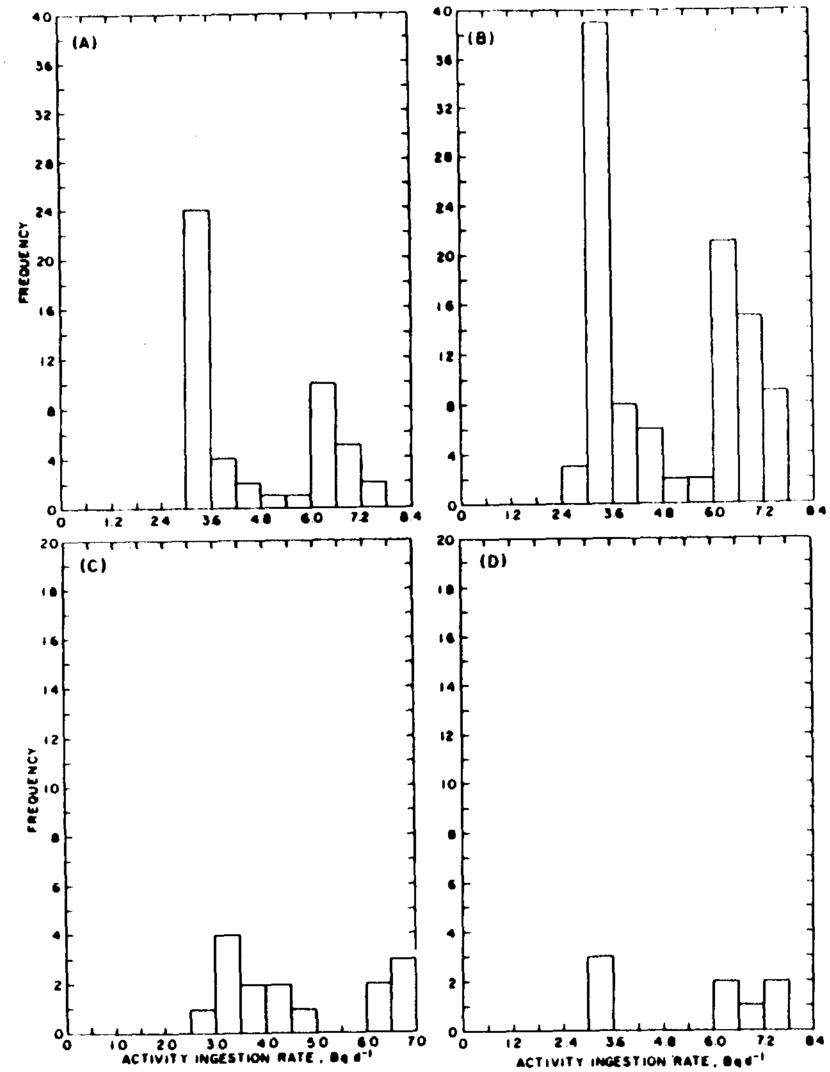

Fig. 13a ^{90}Sr Daily Activity Ingestion Rate For (A) Adults (B) All Residents (C) Infants and (D) Adolescents on Rongelap

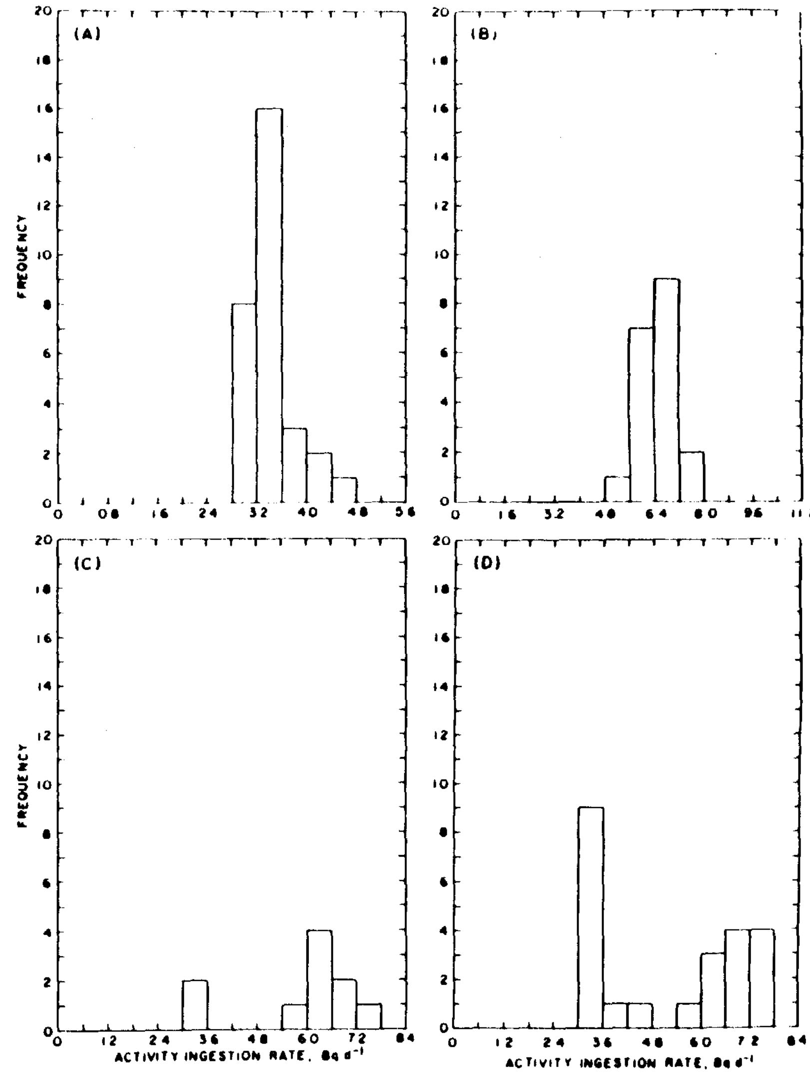

Fig. 13b ^{90}Sr Daily Activity Ingestion Rate for (A) Adult Males (B) Adult Females (C) Young Adults and (D) Children on Rongelap

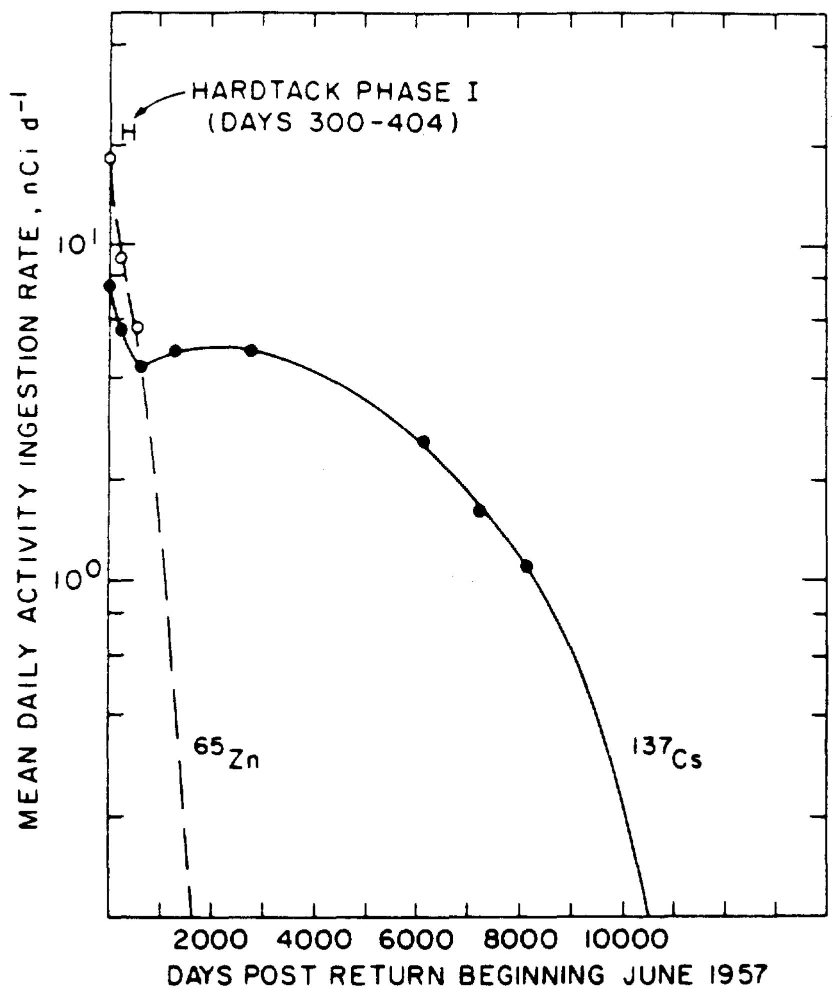

Fig. 14 Adult Mean Daily Activity Ingestion Rate For ^{137}Cs and ^{65}Zn at Rongelap Referenced to Mid-1957

Figure 11 shows the individual data calculated for ^{137}Cs for all Rongelap residents and is referenced to June 1, 1957. The individual maximum ^{137}Cs daily activity ingestion rate was approximately 4 times the population mean value. The standard deviation observed for the adult activity ingestion rate distribution was 41% of the mean value, 39% of the mean value for young adults, 48% for adolescents, 38% for children, and 54% for infants. Adolescents and infants exhibited a broader distribution than adults, while children showed a fractional variation in activity ingestion rate similar to that of adults. Breast feeding versus coconut sap supplements would have contributed to the greater variation observed in infants. Adolescents and young adults were the population subgroups which have been observed to move frequently between atolls. This mobility would lead to greater variations in the daily activity ingestion rates relative to those observed in the more stationary population subgroups.

Figure 12 also exhibited a wave pattern; however, a distinct difference between males and females was indicated. This difference arose from the use of values for K_E listed in Table 3 which were derived from urine data for male and female residents at Rongelap Atoll. Its major impact was on the dose equivalent rate, not on the total dose equivalent; and its effect was to cause the dose equivalent rate for males to rise and decline more rapidly than for females.

Figures 13a and 13b summarize the individual data for ^{90}Sr for all Rongelap residents and were referenced to June 1, 1957. A bimodal shape was observed for the distributions which contained both sexes, again reflecting the difference in the ^{90}Sr dietary rate constants. Data from urine bioassay indicated that the observed difference between the male and female values for K_E was not significant. A t-test was performed for consecutive urine measurement data during the 23 year residence interval. The results indicate that because of urine activity concentration variability, there was a 60% probability that the male value for K_E would be different from the female value by the factor observed. Thus differences in the derived activity ingestion rates and dose equivalents were not significant.

Figure 14 shows a semi-log plot of the ^{65}Zn and ^{137}Cs activity ingestion rate histories for adults on Rongelap. A curve was drawn between points, and the appearance of an increasing ^{137}Cs ingestion rate during the 1960's indicated the possibility of another contaminating event. The Hardtack Phase I series was conducted just prior to the observed increase in the curve and fallout from the Cactus, Yellow Wood, and Hickory experiments detonated at Bikini and Enewetak would have reached Rongelap. However, several observations fail to support the conclusion that recontamination was significant. These are as follows: 1) the increase in ^{137}Cs ingestion rate was not in conjunction with an increase of ^{65}Zn; however, since ^{65}Zn is an activation product it may have not been produced in the same proportions. 2) The peak ^{137}Cs body burden at Utirik occurred nearly three years after the initiating event, Castle BRAVO, while the peak body burden at Rongelap followed six years after the potentially contaminating experiments of the Hardtack series in 1958. 3) The activity ingestion rate at Utirik demonstrated a continuously declining pattern versus the humped pattern observed at Rongelap. This occurred even though there was an equal external exposure rate history following the Hardtack series as measured by the U.S. Public Health Service on both Rongelap and Utirik (Un59). 4) The peak exposure rate on Rongelap following the Hardtack series was 10,000 times less than the peak exposure rate following BRAVO. These facts suggest that the Hardtack series was not a major factor influencing the Rongelap body burden patterns. Thus it is postulated that body burden variations were caused by travel away from the atoll or sickness and other factors. Regardless of the cause of individual differences from the mean, a smooth description of the body burden and activity ingestion rate for the population could be adopted. On this basis a declining continuous uptake model was use .

Internal Dose Equivalent Rates

The approximate instantaneous dose equivalent rates for the total body were determined from the body burden data illustrated in Figures 7 and 8 and from the following equation

$$\dot{H} = qI, \tag{4}$$

where

$\dot{H}$ ≡ the total body dose equivalent rate, mRem y^{-1},

I ≡ equilibrium dose equivalent rate to the total body per unit body burden, mRem y^{-1} μCi^{-1},

q ≡ instanteous body burden, μCi.

The approximate nature of the estimate was due to the assumption that the radioactive atoms were distributed among the body tissues as they would be following constant continuous uptake for periods of time much greater than the mean residence time for the total body. In the case of ^{90}Sr, 86% of equilibrium was assumed. These assumptions were not used in the estimate of the total dose equivalent. In addition, since mean adult body burdens were computed, a factor of 1.2 was needed to adjust for differences in body mass relative to a 70 kilogram adult. Table 5 lists values of I which were determined from information given in ICRP59 and corrected for body mass differences.

Table 5

Total Body Equilibrium Dose Equivalent Rate per Unit Body Burden

$^{A}_{Z}X$	I, mRem y^{-1} μCi^{-1}
$^{55}_{26}Fe$	2×10^{0}
$^{60}_{27}Co$	6×10^{2}
$^{65}_{30}Zn$	1×10^{2}
$^{90}_{38}Sr$	3×10^{2}
$^{137}_{55}Cs$	2×10^{2}

Figure 15 illustrates the relative contribution to the composite dose equivalent rate for each dosimetrically significant internally deposited nuclide. For the average Rongelap adult, the residence interval begins June 1, 1957; however, many adults were reported to have resettled during the next 3 to 6 months (Co80b). The composite dose equivalent rate indicated that a broad maximum of approximately several hundred millirem per year persisted for several hundred days. Most of the dose rate is attributable to the ^{137}Cs component Cesium dominated over the entire post return period and would be of prime concern for populations returning to a contaminated environment years after a fission type initiating event.

Figure 16 illustrates two possibilities for the Utirik dose equivalent rate resulting from the ^{65}Zn body burden history during the first three years post-return. The higher body burden resulted from use of the two measured ^{65}Zn

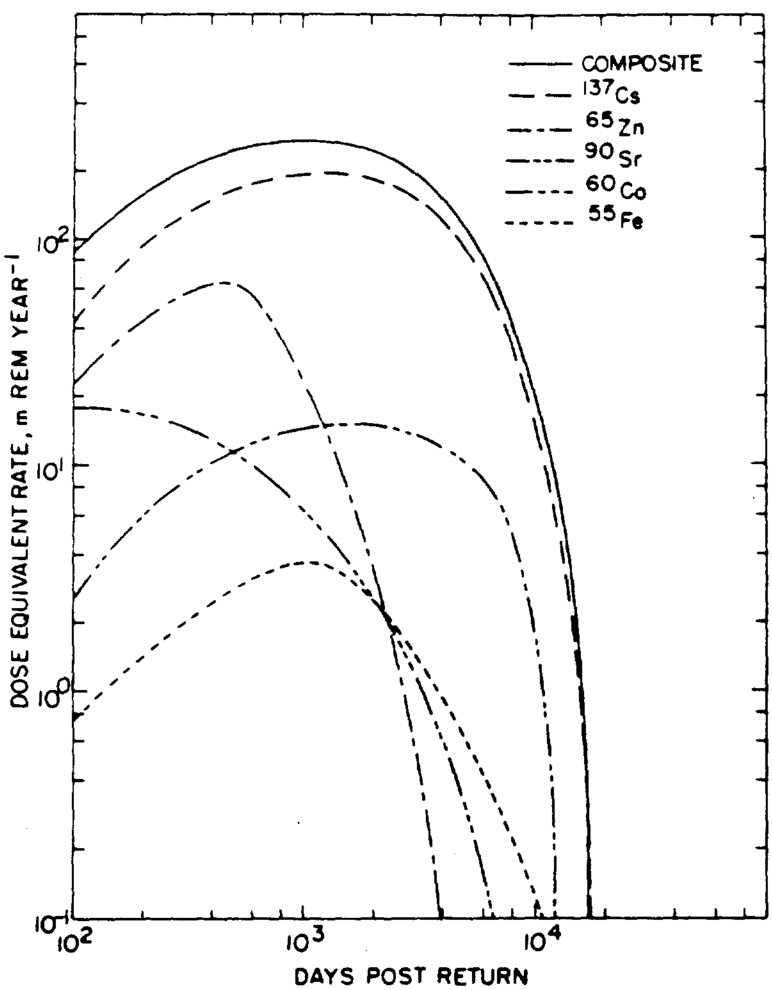

Fig. 15 Adult Mean Total Body Dose Equivalent Rate at Rongelap Atoll Post Mid 1957

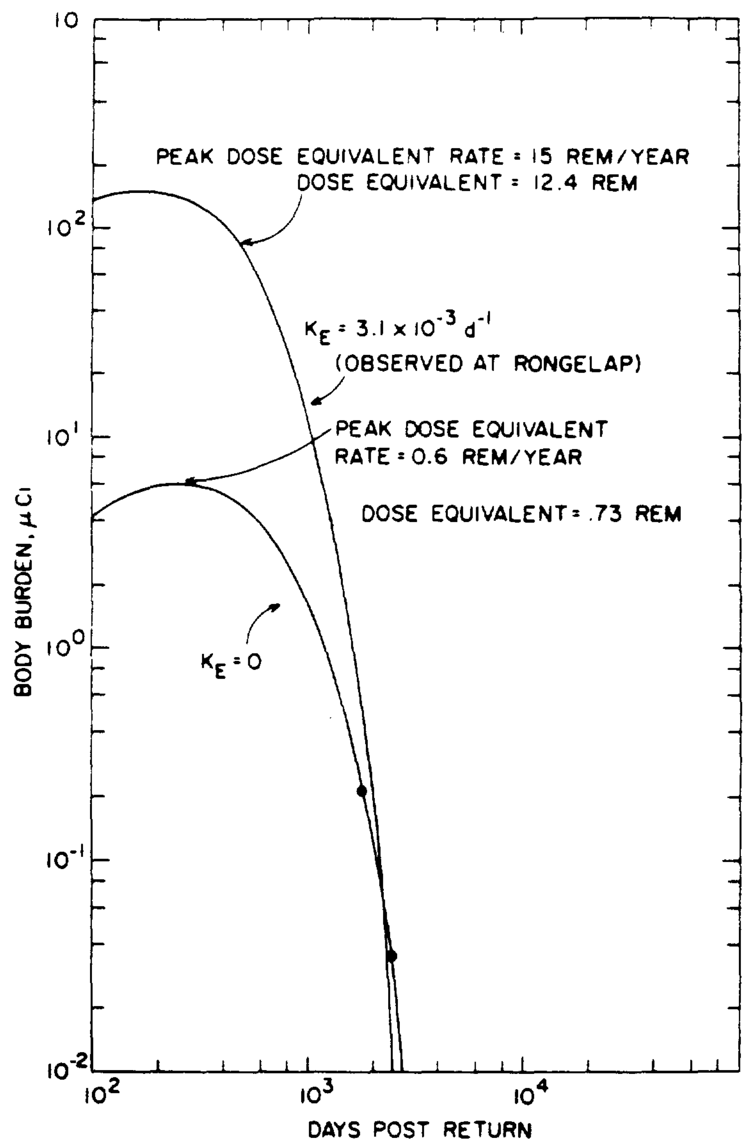

Fig. 16 Mean Adult ^{65}Zn Body Burden, Peak Dose Equivalent Rate and Dose Equivalent For Utirik Atoll

body burden means for adults on Utirik and the observed K_E rate constant from Rongelap. It was observed on Rongelap that .031% of ^{65}Zn was removed from the diet pathway each day in addition to radioactive decay. Additionally, reduction in dietary radioactivity on Rongelap had been observed for ^{137}Cs, ^{90}Sr, and ^{60}Co to be greater than that predicted by radioactive decay alone. Instantaneous reduction fractions very similar to those at Rongelap were observed at Utirik for the ^{90}Sr, and ^{137}Cs nuclides. The lower curve on Figure 16 reflects the dose equivalent, dose equivalent rate, and body burden which would have occurred had radioactive decay alone accounted for the removal of ^{65}Zn from the Utirik environment. Since additional mechanisms could be measured for other nuclides at Utirik and for the ^{65}Zn nuclide on a nearby atoll, the upper curve was chosen as the most likely body burden history for adults post return to Utirik Atoll.

Figure 17 indicates the Utirik adult mean total body dose equivalent rate for each nuclide. An obvious difference relative to the Rongelap history exists; ^{65}Zn not ^{137}Cs was the major nuclide contributing to the dose equivalent rate. This was due to the Utirik population returning 3 to 4 months after the initial contaminating event, and the Rongelap population returning after 3 years. The age of the fallout had a dramatic influence on the importance of each nuclide contributing to the internal dose equivalent. In fact ^{60}Co and ^{65}Zn played major roles during the first 3 years, a time interval that corresponded to the period during which field whole body counting facilities were being developed at Brookhaven National Laboratory and when medical examinations for people on Utirik Atoll were not done. Additionally, pooled and/or individual radiochemical analysis of urine was not performed during this period. The impact of ^{65}Zn and ^{60}Co was such that even if the least conservative rate

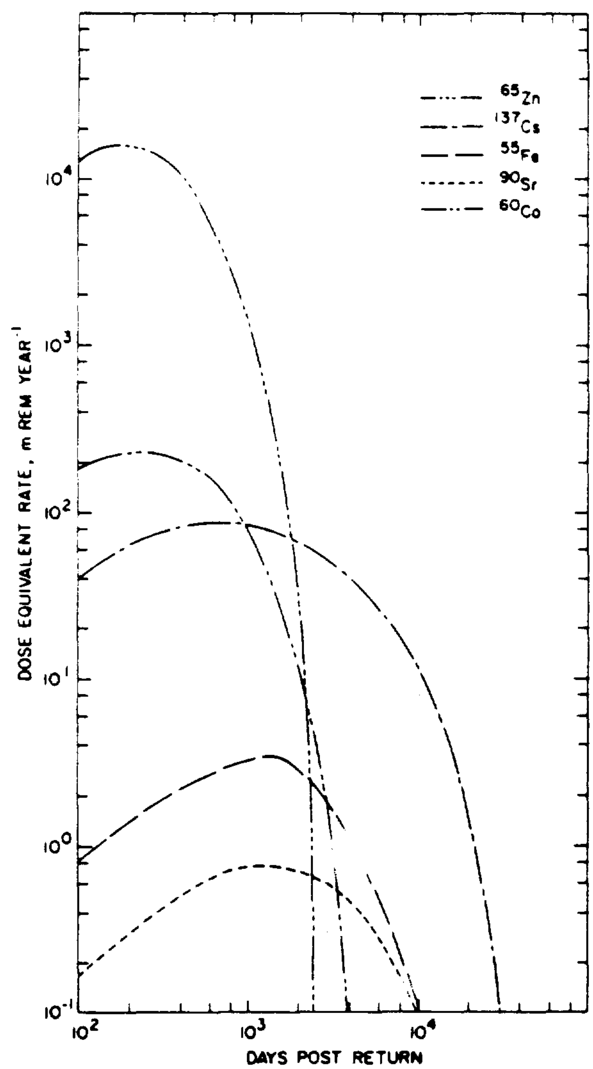

Fig. 17 Adult Mean Total Body Dose Equivalent Rate at Utirik Atoll Post Mid 1954

constant (K_E=0) was used for Zn, the dose equivalent rate for the average adult was in excess of Federal Radiation Council Guidelines for the first 2 years following the return to Utirik.

Internal Dose Equivalents

Disintegrations occurring in the total body of an individual during residence following repatriation were determined by several methods. Equation (3), together with personal body burden histories and atoll specific K_E rate constants from Table 3, provided an initial estimate of disintegrations between consecutive body burden measurements. The second method used was a log-log plot of the subject's body burden history and an algebraic determination of area between two consecutive measured points. The third method used a linear plot of the subject's body burden history. The area under the curve was cut and weighed and compared to a standard weight of known area. Quality control procedures required that all three methods agree within ±10% before a subject was assigned his or her total body disintegrations during residence post return. In general, the methods compared to within ±5%.

After the total number of disintegrations occurring in a subject's body was assigned, they were apportioned among the body organs according to the following equation

$$F = \frac{f_2' \; \Sigma_i A_i B_i \; (\Sigma_i C_i D_i + \ln 2/\lambda)}{\Sigma_i C_i D_i (\Sigma_i A_i B_i + \ln 2/\lambda)} \quad , \qquad (5)$$

where

F ≡ the fraction of total body disintegrations occurring in the organ of interest,

A_i ≡ organ compartment deposition fraction for the element,

B_i ≡ organ compartment biological half time for the element,

C_i ≡ total body compartment deposition fraction for the element,

D_i ≡ total body compartment biological half time for the element,

f_2' ≡ fraction of the element from blood to organ of reference.

Equation (5) applied where significant decay occurred at the deposition site, and not during transit or re-transit to the organ of interest. Values for compartment deposition fractions and compartment half times were obtained from Ki78. Values for the remaining quantities were from ICRP59.

The dose equivalents to a specific organ or the total body were determined by using the source to target dose equivalent per unit cumulated activity parameters from Ki78. The total target dose equivalent was obtained by summation of the dosimetric contributions from all source organs. Several important modifications to the general procedure were made in order to compute individual dosimetric results. For each person, the source to target dose equivalent per unit cumulated activity was weighted by the ratio of a standard man's body mass relative to the actual mean body mass during the interval for which the dose equivalent was determined. In the case of ^{137}Cs, the long term biological removal rate constant for the Marshallese population was highly dependent upon body mass (Mi81). Appropriate modifications to Eq. (2), (3), and (5) were made to reflect this dependence. Finally, for ^{90}Sr deposition in bone, 28% of the source to target dose equivalent per unit cumulated activity was assumed from cancellous bone and 72% from cortical bone.

Figure 18 demonstrates the mean dose equivalent from ^{137}Cs for various age and sex groupings. The residence interval was from 1957 to 1980 for this population. The adolescents and persons above 50 years of age in 1957 maintained the lowest dose equivalent. Persons who died during this period were not included

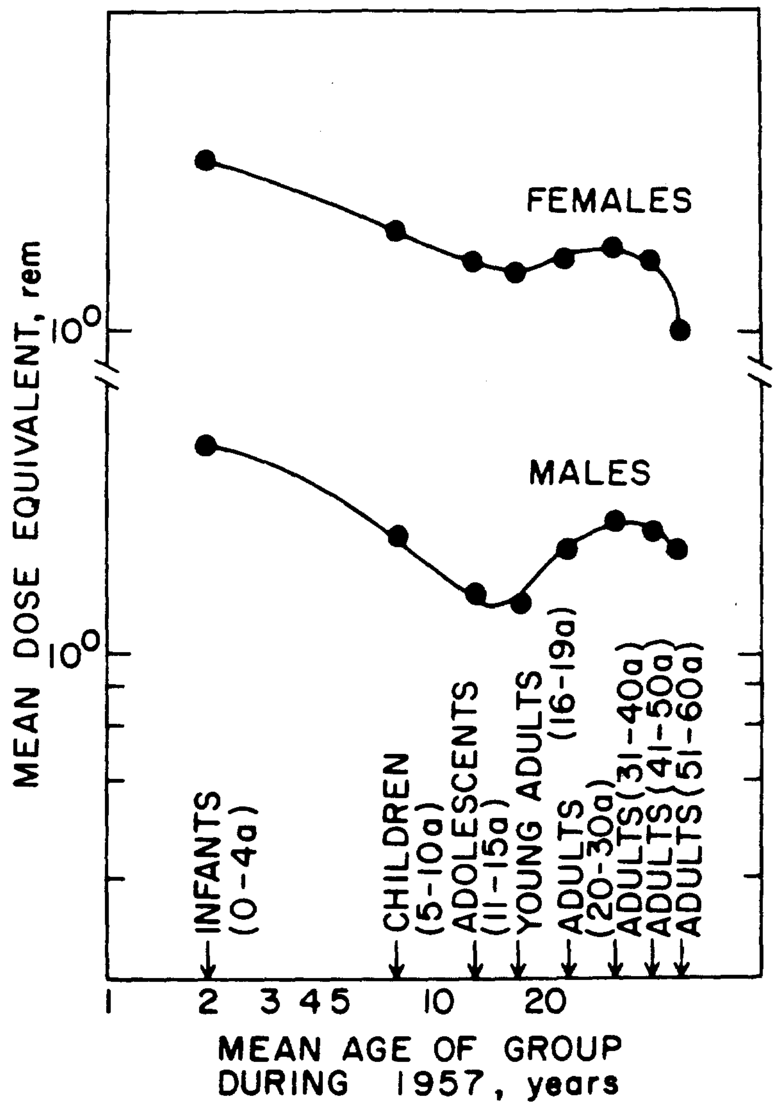

Fig. 18 ^{137}Cs Mean Dose Equivalent For Various Mid 1957 Age Groups for the Interval 1957 to 1980 at Rongelap Atoll in the figure nor were they included in any dosimetric distributions for any of the nuclides. Thus all persons considered, regardless of initial age in 1957, experienced a 23 year exposure interval.

Figure 19 shows dose equivalent distributions according to age and sex for ^{137}Cs among the Rongelapese. The shape or the population distribution was skewed with a mean of 1.7 Rem and a maximum of 9.0 Rem. Thus the maximum was 5.3 times the mean value for ^{137}Cs on Rongelap. An examination of the subgroup distributions reveals that persons who were infants at the time of rehabitation at Rongelap also were the recipients of the higher doses. This was due to the combined effects of lower average body mass, a higher average ingestion rate, and more rapid turnover of ^{137}Cs than that for adults or even children. The parameter having the greatest impact on the infant dose equivalent was body mass. The standard deviation for the adult male distribution was 49% of the mean dose equivalent, for adult females 43% of the mean dose equivalent, and for adolescents 47%. Within a subgroup, the maximum observed dose equivalent was approximately twice the mean value for all distributions considered here.

Figure 20 shows mean dose equivalents as a function of returning age groups for ^{65}Zn on Rongelap. Adolescents, young adults, and adults 50 and up were the groups receiving lower total dose equivalents, while children and middle aged persons received higher dose equivalents during the residence interval. Measured ^{65}Zn data for persons who were infants at the return date were not reported in the publications by Conard et al.

Figure 21 shows the dosimetric distributions observed for members of the Rongelap population for ^{65}Zn. Again the population overall exhibited a skewed distribution of dose with a maximum value nearly three times the mean. Children demonstrated higher doses than persons who were adults during the entire 23

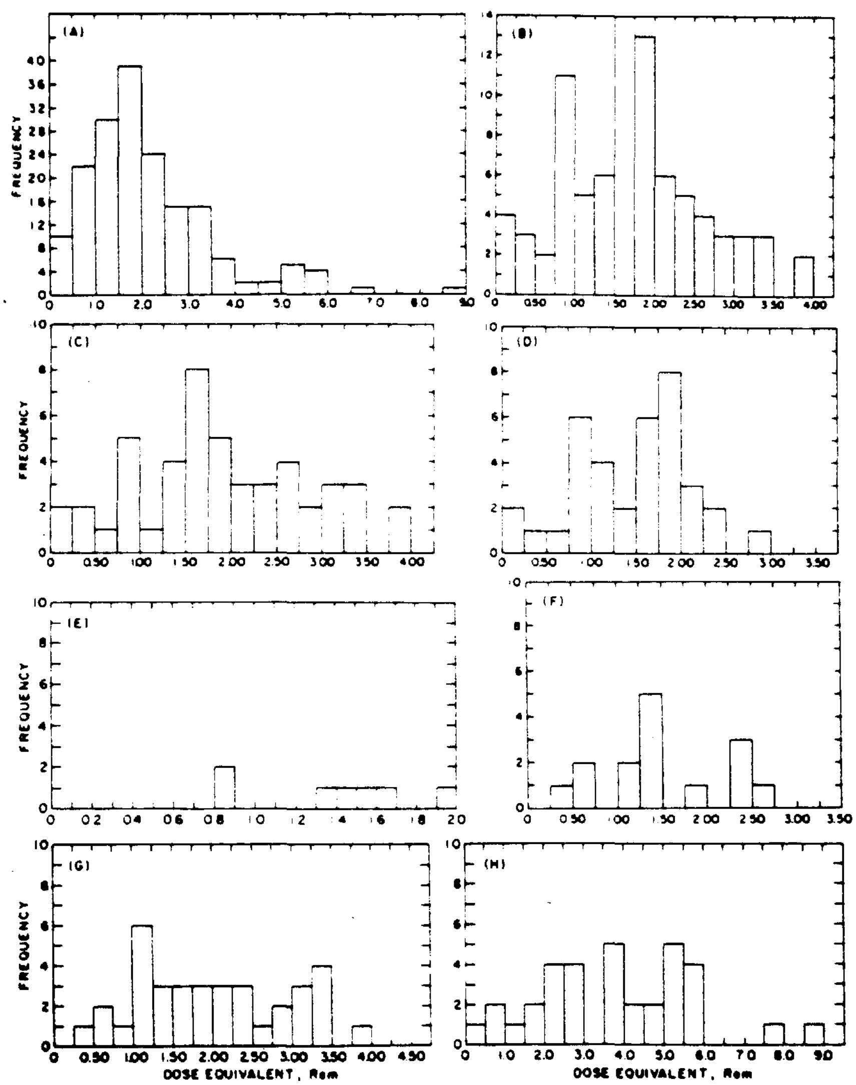

Fig. 19 ^{137}Cs Dose Equivalent to (A) All Residents (B) Adults (C) Adult Males (D) Adult Females (E) Young Adults (F) Adolescents (G) Children and (H) Infants on Rongelap

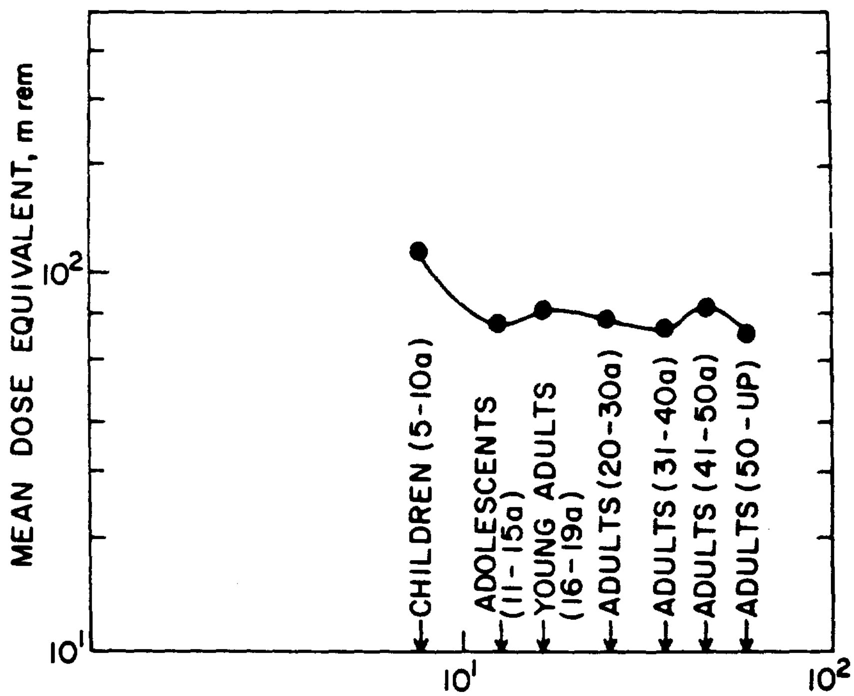

Fig. 20 ^{65}Zn Mean Dose Equivalent for Various Mid 1957 Age Groups for the Interval 1957 to 1980 at Rongelap Atoll

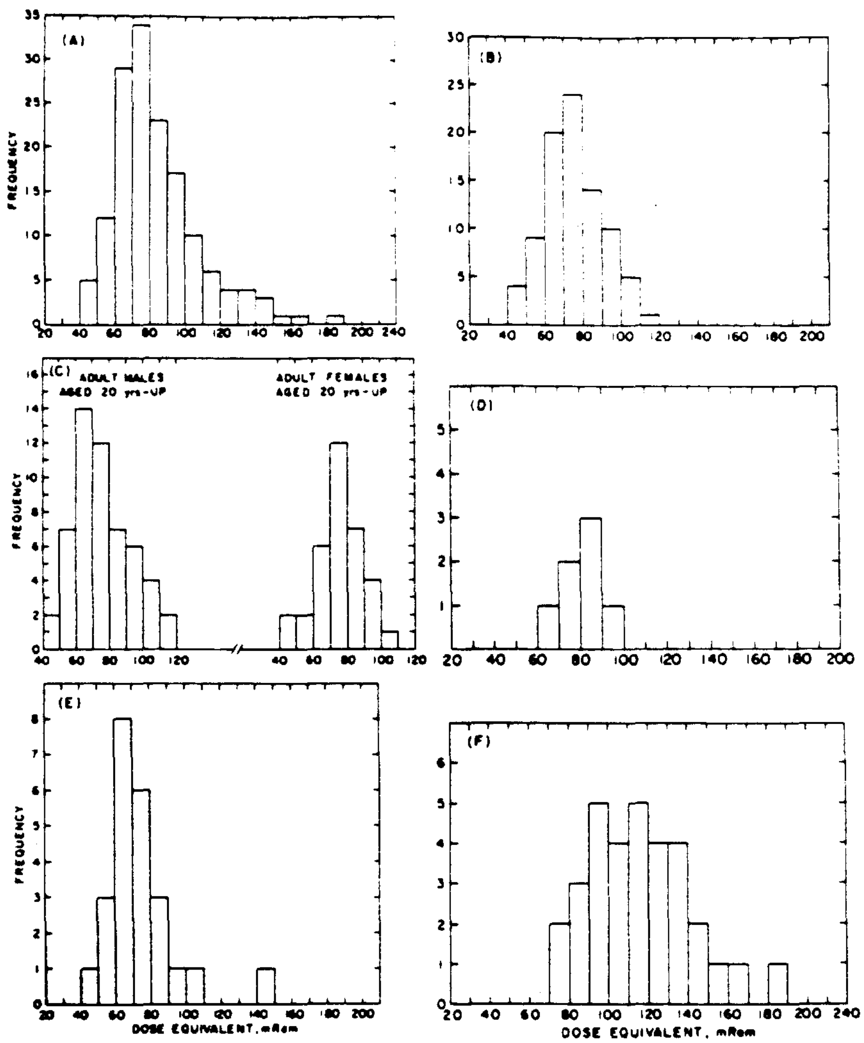

Fig 21 ^{65}Zn Dose Equivalent to (A) All Residents (B) Adults (C) Adult Males and Females (D) Adolescents (E) Children and (F) Infants on Rongelap Atoll year period. The standard deviation was in general 30% of the mean value for all age and sex subgroup distributions. This less pronounced variation may be due to the fact that ^{65}Zn measurements took place over a 3 year interval while ^{90}Sr and ^{137}Cs occurred over a 23 year interval and thus was contained in a more homogeneous population than were the longer lived nuclides.

Figures 22 and 23a and 23b summarize the ^{90}Sr dose equivalent results for individuals at Rongelap.

In this analysis, only the ingestion pathway was considered important. Some radioactivity would enter the body via the resuspension and direct inhalation pathways. It is known that for a given soil concentration of the stable naturally occurring analogs to the radionuclides considered here, the ratios of food and fluid intake to blood relative to airborne intake to blood, are as follows:

Co > 3000	Zn > 130
Fe > 550	Sr > 10,000
Cs > 400	

Thus, dietary intake of radioactive material is the principal pathway leading to internal deposition. This applies to most nuclides in the environment, however, there are notable exceptions including I, U, and Pu.

<u>External Exposure</u>

A value of .73 rads in tissue of interest per röntgen, measured in air at one meter above the surface, was used to convert exposure in air to absorbed dose in tissue. The source was assumed to be an exponential distribution of ^{137}Cs activity with depth in soil, typical of aged fallout (Be70). Because of the multidirectional nature of the source, variation of absorbed dose with depth of organ was minimal. Additionally, external doses were adjusted for living pat-

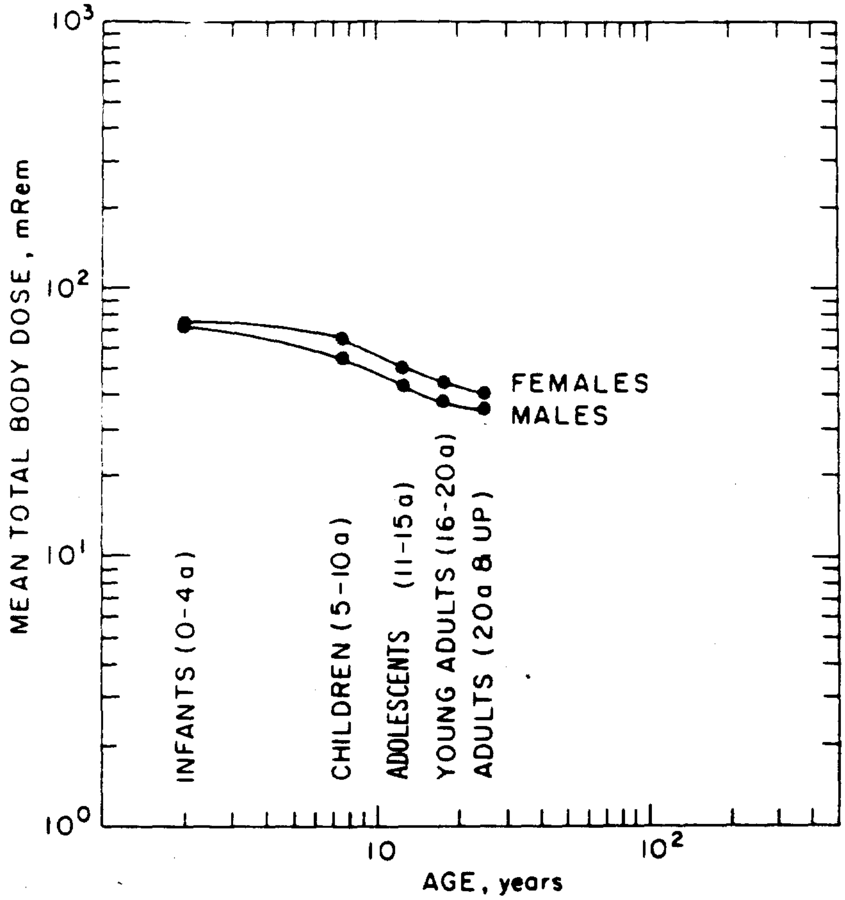

Fig. 22 Age and Sex Groups Mean Values for ^{90}Sr Dose Equivalent For The Interval 1957 to 1980 at Rongelap Atoll

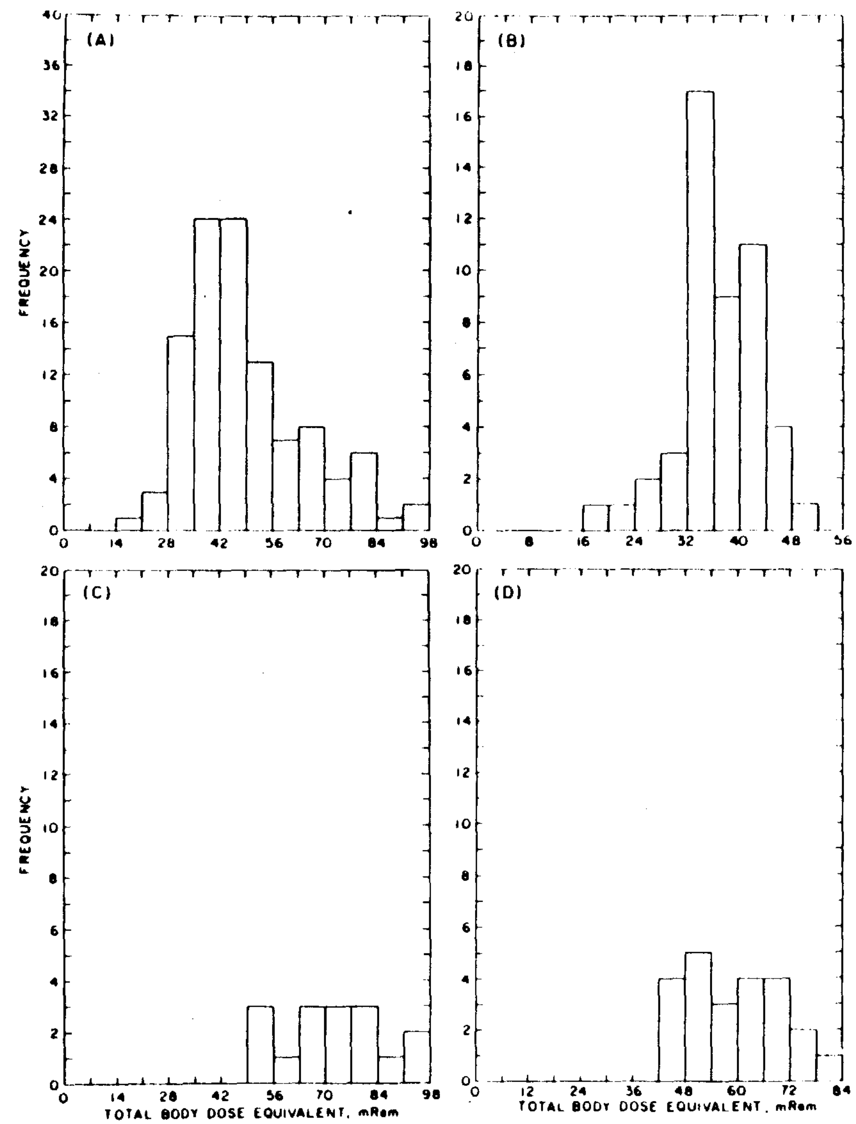

Fig. 23a ^{90}Sr Dose Equivalent for (A) All Residents (B) Adults (C) Infants and (D) Children on Rongelap

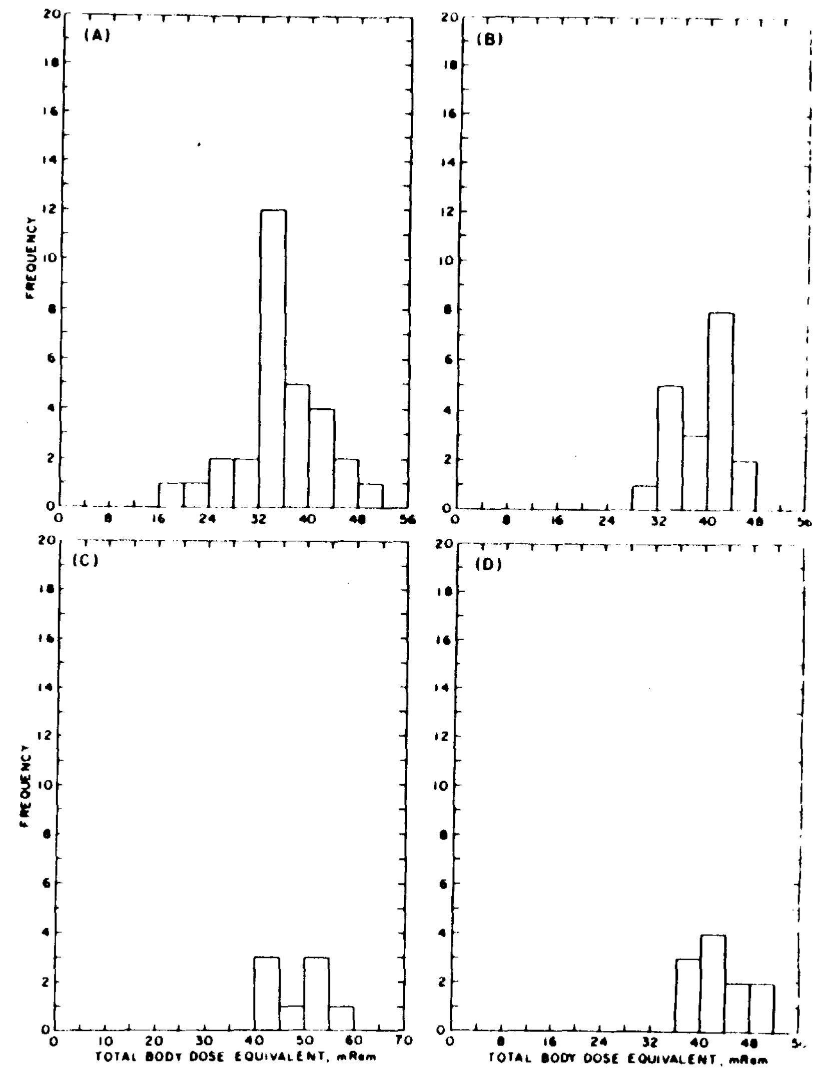

Fig. 23b ^{90}Sr Dose Equivalent for (A) Adult Males (B) Adult Females (C) Adolescents and (D) Young Adults on Rongelap tern variations since the atolls present a heterogeneous exposure rate environment (Gr77).

External exposure calculations are based on Figures 24 to 26 which were derived from data listed in Cr56, Sh57, Un59, and Gr77. The area under straight line portions of the curve was determined by

$$X = \frac{R_2 t_2 - R_1 t_1}{n + 1} , \qquad (6)$$

where

X ≡ external exposure during straight line interval, mR,

R_2 ≡ exposure rate at the end of the interval, mRh^{-1},

R_1 ≡ exposure rate at the beginning of the interval, mRh^{-1},

t_2 ≡ time post detonation at the end of interval, hours,

t_1 ≡ time post detonation at the beginning of interval, hours,

n ≡ slope of a straight line.

Data from 11 detonations during May, June, and July of 1958 (Sh57) indicated a mean fallout deposition exponent of 18.8. This mean value was observed at Utirik, Rongelap, Parry, and Wotho and was applied to early time post detonation of BRAVO to obtain the initial increasing exposure rate history shown on Figures 24 and 26. This method yielded a fallout deposition period of 5.5 hours on Rongelap and 12 hours on Utirik. This time compares well with the original observations reported by the Marshallese and by U.S. Navy personnel stationed in the area (Sh57). Initial dose equivalents on "acute doses" are developed in greater detail in another report.

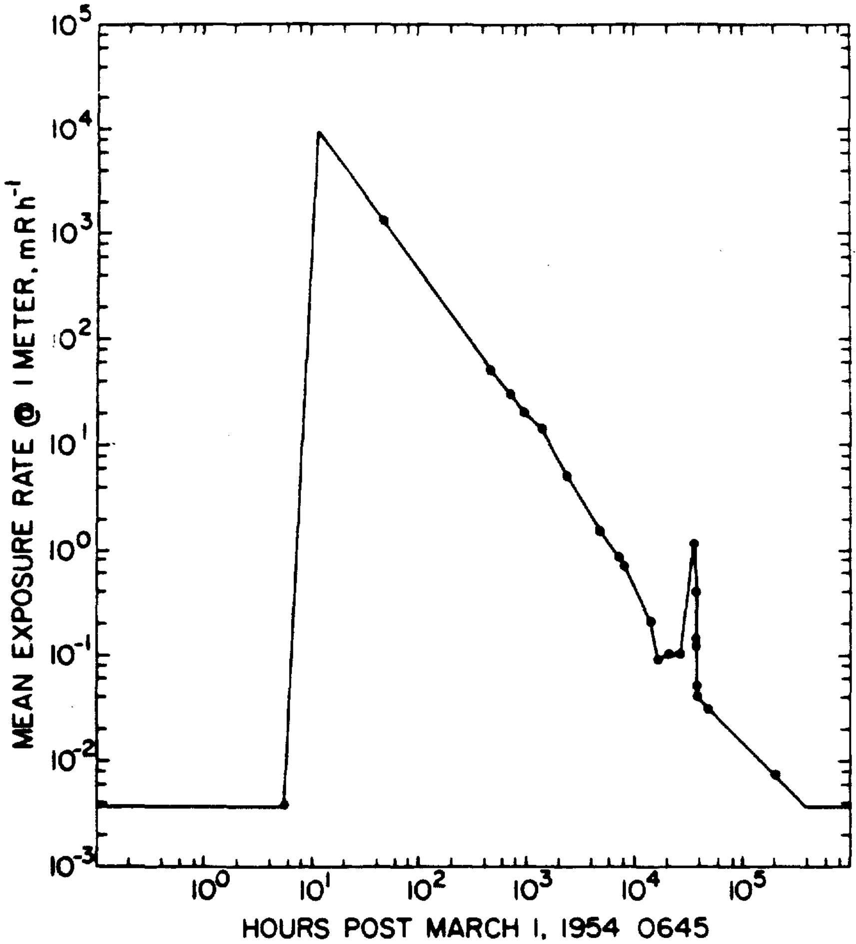

Fig. 24 Rongelap External Exposure Rate History
Post Bravo

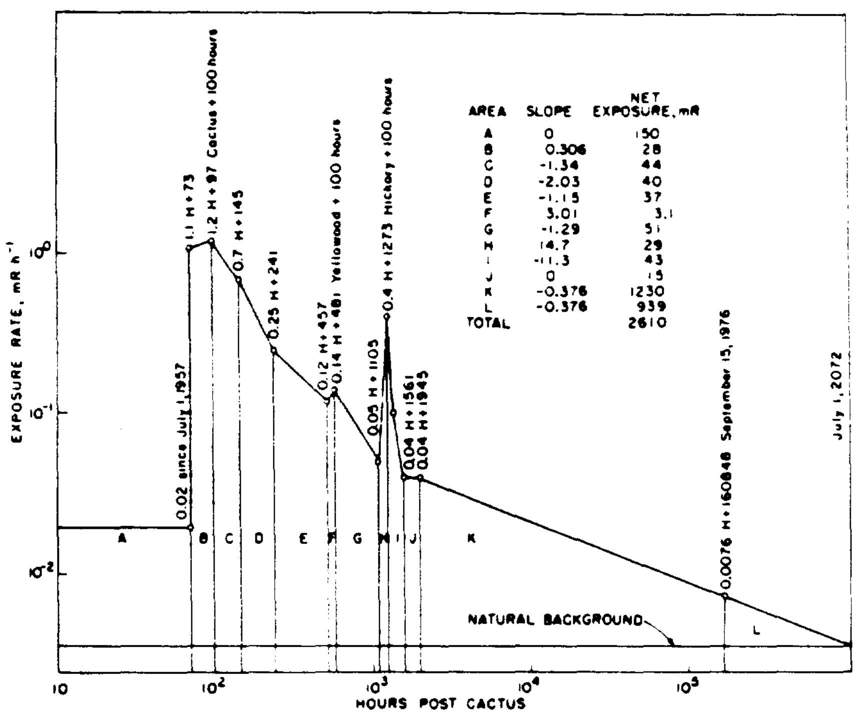

Fig 25 Rongelap External Exposure Rate History Post Cactus

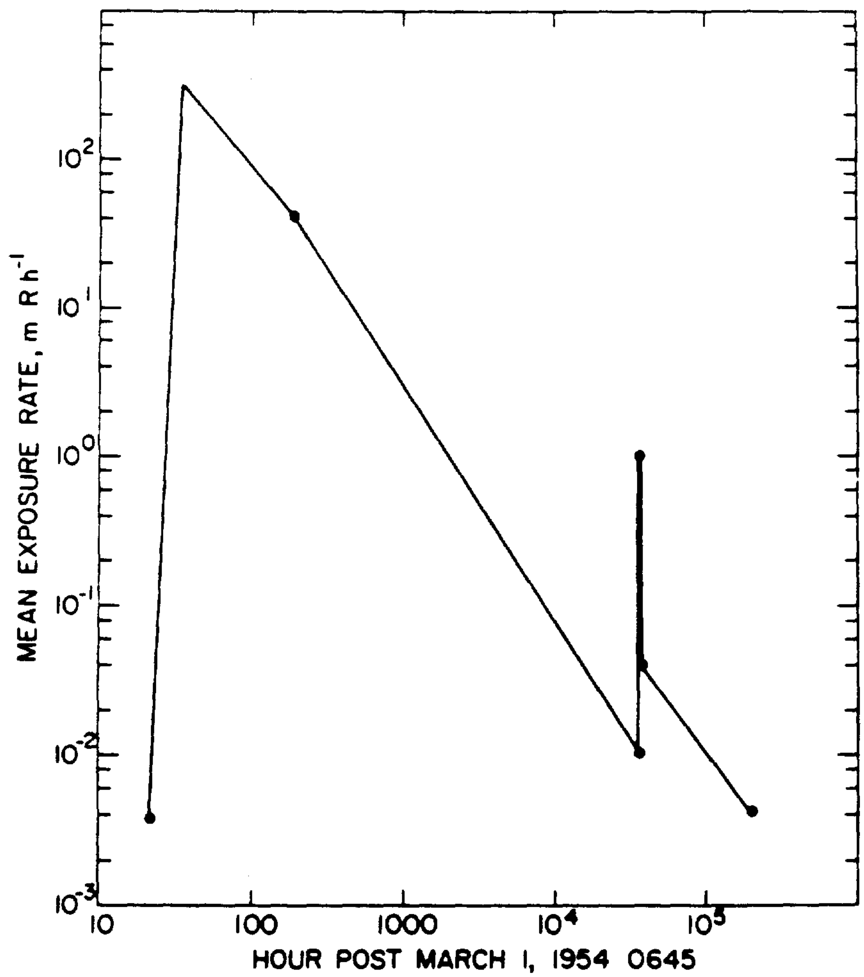

Fig. 26 Utirik External Exposure Rate History
Post Bravo

Figure 25 demonstrates the external exposure following the 1958 testing series. Since return to Rongelap followed 3 years after the BRAVO contamination, this series contributed in large part to the external exposure post return.

SUMMARY

The Castle BRAVO shot of March 1954 caused the contamination of the inhabited atolls Rongelap and Utirik. Evacuation from Rongelap commenced 50 hours after detonation and from Utirik 55 hours after detonation. During June 1954 and June 1957 the return of the Utirikese and Rongelapese occurred respectively. Body burden data for dosimetrically significant nuclides were obtained throughout the residence interval post return primarily by direct in vivo gamma spectroscopy and by indirect radiochemical analysis of urine and blood.

The dosimetric models used in this analysis were representative of a declining continuous uptake regime. Dietary decline of radioactivity included radioactive decay of the source and a conglomerate of other factors which might have included increased use of imported foods and weathering of the source. Dietary loss rate constants were estimated from sequential body burden data and were comparable for both atolls.

Variation in body burden history data for a particular nuclide on a particular atoll was observed in whole body counting data and urine bioassay results. This was attributed principally to the statistical variation encountered when small groups are sampled from a heterogeneous group of body burdens in people, and in the case of urine bioassay additional variation was introduced during the laboratory analysis of samples.

Daily activity ingestion rates were determined for all measured radionuclides. In general, infants, children, and adults between 20 and 40 years of age ingested more activity each day than did adolescents and persons greater than 40 years of age. Maximum deviation from the average value of the daily activity ingestion rate for members of an age subgroup was no greater than a factor of 3. However, the population distributions illustrated a maximum factor of 5 times the mean activity ingestion rate value.

Dose equivalent rates post return were determined for members from both atolls. For Rongelap Atoll, the residents received approximately 100 to 200 mRem per year during the first 5000 days post return from internal emitters. The principal contributing nuclide was ^{137}Cs. For Utirik Atoll, the residents received up to 15 Rem per year during the first 400 days post return. The major contributing nuclides were ^{65}Zn and ^{60}Co. Dose equivalent rates to the Utirikese from internal emitters fell below 500 mRem per year at approximately 1200 days post return.

The dose equivalent for population subgroups and for individuals was determined. Table 6 summarizes the results for the total body, thyroid, red marrow, testes, ovaries, lower large intestine wall, and liver. The catenary compartment model of Bernard and Hayes (Ber70) was used to determine doses to various segments of the gastrointestinal tract. The Utirikese received significantly more radiation dose from ^{65}Zn, ^{60}Co, and ^{55}Fe than did the Rongelapese because of short mean residence times of these nuclides in the environment. ^{90}Sr doses to the Rongelapese were 2.5 time greater and ^{137}Cs doses 1.5 times greater than doses received by persons at Utirik. This occurred even though Utirik residents returned to their atoll 3 years earlier and somewhat reflects the degree to which Utirik was less contaminated than Rongelap.

Table 6

Chronic Phase
Dose Equivalent Summary, Rem

Nuclide	Total Body: Utirik Adults	Total Body: Rongelap Adults	Thyroid: Utirik Adults	Thyroid: Rongelap Adults
^{90}Sr	.012	.027	.00075	.0017
^{55}Fe	.033	.023	.059	.042
^{137}Cs	1.1	1.7	1.6	2.4
^{60}Co	.51	.014	.36	.010
^{65}Zn	13.	.076	11.	.067
Internal	14.	1.9	13.	2.5
External	3.2	2.0	3.2	2.0
Total	17.	3.9	16.	4.5

Nuclide	Red Marrow: Utirik	Red Marrow: Rongelap	Testes-Ovaries: Utirik	Testes-Ovaries: Rongelap
^{90}Sr	.054	.12	.00075-.00075	.0017-.0017
^{55}Fe	.060	.042	.058-.062	.074-.043
^{137}Cs	1.7	2.6	1.5-1.7	2.3-2.6
^{60}Co	.63	.018	.44-1.8	0.12-.050
^{65}Zn	17.	.10	11.-16.	.069-.099
Internal	20.	2.9	13.-20.	2.5-2.8
External	3.2	2.0	3.2	2.0
Total	23.	4.9	17.-23.	4.5-4.8

Nuclide	Lower Large Intestine Wall: Utirik	Lower Large Intestine Wall: Rongelap	Liver: Utirik	Liver: Rongelap
^{90}Sr	.23	.57	.00067	.0015
^{55}Fe	.067	.047	.12	.080
^{137}Cs	.59	.90	1.8	2.7
^{60}Co	4.7	.13	.79	.022
^{65}Zn	15.	.091	17.	.14
Internal	21.	1.7	19.	3.0
External	3.2	2.0	3.2	2.0
Total	24.	3.8	22.	5.0

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This report was typed by members of the Word Processing group. Their painstaking effort is commended and recognized.

Marshall Islands: A Study of Diet and Living Patterns

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Abstract

This study summarizes information on diet and living patterns for the Marshallese. The data was derived from literature, answers to questionnaires, personal observations while living with the Marshallese for periods extending from months to years, and from direct participation in their activities. The results reflect the complex interactions of many influences, such as, the gathering of local foods, the receipt of food aid through programs, such as, school-lunch, typhoon-relief, food distributed to populations displaced as a result of nuclear testing, and in recent times the availability of cash for the purchase of imported foods. The results identify these influences and are therefore restricted to local food diets while recognizing that the living patterns are changing as local food gathering is replaced by other food supplies. The data will therefore provide the necessary information for input into models that will assess the radiological impacts attributable to the inhabitation of the Marshall Islands. It is recommended that this study should be continued for at least two to three years in order to more accurately identify trends in local food consumption and living patterns.

Objective

The goal of this study is the evaluation of dietary and living patterns among the inhabitants of the Northern Marshall Islands. These data will be used as input to the dose estimation models (external and internal) that are being developed for the Marshallese who continue to inhabit or will inhabit areas previously contaminated by radioactive fallout from U.S. Pacific Nuclear tests.

Introduction

This study, by the Safety and Environmental Protection Division (S&EP) of the Brookhaven National Laboratory, is a continuation of work which began in 1974 as part of environmental monitoring programs for Bikini, Rongelap and Utirik. The Northern Marshall Islands Radiological Survey (NMIRS) of 1978 provided an opportunity to carry out a study in extensive detail, since the role of S&EP was devoted exclusively to diet and living patterns. Since then, two of the authors, (G. Knight and J.R. Naidu), have continued the study in order to increase the data base obtained through this work. As pointed out in a prelimi-

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nary report to the NMIRS group, one of the key requirements for reliable data gathering is the isolation of the islanders from the "outside" influence of field trip ships and from scientists conducting environmental or medical studies. This stems from the fact that the Marshallese tend to give such inquires answers which they think are being sought, rather than to provide the objective information desired. Thus the NMIRS program, wherein three of the authors spent short periods of time in residence at each island, served to provide a basis for comparisons with past observations, and to establish a foundation for subsequent studies following the NMIRS. These studies have now been extended through 1979 and are expected to continue indefinitely.

Methods

A thorough review of all existing literature was performed (1-6). Earlier studies (1,2) had as their goals the quantitative and qualitative assessments of food intake, and the establishment of its nutrient value. However, it became apparent during the current study that the earlier studies suffered from certain unintended biases which were the result of inquiries made during short field trip visits. We have ascertained that these biases can be minimized by utilizing an observer who has become integrated into the local community to the extent that his or her presence has a negligible impact on community life. The authors of this report have spent periods extending from months to years on the various islands in the Marshalls, during which time they have become an integral part of the island communities, partaking of the local food and participating in (as well as observing) community living patterns. On the basis of this experience, the authors developed a questionnaire which was used to generate much of the dietary information presented in this report.

The generalized information presented in the main body of this report represents a synthesis of the direct observations of the authors, and of the survey data from the questionnaire. Most of the detailed information, which forms the basis for these generalizations, pertains to the following: Islands/Atolls studied, specific aspects of island living patterns, seasonal phenomena, types of fish and methods of fishing, edible birds, individual family food consumption patterns, (imported) food subsidy programs, community cooperative store stocks, and satistics on the edible fractions of local foods. All of the above information is included in the Appendices.

The following dietary interview was prepared in an attempt to determine the local diet by posing questions to the islanders themselves. It was taken to a number of communities at Rongelap in Rongelap Atoll, Utirik in Utirik Atoll, Mejit, Ailuk, Wotho, Jabor in Jaliut Atoll, at Killi Island and Majuro.

The questionnaire of the dietary interviews, which is in Marshallese but presented here as a literal English translation, was as follows:

Marshall Islands Dietary Interview

In answering these questions, please answer in respect to those of your family who presently live at your house and in respect to only those who eat with you every day.

How many people of school age or over are in your family and eat with your family every day?

What is the name of the island where you presently live.

1) How many mature coconuts do you use to prepare coconut milk to mix into your family's food in a typical week?

2) How many mature coconuts do you grate to mix into your family's food in a typical week?

3) If you are an adult and 18 years or over, other than the mature coconuts mixed into your family's food, how many other coconuts do you eat in a typical week?

4) With respect to your children or brothers and sisters of ages 10 through 18, other than the mature coconuts mixed in the family's food, how many would you expect one of them to eat in a typical week?

5) If you are an adult, how many drinking coconuts do you consume in a typical week?

6) And if you are an adult, how many of these coconuts that you drink will you also eat the soft meat thereof?

7) With respect to your children or younger siblings of ages 10 through 18, how many unripe coconuts would you expect one of them to drink in a typical week?

8) And in respect to these children, how many of these unripe coconuts that one of them would drink would you expect him to also eat the meat thereof?

9) If you are an adult, how many of the kenawe coconuts (in a similar fashion as pandanus, the entire husk is sucked and chewed and a considerable portion is eaten) do you eat during a typical month?

10) In respect to your children or younger siblings from ages 10 to 18, how many of the kenawe coconuts would you expect one child to eat during a typical month?

11) How many of the sprouted coconuts do you cook the iu (haustorium) thereof in preparing traditional dishes to be served at family meals in a typical week?

12) Other than the iu prepared for the family meals, how many iu do you eat in a typical week?

13) In respect to the children, how many iu does one child eat in a typical week?

14) If you are a man who makes jekaru (tapped nectar of the coconut flower), how many half-gallon bottles does your family use to drink or mix with the family food each day?

15) How many pandanus do you cook and make into pulp to mix with the family food or to preserve into Jankwon in a typical week during pandanus season?

16) Other than the pandanus you mash into pulp, how many will you eat yourself?

17) In respect to the children, on a typical day how many pandanus does one child eat?

18) During breadfruit season, how many of the bukrol or batakatak varieties do you prepare for your family in a typical week?

19) How many of the bukrol or batakatak varieties do you use to preserve into bwido to be eaten by your family during a typical year?

20) During the season for the mejwan variety of breadfruit, how many do you prepare for your family in a typical week?

21) Other than the mejwan you cook for the family, how many of the ripe fruits do you eat in a typical week when this variety of breadfruit is in season?

22) In respect to the children, how many of the ripe fruits do you think one child eats in a typical week?

23) How many of the mejwan variety of breadfruit do you preserve into jankwon for your family to eat during a typical year?

24) Other than the mejwan breadfruit itself, how many nuts of this variety do you eat in a typical week when it is in season?

25) In respect to the children, how many nuts of the mejwan do they eat in a typical week when it is in season?

26) How many blocks of arrowroot starch (about 10 lbs) do you dig and prepare for your family to eat during a typical year?

27) How many (pounds of) fish do you cook during a typical week for your family to eat? (A good sized rijin species weighs about 2 lbs.)

28) How many pumpkins do you cook for your family during a typical year?

29) How many stalks of starch bananas do you cook for your family during a typical year?

30) How many stalks of sweet bananas does your family eat during a typical year?

31) If you are an adult, how many papayas do you eat during a typical month?

32) In respect to the children, how many papayas would you expect one child to eat during a typical month?

33) How many (pounds of) sweet potatoes do you cook for your family during a typical year?

34) In respect to any other locally grown foods not previously mentioned, please list the foods and the amount eaten by the family during a typical month or year.

35) How many chickens do you kill and prepare for your family during a typical month or during a typical year?

36) In respect to wild birds, how many times do you make a meal of them during a typical month or year?

37) How many times do you make a meal of pig during a typical month or year?

38) How many times do you eat turtle during a typical month or year?

39) How many times do you eat lobster during a typical month or year?

40) How many times do you eat giant clam during a typical month or year?

41) How many times do you eat the various types of ocean snails during a typical month or year?

42) How many times do you eat octopus during a typical month or year?

43) How many times do you eat the coconut crab during a typical month or year?

44) How many times do you eat clams (other than giant) during a typical month or year?

45) Please circle the months that breadfruit is in season.

Jan.---
Feb.---
March--
April--
May----
June---
July---
Aug.---
Sept.--
Oct.---

Nov.---
Dec.---

46) Please circle the months that pandanus is in season.

Jan.---
Feb.---
March--
April--
May----
June---
July---
Aug.---
Sept.--
Oct.---
Nov.---
Dec.---

The feasibility of obtaining a total profile of a typical diet from an interview stems from the prevailing environmental conditions in which the variety of available foods is quite restricted. There is also a very limited trading economy - both the variety and availability of imported foods being restricted by the limited capital of those who import and retail such goods. Thus the limited availability of cash affects both the variety of traditional foods and the amount of contemporary imports as well. Thus, the typical diet is very "day to day". This makes it possible to obtain relatively accurate estimates on a question and answer basis.

Traditionally, one of the most respected talents is the ability to quickly divide large amounts of local food equitably among large numbers of families at island celebrations. The authors have observed the skill of both men and women at this task. Therefore, due to these environmental, economic and cultural factors, it appears that the islanders themselves may eventually produce more accurate estimates of the foods they eat than those likely to be obtained by outside observations.

A crucial problem for an outside observer is that of finding the "typical" family upon which to base his observations, since individual families consume variable amounts of local foods. Some appear to eat primarily a local diet, while that of others contain many imported foods. An analysis of the individual answers of the interviews shows the scope of this variability. However, observations indicate a large variance about the average which reflects wide variations in personal preferences for foods. This is not to suggest that direct observations, especially if made during a complete 365 day cycle, would not yield significant results - but only that such results could not be considered "average" unless observations of a large number of individuals were made. Such a study would show a "typical maximum" or "typical minimum" diet of such families, due to the fact that they would represent such extremes from the norm that they would stand out to the observer whereas the "typical average" diet of the normal family does not. Therefore an outside observer would have no way of choosing which typical family to observe.

The interview data does not provide the "typical average" of the local food consumed by the islanders of the various communities. Rather they provide estimates which approach the "typical average." An interview of forty-four questions cannot provide a direct and straight forward "typical average" of local food actually consumed. The islanders provide better estimates on food they prepare rather than on food actually eaten. Within the interview, emphasis was placed on the amounts of food prepared for the family on a weekly basis, since this was felt to be the most easily answered question to pose concerning the local diet. Since the Marshallese are by culture food gatherers they know more or less how much food they regularly gather and how much they have to cook to keep their families adequately fed. However, not all the food cooked for the family is eaten. Since there is no refrigeration, an undetermined quantity of left-overs is probably on many occasions wasted or more likely fed to pigs or in some cases chickens. Most families keep a pig or two and at least half the diet of these pigs consists of left-overs. Thus, the present study provides a more usable indication for food cooked but not necessarily eaten by the family.

Another problem in obtaining accurate estimates of food consumption is due to food sharing, which introduces a significant variable into the calculations based on the outside observer and interview methods. Food sharing is a culturally induced readiness to feed not only family members, but anyone present as well. An island society is quite open and islanders roam freely from one house to another at leisure. Thus there is a tendency to prepare a larger amount of food then needed for ones immediate family. The problem then is to estimate the amount of food given away. This is a difficult estimate to make, even for an Islander, as it is by no means a consistent amount. What is known is that the Marshallese cook regular amounts, and that they can provide reasonably accurate estimates on how much they prepare. It is not clear how much of this the family actually consumes. To try and pin the islanders down on this question during an interview is difficult. Every man knows from habit how much food he needs to regularly gather to provide for his family. He can only guess how much of this food he occasionally gives away. It was this circumstance that prompted us to concentrate our interview questions on the amount of food regularly prepared, even though it appears that some portion of this food is given away. In the authors' judgement, it seemed best to start with the most reliable estimates possible, and then to proceed from there with further study and comparison.

It should be noted then that the averages obtained from the answers to the various questions of the interview are in many cases based on food prepared for family members. Such averages are labeled per family member (PFM). They were computed by dividing the total amount of food prepared by all families by the total number of family members associated with the individual adults interviewed. Had each member of the family been interviewed (an obviously important step in future studies) the amount cooked (less the amount wasted) should be roughly equal to the total amount eaten. Thus, the problem of food sharing could have been successfully by-passed. However, due to time limitations, the inability to interview those reluctant to participate, and a concern not to inconvenience the islanders in any way meant that an inclusive study of all family members (which would entail active cooperation at all levels of the government of the Marshall Islands) has yet to be completed.

Therefore, this attempt to seek estimates from the islanders themselves concerning the actual amounts of local foods in their contemporary diet should be used not as a definitive answer to the question of what constitutes the "typical average." Rather it should be regarded as a feasibility study on the possibility of obtaining the desired information in this way. In the authors' judgement, the averages obtained from the interview study represent overestimates. They should be so considered until such time as further study proves them accurate or (more likely) provides representative estimates of food sharing and wastage, which could be folded into the study to provide more accurate consumption estimates. Until such time as the factors involved are more thoroughly understood, the feasibility of obtaining a "typical average" estimate from the interview method is in question. However, the present study establishes an upper limit, which has been confirmed by (a) an estimate of the calorie intake based on calorie value of foods (1, 2), and (b) the quantity of food that is available and is gathered on the islands.

Results

The data obtained from the interviews and observations made by the authors since 1970 suggests that the diet patterns can be divided into three typical categories or communities. These communities have the following characteristics:

Community A:

a. Maximum availability of local foods

b. Highly depressed local economy - living within income provided by selling copra

c. Low population

d. Little or no ability to purchase imported food

Community B:

a. Low availability of local foods - except fish (which can form as much as 33% of the total diet as a result of excellent fishing in the area).

b. Overpopulated - resulting in low per capita availability of local foods.

c. A good supply of imported foods (supply boat comes in every two to three weeks) along with the availability of jobs.

Community C:

a. Low availability of local foods, even the fishing is poor

b. Large government food program

c. Overpopulated

d. A good supply of imported foods and availability of cash to buy them.

The results of the interviews and observations are therefore categorized according to the three communities defined above and are tabulated as follows:

Table - 1: For Community A indicating the quantities of local foods consumed

Table - 2: For Community B indicating the quantities of local foods consumed

Table - 3: For Community C indicating the quantities of local foods consumed

Results and Discussion

One of the most significant results of the dietary interview was the determination of the relative portions of local foods in the islander's diet. Tables 1 to 3 show that the amounts of local foods prepared and eaten varies considerably in each community, but that the relative proportions of the local foods which are prepared and eaten are strikingly consistent, regardless of the respective availability of imported foods in each of the three communities. With respect to imported foods, Community (A) was chosen on the basis of low availability. All islanders of this community are primarily copra producers and retain their traditional food gathering lifestyle in an area of correspondingly maximum local food availability. Community (B) was chosen because of high availability of imported foods due to the presence of a well stocked co-op store and the proliferation of government jobs. No copra is made at community (B) and as noted elsewhere in the Marshall Islands the development of a "westernized" economy results (primarily due to the limited land area) in a corresponding minimizing of local food availability. Community (C) was chosen for its large food subsidy and the low availability of local foods resulting from high population density. It is assumed that imported foods are highly available at (C), moderately available at (B) and of limited availability at (A). From Tables 1, 2 and 3 it appears that the consumption of local foods is 100% for Community A, 33% for Community B and 25% for Community C, of the total diet (local and imported food). There is a tendency for the islanders to prepare and cook less local food as imported foods become more and more available. Nevertheless, the relative portions of the local foods eaten appear to remain constant regardless of the availability of imported foods either from a "westernized" economy or a food subsidy program. This is dramatically evident when we compare the amount of coconuts (in all stages of growth and in the different modes of preparation) consumed, for example, they constitute: 55% of total local diet in Community (A), 58% in Community (B) and 47% in Community (C). The relative portions of the various other local foods seems only to change significantly due to environmental conditions. For instance, the fishing at community (B) is widely reputed to be the best in the Marshalls. This explains why fish accounts for 36% of the local diet at (B) as compared to 29% at (A); whereas the islanders at (C) (where there exists limited opportunity for fishing) estimate fish to be only 19% of the local food they prepare for their families to eat. It may therefore be concluded that the local diet is basically quite uniform and that it changes primarily due to environmental conditions. The effect of imported food is not so much to change the elements of the local diet but simply to reduce them proportionately. The only exceptions to this tendency towards proportionate over-all reduction are Jekaru (coconut sap), Mokmok (arrowroot), and Jankwon (preserved mejwan breadfruit and preserved pandanus). This may be due to the intense labor involved in the processing and preparation of these three foods. They appear to be the first traditional foods to be replaced from a total local food diet by imported sugar, rice and flour. However, further studies are needed to conclusively demonstrate this.

With respect to community (A) where estimates showed the food prepared and eaten to be nearly 100% of the total diet, it is clear that these estimates exceed the actual amount that could conceivably be consumed, even by all the family members. This is especially so considering the fact that this group of family members includes women and children who could not possibly consume all that food on a daily basis when we know that they are eating significant quantities of imported foods as well.

Table 4A and 4B represent a typical maximum diet. It represents the most conservative estimate on the total gram weights of the various local foods which could conceivably be consumed under the assumption of a 100% local diet.

These estimates are based on the assumption that all the Marshallese living on outer islands regulate their dietary habits to a certain extent to a pattern parallel to environmental conditions and the natural food gathering cycles that are governed by these conditions. It is based on a general observation that most islanders do eat local foods. These estimates also indicate how much of a particular food is eaten (by a typical adult and child) during a given foods' peak season or seasons. They do not consider those periods when a particular food is scarce or otherwise difficult to obtain. Since these estimates are based on a cycle of one year, it seems reasonable to assume that this method could provide an estimated maximum. It has also the advantage of being based on principles and assumptions which are scientifically verifiable. The various growing seasons are subject to yearly change. Also the length and production of each growing season varies somewhat from year to year. In calculating the maximum diet the tabulations reflect a somewhat higher percentage of jekaro, coconut and pandanus than could reasonably be expected.

It should be noted that an individual existing totally on such a diet would have to be carrying out a very active food gathering existence, and would therefore have very little time for other endeavors. In short, he would have to return to the premodernized state his ancestors were living 200 years ago. It should also be noted that a higher maximum consumption of any one type of food is conceivable though it would be unlikely for two reasons. One, is the fact that the premodern Marshallese society as well as the contemporary society is very communal in its food consumption patterns. This means that food sharing is extremely important, and therefore if any one person gathers a great deal of any one particular type of food, he is more likely to divide it up and give it away

Table 1: Community A

Interview Question No.	grams/ weeks	No. of weeks	grams/ yr	Marshallese name for food	English equivalent
1	192	52	9984	el	coconut grated for coconut milk
2	480	52	24960	Waini	coconut ripe for copra
3	1248	52	64896	Waini	coconut ripe for copra
4	1104	52	57408	Waini	coconut ripe for copra
5	7199	52	374348	drenin ni	coconut water
6	1820	52	94640	Medi	tender coconut meat
7	6440	52	334880	drenin ni	coconut water
8	2197	52	114244	Medi	tender coconut meat
9	160	52	8320	Kenawe	coconut variety-can be eaten raw
10	230	52	11960	Kenawe	coconut variety-can be eaten raw
11	1380	52	71760	iu	coconut 'apple'
12	2340	52	121680	iu	coconut 'apple'
13	1740	52	90480	iu	coconut 'apple'
14	2646	52	137592	Jekaru	nectar from coconut bud
15	225	52	11700	Jankwon	pandanus pulp
16	4158	12	49896	Bob	pandanus
17	4326	12	51912	Bob	pandanus
18	2500	11	27500	Batakatak or	breadfruit different variety
18	1500	11	16500	(Bukrol)	breadfruit different variety
19	2000	15	30000	(Bukrol)	breadfruit different variety
20	1496	12	17952	Mejwan	breadfruit with seeds
21	720	6	4320	Mejwan	breadfruit with seeds
22	315	6	1890	Mejwan	breadfruit with seeds
23	300	10	3000	Mejwan	breadfruit with seeds
24	248	6	1488	Kole Nut	seeds of breadfruit
25	263	6	1578	Kole Nut	seeds of breadfruit
26	278	7	1946	mokmok	arrowroot
27	3084	52	160368	ik	fish
28			2000	punki	pumpkin
29			7500	binana	banana
30	weekly consumption not possible		7500	binana	banana
31			12120	kanapu	papaya
32	to determine as such only annual		12600	kanapu	papaya
33			364	potato	sweet potatoe
34	figures given.		7182	local vegetable foods	local vegetable foods
35			500	bao lol	poultry
36			2037	bao lin	wild bird
37			850	pik	pork
38			1000	won	turtle
39			500	wor	lobster
40			750	kabor	giant clams
41			11400	jerol	snails
42			913	kwid	octopus
43			4500	barolab	coconut crab
44			2150	clams	clams (small)

Table 2: Community B

Interview Question No.	grams/ weeks	No. of weeks	grams/ yr	Marshallese name for food	English equivalent
1	49.4	52	2569	El	coconut grated for coconut milk
2	264	52	13728	Waini	coconut ripe for copra
3	216	52	11232	Waini	coconut ripe for copra
4	144	52	7488	Waini	coconut ripe for copra
5	3611	52	187772	drenin ni	coconut water
6	702	52	36504	Medi	tender coconut meat
7	2300	52	119600	drenin ni	coconut water
8	416	52	21632	Medi	tender coconut meat
9	0.25	52	13	Kenawe	coconut variety-can be eaten raw
10	0.5	52	26	Kenawe	coconut variety-can be eaten raw
11	350	52	18200	iu	coconut 'apple'
12	700	52	36400	iu	coconut 'apple'
13	830	52	43160	iu	coconut 'apple'
14	-	-	-	jakaru	nectar from coconut bud
15	1200	13	15600	Makon (jankwon)	pandanus pulp
16	2688	13	34944	Bob	pandanus
17	1680	13	21840	Bob	pandanus
18	450	12	5400	Bukrol or	breadfruit different variety
19	-	-	1750	Batakatak	breadfruit different variety
20	245	12	2940	Mejwan	breadfruit with seed
21	380	8	3040	Mejwan	breadfruit with seed
22	272	8	2176	Mejwan	breadfruit with seed
23	-	-	-	Mejwan	breadfruit with seed
24	18.3	8	146	kole nut	seeds of breadfruit
25	40.8	8	326	kole nut	seeds of breadfruit
26	-	-	-	mokmok	arrowroot
27	1364	52	70928	ik	fish
28			-	punki	pumpkin
29			2800	binana	banana
30	weekly consumption not possible		4000	binana	banana
31			-	kanapu	papaya
32	to determine as such only annual		-	kanapu	papaya
33			-	potato	sweet potatoe
34	figures given.		-	local vegetable foods	local vegetable foods
35			1200	bao lol	poultry
36			3250	bao lin	wild birds
37			500	pik	pork
38			41	won	turtle
39			50	wor	lobster
40			4250	kabor	giant clam
41			4250	jerol	snails
42			7125	kwid	octopus
43			350	barolab	coconut crab
44			1075	clams	clams (small)

Table 3: Community C

Interview Question No.	grams/ weeks	No. of weeks	grams/ yr	Marshallese name for food	English equivalent
1	874	52	45448	El	coconut grated for coconut milk
2	264	52	13728	Waini	coconut ripe for copra
3	312	52	16224	Waini	coconut ripe for copra
4	336	52	17472	Waini	coconut ripe for copra
5	2139	52	111228	drenin ni	coconut water
6	936	52	48672	Medi	tender coconut meat
7	1035	52	53820	drenin ni	coconut water
8	286	52	14872	Medi	tender coconut meat
9	12.5	52	650	Kewane	coconut variety-can be eaten raw
10	55	52	2860	Kewane	coconut variety-can be eaten raw
11	100	52	5200	iu	coconut 'apple'
12	460	52	23920	iu	coconut 'apple'
13	240	52	12480	iu	coconut 'apple'
14	-	-	-	jekaru	nectar from coconut bud
15	200	13	2600	Mokon (jankwon)	pandanus pulp
16	1806	13	23478	Bob	pandanus
17	1680	13	21840	Bob	pandanus
18	800	12	9600	Bukrol or	breadfruit different variety
19			3300	Batakatak	breadfruit different variety
20	408	12	4896	Mejwan	breadfruit with seeds
21	225	8	1800	Mejwan	breadfruit with seeds
22	225	8	1800	Mejwan	breadfruit with seeds
23	-	-	-	Mejwan	breadfruit with seeds
24	56	8	448	kole nut	seeds of breadfruit
25	42	8	336	kole nut	seeds of breadfruit
26	-	-	-	mokmok	arrowroot
27	590	52	30680	ik	fish
28			1700	punkin	pumpkin
29			2800	binana	banana
30	weekly consumption not possible		3200	binana	banana
31			1320	kanapu	papaya
32	to determine as such only annual		2880	kanapu	papaya
33			-	potato	sweet potatoe
34	figures given.		-	local vegetable foods	local vegetable foods
35			-	bao lol	poultry
36			200	bao lin	wild bird
37			250	pik	pork
38			125	won	turtle
39			150	wor	lobster
40			-	kabor	giant clams
41			5325	jerol	snails
42			1013	kwid	octopus
43			638	barolab	coconut crab
44			1950	clams	clams (small)

TABLE 4A : MAXIMUM DIET FOR LOCAL FOODS - FOR ADULT MALES
WEEK NO. STARTING FROM JANUARY AND THEREFORE REPRESENTS SEASONS AS WELL

Week / Question No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	266	266	266	266	266	266	266	266	266	266	266	266	266	266	266	266	266	266	266	266	266	266	266	266	266	266	266
2																											
3	1610	1610	1610	1610	1610	1610	1610	1610	1610	1610	1610	1610	1610	1610	1610	1610	1610	1610	1610	1610	1610	1610	1610	1610	1610	1610	1610
4																											
5	6440	6440	10465	10465	10465	10465	10465	10465	10465	10465	10465	10465	10465	10465	10465	10465	10465	10465	6440	6440	6440	6440	6440	6440	6440	6440	6440
5																											
6	910	910	2275	2275	2275	2275	2275	2275	2275	2275	2275	2275	2275	2275	2275	2275	2275	910	910	910	910	910	910	910	910	910	910
6																											
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-				-	-			
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-		-				
9	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-		
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
12	-	-	-	-	2500	-	2500	-	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	-	-			
12																											
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
14	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	3280	3280	3280	3280	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
18	2350	-	2350	2350	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2350
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20	-	3500	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3500	3500	3500	3500	3500	3500	3500	3500	-
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	700	700	700	700	700
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	700	700	700	700	700
25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26	-	-	-	-	560	560	560	560	560	560	560	560	560	560	560	560	560	560	-	-	-	-	-	-	-	-	-
27	2200	-	2200	2200	2200	2200	-	2200	2200	2200	2200	2200	2200	2200	2200	2200	2200	2200	2200	2200	2200	2200	2200	2200	2200	2200	2200
28	-	-	-	-	-	1250	-	1250	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	875	
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
31	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
33	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
34																											
35																											
36																											
37	Weekly consumption not possible to determine as such, only annual figures given.																										
38																Weekly consumption not possible to determine as such only annual figures given.											
39																											
40																											
41																											
42																											
43																											

TABLE 4A : MAXIMUM DIET FOR LOCAL FOODS - FOR ADULT MALES
WEEK NO. STARTING FROM JANUARY AND THEREFORE REPRESENTS SEASONS AS WELL
(CONTINUED)

Week / Question No.	28	29	30	31	32	33	34	35	36	37	38	39	40
1	266	266	266	266	266	266	266	266	266	266	266	266	266
2, 3, 4	1610	1610	1610	1610	1610	1610	1610	1610	1610	1610	1610	1610	1610
5, 5	6440	6440	6440	6440	6440	6440	6440	6440	6440	6440	6440	6440	6440
6, 6	910	910	910	910	910	910	910	910	910	2275	2275	2275	2275
7	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-
9	300	300	300	300	300	300	300	300	300	300	300	300	300
10	-	-	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-
12, 12	-	-	-	-	-	-	-	-	-	-	2000	-	2000
13	-	-	-	-	-	-	-	-	-	-	-	-	-
14	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300
15	-	-	-	-	-	-	-	-	-	-	-	900	900
16	3280	3280	3280	3280	3280	3280	3280	3280	3280	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-	-	-
18	2350	2350	2350	2350	2350	2350	-	-	-	-	-	-	-
19	-	-	-	-	-	-	450	450	450	450	450	450	450
20	-	-	-	-	-	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-	-
22	-	-	400	-	-	400	-	-	400	-	400	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	-	-	-	-	-
27	2200	2200	2200	2200	2200	2200	2200	2200	2200	2200	2200	2200	2200
28	-	-	-	-	-	-	-	-	-	-	-	-	-
29	-	875	-	-	875	-	-	875	-	-	-	-	-
30	875	-	-	875	-	-	875	-	-	875	-	-	-
31	100	100	100	100	100	100	100	100	100	100	100	100	100
32	-	-	-	-	-	-	-	-	-	-	-	-	-
33	100	100	100	100	100	100	100	100	100	100	100	100	100
34–43	Weekly consumption not possible to determine as such only annual figures given.												

Week / Question No.	41	42	43	44	45	46	47	48	49	50	51	52
1	266	266	266	266	266	266	266	266	266	266	266	266
2, 3, 4	1610	1610	1610	1610	1610	1610	1610	1610	1610	1610	1610	1610
5, 5	6440	6440	6440	6440	6440	6440	6440	6440	6440	6440	6440	6440
6, 6	2275	2275	2275	2275	2275	2275	2275	2275	910	910	910	910
7	-	-	-	-	-	-	-	-	-	-	-	
8	-	-	-	-	-	-	-	-	-	-		
9	300	300	300	300	300	300	300	300	300	300	300	300
10	-	-	-	-	-	-	-	-	-	-	-	
11	-	-	-	-	-	-	-	-	-	-	-	
12, 12	-	2000	-	2000	2500	2500	2500	2500	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-
14	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300	6300
15	-	900	-	900	900	900	900	900	-	-	-	-
16	-	-	-	-	-	-	-	-	-	3280	3280	3280
17	-	-	-	-	-	-	-	-	-	-		-
18	-	-	-	-	-	-	-	-	2350	-	2350	-
19	450	450	450	450	450	450	450	450	-	-		-
20	-	-	-	-	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-
22	400	-	400	-	400	-	-	-	-	-	-	
23	-	-	-	-	-	-	-	-	-	-	-	
24	-	-	-	-	-	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	-	-	
26	-	-	-	-	-	-	-	-	-	-	-	-
27	2200	2200	2200	2200	2200	2200	2200	2200	2200	2200	2200	2200
28	-	-	-	-	-	-	-	-	-	1250	-	1250
29	-	-	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-
31	100	100	100	100	100	100	100	100	100	100	100	100
32	-	-	-	-	-	-	-	-	-	-	-	
33	100	100	100	100	100	100	100	100	100	100	100	100
34–43	Weekly consumption not possible to determine as such only annual figures given.											

Table 4B: Summary of Maximum Diet (Annual Consumption)

Question No.	Grams/ Week	No. Weeks	Grams/ Year	Marshallese	English
1	266	52	13832	EL	coconut graated for coconut milk
2				Waini	coconut ripe for copra
3	1610	52	83720	Waini	coconut ripe for copra
4				Waini	coconut ripe for copra
5	6440	36	231840	drenin ni	coconut water
5	10465	16	167440	drenin ni	coconut water
6	910	25	22750	Medi	tender coconut meat
6	2275	27	61425	Medi	tender coconut meat
7	-	-	-	drenin ni	coconut water
8	-	-	-	Medi	tender coconut meat
9	300	52	15600	Kenawe	coconut variety-can be eaten raw
10	-	-	-	Kenawe	coconut variety-can be eaten raw
11	-	-	-	iu	coconut 'apple'
12	2000	4	8000	iu	coconut 'apple'
12	2500	20	50000	iu	coconut 'apple'
13	-	-	-	iu	coconut 'apple'
14	6300	52	327600	iekaru	nectar from coconut bud
15	900	8	7200	Makon (jankwon)	pandanus pulp
16	3280	16	52480	Bob	pandanus
17	-	-	-	Bob	pandanus
18	2350	12	28200	Bukrol or	breadfruit different variety
19	450	15	6750	Batakatak	breadfruit different variety
20	3500	9	31500	Mejwan	breadfruit with seed
21	700	5	3500	Mejwan	breadfruit with seed
22	400	7	2800	Mejwan	breadfruit with seed
23	-	-	-	Mejwan	breadfruit with seed
24	700	5	3500	kole nut	seeds of breadfruit
25	-	-	-	kole nut	seeds of breadfruit
26	560	14	7800	mokmok	arrowroot
27	2200	50	110000	ik	fish
28	1250	4	5000	punki	pumpkin
29	875	4	3500	binana	banana
30	875	4	3500	binana	banana
31	100	52	5200	kanapu	papaya
32	-	-	-	kanapu	papaya
33	100	52	5200	potato	sweet potatoe
34			-	local vegetable foods	local vegetable foods
35	weekly consumption not		4375	bao lol	poultry
36			1750	bao lin	wild bird
37	possible to determine		3500	pik	pork
38			1750	won	turtle
39	as such only annual		7000	wor	lobster
40			7000	kabor	giant clam
41	figures given.		8679	jerol	snails
42			5250	kwid	octopus
43			7000	barolab	coconut crab

rather than consume a large portion of it himself. Second, the acceptance of food offered is also a very important part of the culture, and therefore it would be very difficult for an individual to isolate his food gathering and consumption patterns from those of the society at large. This latter point is especially true for foods which have limited availability, such as, breadfruit, pumpkin, papaya, bananas, potatoes and during certain times, pandanus and fish. Coconuts and jekaru on the other hand can be gathered in significant quantities at all times. It is therefore much more likely that a maximum (a totally local) diet would be based on them.

If it is assumed that Tables 4A and 4B represent the maximum amount of local foods consumed, and that whatever imported food is eaten will have a tendency to displace proportionate amounts of local foods, then in principle a "typical average" diet could be established. This could be done by subtracting the caloric content of imported food from the total calories of local food consumed per year as shown on the maximum table, and then converting the difference to gram weights using calorie to gram conversion factors for the local foods. By using this method, one can derive the typical amount of local food that could be expected to be consumed in addition to the imported food eaten. Table 5 derives this diet pattern and also presents the averages for the different age groups and sexes.

In summary the results of the study establish maximum estimates of the consumption of local foods, based on the amount of local food that an islander living a traditional life and a totally local diet could consume. These estimates could be further refined by the use of calorie conversion factors specific to the Marshall Islanders and specific to the local food they consume. With reference to the contemporary diet or "typical average" we are continuing our study in two ways. One is by the utilization of the interview method in an attempt to determine the full range of local food consumption in combination with studies of food wasting and food sharing. A second is by the determination of the quantity of imported food consumed in these same communities. In other words, we are suggesting a double approach which would attempt to determine the contemporary diet from opposite directions. This could produce either two corresponding figures or more likely, two reliable figures between which the contemporary or "typical average" diet of the islanders in the community in question would lie.

Table 5: Typical Average Diet as a Function of Age and Sex in Comparison to the Maximum Diet (g/yr).

Question No.	Maximum Diet g/yr. (Table-4)	Male (11-22 yrs.)	Male (23-50 yrs.)	Male (51-70 yrs.) Woman (11-14 yrs.) Child (7-10 yrs.)	Woman (15-22 yrs.)	Woman (23-50 yrs.)	Woman (15+) Child (4-6 yrs.)	Child (1-3 yrs.)	Marshallese name of Food	English Equivalent
1	13832	12864	12449	11066	9682	9129	8299	5948	El	coconut grated for coconut milk
2									Waini	coconut ripe for copra
3	83720	77860	75348	66976	58604	55255	50232	36000	Waini	coconut ripe for copra
4									Waini	coconut ripe for copra
5	399280	371330	359352	319420	279496	361754	239568	171690	drenin ni	coconut water
6	84175	78293	75758	67340	58923	55556	50505	36195	Medi	tender coconut meat
7	-	-	-	-	-	-	-	-	drenin ni	coconut water
8	-	-	-	-	-	-	-	-	Medi	tender coconut meat
9	15600	14508	14040	12480	10920	10296	9360	6708	Kenawe	coconut variety-can be eaten raw
10									Kenawe	coconut variety-can be eaten raw
11									iu	coconut 'apple'
12	58000	53940	52200	46400	40600	38280	34800	24940	iu	coconut 'apple'
13									iu	coconut 'apple'
14	327500	304668	274201	262080	229320	216216	196560	140868	jekaru	nectar from coconut bud
15	7200	6696	6480	5760	5040	4752	4320	3096	Makon (jankwon)	pandanus pulp
16	52480	48806	47232	41984	36736	34637	31488	22566	Bob	pandanus
17									Bob	pandanus
18	28200	26226	25380	22560	19740	18612	16920	12126	Bukrol or	breadfruit different variety
19	6750	6278	6075	5400	4725	4455	4050	2902	Batakatak	breadfruit different variety
20	31500	29295	28350	25200	22050	20790	18900	13545	Mejwan	breadfruit with seed
21	3500	3255	3150	2800	2450	2310	2100	1505	Mejwan	breadfruit with seed
22	2800	2604	2520	2240	1960	1848	1680	1204	Mejwan	breadfruit with seed
23									Mejwan	breadfruit with seed
24	3500	3255	3150	2800	2450	2310	2100	1505	kole nut	seeds of breadfruit
25									kole nut	seeds of breadfruit
26	7840	7291	7056	6272	5488	5174	4704	3371	mokmok	arrowroot
27	110000	102300	99000	88000	77000	72600	66000	47300	ik	fish
28	5000	4650	4500	4000	3500	3300	3000	2150	punki	pumpkin
29	3500	4650	3150	2800	2450	2310	2100	1505	binana	banana
30	3500	3255	3150	2800	2450	2310	2100	1505	binana	banana
31	5200	4836	4680	4160	3640	3432	3120	2236	kanapu	papaya
32									kanapu	papaya
33	5200	4836	4680	4160	3640	3432	3120	2236	potato	sweet potatoe
34									local vegetable foods	local vegetable foods
35	4375	4069	3938	3500	3063	2888	2625	1881	bao lol	poultry
36	1750	1628	1575	1400	1225	1155	1050	753	bao lin	wild bird
37	3500	3255	3150	3800	2450	2310	2100	1505	pik	pork
38	1750	1628	1575	1400	1225	1155	1050	753	won	turtle
39	7000	6510	6300	5600	4900	4620	4260	3010	wor	lobster
40	7000	6510	6300	5000	4900	4620	4200	3010	kabor	giant clam
41	8679	8071	7811	6943	6075	5728	5207	3732	jerol	snails
42	5250	4883	4725	4200	3675	3465	3150	2258	kwid	octopus
43	7000	6510	6300	5600	4900	4620	4200	3010	barolab	coconut crab
44	-	-	-	-	-	-	-	-	clams	clams (small)

List of Local Foods and Conversion Factors

1) Coconut milk - el - One nut produces 38 grams of milk[1] at 2.6 cal/g.[2] A solution produced by squeezing freshly grated coconut. Often water is mixed with the coconut gratings to enhance the extraction process. Coconut milk can be used to enrich all traditional dishes and is normally mixed into food before cooking. EL is produced from waini (the mature nut).

2) Coconut meat - waini - one nut = 240 grams[3] at 3.1 cal/g.[4] (12 months stage). Often grated and mixed into food but more often eaten as a side dish with breadfruit or fish.

3) Coconut water - dren in ni - 230 grams/nut at .109 cal/gram.[5] The water of the immature coconut at its 7 to 9 month stage is consumed by islanders of all ages regularly when available. The ni must be cut from the tree as opposed to waini which falls by itself. Certain varieties of ni are preferred among others for regular drinking, some varieties being seldom or never consumed.

4) Coconut Flesh - medi - 130 grams/nut at 1 cal/gram.[6] Medi is the soft flesh which forms inside the shell of the ni stage. It is seldom used in cooking and eaten primarily as an in between meal snack.

5) Kenawe - 100 grams/nut at .109 cal/gram. Kenawe comes from a particular variety of coconut palm of which the immature, 3 to 5 month stage fruits are sweet to the taste and edible. The shell is soft at this stage and eaten like raw cabbage. The husk in its upper portion at the eye is also edible. The lower portions of the husk are chewed and the juice sucked and then these portions are discarded. Both gram weight and calorie content listed above are estimates as no data on kenawe have been published.

6) Sprouted embryo - iu - 100 grams/nut at .78 cal/gram.[7] The embryo begins to form around the 15th month of the waini stage, and normally takes two to three months to sprout. When the sprouted nuts are used in copra making the iu is first removed before the nut is set out to dry. It is often cooked in a pot with flour and coconut milk. Sometimes it is baked still within the shell. More often it is simply eaten raw mixed with sugar water or jekaru as a meal or plain as a snack.

7) Jekaru - .45 cal/grams.[8] Jekaru is the sap of the tree tapped from the flower while still at the bud (4 week) stage. Up to one gallon of Jekaru can be produced from one tree per day. Jekaru is used as a sweetener in cooking and it is drunk by children and adults fresh in a solution of 50% water. Fermentation begins immediately. It is often boiled and given to babies as a substitute of mother's milk. Unless the fermentation process is arrested it turns into a wine by about 36 hours. Fresh jekaru is often boiled into a syrup called Jekami.

8) Pandanus (preserved) - Jankwon - 9.93 cal/gram.[9] Jankwon is produced by mashing the cooked pandanus keys into mokon, straining out the fibers which were loosened from the cores in the process, baking the resulting mash into

a deep brown paste like substance and drying this under the sun until it is dehydrated to the point where preservation is possible. It is then wrapped in dry pandanus leaves and tied into a neat roll until needed.

9) Pandanus keys - bob. There are two basic types pf pandanus. One is used to mash into mokon and averages about 50 grams per key;[10] another type is seldom cooked, contains little pulp and only about 30 grams of juice. This latter type is typically eaten raw by chewing and sucking and then discarding the inedible core. There are about 40 keys to a stalk. No known reliable calorie comparison factors for this latter type of pandanus key exist so we have used .58 calories/g.[11] for both types has been assumed even though this is an overestimation for the latter. Depending on location (island/atoll) pandanus is eaten consistently for 4 months.[12]

10) Breadfruit - batakatak, bukrol. These are the seedless varieties of breadfruit. They contain about 500 grams of cooked edible portion at 1.3 cal/gram.[13] Three types of breadfruit are eaten consistently over a period of about 12 weeks per year.[14]

11) Preserved breadfruit (batakatak and bukrol) - buido - 1.3 cal/gram with one fruit equal to 500 processed grams of buido.[15] The breadfruit is picked in large numbers at the peak of season, skinned, and decored, sliced and soaked within a copra sack in the lagoon for a period of hours or days. The sliced fruits are then mashed and allowed to sit and ferment underground within breadfruit leaves where drainage can take place. Before eating it is often rinsed in fresh water to reduce the salt content.

12) Breadfruit (variety with seeds) - Mejwan - 272 grams/fruit at 1.12 calories/gram, cooked and 1.22 calories/gram eaten raw.[16] Mejwan is always cooked in its unripe stage though unlike other varieties of breadfruit when ripe it can be eaten raw. It can also be prepared into Jankwon by baking the ripe fruits and then drying them under the sun. The jankwon so produced contains about 2.83 calories/gram.[17] Mejwan is eaten consistently for about 9 weeks/yr. in its unripe stages and for about 5 weeks/yr.[18]

13) Breadfruit seeds (from mejwan) - Kole - each nut weighs about 2.5 grams and contains about 1.5 cal/gram.[19] The nuts must be cooked to be eaten, and can be considered as a significant portion of the diet for only about 5 weeks per year.

14) Arrowroot - Mokmok - 3.5 calories/gram.[20] The tubers are dug up in the winter months when the plant itself dies. They are dumped into a copra sack and rinsed of dirt in the lagoon. They are then grated into pulp which is mixed with salt water and strained to separate the starch out of the solution. The solution containing the starchy material is usually trapped in a canvas lined pit which permits the salt water to seep through the canvas into the sand leaving the chalky starch behind which resembles plaster of Paris. The starch is then wrapped in a towel and hung up to drain and dry. It can then be used in cooking without further processing.

Footnotes for List of Local Foods and Conversion Factors.

1. Murai, Mary. Some Tropical South Pacific Island Foods, University of Hawaii Press, Honolulu, Hawaii, 1958;118.

2. Ibid 118

3. Ibid 52-7. (Murai documents the average weight of the mature coconut at 350 grams. However, as most of the coconut eaten is grated and as only 2/3 of this amount is actually extracted from the shell, we have reduced Murai's figure by 1/3 to 240 grams/nut.)

4. Ibid 52-7

5. Ibid 52-4

6. Ibid 52-4

7. Ibid 52-8

8. Ibid 58

9. Ibid 76

10. Ibid 67-82
(Murai documents the average edible portion of a pandanus key at 75 grams. There are many dozens of variety of pandanus eaten in the Marshall Islands, however, though the two varieties used in Murai's study happen to be the largest. We feel 50 grams/key for the variety which produces mokon and 30 grams/key for the other type to be more accurate overall average.)

11. Ibid 58

12. See page (5 & 6) of Dietary Interview.

13. Murai, Mary. Some Tropical South Pacific Island Foods, University of Hawaii Press, Honolulu, Hawaii, 1958;24-30.

14. See page (5 & 6) of Dietary Interview.

15. Murai, Mary. Some Tropical South Pacific Island Foods, University of Hawaii Press, Honolulu, Hawaii, 1958;24-30.

16. Ibid 24-30

17. Ibid 24-30

18. See page (5 & 6) of Dietary Interview.

19. Murai, Some South Pacific Island Foods, University of Hawaii Press, Honolulu, Hawaii, 1958;34.

20. Ibid 104.

Living Pattern Study:

The living patterns among the Marshall Islanders vary somewhat from atoll to atoll. However, due to the consistency of an atoll environment and its limited land area, as well as the limitations it presents to economic development, reliable estimates can be produced if based on the average amount of time spent at the various tasks necessary for subsistence. Tables 6, 7, 8 list the time spent in various activities by males (ages 15-50 years), females (ages 15-50 years) and children (ages 6-14 years).

From information provided by the Tobolar Copra Plant which keeps copra production works for the various atolls in the Marshalls, it has been determined that the islanders of Utirik Atoll produced about 113 short tons of copra between the Fall of 1957 to the Fall of 1978. Thus this averages to about 90 lbs./week per person. This copra production represents the output of 48 males from ages 14 to 95. As all of these individuals are not involved in copra production to the same extent, it is estimated that those actually working produced about one bag (between 100 and 125 lbs.) per week. This per capita production at Rongelap seemed to be considerably less, while at Ailuk it proved somewhat more. At any rate copra production - the main island commercial activity - could not possibly exceed that possible during the hours taken for coconut collecting and husking per week which we have used as the basis for island activities estimates. It has been estimated that plantation clearing (for undergrowth) adds another 4 hours per individual per week to inland activities associated with copra production. In addition to copra production, another two hours per day of inland activity has been estimated for food gathering.

This is not to say that some individuals do not spend considerably more than 26 hours/week inland. The apparent range over the entire male population is very broad, with some individuals spending in excess of 40 hours and others as little as 7 or less.

The living patterns of women on the other hand, are noteworthy in the relative lack of inland activity. Some of the younger women are involved in coconut gathering, and, to a limited extent, food gathering. Some of the elderly women are engaged in activities related to handicraft production, (such as gathering of pandanus leaves).

Female activities on the lagoon, at the shoreline and on other small islands of the atoll appear to be an insignificant portion of their living patterns. An exception to this is found only when actual settlement of a small island for copra making purposes takes place. In general, women do not go along on the two to three day trips which the men periodically make for cleaning up of the coconut plantation area.

In respect to male activities in the area of ship repair, a direct relationship was apparent between the number and state of repair of traditional canoes and other vessels and the amount of time spent on the lagoon and at other islands.

Shore time activities for men are primarily limited to fishing with throw nets, long nets and cane poles.

On the other hand children spend long hours playing on the beach and in the sand. It was estimated that as a minimum, they occupy this area during two hours of daily activity.

From the above discussion it can be seen that by far the largest amount of time in the living pattern of the islanders is spent within the village area. During the largest proportion of it (45 to 49 hours), they are involved in child raising, handicraft fabrication and relaxation. Indeed it is a rare instance when one stops at an islander's house to find no one there. Such situations occur only during major celebrations or during the arrival of a trading vessel.

To understand the leisurely pace of life on the outer atolls of the Marshalls, it is perhaps best to pay attention to the subsistence activities, and the life and culture supporting functions which are based upon the coconut palm. The palm has been said to be the mother of Pacific man and truly it is the pillar upon which island life revolves. From the preceding section on diet, it is apparent that by the islanders own estimate, the coconut palm provides from 48 to 58 percent of the food for the traditional as well as the contemporary local diet. Fish, which can also be gathered quickly and in great abundance constitute the second major portion of the diet and the other main support for island life and culture. Together these two items provide from 78 to 84 percent of the local food diet. It is upon the availability of these staples, which the environment provides abundantly, that atoll life, as we know it today was established. Even though many of the subsistence skills which enabled the ancestors of the present islanders to thrive and establish their once self-reliant culture have been lost, and though the islanders can in no sense be considered or expected to be totally self-sufficient in terms of their diet, the local food resource foster and support this leisurely pace of life. They can be expected to turn to it in lean times, when for one reason or another the much preferred rice, sugar and flour imports become scarce or unattainable.

Table 6: Male Activities

(15-50)

			hrs./week
A.	Inland activities - (26 hrs./week)		
1.	Brushing plantation		4
2.	Coconut collecting		4
3.	Coconut husking		4
4.	Food gathering of pandanus, breadfruit, ni, iu, Jekaru		14
		total (A)	26
B.	Activities on lagoon (9 hrs./week)		
1.	Fishing on lagoon		7
2.	Inter atoll travel (0-2 hrs.)		2
		total (B)	9
C.	Activities at shoreline (7 hrs./week)		
1.	Fishing at shoreline	total (C)	7
D.	Activities on other island (2 hrs./week)	total (D)	2 (0-2 hrs.)
E.	Activities in Village area (124 hrs./week)		
1.	Canoe and net making and repair		4
2.	Clean up of living area		7
3.	Coconut cutting and drying		4
4.	Church activities, meetings, celebrations		8
5.	Sleeping		56

Table 6: Male Activities (Cont'd)

(15-50)

		hrs./week
6.	Child rearing (and monitoring), handicraft, relaxation	45
	total (E)	124
	Total (A-E)	168

Table 7: Female Activities

(15-50)

A.	Inland activities (8 hrs./week)		hrs./week
1.	Coconut gathering and splitting, gathering pandanus leaf	total (A)	8
B.	Activities on lagoon (none)	total (B)	nil
C.	Activities at shoreline (insignificant)	total (C)	insignificant
D.	Activities on other islands (insignificant)	total (D)	insignificant
E.	Activities in village area		
1.	Preparation of food		28
2.	Splitting coconut shells and drying		4
3.	Clean up of living area		7
4.	Washing clothes		8
5.	Church activities, meetings and celebrations		16
6.	Sleeping		56
7.	Child rearing, handicraft, relaxations		49
		total (E)	160
		Total (A-E)	168

Table 8: Children (ages 6-14)

			hrs./week
A.	Inland Activities		
1.	Collecting iu, gathering coconuts	total (A)	10
B.	Activities on lagoon		
1.	Inter Atoll travel (0-2 hrs.)	total (B)	2
C.	Activities at shoreline		
1.	Play	total (C)	10
D.	Activities on other islands (0-2 hrs.)	total (D)	2
E.	Activities in village area		
1.	School		30
2.	Clean up of living area		4
3.	Washing clothes or drying copra or household chores, etc.		26
4.	Sleeping		52
5.	Play and relaxation		32
		total (E)	144
		Total (A-E)	168

References:

1. Murai, Mary (1954). Nutrition Study in Micronesia. Atoll Research Bulletin #27. Pacific Science Board, NAS - NRC. Washington, D.C.

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3. Personal Communication Notes:
   a. E.E. Held, University of Washington (May 1958)
   b. R.A. Conard, Brookhaven National Laboratory

4. Chakravarti, D., and E.E. Held (1961). Chemical and Radiochemical Composition of the Rongelapese Diet, Report #UWFL-77, University of Washington, Seattle, Washington.

5. Robinson, W.L., W.A. Phillips and C.S. Colsher (1977). Dose Assessment at Bikini Atoll. Report #UCRL-51879 Pt. 5. Lawrence Livermore Laboratory, Livermore, California.

6. USAEC (1973). Enewetak Radiological Survey. Report #NVO-140 Volume 1. Nevada Operations Office, Las Vegas, Nevada.

Appendices

A. Seasons: i. Local foods
ii. Seasons of the year

B. Marshallese (local) foods

C. Other Islands used for food gathering

D. Data on edible portions of Marshallese foods

E. Fishes: Types of fishes and methods of fishing

F. School children - lunch program

G. Typhoon relief

H. Food supply ships - trip reports

I. Private or community stores - types of foods available

Appendix A

SEASON (WOTOM) - Local Foods

Pandanus - various observations

Spokesman	Ripens
	1a) June - July, b) November - January
Nagal - Ailuk	2a) June - July, August, September, b) November, December January, February
Cement - Ailuk	3a) April, May, June, July, b) December, January, February
Cement - Ailuk	4) all year June - December
Paul - Rongelap	5) 8 months September/October - April/May
Jetai - Rongelap	6) May, June, July (begins growing January)
Ailuk	7a) June, July, b) November, December, January
*	8) October, December, January but some ripens throughout year in small numbers
Henas - Rongelap	9) December begins to grow/March, April ready to eat
Ailuk	10) January, February, April, May, June, July, August, September

Comments: during a drought-smaller and smaller fruits

Breadfruit - various observations

Spokesman	Ripens
Henas - Rongelap	1) May, June, July, August, September, (little October)
	2a) June, July, b) December, January
Nagal - Ailuk	3) April, May, June, July, August
Cement - Ailuk	4a) June, July, August, September, b) December, January
Ailjen - Ailuk	5a) June, July, b) December, January
	6a) summer, b) November, December
Rongelap	7a) July, August, September, b) December, January
	8) May - September, peak May through July some be may be present until December

*Bryan Jr., E. H., Life in the Marshall Islands, p. 129.

9) December, January, February, April, May, June, July (mokan)

Comments: After a breadfruit season, pandanus follows. They alternate seasons. (Nagat - Ailuk)

Bananas - various observations

Spokesman

Nagal - Ailuk — all year around

Hemos - Rongelap — all year - more in rainy season

Arrowroot

Spokesman

Hemos - Rongelap — November, begins growing, December and January ready to eat

Nagal - Ailuk — December, January, February

* — October through January

Rongelap — January, February, March, April

Coconut - iu (flowering coconut)

Spokesman

Nagal - Ailuk — whenever anybody wants to find and eat it

Pumpkin

Spokesman

Nagal - Ailuk — all year

Cement - Ailuk — all year

Sue - Rongelap — all year
1 month for pumpkin to become large

*Bryan Jr., E. H., Life in the Marshall Islands, p. 129.

Cement - Ailuk

Pandanus Season - January, February, March, April, May, June, July, August, September

	Pandanus Types
First pandanus season beginning March-end of May	Jablower Kobarwa
Second pandanus season beginning of June-end of August	Lejokrer Lokotwa Lebo
Third pandanus season beginning of September-end of November	Edmerma Leomtur Ailuk Kemelij Lemoen
Fourth pandanus season beginning of January-end of March	Lekman Lejmou Liman Mojel Wottet Nibun

The information given by the Marshallese seems to show two seasons for both breadfruit and pandanus. This is a widely accepted fact and tends to support our own observations made during our extended stay on the islands in the Marshalls. According to the above figures, one would expect that the summer season, which bears the largest crop and is the time when preserving is normally done, begins around the second week of May and continues progressively until July--the month when the preserving is traditionally done and continues on into the second or third week of August. The second or winter breadfruit crop fails in December and January.

It should be noted that the pandanus season is markedly different in the Northern Marshalls where due to lack of rain in the winter months, the summer crop is normally much larger. To some extent, this holds true for breadfruit as well--the winter crop being much smaller.

Taro

Spokesman

Nagal - Ailuk	grows all year

OBSERVATIONS ON SEASONS OF YEAR

Summer	season of maximum rainfall in the year*
rainy season on Ailuk	May, June, July, August; slows down September, October, November, December
Rainfall	decreases as you go north average rainfall: Jaluit - 160" Wake Island 30 to 50" (350 miles further north) Majuro - 120" Ujelang - 80" Eniwetak - 60 to 70"*
Winter	December - April, season of strong winds from the northeast. Dry period of the year.*
Temperature °F	range varies less than 10-12°* Minimum: 68° Maximum: 80°

*Bryant Jr., E. H., Life in the Marshall Islands, p. 135-36.

Appendix B

Marshallese Foods

a: Marshallese names for food types

Local Foods

- breadfruit - ma
- coconut
  - drinking - ni
  - copra - waini
  - oldest stage - iu (sprouted)
- pandanus - bob
- arrowroot - mokmok
- taro - iaroj
- pumpkin - baanke
- papaya - keinabbu
- banana - pinana
- sweet potatoe
- coconut sap - jekeru
- chicken - bao
- pig - piik
- turtle - won
- fish - ek
- clams - kapwor
- lobsters - wor
- birds - bao
- coconut crabs - barulep
- eggs - lep
  - turtle
  - bird
  - chicken

Imported Foods

- rice - raij
- flour - pilawa
- can - kuwat
  - tuna - bwebwe
  - chicken - bao
  - beef - cow
  - mackerel
  - cornbeef
  - sardine
  - vienna sausage
  - spam
  - beef hash
- biscuits - ship, crab
- Ramen soup
- peanut butter
- kim chee
- shortening
- sugar
- soy sauce
- mayonnaise
- yeast
- baking powder
- candy - M&M's, gum, chocolate bars
- coffee
- tang
- tea
- milk - Carnation Instant

b: Cooking Modes

(1) Ground oven - UM - The ground pit is fueled by a coconut shell or husk fire. Rocks are then added to cover the coals. When the rocks have been warmed the food is placed in. The pit is covered over with banana leaves, canvas or a heavy rubber sheet. Weights are added.

(2) Stove Type Cooking - is always done either over a kerosene stove or an open fire fueled by coconut shells or husks.

a) boiling - using rainwater, brackish water when rainwater supply is low.
b) frying - using Crisco, other shortenings, occasionally pig grease, rarely if, ever coconut oil.
c) steamed -

(3) Roasting - is done over a coconut shell or husk fueled fire, when it has turned to coals.

c: Description of the Food Types

1. Breadfruit - MA

(1) Kwanjin - green breadfruit roasted on coals until skin is black. The outside is then scraped with pieces of broken glass or shell. Approximately 1½ hours to cook.

(2) Steamed - fill the iron pot with water up to metal disk. Cooking time varies according to type being cooked.

a) bwiro - 2 hours to steam on fire
b) raw breadfruit (whole) 30 minutes by stove

(3) Boiled - wash green breadfruit leave whole and boil.

(4) Kopjar - baked breadfruit in ground oven.

(5) Jokkwapin Ma - Breadfruit soup is made by removing the core and skin, cutting the rest into pieces which are boiled, mashed, mixed with coconut milk and salted to taste.

(6) Fried - Cut the ripe breadfruit into slices removing the outer green peel. Soak the wedges in salt water or salt them before frying. Cooking time approximately 10 minutes on each side until brown or french fried.

(7) Kalo - very ripe breadfruit mixed with coconut milk.

(8) Mijiwan - a type of breadfruit which is eaten raw when it is very ripe; as is or with coconut milk.

(9) Kwolejiped - name of nuts (kwole) cooked. They are roasted on coals or taken out of a steamed, baked, or boiled Mijiwan Breadfruit.

(10) Bwiro - preserved breadfruit or Marshallese cheese. The skin is removed from the ripe green breadfruits then cut in wedges and placed in a burlap bag and taken to the lagoon. The bag is anchored for one or two days in the saltwater or stomped on for an hour or so to hasten the fermentation. The bag is then taken from the water and left on coconut leaves in the open air for one or two days. The breadfruit is then placed in a pit lined with breadfruit leaves. Leaves, a cloth cover and weights are then placed over the breadfruit. The breadfruit leaves are changed after every month and the bwiro is ready for cooking after two months. Supply can be kept six months to a year or two. (Type of breadfruit used--bakrol, batatak, koutroro.)

Bwiro Food Preparation

The quantity of preserved breadfruit that is needed to cook with is taken from the pit or box and thoroughly washed in fresh water Coconut milk is then mixed with the rainwater. Sugar is also added along with flour which is optional. A ladle full of the mixture is then placed in a breadfruit leaf and is either steamed, boiled, or baked. Another method of cooking is to roll the bwiro into balls and then steam or boil.

(11) Baked - The inside stem of a ripe breadfruit is removed and coconut milk replaces it. The breadfruit is then wrapped in leaves and baked.

(12) Jankwin - Mijiwan seeded breadfruit is picked green; allowed to ripen; seeds, core and skin removed; placed in a coconut leaf basket; baked in earth oven all night; taken out; unwrapped; flattened and allowed to dry in sun. When dry, it is rolled, wrapped in pandanus leaves, tied with sennit twine and preserved as a roll.

2. Coconut

The coconut was traditionally and still in some circumstances continues to be the focal point upon which the Islander's diet revolves. Indeed nothing is found in greater abundance among the atolls than coconut. The tree itself was an important foundation upon which Island life evolved. The leaves being woven into shelters and the fibrous strands of the husk twisted into sennit rope for the lashings of houses and outrigger canoes. The bud-sheath was used as a bowl in which to pour ingredients to bake in ground ovens. Baskets woven from the leaflets of the tree were, and occasionally still are, commonly used for eating and displaying and transporting food.

The coconut fruit requires approximately 12 months to ripen and usually falls off itself after an additional few months due to stem decay. At this stage it is ready to be husked, broken open and dried under the sun or in a smoke-house into copra, the major island export. And at this stage it can be opened and the nut cut from the shell and eaten as jiral (with something else) fish, for instance or breadfruit or both. It has a high oil content however and a two to four ounce portion is seldom exceeded unless there is a scarcity of imported or other local foods. Children seem to eat considerably more of it than adults do. The elderly, on the other hand, especially those lacking teeth, eat it normally only when it is mixed into the family food. Binbin is a term that is used to describe the preparation of a variety of dishes in which mashed banana or tarro or breadfruit or more likely rice, is formed by hand into a ball and rolled over coconut gratings which stick to the surface and help preserve its shape. These gratings are produced in a process called ranke whereby the nut is scraped from its shell by a rounded, tooth edged blade normally screwed onto a stool on which one can sit while engaged at the grating or ranke process.

The water of the mature coconut or waini is sometimes drunk. More often, however, it is mixed with food as an ingredient before cooking or not being as sweet or flavorful as the water in the unripe nuts discarded altogether. The earliest stage at which the water begins to sweeten and is used for drinking is termed obleb--around its sixth month of growth. The shell is still soft enough to break with the fingers and the nut itself--if it has started to form at all--is but a thin gelatin lining the bottom of the shell that can be loosened with a thumbnail and drunk. The next stage when the gelatin hardens as does the shell allowing itself to be husked is called ni. This is the stage at seven to nine months when the nut is normally used for drinking. During this period, the nut continues to form though its texture remains soft and removable from the shell by the thumbnail. When it becomes too hard for this and begins to become cemented to its shell at around nine to ten months, it is called mejob. The meat of the nut is hard though not quite as hard as in the mature, waini, stage and not as oily. Mejob is seldom eaten today though it was in the past and may one day again be a staple to ward off hunger in times of famine. This is due to its abundance and to the fact that the lower oil content allows for a larger quantity to be eaten before bringing distress to the bowel. It can be grated by the ranke process and is sometimes used in this way mixed as an ingredient into food or put in a bowl with jekaro and eaten as a sort of cereal called jekbwa.

Jekaro is a nectar collected by binding and repeatedly (morning and evening) cutting the budding composit flower of the coconut tree. As the tree produces one bud a month and as a bud can be tapped for a period of up to four months, a good tree can have up to four bottles containing up to a gallon of jekaro hanging and waiting to be collected each morning. The tree will produce a similar quantity that must be collected in the evening. It is very sweet and is usually mixed with water for drinking and very nutritious, especially after four to six hours at which point the yeast content is greatest. After this it begins to become noticeably alcoholic and at 36 hours when the fermentation process stops, it can be drunk as a wine. In its sweet, unfermented stage it has been used as a substitute for mother's milk. When available, it can be used as a sweetener in any or all of the traditional dishes. When it is boiled down, it yields on an eight to one ratio a delicious syrup termed jekami which is used as a sweetener in drinking and also eaten with coconut at its various stages. It can be mixed and further cooked with coconut gratings to produce a type of coconut candy, much prized, called amitama.

At around the 15th to 18th month, the coconut begins to sprout. At this time, the inside of the nut turns gradually to a sweet apple-like, spongy substance called iou. A side product in copra making, it is eaten in the interior islands by those gathering the nuts. Then again eaten by those while husking. When the nuts are cracked, children flock to the area to scoop out the soft iou before the nuts are layed out under the sun. Iou is sometimes crushed and mixed raw with jekaro and thickened with flour into a pudding--aikiou. Also it can be steamed or baked in a basket (iutur) or even while still in the nut (umum ilo lot).

To the aikiou dish el is often added. Indeed it is through the el or famous "coconut milk" that the coconut can be seen as the central ingredient in all traditional cooking. El is obtained by mixing the grated coconut or waini with a little water and squeezing. Much of the oil and a great deal of flavor is thereby released into solution--pure white in color. El can, and often is, mixed into every dish conceivable. When available, it is normally mixed into the rice on a daily basis at the rate of about one coconut per two cups of rice.

Coconut - ni

ni - 1 to 5 months growth

1) young drinking
method - drink through hole in husk, shell too fragile to husk, gelatinous coconut meat

2) mature drinking coconut
method - husk coconut before drinking coconut meat firm, use knife to cut from side

3) waini - 6 to 7 months growth

copra-producing coconut
use of liquid - usually thrown away, children drink occassionally
use of meat - eaten a) cut in wedges-with fish or by itself
b) grated and squeezed for coconut milk
c) use gratings in cooking, rice balls, mokan

4) iu - 8 to 8 1/2 months growth
spongy food inside sprouted coconut
use of iu a) eaten raw
b) cut up and boiled with sugar or jekeru
c) cut up and boiled with flour, sugar or jekeru
d) raw iu cut up and sweetened with sugar or jekeru
e) iuwumum - spongy meat of sprouted coconut baked in its shell
f) iutir - baked spongy meat

Food from coconut sap

jekeru - sap from coconut blossom
uses - a) drinking
b) used as a sweetener in place of sugar, i.e., donuts, bread

jakamai - boiled jekeru into a syrup
uses - a) used mixed with cold or hot water as a drink
b) used for pancake syrup
c) used as a sweetener

amedama - jakamai syrup mixed with grated coconut rolled in a ball - coconut candy

coconut **milk** - produced from waini
method of extracting grated coconut from coconut meat is called roanke.
Then coconut milk is squeezed out of these coconut gratings.
uses - rice - Coconut milk squeezed into water at start of cooking.
Amount - coconut milk squeezed from one or two grated coconuts per 500 g of rice.

mokan - cooked pandanus meat that has been removed from the key (kilok)
a) coconut milk added to mokanas as gravy

gravy - with clams, fish, breadfruit, pumpkin, used with all foods available.

3. Pandanus

The Pandanus fruit resembles a huge pineapple at superficial external glance. However, a closer inspection shows it to be made of large, individually extractable kernels surrounding a central inedible core, much like corn does on its cob. A pandanus fruit can weigh up to thirty pounds and consist of up to forty kernels or keys. These keys themselves are stringently fibrous in nature (indeed, a spent and dried key makes an excellent paintbrush), the inner portion of which contains the flavorful though somewhat stringy pulp which when raw has the consistency of a carrot and likewise can be mashed upon being cooked. The bulk of the pandanus fruit and a considerable portion of its weight is attributed to the upper inedible partially external portion or the keys. This external portion, which is particularly fibrous, is capped by a tough and nobby rind.

Pandanus is traditionally a very important staple for the Marshall Islanders, especially among the northern atolls where due to lack of sufficient rainfall depend less on Breadfruit, tarro, bananas and papayas then do those Islanders living in the southern Marshalls. All over the islands it is eaten when ripe uncooked and in sufficient quantity to be considered a staple. Because of its availability throughout the interior or most islands and because it grows on even the distant unpopulated islands on all atolls, it is often used to ward off hunger during copra harvesting, brushing, fishing and inter-atoll travel. It is considered to offer relief from "morning sickness" and is sought by pregnant women who often eat tremendous quantities of it. Said to be good for sea-sickness it is piled onto vessels of all types and destinations and eaten by nearly everyone aboard during the entire length of the trip. The fact that it can be knocked about a great deal without danger of spoilage (due to its particularly tenacious rind) makes it especially suitable for inter-atoll export where it brings a good price in the district center and on Ebeye.

There are many different varieties of pandanus, some of which are always eaten raw. Others are normally boiled, steamed or baked in a ground oven before eating or processing because they are more starchy, very difficult to chew in their raw state and much more tasty and in particular sweeter after being cooked. These later are the varieties used in the preparation of mokon--the mashed pulp once it has been separated by mechanical means from the fibrous core using an apparatus called the bakan--in the process called kilok. Cooking allows pandanus to be eaten even in its unripe stages though generally speaking the more ripe the fruit the more mokon is produced in the kilok process. The varieties of pandanus are seemingly endless. Each variety has a characteristic shape, consistency, and flavor.

Jankwon is prepared from mokon by baking it to further reduce its water content and then by spreading it out usually on leaves to dry in the sun. The final product is then traditionally wrapped in pandanus leaves and tied with sennit. Though jankwon production is nearly a lost art over much of the Marshalls, it is still continued among the northern atolls, including Rongelap and Utirik where it is apparently a more firmly rooted tradition.

Pandanus - bob

fresh - eat when ripe or uncooked
eroum - boiled pandanus
bake - bake keys in ground
peru - Pandanus pulp and juice mixed with grated coconut and coconut oil and optionally with arrowroot starch, wrapped in breadfruit leaves and boiled or baked.

mokan - The pudding from a cooked pandanus key. The food is removed from the key by a process known as kilok. The cooked pulp is then mixed with other foods or eaten as is.
Examples: a) often mixed with grated coconut
b) mixed with coconut milk
c) served with fish
d) by itself as a dessert

jankwin - Cooked pandanus, extract from keys keys--mokkay, dry in sun, wrap in pandanus leaves and tie with sennit twine.

unripened pandanus - mashed with sugar or jekeru and water.

4. Arrowroot - mokmok

The arrowroot is dug up from the oceanside of the island, placed in a burlap bag, and washed until white. Each separate piece is then grated with a rock. The arrowroot is placed in a wanliklik made of sennit (from fibers of coconut husk)used for straining arrowroot starch. It is then rinsed with two buckets of saltwater. The arrowroot powder is then saved from the canvas or wanliklik, wrapped in a cloth and tied in a tree to dry. The powder is then removed from the cloth (bag), dried in the sun and then stored for future use.

ways of cooking - a) boiling with waini
b) Beru Pandanus and mokmok

5. Taro - iaraj

Stem and leaves are cut off and the remaining root and sugar (optional) added to boiling water. Cook one hour.

The root is also baked.

6. Fruit - kwale

banana - binana

when consumed and cooking method
a) eaten when ripe
b) baked, when not ripe
c) fried
d) boiled in skin
e) mashed and mixed with coconut milk and coconut syrup, when ripe

papaya - keinabbu

when consumed and cooking method
a) raw
b) boiled and added to meat gravy
c) boiled

pumpkin - baanke

when consumed and cooking method
a) boiled
b) cooked in gravy
c) with coconut milk

sweet potato

when consumed and cooking method
a) baked

7. Meat - kanniok

	When eaten
chicken - bao eaten: meat, liver, kidney, heart methods: cleaned, boiled cleaned, boiled, fried cleaned, fried baked (rarely) gravy - flour, shoyu, pumpkin, ma, keinappu bop soup rice, same fruits as above	special occasions--birthday, Christmas, Easter, parties made leftover chicken
fish - ek eaten: most meat on head, eyes, suck on bones methods: not cleaned - cooked in skin on coals fried with salt cleaned, wrapped in coconut leaves - boiled baked (rarely) gravy - flour and fruits soup - rice, fruits cleaned, salted, dried in sun fresh or sashmi salted - 2 days in sun - meat good for 3 or 4 days fry with coconut milk - stays good for months (preserves)	whenever the man in house goes fishing depending on productive nature of man

Note: one can eat fish for three days if it is cooked everyday

When eaten

pig - pik eaten: meat, fat, heart, kidney, brain, suck on bones and skin methods: fried salted gravy - flour, shoyu baked (rarely) boiled - 20 minutes, add seasonings such as onions, garlic, vinegar, shoyu, salt if available	special occasions--birthday, Christmas, Easter, parites
turtle - won eaten: meat methods: baked - most common method of cooking fried - when there is grease	the whole island eats when a turtle is caught-no special time
wild birds eaten: meat, suck on bones methods: cook on coals fry if grease available ground oven baking	mostly when overnight on other island, enroute to other islands, or special food gathering, trip made
clams - kapwor - killer clams methods: boil fry eat with el - coconut milk	whenever diving for them mostly in conjunction with fishing
lobsters - war eaten: tail and legs methods: cook on coals boil	on fishing trips, when full moon is out and man goes to oceanside to get it.
coconut crab - barulep eaten: tail, claws methods: cook on coals	on fishing trips, overnights

Eggs

wild bird eggs method: boil	Easter time and when special food gathering trips may have been made
chicken eggs methods: boil fry used in other cooking ground oven baking	not eaten much, reserved for production of chickens; eggs, generally thought to be for sick and pregnant people
turtle eggs methods: boil	eaten when found - usually no special trip is made to get them

8. Rice

Rice is cooked with coconut milk (el) which has been squeezed from coconut gratings. These gratings come from the copra producing coconut (amounts- one or two coconuts used per 500 grams of rice.

rice jokkwop - soft rice soup--water, rice flour, sugar, coconut milk

rice balls - cooked rice rolled in balls with grated coconut on outside used on special occasions, size of tennis ball.

9. Flour

bread - yeast
sugar or jekeru - coconut sap
flour
water
shortening

Doughnuts - yeast or baking soda
sugar or jekeru - coconut sap
flour
shortening
water

cakes - flour
baking soda
sugar
water
egg (occasional)
milk

gravy - flour
water
sugar
additional food: pig, chicken fish, pumpkin, papaya, iu)
optional: shoyu
spices

pancakes - flour - 7 cups
shortening - two tablespoons
baking soda
milk - 13 oz. can
water
sugar - 1 cup
eggs - USDA 6 oz. (1 package)

Appendix C

Other Islands Used for Food Gathering

RONGELAP

No. of Times a Year Frequented	Name of Island	Foods gathered and Copra
4	Eniutok	pandanus, breadfruit, coconut crab, iu, fish, turtle and copra
	*people are apt to stay over while they make copra	
2 4 days	Edbot	coconut crab, pandanus, iu, fish, lobster, turtle, coconuts, copra
24 days	Luwataki	pandanus, coconuts, fish, iu, turtle, coconut crab, copra
12 days	Likaman	coconut, iu, pandanus, turtle, coconut crab, copra
	*people stay over 2 weeks a year	
12 days	Arbar	coconut crab, fish, pandanus, iu, turtle, coconuts
12 days	Keruke	fish, iu, coconut crab, arrowroot, turtle, pandanus breadfruit, clam, copra
6 days	Burok	coconut crab, pandanus, breadfruit, fish, iu, turtle, coconuts, copra (but not presently making it)
6 days	Kapelle	coconut crab, pandanus, breadfruit, fish, iu, turtle, coconuts, copra (but not presently making it)
6 days	Naen	fish (reef, lagoon), turtle, eggs, coconut crab, coconuts, copra (but not presently making it)
6 days	Ailañinai	Birds, bird eggs, coconut, coconut crabs, clams, turtle
6 days	Rongerik	birds, birds eggs, coconut, pandanus, turtle, clams
6 days	Malu	no information
4 days	Jokrak	fish, iu, turtle, coconut crab (don't normally eat), birds, eggs
4 days	Einablar	no information

Note: Now they have five outrigger canoes plus their community boat which they had before (often times not working). They are more mobile now and have more money to use the community boat so these figures are sure to change.

UTERIK

Awan - pigs, iu, breadfruit, pandanus
occasionally drinking coconuts, fish

Bekrak - iu, fish, pandanus, breadfruit, coconuts

Taka - birds, turtles, fish

Bikar - turtles

Nalap - fish, pandanus, coconut

Nate - fish, pandanus

Ellikiki - fish, pandanus, breadfruit, coconuts, coconut trees for planting

Biki - fish, pandanus, breadfruit, coconuts, coconut trees for planting

AILUK

People living on

Ajikik - 2

Ailuk - 250

Enejelar - 35

Enejabrok - 12

Kaben - 8

Bikan - 8

Baojen - 2

Aliej - 2

Akilwe

They go to all of the islands in their atoll to gather food.

Rarely visited: Jaeo, Binajrak, Bikrak, Enen Arno, Bokekan

Fishing only: Marme, Jebamit, Jirankan, Bakanneaken, Alirok, Eense

Island	Food Gathered
Kaben Enejabruk Enejelar Bikon Ajilep Aliej Akulwe*	breadfruit, fish pandanus coconuts, pigs coconut crabs arrowroot

WOTHO

Bigkin - birds }
Anibling - birds } especially during Christmas and other special occasions

Kapen - breadfruit, pandanus

Medron - breadfruit, pandanus

Eneobinek - breadfruit, pandanus

all islands - coconuts, coconut crab, turtle, lobster

Appendix D

Data on Edible Portions of Marshallese Foods

COCONUTS - DRINKING

Rongelap

Volume (cc)	Meat (g)	Volume (cc)	Meat (g)	Volume (cc)	Meat (g)
250	100	260	115	480	280
260	62	300	120	230	90
300	110	550	240	240	130
350	152	500	160	370	100
350	80	350	124	580	220
300	46	350	80	260	144
500	130	600	130	260	150
250	75	350	46	350	125
230	80	300	130		
		Average		358	124
		Standard deviation		±116	± 56

Uterik

Volume (cc)	Meat (g)	Volume (cc)	Meat (g)
340	100	350	115
240	80	220	60
370	125	300	70
260	110	270	140
260	115	270	130
350	130	220	70
300	110	290	125
200	60	260	72
260	115	260	80
260	125	250	100
270	140	260	115
240	125	270	150
250	110	300	150
250	125	260	140
250	130	250	100
260	110	290	150
290	135	350	145
250	110	440	150
240	100	270	62
300	150	260	126
350	130	350	110
440	140	280	125
280	125		
250	105		
290	130		
Average		283	115
Standard deviation		± 51	± 26

Ailuk

Volume (cc)	Meat (g)	Volume (cc)	Meat (g)
430	110	430	120
380	35	620	165
450	170	450	170
280	110	240	50
440	140	330	165
180	45	370	110
180	50	450	130
180	60		
180	55		
240	70		
240	75		
240	65		
240	60		
240	58		
240	45		
240	60		

	Volume (cc)	Meat (g)
Average	316	92
Standard deviation	±120	±46

Wotho

Volume (cc)	Meat (g)
330	95
310	85
340	100
330	59

	Volume (cc)	Meat (g)	
$\bar{X}$	338	85	Average
S	±13	±18	Standard deviation

Coconut Data (Waini or Grating Type)

No.	Weight coconut (g)	Weight of coconut meat (g)	No.	Weight of coconut (g)	Weight of coconut meat (g)
1	340	227	29	494	343
2	397	255	30	416	277
3	300	205	31	340	236
4	360	253	32	465	282
5	446	267	33	490	350
6	500	312	34	476	280
7	490	288	35	433	259
8	280	200	36	346	237
9	400	250	37	490	306
10	420	262	38	510	319
11	460	270	39	496	282
12	440	293	40	355	237
13	400	267	41	418	271
14	480	300	42	455	292
15	360	225	43	515	303
16	320	229	44	316	226
17	380	238	45	296	206
18	410	263	46	314	209
19	354	230	47	356	244
20	395	271	48	294	216
21	375	257	49	456	275
22	330	224	50	399	256
23	440	268	51	482	313
24	472	311	52	509	299
25	426	284	53	365	235
26	386	280	54	492	319
27	349	253	55	515	334
28	420	247	56	338	241
		Average		410	265
		Standard deviation		± 68	± 36

1.

Pandanus number	Weight (g) before*	Weight (g) after*	Weight (g) of food eaten
1	144	93	51
2	165.5	98.5	67
3	148.5	103.5	45
4	204.5	140	64.5
5	139.5	83	56.5
6	151	107.5	43.5
7	137.5	90	47.5
8	139.5	88	51.5
9	154	107	47
10	157	108.5	48.5
11	161	109.5	51.5
12	177	127	50
13	133.5	87	46.5
14	289(double)	188	101
15	148	104	44
16	155.5	105.5	50
17	164	117.5	46.5
18	189.5	131	58.5
19	152	109.5	42.5
20	131.5	89.5	42
21	160.5	113.5	47
22	171.5	123	48.5
23	153.5	105.5	48
24	142	102.5	39.5
25	151	105.5	45.5
26	156.5	116.5	40
27	151.5	115.5	36
28	127.5	91.5	36
29	114.5	83.5	31
30	134.5	82	52.5
31	178	132	46
32	186	139.5	46.5
33	149	131	18
34	168.5	122.5	46
35	106	69	37

*weight before + after process known as kilok method of extracting pudding from cooked pandanus

Average	156	106	46
Standard deviation	±20	±17	±9

PANDANUS

2.

Pandanus number	Weight before (g)	Weight after (g)	Net consumed (g)
1	171	99	72
2	173	114	59
3	175	116	59
4	182	123	59
5	164	101	63
6	143	81	62
Average	168	106	62
Standard deviation	±14	±15	±5

3.

Pandanus number	Weight before (g)	Weight after (g)	Net consumed (g)
1	98	63	30
2	94	66	28
3	74	51	23
4	90	64	26
5	85	56	29
6	84	52	32
7	81	51	30
8	84	55	29
9	89	69	20
10	78	52	26
11	88	59	29
12	91	63	28
13	81	55	26
Average	86	58	37
Standard deviation	±7	±6	±3

BREADFRUIT DATA

Type	Total wt. (g)	Center (unedible) (g)	Edible wt. (g)	seeds
Batakatak	1193	63	1130	
	964	33	931	
	308	14	294	
	820	30	790	
	1040	23	1017	
	440	11	429	
	1856	51	1805	
Average	903	32	913	
Standard deviation	± 51	±19	±497	
Mejwan (with seeds)	520	23	387	110
	490	18	276	96
	380	14	264	102
	476	19	365	92
	505	18	365	122
	396	12	289	95
	350	15	247	88
	412	21	290	101
Average	441	18	310	41
Standard deviation	± 64	± 4	± 56	±11

Appendix E

Types of Fish and Methods of Fishing

1. NET FISHING - LONG NET, THROWN NET

Marshallese Name	Scientific Name	Island Method
Ik kadre	A fish Chelon vaigiensus	Rongelap - long net
Utot or dibab or wut wot	butterfly fish Chaetodon anriga	Uterik - long net
Pajrok	chub or rudder fish Kyphosus vaigiensis	Rongelap, Wotho, Ailuk
Balle	starry flounder Platichthys stellus	Ailuk - long net
Jome	goatfish Mulloidichyhys auriflama	Rongelpa, Uterik - thrown net
Jo	goatfish Mulloidicthys samoensis	Rongelap - long net Rongelap - thrown net Wotho - not specified Ailuk -
Momo	grouper Epinephelus hexagonatus	Rongelap, Ailuk - long net
Tinar	small grouper	Ailuk -
Kalemeej	blue spotted grouper Cepahalopholis argus	Ailuk -
Kuro	grouper Epinephelus fuscogultatus	Ailuk -
Ettou	mackerel Trachurops crumepthalmus	Rongelap - thrown net, long net
Iool	mullet Crenmugil crenilabis	Rongelap, Wotho - long net
Akor	mullet Chelon vaigiensis	Uterik - long and thrown net
Tak	needle fish Belone platyura, Raphiobelone robusta	Rongelap, Ailuk - long net
Mao or Mera	parrot fish Scarus jonesi/sordidus	Wotho, Ailuk

Lala or Lolo	parrot fish Callyodon pulchellus	Ailuk, Rongelap
Ik mouj	white parrot Scarus harid	Ailuk Wotho Uterik - long net
Ellek or Mole	rabbit fish Sigannus rastratus or poellus	Rongelap - long and thrown net Uterik - long net Wotho Ailuk
Ek-Airik	rainbow runner Elagatis bipinnulatus	Uterik - long net
Kabro	rock cod Anyperodon leucogrammicus	Ailuk
Badet	Sergeant Major Abudefduf stemfasciatus	Wotho
---	moomoa Abudefduf abdominals	Wotho
Kwarkwar	Sardines Sardinella sp.	Rongelap - long net
Kupkup	skip jack (immature form) Carant lessonii needle fish Belone platyura, Raphiobelene robusta	Ailuk Rongelap - long net
Jetaar	snapper Lutjanus kasmira forskal	Ailuk
Kur	spuirrel fish Holocentrus binotatus/scythraps	Ailuk
Mōn	squirrel fish Myripristis berndti	Rongelap Uterik - long net Ailuk
Mone or eanrok	sturgeon fish Naso unicornis	Ailuk

Kupan	banded sturgeon fish Acanthurus triostegus/linnaeus	Rongelap - long and thrown net Uterik - long net Wotho -
Tiepdo	black sturgeon fish Acanthurus nigicans	Ailuk
Bub	black trigger fish Melichthys ringens	Ailuk, Rongelap
Ael	unicorn fish Hepatus divaceus/scheider Bloch	Ailuk
---	orange spot tang Acanthurus olivaraceus	Ailuk
Bataklaj	unicorn fish Naso brevirostris	Ailuk
Kibu	---	Uterik - long and thrown net Ailuk
Jorot	---	Uterik - thrown net
Akuba	---	Ailuk
Debijdreka	---	Ailuk
Ebil	---	Ailuk

2. FISHING LINE*

Marshallese name	Scientific name	Island
Niitwa or Jure	barracuda Sphyraena forsteri	Ailuk, Wotho, Rongelap
Lejabwil	bonito Katsuwanus pelamis	Ailuk, Rongelap
Koko	dolphin Coryphoena hippurus	Ailuk
Al	kingfish	Ailuk, Rongelap
Ikaidrik	rainbow runner	Ailuk, Rongelap
Jilo	dogtoothed tuna Gymnosarda nuda	Ailuk, Rongelap
Bwebwe	tuna Neothunus macropterus	Ailuk, Rongelap

*method used at oceanside (off the reef)

3. FISHING LINE *

Marshallese name	Scientific name	Island
	caught in deep water by lagoon or ocean	
Kuro	grouper Epinephelus fuscagultatus	Ailuk, Rongelap, Uterik, Wotho
Lejebjeb	rock grouper or rockhind Epinephulus adscenscionis Epinephulus albofasciatus	Ailuk, Rongelap (bottom fishing), Uterik, Wotho
Perak	scavanger Lethrinus kollopterus	Ailuk, Rongel[illegible], Uterik
Dijin	scavanger Lethrinus variegatus	Ailuk, Rongelap, Wotho
Jato or Ikonbōn or Jaap	red snapper Lutjanus gibbus	Ailuk, Wotho, Rongelap (bottom fishing)
Jera	squirrel fish Holocentrus sp./Myrispistis sp.	Ailuk, Uterik
Ewae or Loom	streaker Aprion virescens	Ailuk, Uterik, Rongelap
Lane or Ikbwij	skip jack Caranx lessoni/crevally	Uterik, Rongelap, Ailuk
Bwilak	unicorn sturgeon Naso lituratus	Ailuk
Weo	---	Wotho, Uterik, Ailuk, Rongelap

*used in deep water (lagoon or ocean)

Kupan	banded sturgeon fish Acanthurus triostegus/linnaeus	Rongelap - long and thrown net Uterik - long net Wotho -
Tiepdo	black sturgeon fish Acanthurus nigicans	Ailuk
Bub	black trigger fish Melichthys ringens	Ailuk, Rongelap
Ael	unicorn fish Hepatus divaceus/scheider Bloch	Ailuk
---	orange spot tang Acanthurus olivaraceus	Ailuk
Bataklaj	unicorn fish Naso brevirostris	Ailuk
Kibu	---	Uterik - long and thrown net Ailuk
Jorot	---	Uterik - thrown net
Akuba	---	Ailuk
Debijdreka	---	Ailuk
Ebil	---	Ailuk

3. FISHING LINE *

Marshallese name	Scientific name	Island
At-kadu	A fish Moi polydactylus	Uterik
Kanbok	bass Variola louti	Rongelap
Kie	big eye or burgy Monotaxis grandoculis	Rongelap, Uterik
Dibab	butterfly fish Chaetodon ocellatus	Uterik
Pajrok	chub ro rudderfish Kyphosis vaigiensis	Uterik, Rongelap
Jojo	flying fish Exocoetidae sp.	Rongelpa, Uterik, Ailuk
Jo	goatfish Mulloidichthy samoensis	Uterik
Jome	goatfish Mulloikicthys samoensis	Uterik
Momo	grouper Epinephelus hexagonatus	Rongelap, Uterik, Wotho
Pako	ground shark Carcharhinus melanopterus	Uterik, Rongelap
Lappo	hogfish Chelinus undulatus	Rongelap, Uterik
Īōōl	mullet Crenmugil crenilabis	Uterik
Ikuut	pilot fish Haucrates ductor	Uterik

3. FISHING LINE*

Imim	reef triggerfish Balistopus retangulus/oculeatus	Uterik, Rongelap
Mōn or Arōn	squirrel fish Myristis berndti	Rongelap - trolling
Kupkup	skip jack (immature form) Caranx lessonii	Uterik
Lojkan	shell fish	Rongelap
Jetaar	snapper Lutjanus kasmira/forskal	Uterik, Rongelap
Ban	snapper	Rongelap, Wotho
Kejwar	---	Rongelap
Lele	triggerfish, Rhinecanthus aculeatus	Wotho, Rongelap - bottom fishing
Jebos	---	Uterik
Kibu	---	Uterik
Melij	---	Rongelap
Januron	---	Wotho
Boklim	---	Wotho, Uterik, Rongelap - bottom fishing

*used in deep water (lagoon or ocean)

4. FISHING LINE*

Marshallese name	Scientific name	Island
Pajrok	chub ro rudderfish Kyphosus vaigiensis	Ailuk
Balle	starry flounder Platichthys stellatus	Ailuk
Jo	goatfish Mullaoidichthys samoensis	Ailuk
Tinar	small grouper Lutjanus kasmira forksal	Rongelap
Momo	grouper Epinephelus hexangonatus	Ailuk
Kuro	grouper Playichthys stellus	Ailuk
Tak	needlefish Belone platyura, Raphiobelone robusta	Ailuk, Rongelap
KupKup	skip jack (immature form) Caranx lessonini	Ailuk
Kur	squirrel fish Holocentrus binotatus/scythrops	Ailuk
Mōnor (Arōn)	squirrel fish Myristis berndti	Ailuk, Rongelap
Kibu	---	Ailuk
Akuba	---	Ailuk
Ebil	---	Ailuk

*pole fishing in shallow water

5. SPEARING FISH

Marshallese name	Scientific name	Islands
Dep or Eddeup	A fish	Uterik
Kie	big eye or burgy Monotaxis grandoculis	Rongelap, Uterik
Utot or Dibab or Wutwot	butterfly fish Chaetodon onriga	Uterik
Kanbōk	bass Variola louti	Rongelap
Jawe	giant sea bass Promicrops lancelatus/truncatus Plectropomus truncatus	Rongelap, Uterik
Pajrok	chub or rudder fish Kyphosus vaigiensis	Rongelap, Uterik, Wotho
Monaknak	file fish Amansis carolge	Uterik
Bale	starry flounder Platichthys stellatus	Rongelap, Uterik
Jo	goatfish Mulloidichthys samoensis	Uterik, Wotho
Jome	goatfish Mulloidicthys samoensis	Uterik
Tinar	small grouper Lutjanus kasmira/forskal	Ailuk, Rongelap
Momo	grouper Epinephelus hexagonatus	Uterik, Wotho

continued

5. SPEARING FISH

Kuro	grouper Epinephelus adscenscionis	Ailuk, Rongelap, Wotho, Uterik
Kalemeej	blue spotted grouper Cepahalopholis argus	Ailuk, Uterik
Lappo	hogfish Cheilinus undulatus	Rongelap, Uterik
Lala	parrotfish Callyodon pulchellus	Ailuk, Rongelap
Mao or Mera	parrotfish Scarus jonesi/sordidus	Rongelap, Wotho, Uterik, Ailuk
Ellek or Mole	rabbitfish Sigannau rostratus/puellus	Ailuk, Rongelap, Uterik, Wotho
Moramor or mormor	rabbitfish Siganus sp.	Rongelap
Kabro	rock cod Anyperodon leucogrammicus	Ailu, Rongelap
Lojebjeb	rock hind Epinephelus albofasciatus	Uterik, Wotho, Rongelap
---	grouper Epinephelus adscenscionis	Uterik
Perak	scavanger Lethrinus kollapterus	Uterik
Mōn or Moned	squirrel fish Myripristis berndti	Uterik
Jera	squirrel fish Holocentrus sp./Myripistis sp.	Rongelap, Uterik

continued

5. SPEARING FISH

Badet	sergeant major Abudefduf	Wotho
Jetaar (Jetaad)	snapper Lutjanus kasmire/forskal	Ailuk, Rongelap
Bonej	snapper Lutjanus vitta	Uterik
Ioōl	mullet Crenmugil crenilabis	Wotho
Tiepdo	black surgeonfish Acanthurus nigicans	Ailuk
Kupān	banded surgeonfish Acanthurus triostegus/linnaeus	Wotho, Uterik
Mone eanrok	surgeonfish Naso unicornis	Rongelap, Uterik
Imim	reef triggerfish Balistapus retangulas/aculeatus	Rongelap, Uterik
Bub	black triggerfish Melichthysringens	Ailuk
Lele	triggerfish Rhinecanthus aculeatus	Rongelap
Baraklaj	unicorn fish Naso brevirostris	Ailuk
Ael	unicorn fish Hepatus olivaceus/schneider Bloch	Rongelap, Ailuk, Wotho
---	orange spot tang Acanthurus divaceus	Ailuk

continued

5. SPEARING FISH

Bwilak	unicorn - surgeon Naso lituratus	Rongelap, Uterik
Ik mouj	white parrot Scarus harid	Ailuk, Rongelap, Uterik, Wotho
Jiborbor	---	Rongelap
Kibuj	---	Uterik
Jonuron	---	Wotho
Boklim	---	Wotho, Rongelap
Ieo	---	Uterik
Ikenae	---	Wotho
Pebijdreka	---	Ailuk
Karlas	---	Uterik

RONGELAP

Fish poisoning from

imim - reef fish, trigger fish
Balistapus retangulus/oculeatus

jaliia - a fish scavanger, Lethrinus miniatus

jowe - giant sea bass, Promicrops lanceolatus/truncatus
bass, Plectropomus truncatus

iool - mullet, Crenmugil crenilabis

WOTHO

Fish poisoning from

mao
ekmouj
iōl
ael
lele
ikenae

Appendix F

School Children's Feeding Program

1. The school children's feeding program requires that each child should receive:

Type A Menu

Breakfast

Fruit - 1/2 cup
or
Fruit juice - 1 cup

Bread - 1 slice

Milk - 1 cup

Meat - 1 ounce (optional)

Lunch

Meat - 2 ounces

Fruit and vegetables - 3/4 cup

Milk - 1 cup

Bread - 1 slice

Butter - 1/2 teaspoon (optional)

Substitutions:

For meat we can use any canned meat, fish, pork, chicken, shell fish, jokra, clams, turtle, eggs, and peanut butter.

Instead of bread we can use 1/2-3/4 cup of rice, taro, breadfruit, coconut meat, bananas.

Fruit and vegetables can be any of the canned fruits and vegetables, papaya, pumpkin, taro leaves, sweet potato, Chinese cabbage.

Note: Each school is allowed $100/month for purchase of local food.

2. Lunch program as carried out at the different Atolls/islands.

a. Number of school days a week - 5
b. Number of school days a year - 210
c. Items and quantities

I: Breakfast

Basic	Substituted by	Amount
1. Fruit	Fruit cocktail, peaches apple sauce, pineapple	57 g
or		
Fruit juice	orange, grape, apple	240 cc
2. Bread	flour	30 g
or		
Rice	macaroni, oatmeal or taro, breadfruit, coconut meat, bananas	115-200 g (cooked weight)
3. Milk (powdered)	---	230 g
4. Sugar	---	15-30 g
5. Meat (canned) (fresh)	eggs (processed), peanut butter, spam, beef stew, chicken, pork	30 g
or		
Fish (canned)	mackerel, tuna	
or	or	
Fish (fresh)	fish, turtle, shellfish	

II. Lunch

Basic	Substituted by	Amount
a. Meat - canned or - fresh* or Fish - canned or - fresh*	spam, beef stew, pork, chicken mackerel, tuna fish, shellfish, turtle or peanut butter	57 g
b. Fruit and vegetable	Fruit cocktail, peaches applesauce, pineapple or mixed vegetables, peas, tomatoes, corn, greenbeans	57-85 g
c. Milk	---	240 cc
d. Bread	---	29 g
or Oatmeal		114-170 g
or Rice	taro, breadfruit coconut meat, bananas	114-170 g (cooked weight)
e. butter	---	8 g

Appendix G

Typhoon Relief

Family Distribution Guides for Donated Commodities

COMMODITY	UNIT	PER PERSON/MONTH	Number of persons in family: 1	2	3	4	5	6	7	8	9	10
BUTTER/MARGARINE	3# CN	1# (1 LB) 454 g	1	1	1	2	2	2	3	3	3	4
POULTRY CANNED	29 OZ.	1 CN (29 OZ) 830 g	1	2	3	4	5	6	7	8	9	10
BEEF CANNED	29 OZ.	1 CN (29 OZ) 830 g	1	2	3	4	5	6	7	8	9	10
EGG MIX	6 OZ.	1 PKG (6 OZ) 170 g	1	2	3	4	5	6	7	8	9	10
FLOUR A/P	10# PKG	5# (5 LBS) 2290 g	1	1	2	2	3	3	4	4	5	5
ORANGE JUICE	46 FL OZ	1 CAN (46 FL OZ)1380 cc	1	2	3	4	5	6	7	8	9	10
PEAS CANNED	#303 CN	1 CAN (1 lb) 454 g	1	2	3	4	5	6	7	8	9	10
BEANS CANNED	#303 CN	1 CAN (1 lb) 454 g	1	2	3	4	5	6	7	8	9	10
MILK EVAPORATED	14.5 OZ CN	1 CAN (14.5 OZ) 435 cc	1	2	3	4	5	6	7	8	9	10
MILK INSTANT	4# PKG	1# (1 LB) 454 g	1	1	1	1	2	2	2	2	3	3
PEANUT BUTTER	2# CN	1# (1 LB) 454 g	1	1	2	2	3	3	4	4	5	5
MACARONI	1# PKG	1 PKG (1 LB) 454 g	1	2	3	4	5	6	7	8	9	10
SHORTENING	3# CN	1# (1 lb) 454 g	1	1	1	2	2	2	3	3	3	4
CORN SYRUP	16 FL OZ	1 BTL (16 FL OZ) 480 cc	1	2	3	4	5	6	7	8	9	10
RICE	2# PKG	20# (20 LBS)9080 g	10	20	30	40	50	60	70	80	90	100
POTATOES DEHYDRATED	1# PKG	1 PKH (1 LB) 454 g	1	2	3	4	5	6	7	8	9	10
CORN CANNED	24/#303 CN	1 CAN (1 lb) 454 g	1	2	3	4	5	6	7	8	9	10

Source: Trust Territory (Majuro)

Appendix H

Food Supply Ships - Trip Schedule

(as carried out during 1977-1978)

MONTH	SOUTHERN ATOLLS	WESTERN ATOLLS	EASTERN ATOLLS	CENTRAL ATOLLS	NORTHERN ATOLLS
OCT	1- FTS	1- FTS	-0-	2- FTS	1- FTS
NOV	1- FTS	-0-	2- FTS	1- FTS	1- FTS
DEC	2- FTS	1- FTS	-0-	-0-	1- FTS
JAN	-0-	1- FTS	-0-	-0-	1- FTS
FEB	1- Spc	-0-	-0-	1- FTS	2- FTS
MAR	1- Spc, 1- FTS	1- FTS	-0-	1- FTS	-0-
APR	1- FTS	-0-	2- FTS	1- FTS	1- FTS
MAY	1- Spc-Kili, 1- FTS, 1- Spc-Kili	1- FTS	-0-	-0-	1- FTS
JUN	2- FTS	1- FTS	1- FTS	1- FTS	1- Spc
JUL	1- FTS, 1- Spc 1- Spc-Kili	1- FTS	1- FTS	1- UN Mission 1- B-Pick up	1- Spc 1- FTS
AUG	1- Spc, Kili, Jabor 1- Kili, 2- FTS	-0-	2- FTS	1- FTS	1- FTS
SEP	1- Spc, Jabor-Kili	1- FTS	1- FTS	2- FTS	1- FTS
OCT	1- FTS	1- FTS	1- FTS	1- FTS	1- FTS, 1-Spc, Utirik, Rongelap
	13 - FTS 7- Spc	9-Regular	10-Regular	11-Regular 2-Special	11-Regular 2-Special

Appendix I

Private or Community Stores

Types of Food Available*

Rice	Corned beef	Tang	Shoyu
Flour	Tuna	Milk (powdered)	Shortening
Sugar	Sardines	Coffee	Iodized salt
Yeast	Mackerel	Tea	
Biscuit		Milk (canned)	
Peanut butter		Baby food	

Thyroid Dose Assessm't for Rongelap and Utirik Residents-Draft

Thyroid Absorbed Dose Assessment for Rongelap and Utirik Residents

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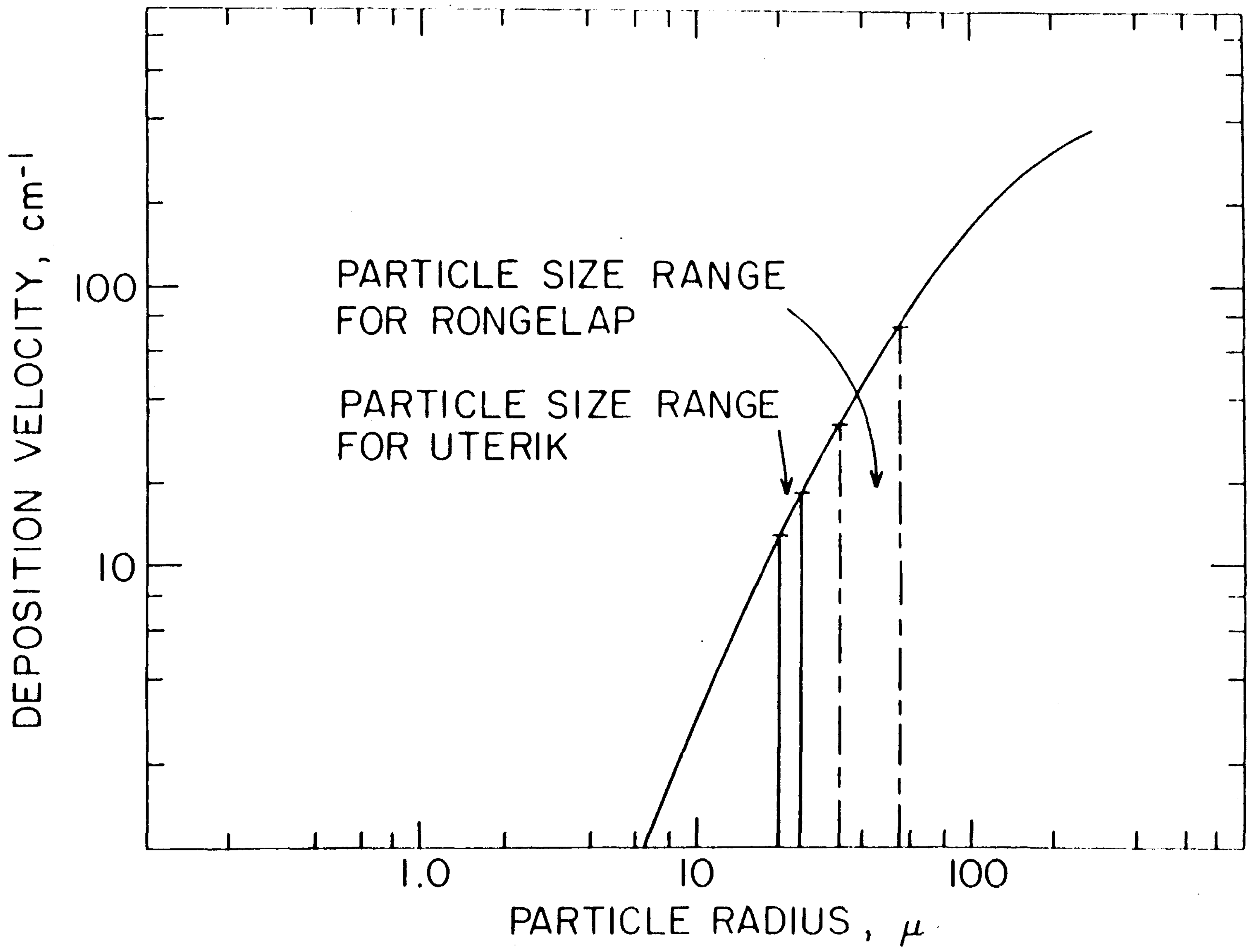
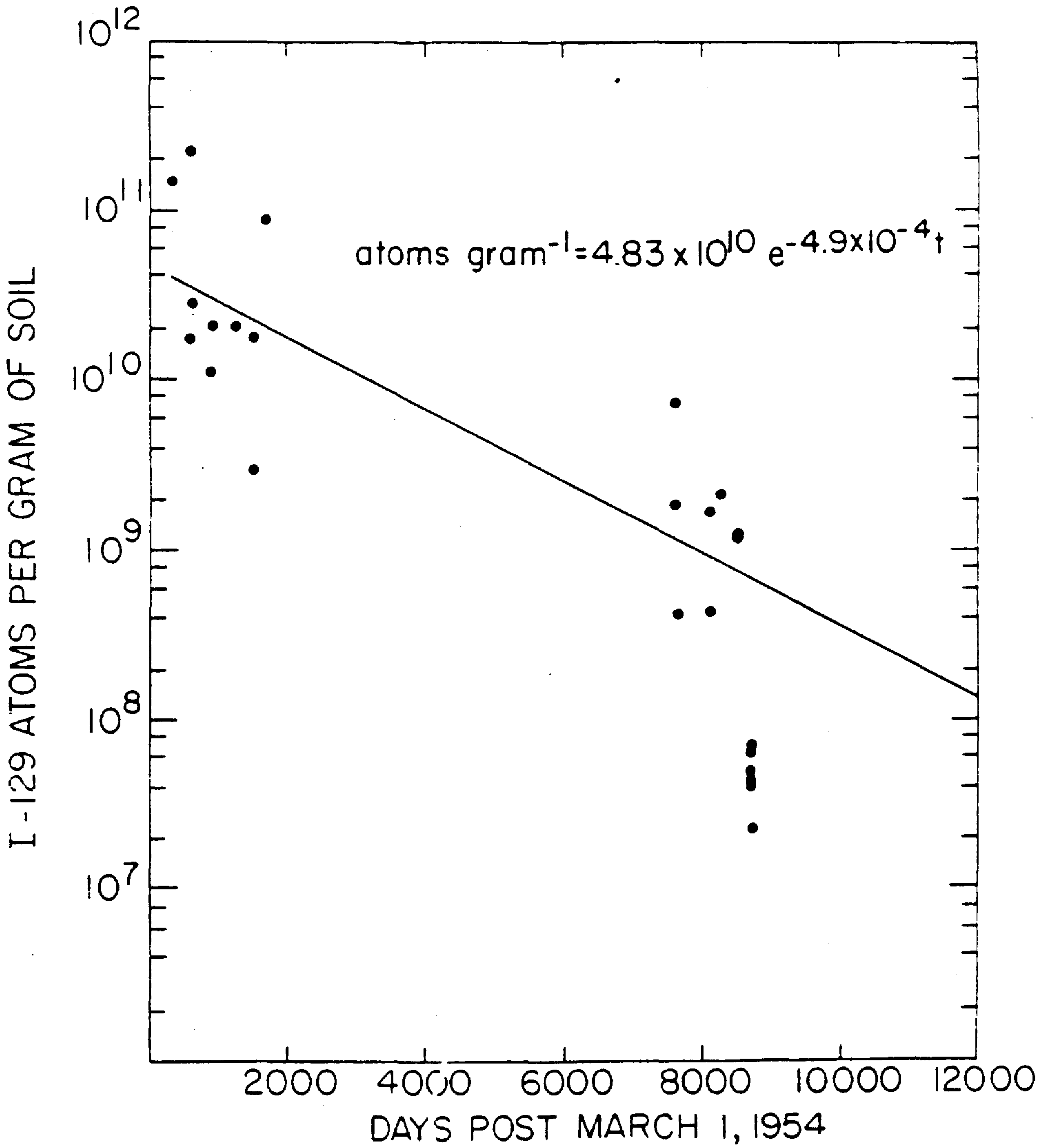
ABSTRACT

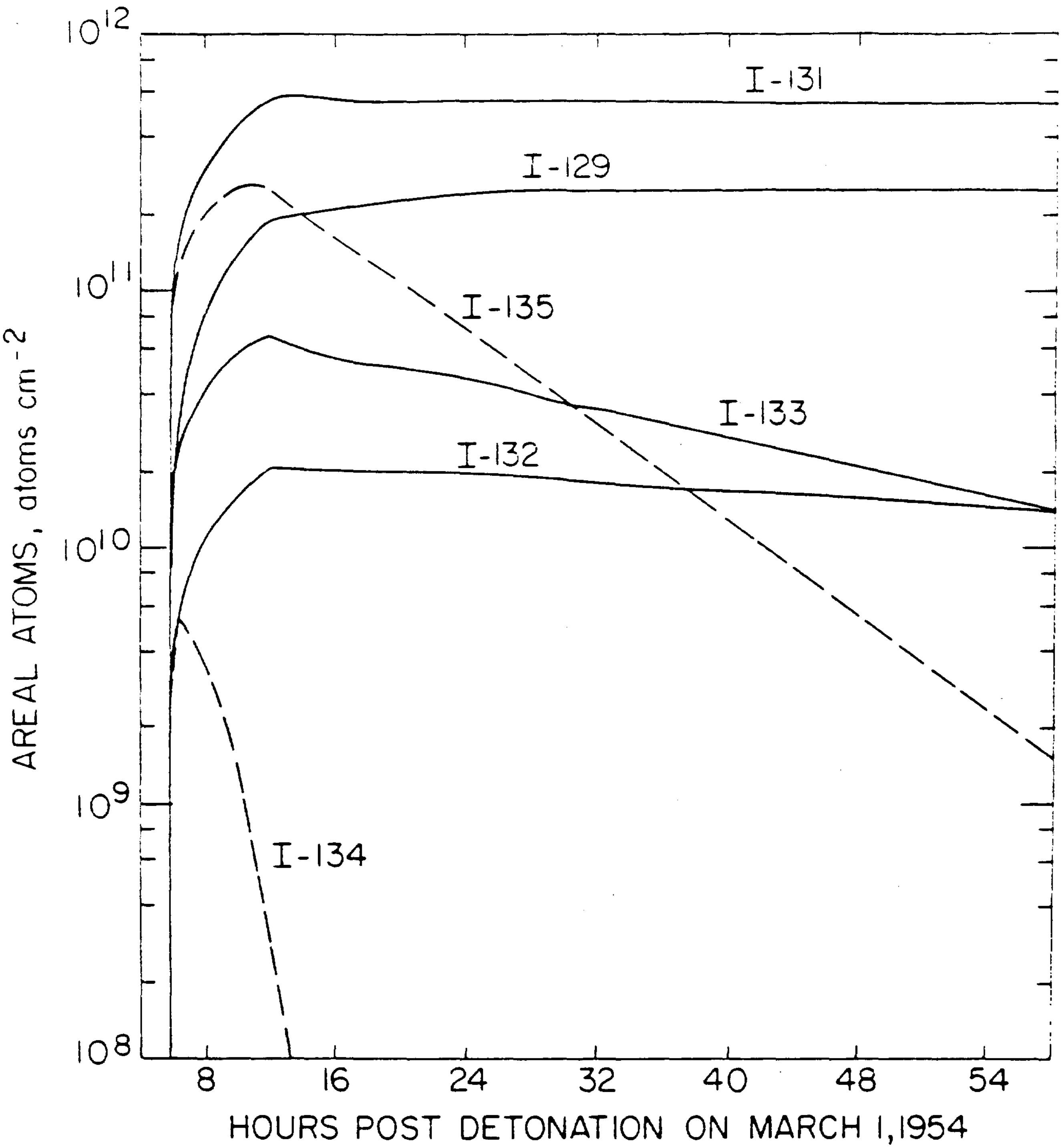
The internal thyroid absorbed dose from Castle Bravo fallout affecting Rongelap and Utirik Atolls, Marshall Islands, is reassessed using independent approaches encompassing 1) the single pooled urine radiochemical analysis of March 1954 and current uptake, retention and excretion models, 2) airborne concentrations and areal activities of the iodine isotopes derived from historic soil samples and, 3) airborne concentrations and areal activities of the iodine isotopes derived from weather data obtained during the thermonuclear test experiment at Bikini Atoll and current fallout deposition models. Factors such as solubility of iodine isotopes, the possible contribution from neutron induced activity, the impact of thyroid seekers other than iodine isotopes on dose, and confidence levels for values of derived quantities such as airborne activity concentrations are also considered. Additionally, these thyroid absorbed dose estimates are compared to the incidence of thyroid nodules reported for the accidentally exposed people.

Research carried out under the auspice of the U. S. Department of Energy under Contract No. DE-AC02-76CH00016.

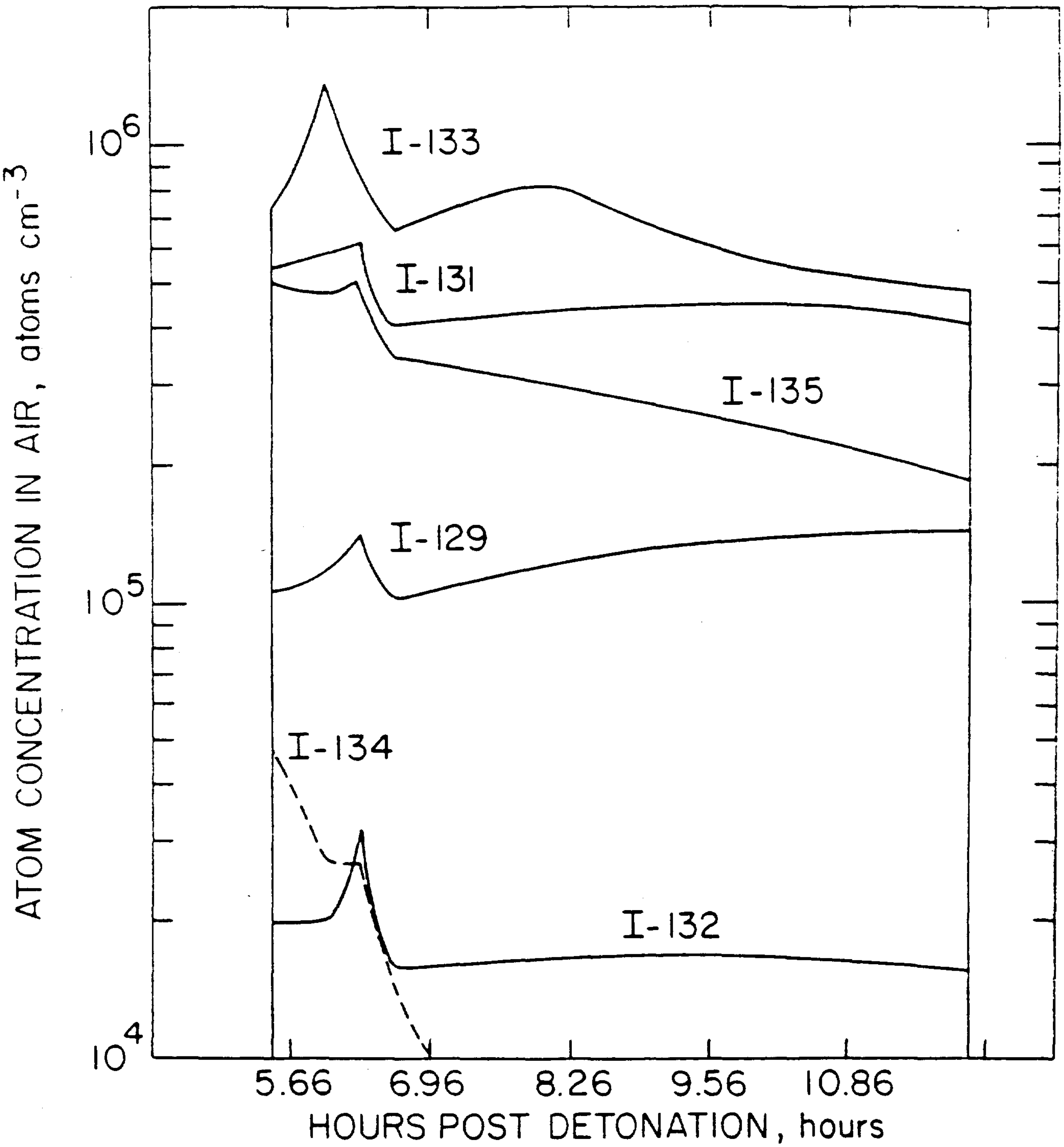

PARTICLE SIZE RANGE
FOR RONGELAP
PARTICLE SIZE RANGE
FOR UTERIK
DEPOSITION VELOCITY, cm⁻¹
100
10
1.0
10
100
PARTICLE RADIUS, μ



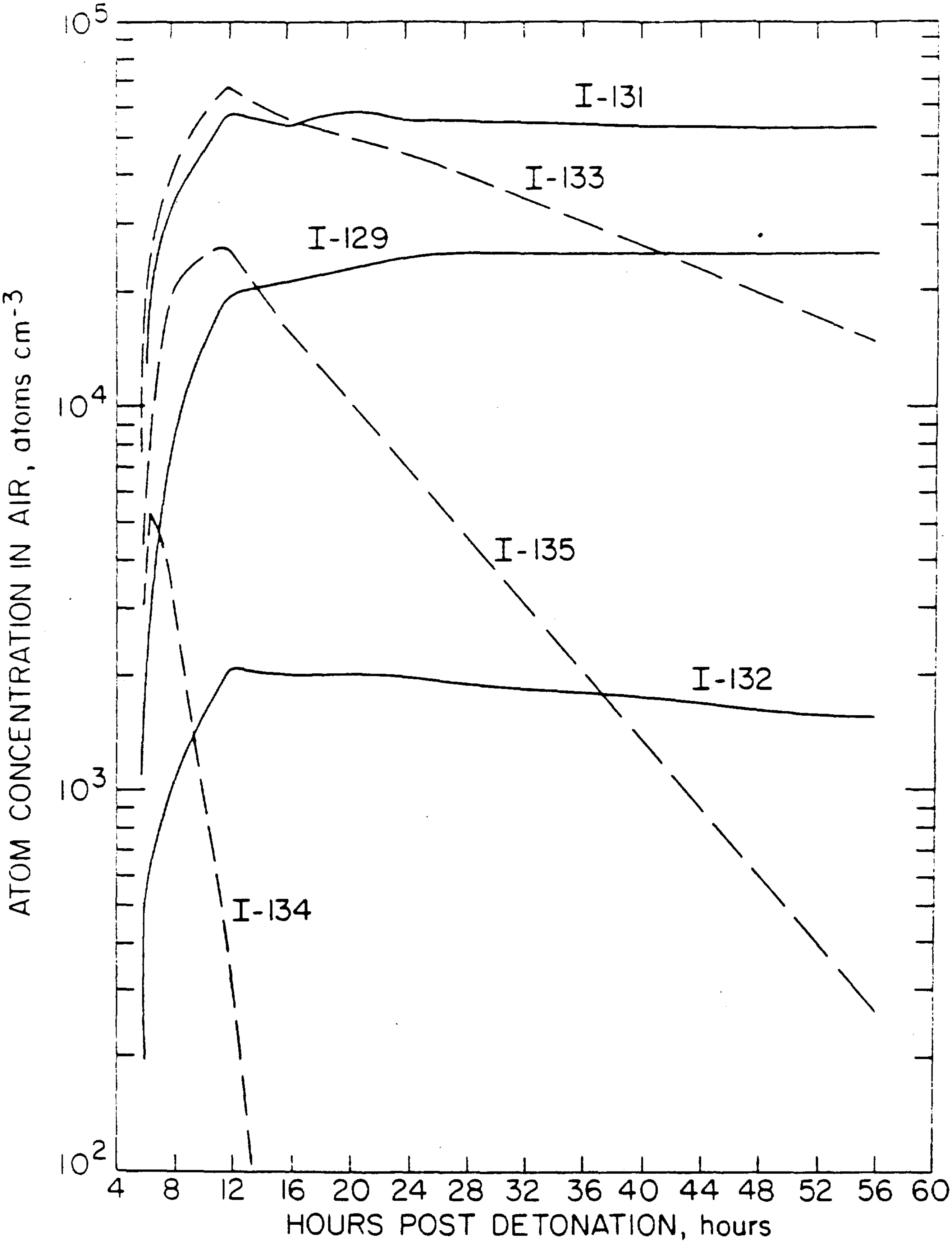
atoms gram^{-1} = $4.83 \times 10^{10} e^{-4.9 \times 10^{-4} t}$
I-129 ATOMS PER GRAM OF SOIL
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
2000
4000
6000
8000
10000
12000
DAYS POST MARCH 1, 1954



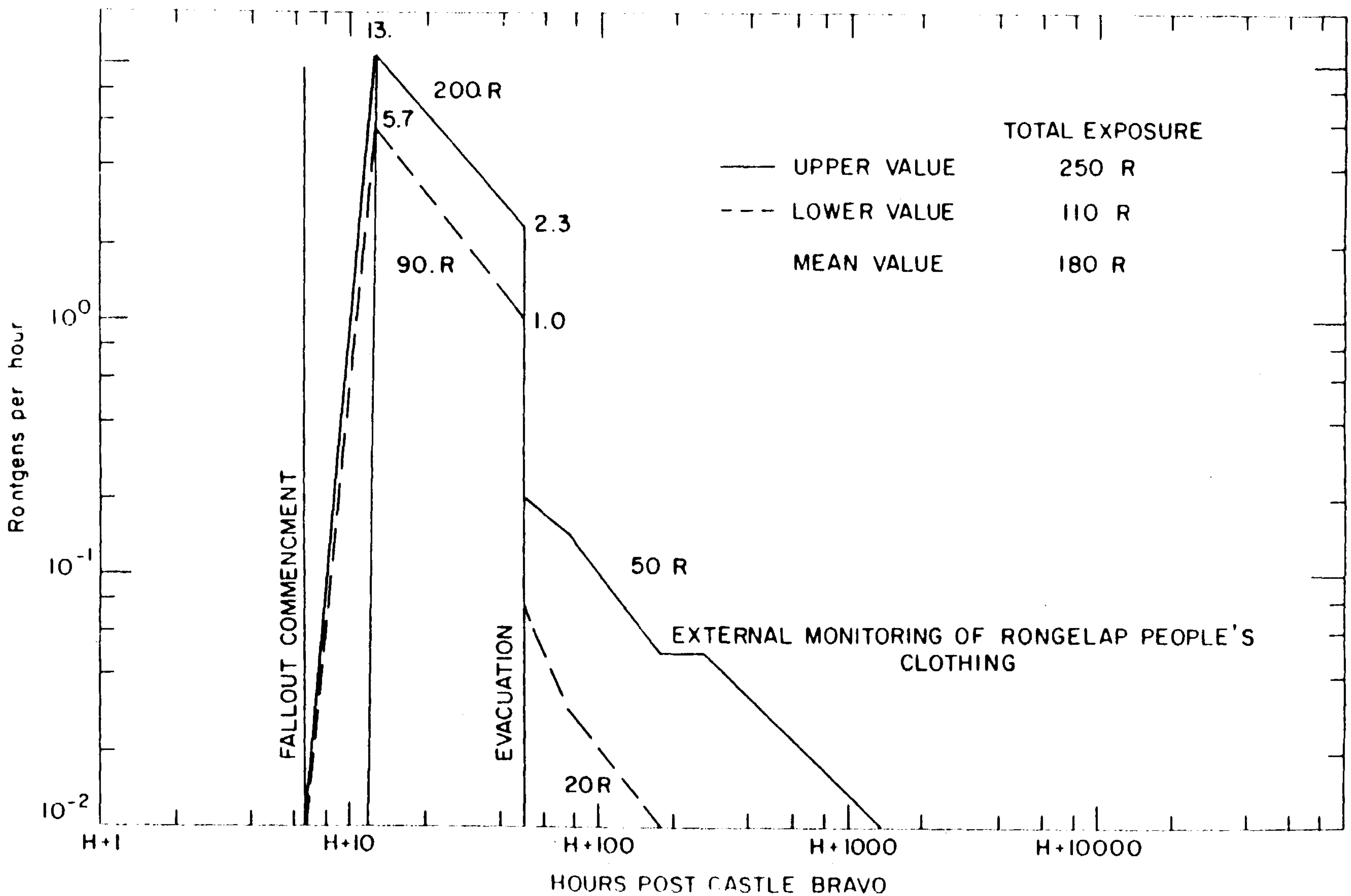
I-131
I-129
I-135
I-133
I-132
I-134
AREAL ATOMS, atoms cm⁻²
HOURS POST DETONATION ON MARCH 1,1954



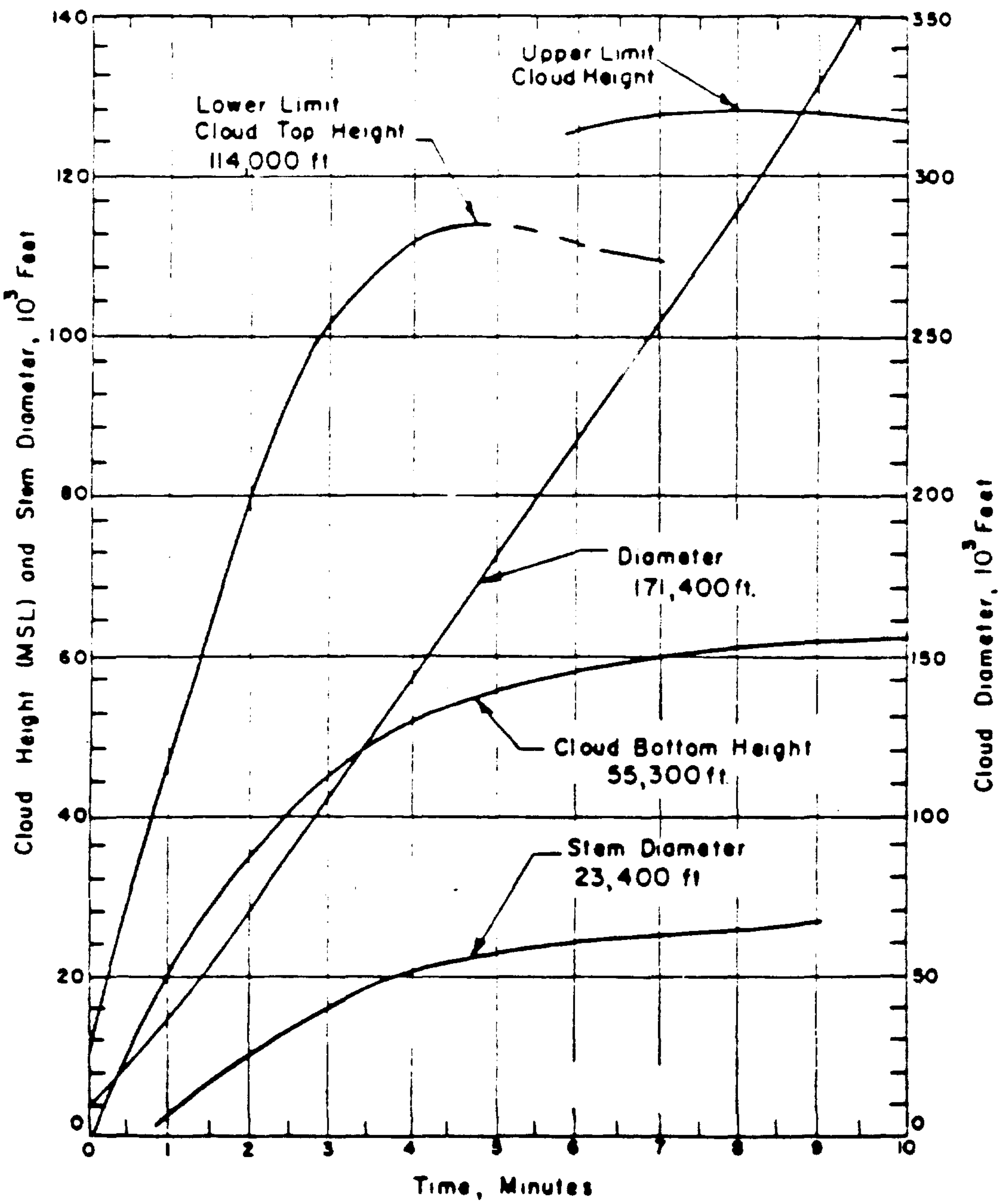
I-133
I-131
I-135
I-129
I-134
I-132
10^6
10^5
10^4
ATOM CONCENTRATION IN AIR, atoms cm^{-3}
5.66
6.96
8.26
9.56
10.86
HOURS POST DETONATION, hours



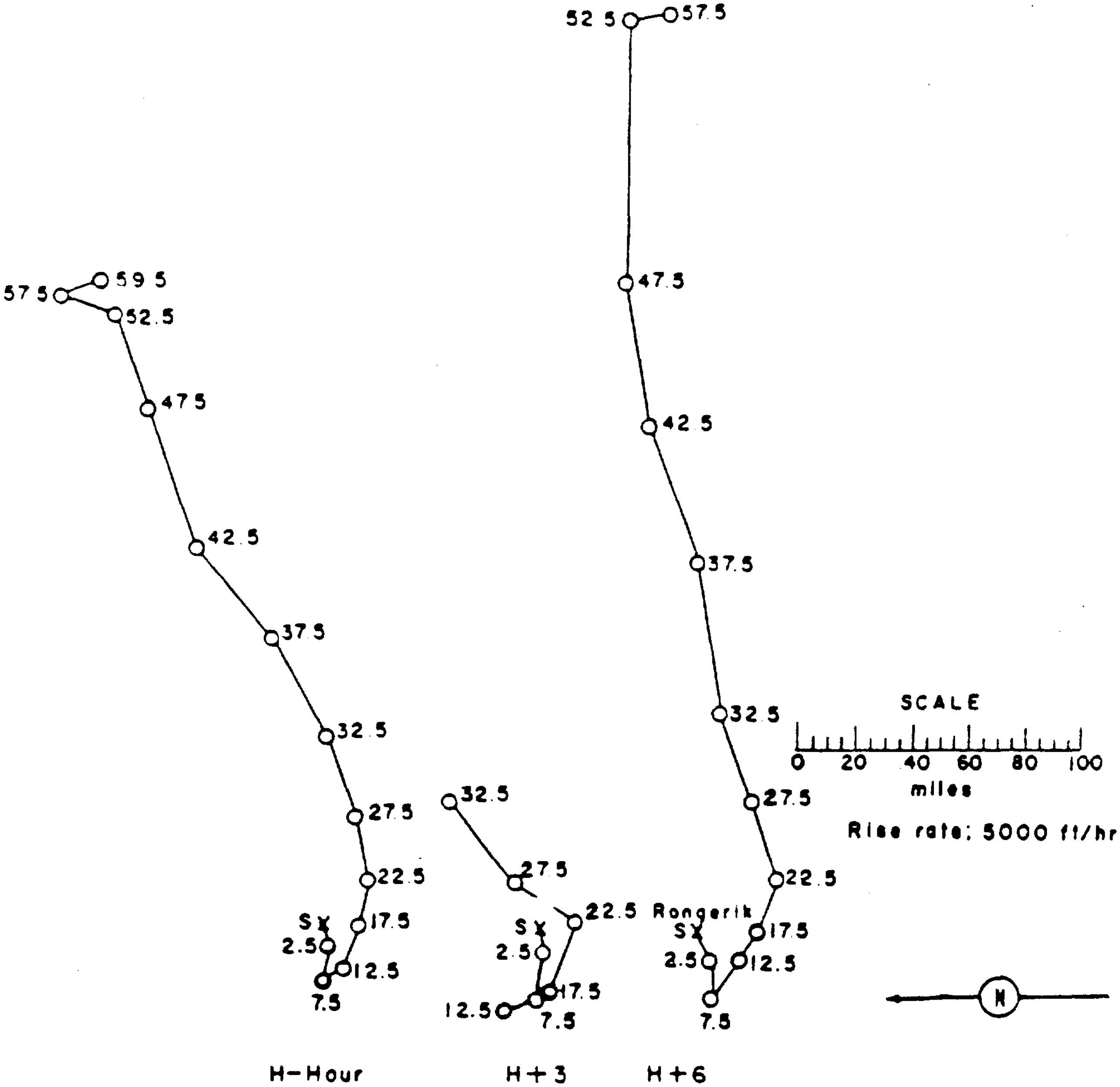
I-131
I-133
I-129
I-135
I-132
I-134
10^5
10^4
10^3
10^2
4 8 12 16 20 24 28 32 36 40 44 48 52 56 60
HOURS POST DETONATION, hours
ATOM CONCENTRATION IN AIR, atoms cm^{-3}



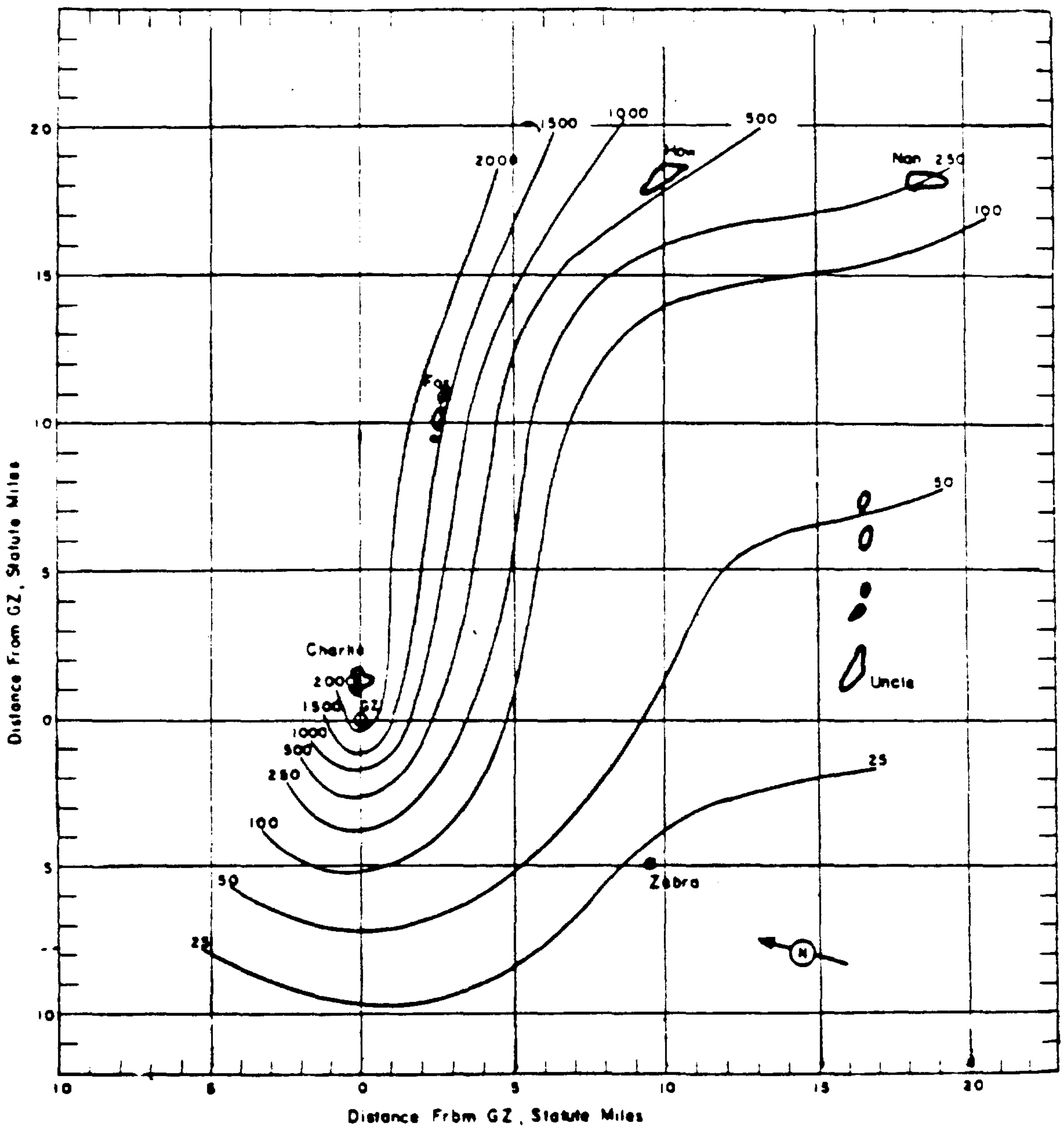
13.
200 R
5.7
2.3
90. R
1.0
TOTAL EXPOSURE
UPPER VALUE 250 R
LOWER VALUE 110 R
MEAN VALUE 180 R
10^0
10^{-1}
10^{-2}
Rontgens per hour
FALLOUT COMMENCMENT
EVACUATION
50 R
EXTERNAL MONITORING OF RONGELAP PEOPLE'S CLOTHING
20 R
H+1
H+10
H+100
H+1000
H+10000
HOURS POST CASTLE BRAVO



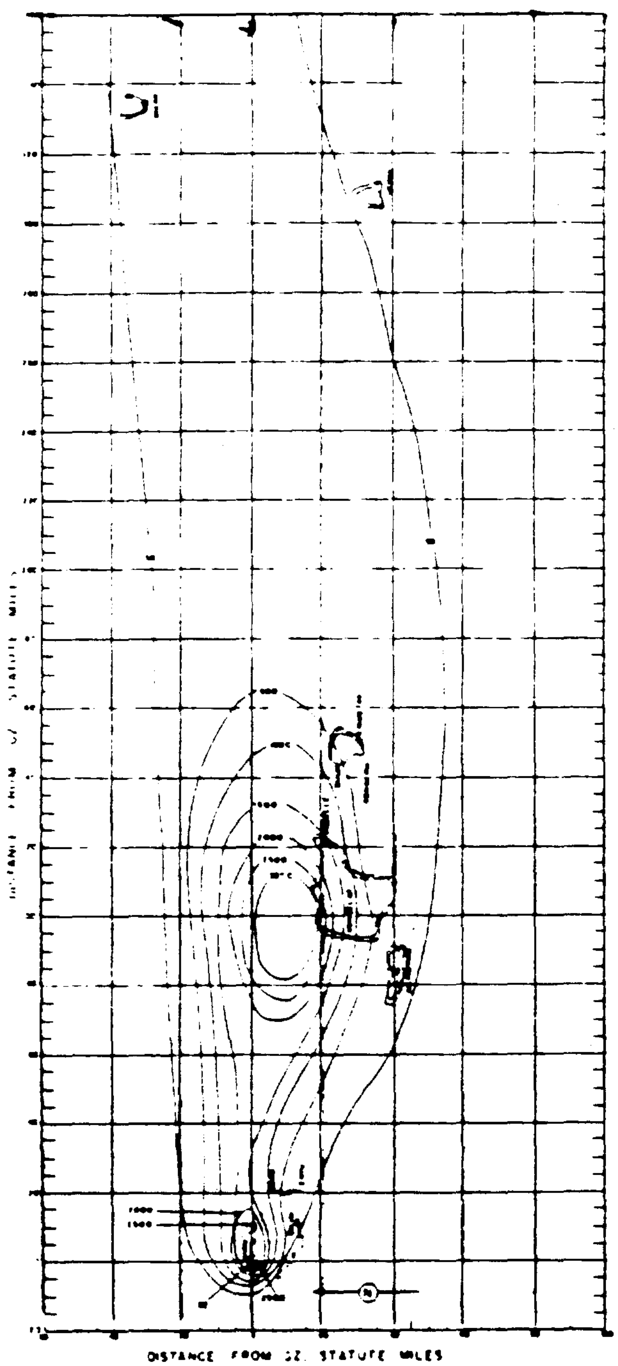
Cloud Dimensions: Operation CASTLE - Shot 1 - Bravo.



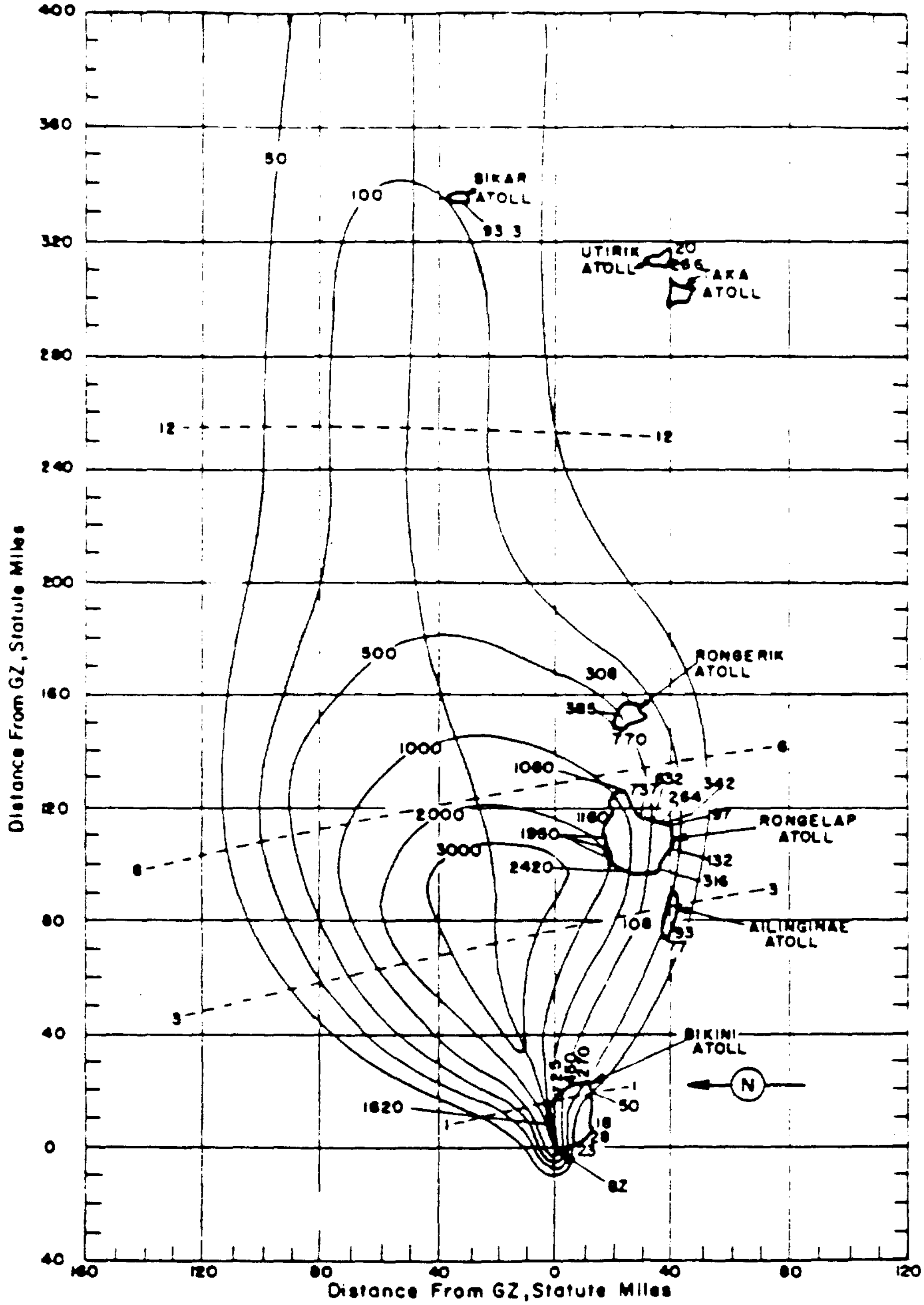
Hodographs for Operation CASTLE - Shot 1 - Bravo.



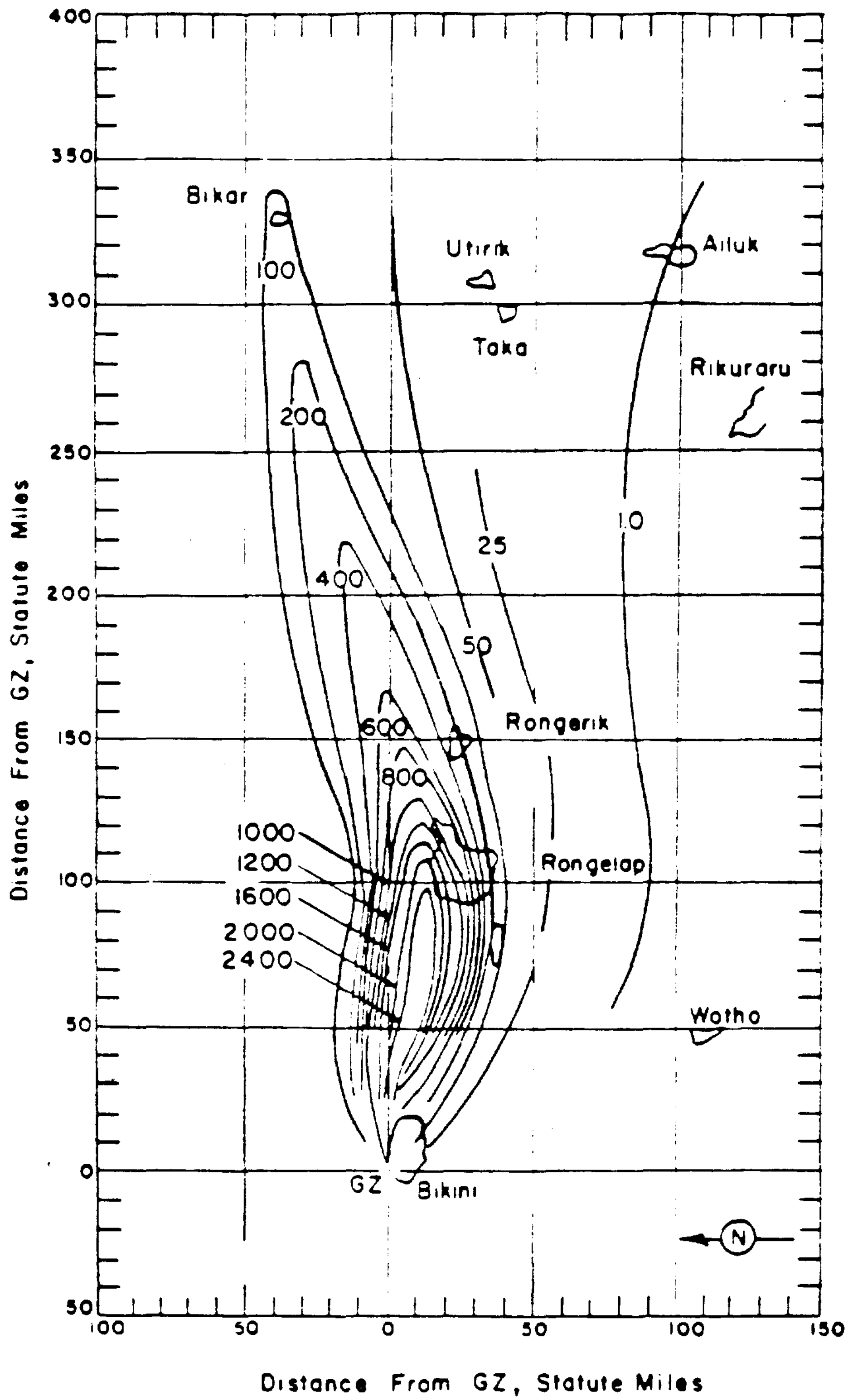
Operation CASTLE - Shot 1 - Bravo.
On-site dose rate contours in r/hr at H+1 hour.



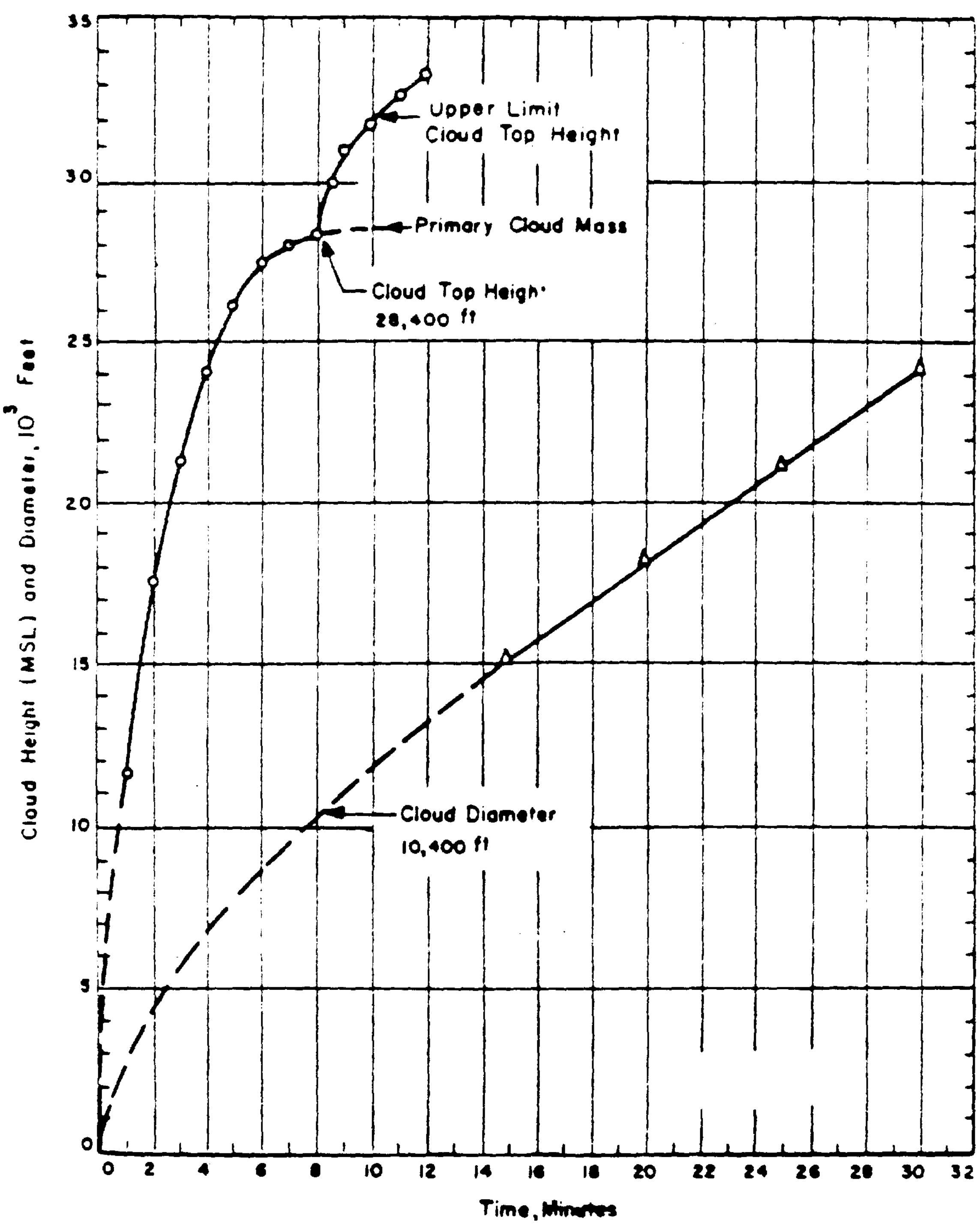
Operation CASTLE - Shot 1 - Bravo.
Off-site dose rate contours in r/hr at H+1 hour (RAND).



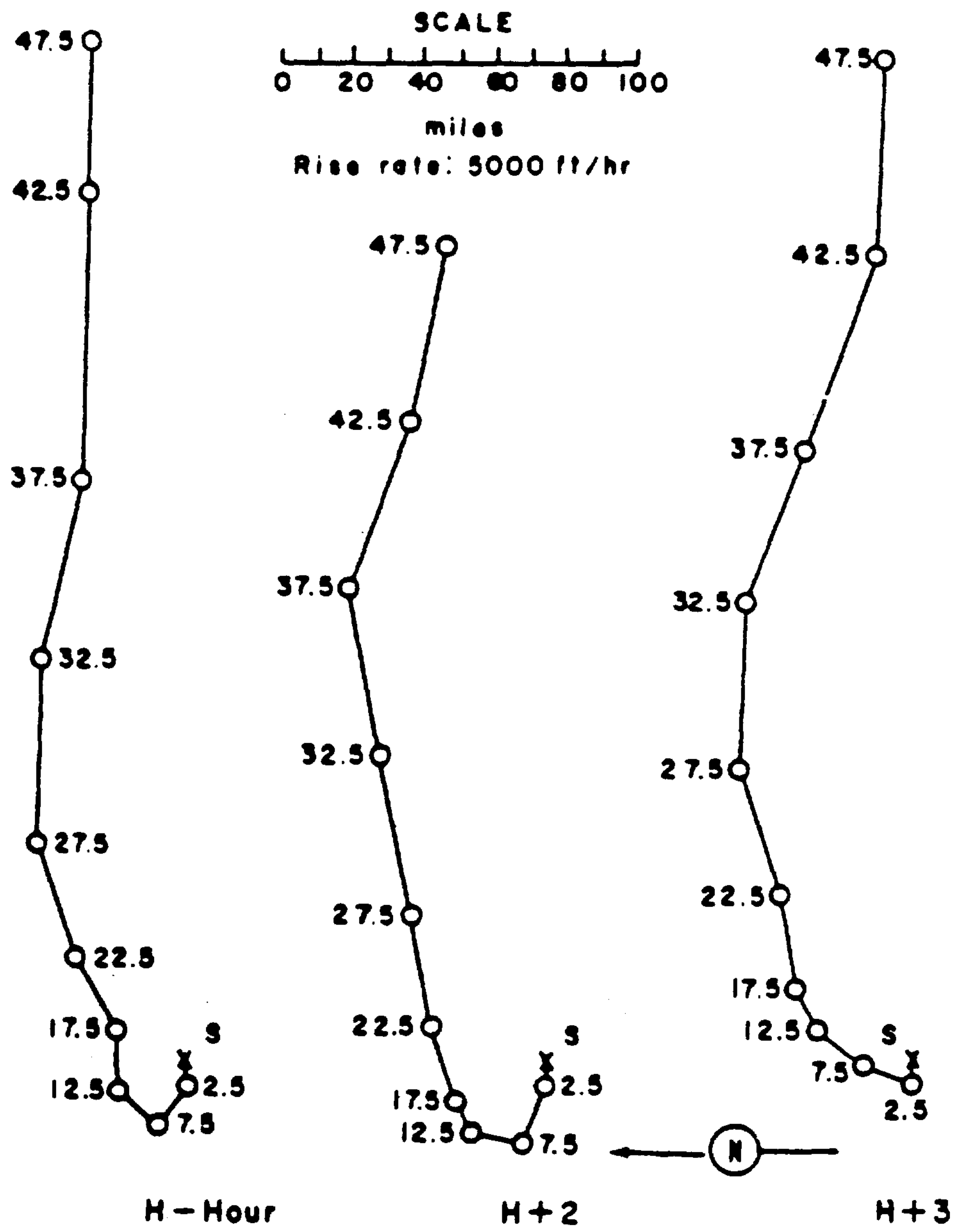
Operation CASTLE - Shot 1 - Bravo.
Off-site dose rate contours in r/hr at H+1 hour (NRDL).



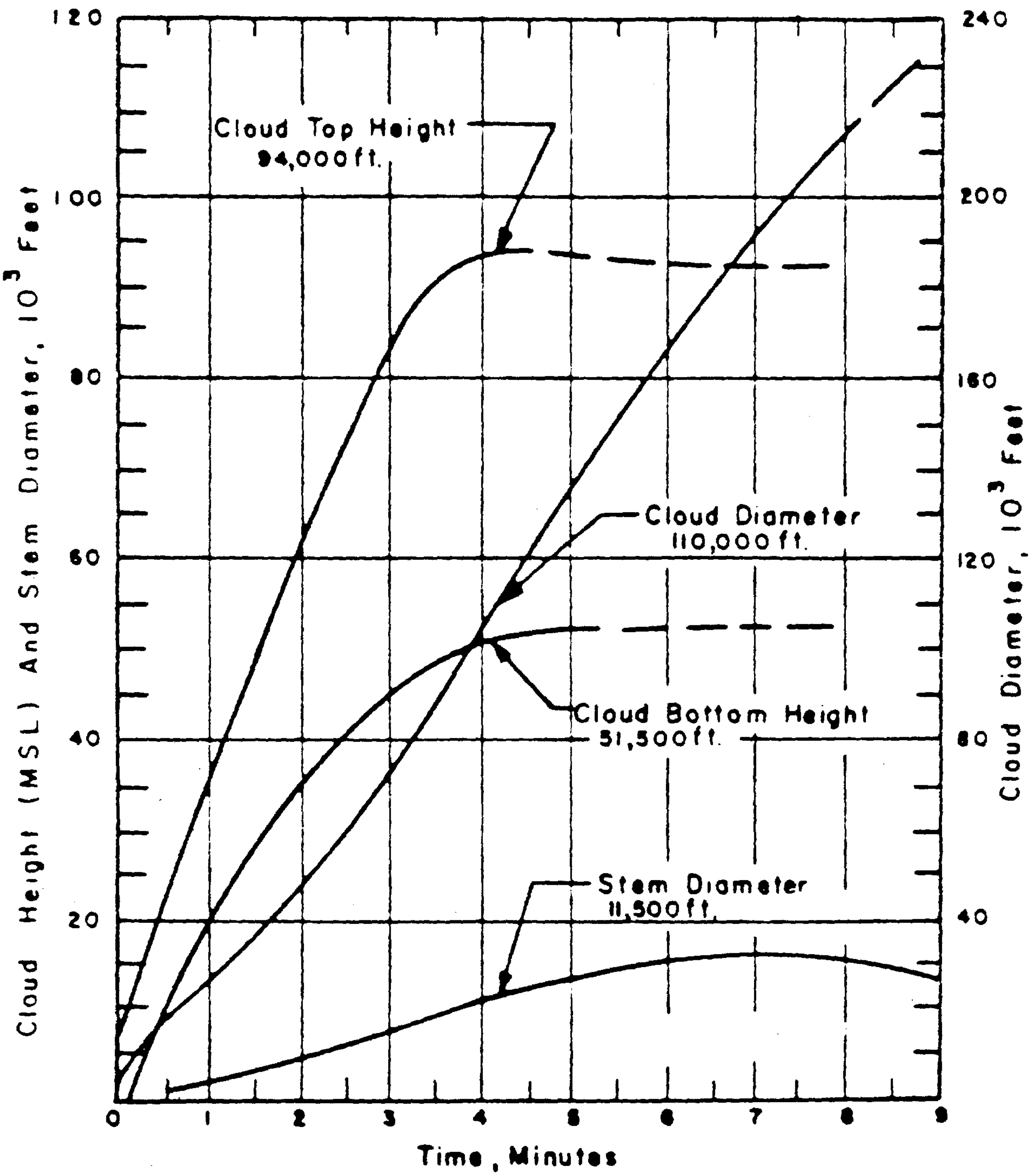
Operation CASTLE - Shot 1 - Bravo.
Off-site dose rate contours in r/hr at H+1 hour (AFSWP).



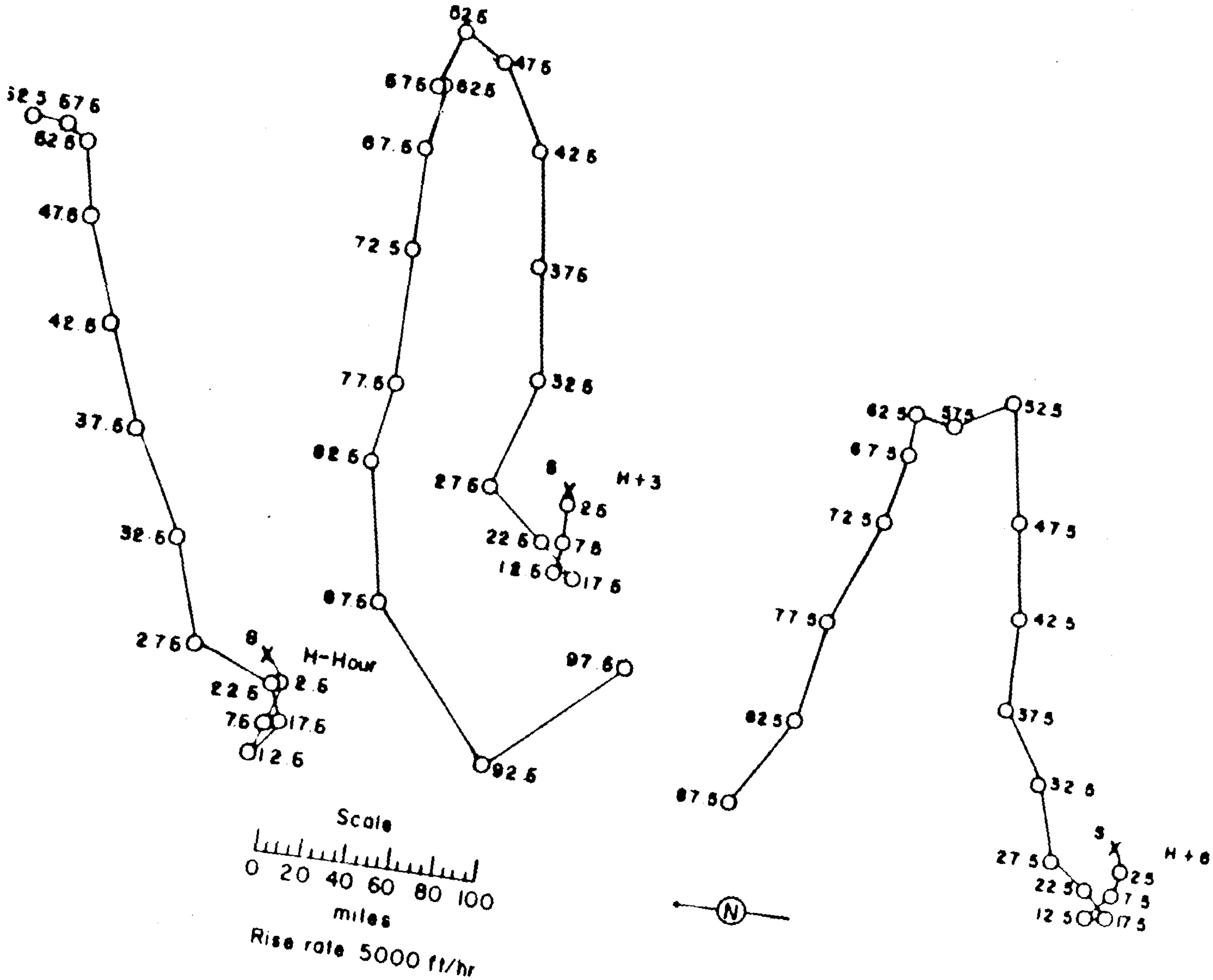
Cloud Dimensions: Operation SANDSTONE - Shot 3 - Zebra.



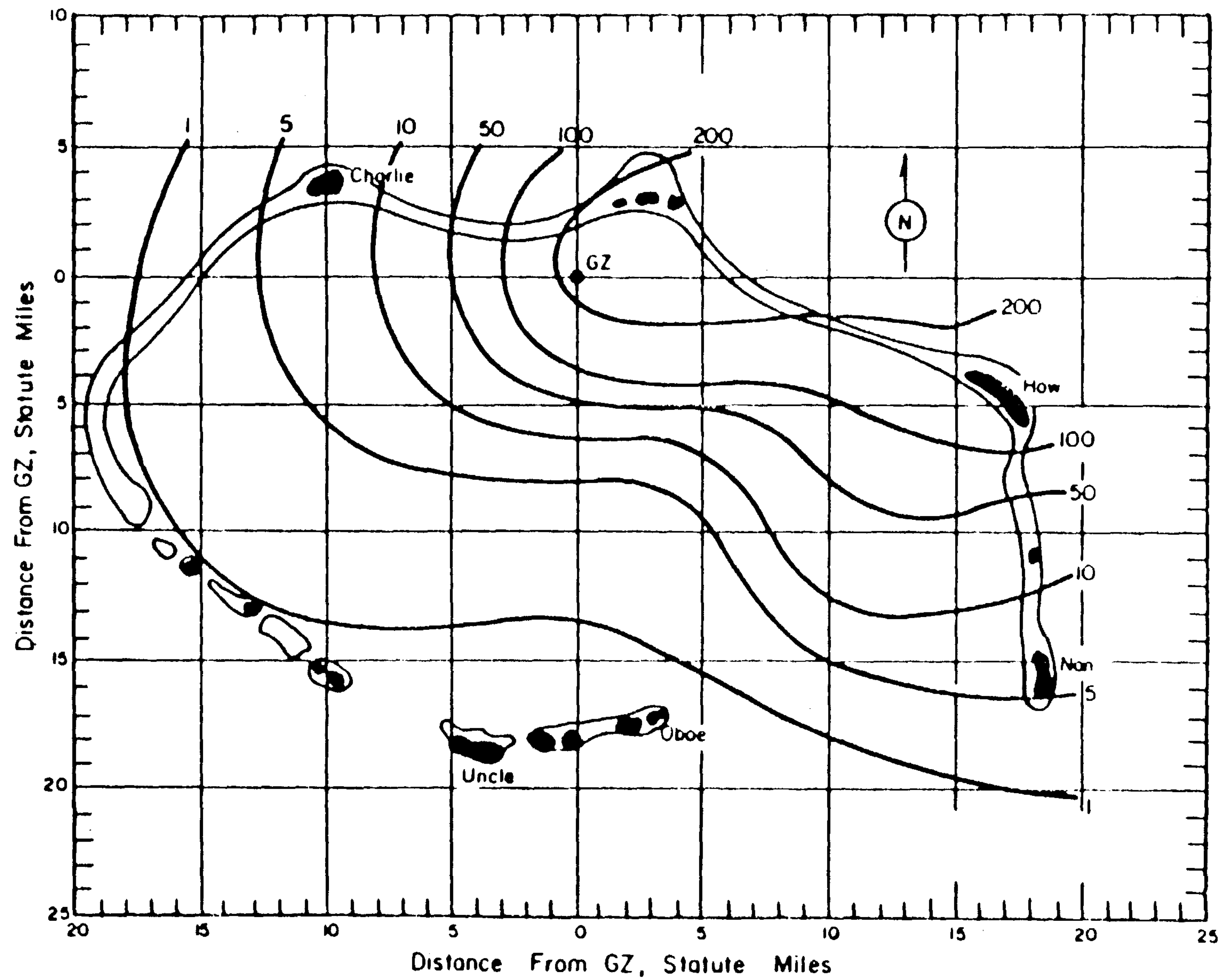
Hodographs for Operation SANDSTONE - Shot 3 - Zebra



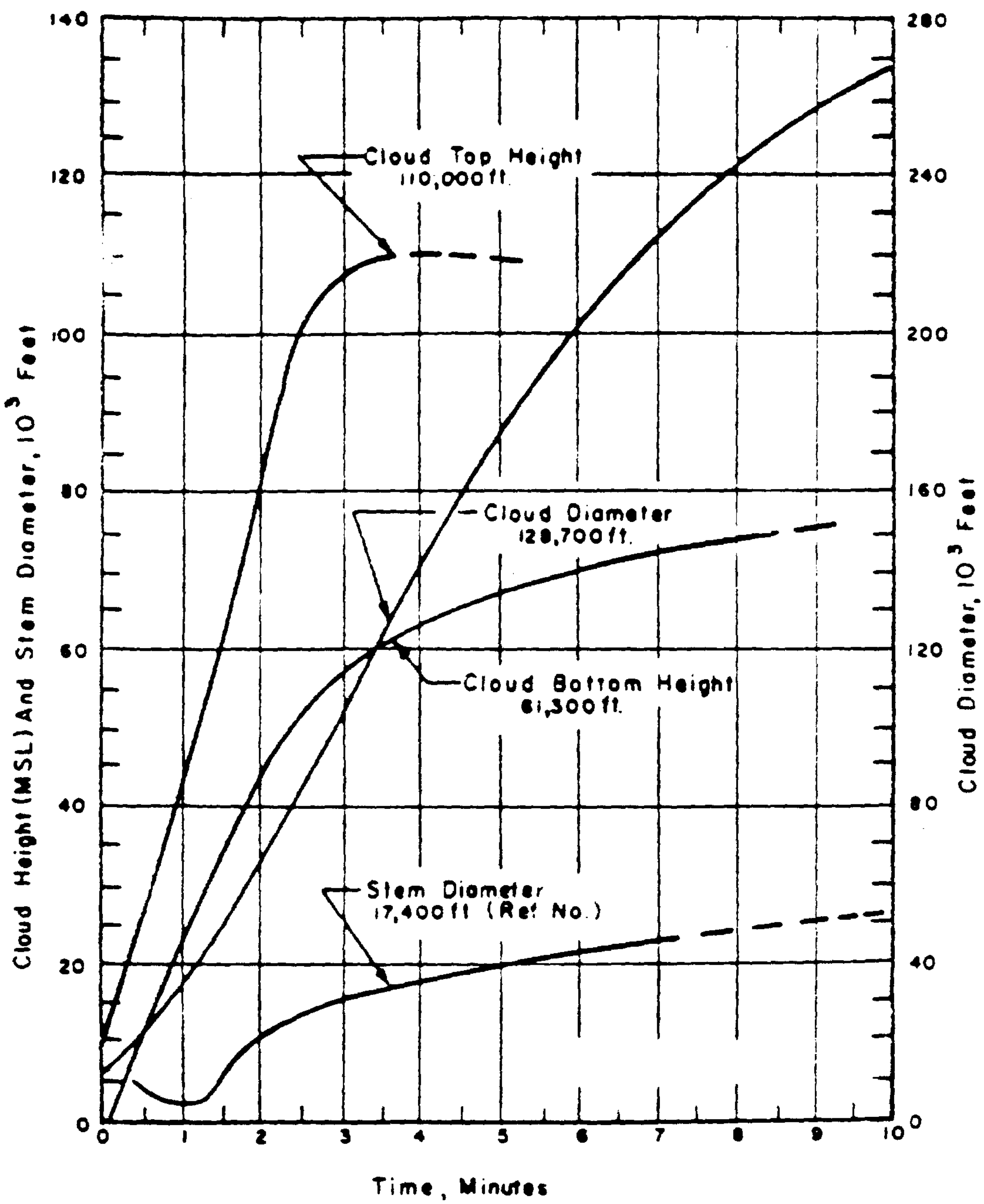
Cloud Dimensions: Operation CASTLE - Shot 4 - Union.



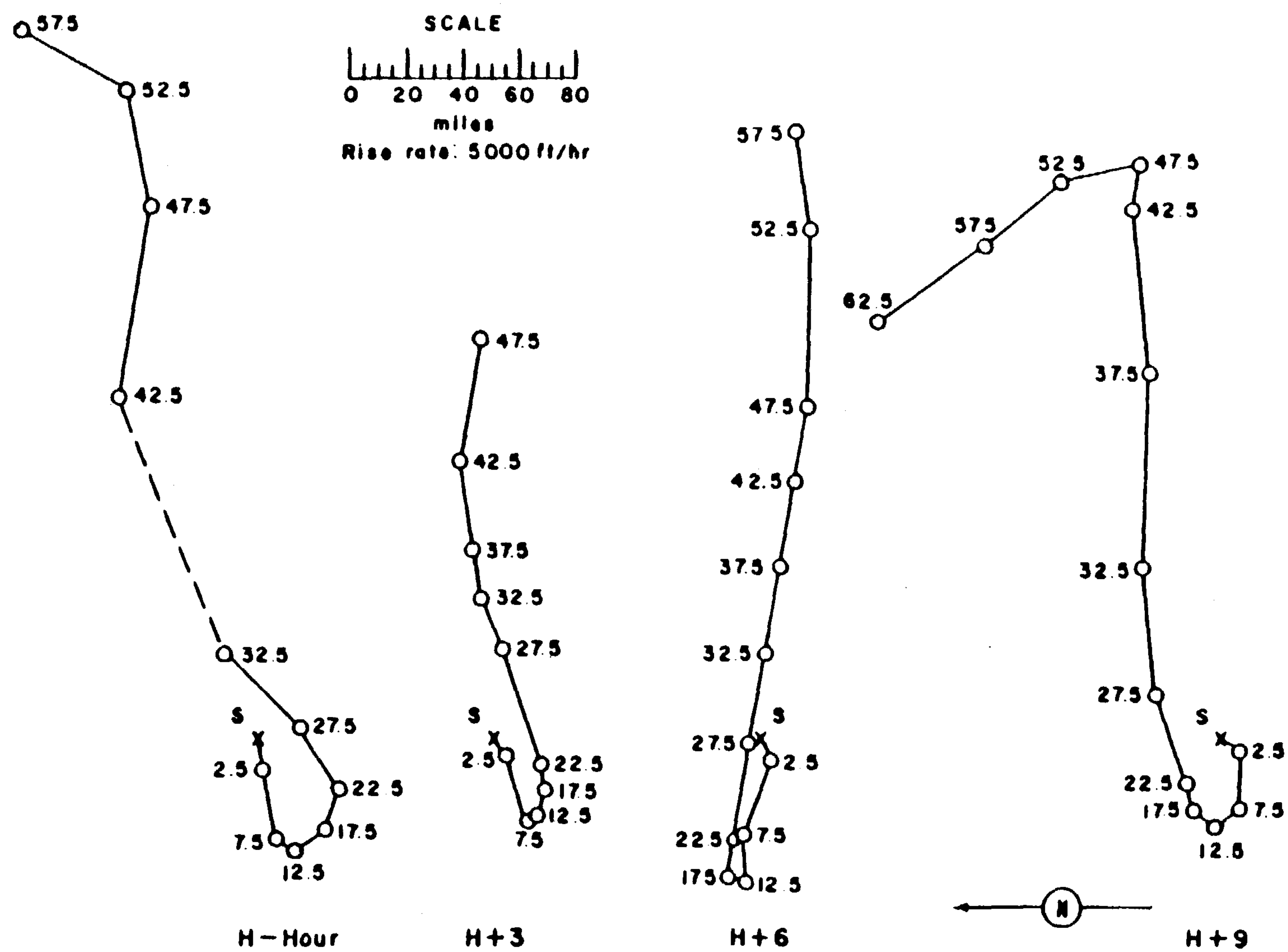
Hodographs for Operation CASTLE - Shot 4 - Union.



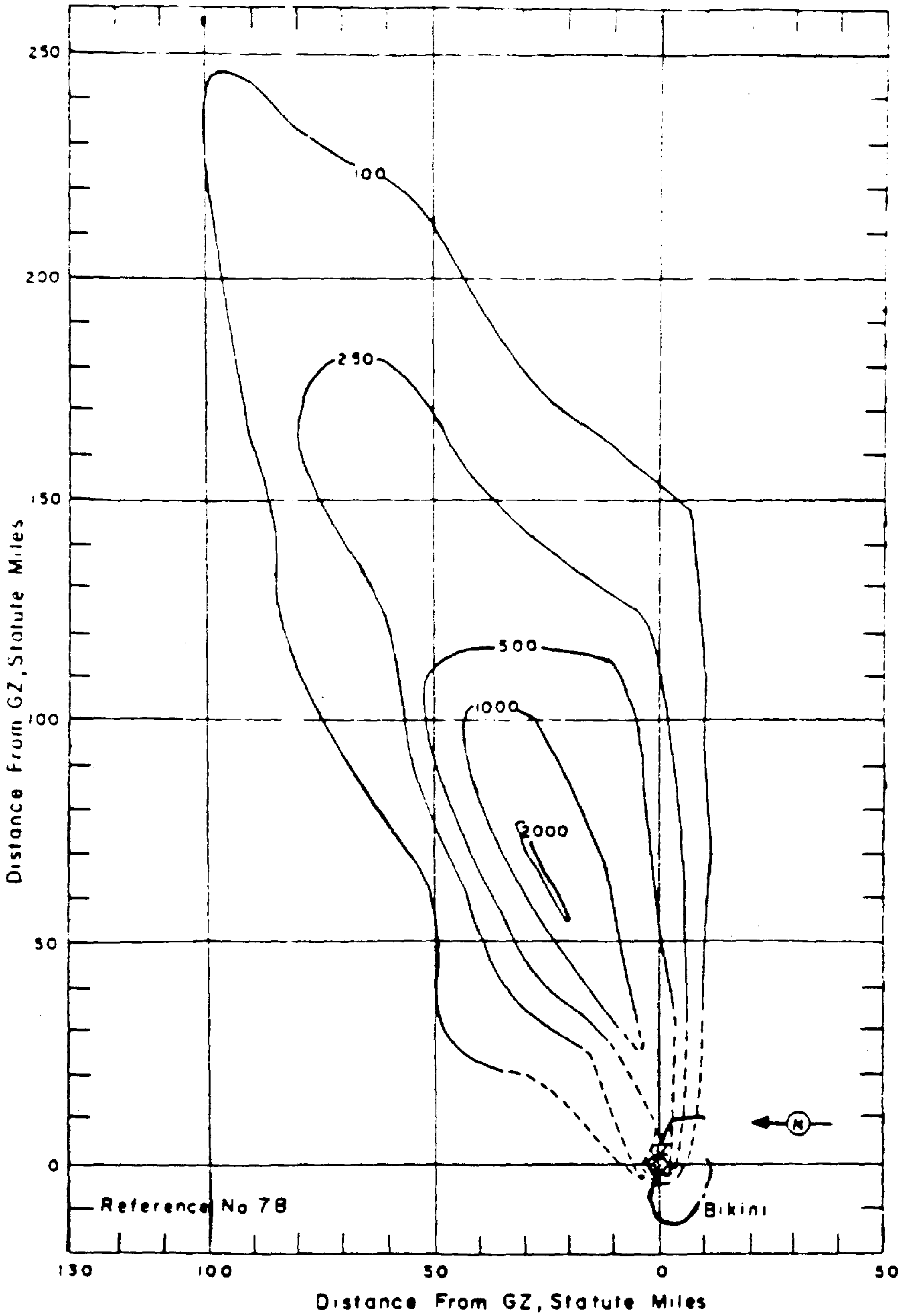
Operation CASTLE - Shot 4 - Union. On-site dose rate contours in r/hr at H+1 hour.



Cloud Dimensions: Operation CASTLE - Shot 5 - Yankee.



Hodographs for Operation CASTLE - Shot 5 - Yankee.



Operation CASTLE - Shot 5 - Yankee.
Off-site dose rate contours in r/hr at H+1 hour.

Bikini Atoll inhabitants were moved first to Rongerik Atoll and then finally to Kili Island. In 1968 President Johnson declared Bikini Island safe for resettlement.

Rehabilitation efforts of Bikini Atoll began in 1969. These activities required persons to reside on Bikini Island. By April 1978, the population numbered 143 persons and consisted of caretakers and agriculturalists employed by the Trust Territory plus a few Bikini land owners and their families who found their way back via Trust Territory trade ships. This population remained on Bikini Island until they were relocated in August 1978 to Kili Island in the southern Marshalls and to Ejit Island, Majuro Atoll.

During the rehabilitation and repopulation years, the medical services already provided by Robert Conard, M.D. and the Brookhaven Medical Team on other atolls of the Marshall Islands were expanded to include sick call and body burden measurements on Bikini Islands. This team made body burden measurements in 1974 (CO 75) and in 1977 (CO 77). In August 1977, the responsibility for providing body burden measurements was transferred from the Medical Department to the Safety and Environmental Protection Division (SEP) at Brookhaven National Laboratory. The 1978, 1979 and 1980 body burden measurements of the Bikini population were conducted by the SEP organization.

This report summarizes all personnel monitoring activities which were conducted on the Bikini Atoll residents from 1970 through 1980. Using the body burden data along with the reported residence interval, individual dose equivalents have been calculated and are also reviewed.

A. Body Burden Measurements - Radiochemical Analysis of Urine

Prior to the assumption of responsibility for the total personnel monitoring program by the SEP Division in 1977, analysis of urine samples for fission products and transuranic elements was conducted under contracts to Battelle Pacific Northwest Laboratories (BNWL) and Environmental Measurements Laboratory (EML). Analytical procedures for processing and analysis are similar and can be found in OL 81.

Urine data collected after 1977 were processed by the SEP Division. Sample collection and analysis procedures used by this division are outlined below.

1. Urine Collection Protocol

Twenty-four hour and five day urine samples were collected from Bikini Atoll residents. Twenty-four hour samples were used to define fission product body burdens while the five day urine samples were used both to determine fission products and transuranic body burdens. The normal procedure was to distribute the urine collection bottles just after the individual received a whole-body count. Individuals were informed to collect all urine excreta in the bottle for the specified collection period. Sample containers were collected after the selected sample period had elapsed.

Once collected, acidification procedures were followed to inhibit biological degradation of the sample. From 1977 to 1978, urine bottles were pretreated with 15 ml of a 10% thymol-alcohol solution. After urine collection, 10 ml of HNO_3 was added. This procedure was halted because of skin discomfort caused by thymol contamination during urine collection. In 1979 and 1980, 15g of boric acid was added to each one liter urine bottle after sample collection. Both acidification techniques minimize sample degradation. After acidification, samples were packaged and shipped to BNL for analysis.

Twenty-four hour urine samples are analyzed for gamma emitting nuclides and ^{90}Sr. Samples are first placed in an ultrasonic cleaner to loosen and disperse solids. Total volume is measured and a 300 ml aliquot is then drawn for gamma analysis. Gamma spectroscopy is performed with a 125 cc active volume, 26% relative efficiency Ge(Li) detector which is connected to a computer based multi-channel analyzer. Samples were counted from 4000 to 10000 seconds depending on the activity in the sample. When gamma analysis was completed, the aliquot was returned to the initial sample and the total volume was analyzed for ^{90}Sr - ^{90}Y.

The sample is acidified to a pH of 1, stable strontium and yttrium carrier along with ^{85}Sr tracer are added to the sample. The sample is chemically processed according to the procedure reported in Appendix A. The final processing step results in a ^{90}Y precipitate which is used to determine the ^{90}Sr urine activity concentration. Sample results are corrected for chemical yield and radiological decay of ^{90}Y post separation from ^{90}Sr. Because of the duration between sample collection and sample analysis (in excess of two months) ^{90}Y and ^{90}Sr are in secular equilibrium at time of sample analysis.

^{137}Cs and ^{90}Sr urine activity concentrations for all pooled samples are reported in Table 1. ^{137}Cs and ^{90}Sr urine activity concentrations and the ^{90}Sr body burden at time of removal are reported in Tables 2 through 5 for Bikini Atoll residents sampled between 1973 and 1980. The ^{90}Sr data were used to calculate the bone marrow dose-equivalent commitment.

Five day urine samples were also collected from 1974 to 1978. These samples were analyzed by Battelle Northwest Laboratory (BNWL), Environmental Monitoring Laboratory (EML) and Los Alamos Scientific Laboratory (LASL) for fission products and transuranic nuclides. The results are presented in Table 6. All transuranic analyses were carried out by alpha spectroscopy. The minimum detectable limit was 3.7×10^{-5} Bq for all analysis systems.

Five samples were obtained sequentially from 16 persons during the January 1979 field trip to determine the variability inherent in the 24 hour urine sample program. The results of this study are listed in Table 7. For ^{137}Cs, the mean biological and counting variability (one standard deviation) associated with a single urine sample is 32%. For ^{90}Sr, most of the results were less than the minimum detection limits of the system or the average of the 5 urine sample results had an associated standard deviation which was larger than the result. Consequently, only 6 sample results were used to determine the biological and counting variability of the ^{90}Sr urine data. The mean standard deviation associated with this result is 65%. The counting error contributes 15% of the variability while other sources of variation account for 50%. These other sources are most likely related to the day to day metabolic changes normally exhibited by an individual.

B. Whole-Body Counting

Whole-body counting measurements on the Bikini population that were conducted in 1974, 1977, 1978, 1979 and 1980 are presented. The body burden measurements were performed by two different organizations; consequently, the experimental design included a mechanism to ensure that previous and current results are directly comparable. Key detection components were duplicated and the systems were calibrated in the same manner (CO 63). The operational procedures and counting geometries were basically similar, and an intercomparison study was conducted using Marshallese and Brookhaven personnel to ensure system comparability.

1. Instrumentation

The detector chosen for field use by both Brookhaven organizations is a 28 cm diameter, 10 cm thick, sodium iodide thallium activated scintillation crystal. It is optically coupled to seven, 7.6 cm diameter low background magnetically shielded, photomultiplier tubes. The signal output from each photomultiplier tube is connected in parallel and the combined output routed to a preamplifier/amplifier and then to a microprocessor-based computer/pulse height analyzer (PHA). The PHA data is stored on a magnetic discette, and the results may be analyzed either in the field or at BNL using a matrix reduction, minimization of the sum of squares technique (TS 76).

2. Calibration

Analysis of spectra by the matrix reduction technique requires that the computer library contain individual standards for each radionuclide that is expected in the field measurements and that the field measurements and standards be the same geometry.

To accomplish this, a review of the previous whole body counting data (CO 75, CO 77) indicated the need to calibrate for ^{40}K, ^{60}Co and ^{137}Cs. The present system was calibrated in 1978 using an Anderson REMCAL phantom (CO 63) and in 1979 using a BOMAB bottle phantom. Each radionuclide was introduced into the phantom's organs in an amount equivalent to the fraction in organ of reference of that in total body as defined by the ICRP in Publication 2 (ICRP 59). Under conditions of continuous exposure where equilibrium has been reached these fractions are correct. This is achieved for the nuclide ^{40}K. The nuclides ^{60}Co and ^{137}Cs are in non-equilibrium throughout the exposure and post exposure intervals. Cesium is taken up principally in cells with 80% to muscle and 8% to bone (SP 68) where the mean residence times are both 160 days. This implies a nearly uniform distribution of the nuclide throughout the whole body. Thus, with 88% of the uptake spread throughout the body with a long halftime and with the remaining 12% of the uptake in the extracellular fluid, which retains cesium with a short halftime (1.0 day), the source geometry will not be significantly affected with respect to an ingestion/excretion equilibrium of cesium within the body. ^{60}Co is not distributed uniformly throughout the body with 20% of an oral intake being retained in the liver with a very long biological halftime and about 80% being cleared from the extracellular fluid to out of the body with a biological halftime of one day or less. Thus source geometry will be significantly effected with respect to ingestion/excretion equilibrium of cobalt within the body.

To verify the activity in the phantom prior to use as a standard, an aliquot of the phantom solution was counted on a lithium drifted germanium detector which was calibrated with NBS standard sources. The phantom was then counted in a shadow shield whole body counter (WBC) (PA65). The whole body counting system consists of a stationary crystal and stationary bed. The counter detects radioactive material located principally in the thorax, so positioning of the phantom and the in vivo counting subjects must be as similar as possible. To facilitate reproducible counting geometries, each subject and the standard phantom was positioned such that the central axis of the crystal intersected the central axis of the body about 25 cm below the sternal notch. The distance between the surface of the bed and the bottom of the detector is 32.4 cm. The total system efficiencies for ^{40}K, ^{60}Co and ^{137}Cs are listed in Table 8 as are typical minimum detection limits for these nuclides.

In 1979, a shadow shield chair geometry replaced the shadow shield bed configuration. The chair whole-body counter used the same electronics as in the past. The system was calibrated using a Bomab bottle phantom. Uniformly distributed activity concentrations of ^{40}K, ^{60}Co and ^{137}Cs were used for system calibration. Verification of phantom activity was accomplished as previously described. The chair geometry detects radioactive material located between the neck and the knee. The total system efficiencies are the same for the chair and bed geometries.

3. Quality Control

The quality control (QC) program consisted of a cross comparison of the radionuclide amounts estimated to be in the phantom volume versus NBS calibration standards. Agreement between the two activity concentrations is within plus or minus 5% for all radionuclides. Other quality control mechanisms employed were repetitive counting of secondary point source standards, multiple counts of Brookhaven personnel, repetitive counting of the Marshallese (blind duplicates) and an intercomparison study.

Two point sources were used in the QC program. Initially ^{137}Cs source, which has been used by the BNL medical surveys in previous years, was used to monitor potential changes in system resolution and efficiency as function of time. In subsequent years, a ^{137}Cs + ^{60}Co point source, was used for zero, gain, resolution and efficiency determination.

Replicate counting of Marshallese was conducted on 5% of the subjects. Results indicate that the data obtained from the field whole body counting system is reproducible to within plus or minus 6%. Almost all of this error is due to variable subject position. When subjects remain stationary, the difference between sequential results is plus or minus 1%.

An intercomparison of whole body counting systems was conducted between the field system and the whole body counter operated by S. Cohn for the Brookhaven Medical Department. Persons used in the study included 13 Marshallese with measurable ^{137}Cs body burdens plus several Brookhaven employees with current whole body counting records at the Medical Department. The results of the study indicate that ^{137}Cs and ^{40}K body burdens which exceed the minimum sensitivity of both systems are in agreement to within plus or minus 5%.

RESULTS

Persons listed in Tables 9 through 12 have been identified as medically registered residents. This terminology means these individuals reported to BNL doctors for sick call during the April 1978 field survey and were assigned a registration number. For continuity, these numbers were retained by SEP for radiochemical analysis of urine identification. Individuals who donated urine for analysis of ^{90}Sr and ^{137}Cs in 1979 and did not report for sick call during the April 1978 survey at Bikini Atoll have been termed non-medically registered. Persons who had not resided at Bikini Atoll for more than three years as of January 1979 or had never resided at Bikini Atoll are labeled as comparisons.

Tables 9 and 10 present a list of adult individuals who were counted in 1974 (CO 75), 1977 (CO 77), 1978, 1979 and 1980. There is a general increase in body burdens of adult males from 1974 to 1977 by a factor of 13.3, and from 1977 to 1978 by a factor of 1.8. The general increase for adult females from 1977 to 1978 was slightly higher than that for males over the same period. In most cases, the January 1979 data are significantly lower than the 1978 with an averaged reduction in the ^{137}Cs body burden by a factor of 2.9. The May 1979 and August 1980 data follow the expected decreasing trend.

Tables 11 and 12 summarize the ^{137}Cs body burden data collected for adolescents and children. It must be noted that data reported here are uncorrected for height and weight differences between subjects and the standard, up to 15% deviations have been reported for adult data (MI 76). Body burdens of adolescents and children reported in Tables 11, 12 and 13 were computed using efficiencies obtained from standard adolescent and juvenile Bomab phantoms.

Table 13 summarizes the ^{137}Cs data that are presently available. It shows the mean standard deviation from the mean, and range of values reported for the sampled population segregated by sex and age, as it has changed from 1974 to 1980.

Table 14 compares the observed reduction in ^{137}Cs body burdens from April 1978 to January 1979 with the reduction in ^{137}Cs body burden that was expected as a result of relocating the Bikini population in late August 1978. Values for the biological removal rate constants were obtained from NCRP Report 52 (NRCP 77) and ICRP Publication 10A (ICRP 71).

Table 15 presents the long term biological removal rate constants for individuals in the Bikini population as determined from sequential measurements in 1979 and 1980. Table 16 presents population subgroup mean values for the ^{137}Cs long term biological removal rate constant. The data are in good agreement with ICRP publication 10A (ICRP 71) and NCRP report 52 (NCRP 77).

In addition to the followup whole body counts performed on persons who were initially counted in April 1978 on Bikini Atoll, persons who had resided at Bikini Atoll and were concerned about their current body burdens were counted. Dependents of adult Bikini Atoll residents were counted regardless of their residence history. Results of this work conducted in January 1979, May 1979 and August 1980 at Majuro Atoll, Kili Island and Jaluit Atoll are presented for adult males, adult females, adolescents and juveniles in Tables 17 through 20 respectively. Most of the ^{137}Cs body burdens are at levels which are consistent with world fallout contamination. Some dividuals have higher than anticipated ^{137}Cs body burdens. Interviews with these subjects revealed that they either

...n food products from contaminated atolls or had recently visited these atolls.

Population Census and Residence Atolls

^{137}Cs body burdens from May 1979 of individuals whose residence history on Bikini was minimal and who had not recently (within 2 years of August 1978) resided at Bikini Atoll were grouped together to form a comparison population. In August 1980, a second comparison population was selected from Majuro Atoll and Kili Island residents who had never resided on Bikini Atoll. The whole-body counting data for this group is presented in Tables 21 through 24. Table 25 summarizes the ^{137}Cs data for both the May 1979 and August 1980 comparison populations. The comparison population data were used in the computation of the ^{137}Cs long term biological removal rate constants reported in Table 15.

Table 26 shows the number of April 1978 Bikini residents that were recounted on subsequent field trips. Column 2 lists the total number of people counted on each field trip. Column 3 lists the total number of persons who resided at Bikini Atoll in April 1978. Column 4 lists the number of persons who were medically registered in April 1978. The difference between column 3 and 4 reflects the presence of Rongelap or Utirik residents who had moved to Bikini Atoll between 1970 and 1978. Column 5 lists the number of persons counted that belong to the medically registered population listed in Column 3. Column 6 lists the number of persons counted who reportedly resided on Bikini Atoll at the time of relocation in August 1978. Column 7 lists the number of non-relocated former residents counted.

Table 27 presents the number of adult males, adult females, adolescents and juveniles which composed the medically registered, relocated population sampled in 1978 and 1979. Table 28 presents the same sample breakdown for the non-medically registered population and medically registered children counted only in 1979.

Table 29 summarizes the residence locations of all persons counted. Tables 30 and 31 break this data down by sex, age and registry status for the January 1979 and May 1979 field trips. Tables 32 through 39 provide individual counting dates and residence atoll or island at time of counting. Table 40 lists registry numbers, age, name, sex and last known location of individuals who have not been whole body counted since their departure from Bikini Atoll.

DOSIMETRY

The dose equivalent to Bikini Atoll residents during their residency period was the result of internal and external sources of radiation. In 1975, external exposure measurements were performed (GR 79) at Bikini Atoll. Using these data and an estimate of the Marshallese living pattern developed by Gudiksen (GU 76), an estimate of the mean yearly net exposure rate for adult males, adult females, adolescents and juveniles was developed and reported in a previous publication (GR 79). The net external dose equivalent for each individual was determined as the product of the mean net exposure rate, the residency interval and a correction factor for radiological decay and is presented in Column 5 of Table 41.

The dose equivalent commitment for bone marrow due to ^{90}Sr has been calculated for individuals from urine data reported in Tables 2 through 5. The symbols, constants and equations used are presented in Appendix B. The retrospective dose equivalent was determined using several assumptions. First, persons returning to Bikini Atoll returned with an initial ^{90}Sr body burden at baseline levels. Second, while residing on Bikini Atoll, individuals were subjected to a constant and continuous uptake of ^{90}Sr through the ingestion pathway.

Finally, once strontium is ingested and absorbed into the blood, ^{90}Sr disintegrations are evenly distributed in cortical and cancelous bone tissues. Each individual was assumed to exhibit different ^{90}Sr ingestion rates. The daily activity ingestion rate was determined from urine data. The prospective dose equivalent was determined with the assumption that ingestion of ^{90}Sr ceased when the individual departed from Bikini Atoll. Disintegrations resulting from residual strontium-90 in bone post departure were calculated for an infinite post residence interval versus a fifty year period commonly chosen for radiation workers. The dose equivalent commitment, the sum of the retrospective and prospective dose equivalents, are listed in Table 41, Column 3.

The retrospective and prospective dose equivalent resulting from the ingestion of ^{137}Cs have been calculated for members of the Bikini Atoll population. The symbols, constants and equations used are presented in Appendix C. Data used for these calculations were obtained from Tables 9 through 12 of this report. Because the ^{137}Cs body burden data dramatically increased between 1974 and 1978, constant and continuous uptake of ^{137}Cs could not be assumed. Consequently, the dose equivalent during the uptake interval was calculated using a monotonic increasing uptake regime. The total residency period, was divided into three intervals during which constant and continuous ingestion of ^{137}Cs was assumed. These periods, January 1, 1970 to December 31, 1975, January 1, 1976 to April 5, 1977 and April 6 to August 31, 1978, were determined based on the bioassay data and the maturation period for vegetation planted in the early 1970's. It was also assumed that the initial ^{137}Cs body burdens of individuals returning to Bikini Atoll were at baseline levels. The prospective dose equivalent was determined with the assumption that the ingestion of ^{137}Cs ceased after an individual departed from Bikini Atoll. The dose equivalent commitment as determined from these calculations are listed in Table 41, Column 4.

The total body dose equivalent commitment listed in Column 6, Table 41 is the sum of Columns 4 and 5. The total bone marrow dose equivalent commitment reported in Column 7 was obtained by summing the data in Columns 3, 4 and 5.

Figures 1 through 3 illustrate the distribution of the dosimetric information obtained from Table 41. Figure 1 describes the distribution of residence interval, net external exposure, ^{90}Sr bone marrow dose equivalent commitment, ^{137}Cs total body dose equivalent commitment, the total bone marrow and total whole body dose equivalent commitments for the Bikini population sampled in April 1978. Figure 2 presents this information for males only while Figure 3 presents the female dose distribution.

Discussion of Results

^{90}Sr body burdens do not appear to be significantly different for males, females and adolescents; however, the ^{137}Cs body burden as summarized in Table 13 indicates that male versus female adult body burden means are significantly different. There was also a small difference between the body burdens of the adult females and all children. These differences suggest that dietary and living patterns change as an individual matures thus effecting the body burden.

This problem was addressed for external exposure in an earlier report (GU 77) and an estimated living pattern was developed for children, adult females and adult males. This information indicates that the adult males spend 5% more of their time in an environment which is radiologically substantially higher in activity than do the adult females. If one assumes that 5% more of the dietary uptake of radioactive materials occurs due to the longer duration of time spent in the interior section of the island, then one would expect that the mean adult male body burden would be higher than the mean adult female body burden by a factor of 1.2. The ^{137}Cs data collected in April 1978 indicates that the mean adult male body burden is 1.5 times higher than the mean adult female body burden. Likewise, the mean child body burden for ^{137}Cs would be expected to be lower by a factor of 1.8. Our data indicates that the mean child ^{137}Cs body burden is a factor 2 less than the mean adult male body burden.

Other factors which influence the body burden include the age of the individual, the residence interval on Bikini Island and family relationships. ^{137}Cs body burden results weighted by the individual's body potassium and ordered by sex, age and residence interval were tested to determine the influence of age and residence interval on the body burden. The Bartlett test for homogeneity of variance was used to determine if the sample populations under consideration had the same variances. If the sample variances were the same then a one way analysis of variances was performed on each data set. If the sample variances were not equal, then the data was transformed by taking the log (ln or square root) of the activity and the test for homogeneity repeated. When the data passed the Bartlett test for homogeneity, the one way analysis of variance was performed. The data were grouped by sex because the mean of the adult male and adult female ^{137}Cs body burden were significantly different.

The result of the one way analysis of variance with age of the individual being the variable suspected of influencing the weighted ^{137}Cs body burden results indicates that no age or age group significantly influences the results. This implies that indigenous food products are consumed at a uniform rate by all individuals and that one age group does not have a preference for a type of food not found in the diet of other generations.

The result of the one way analysis of variance with residence time on Bikini as the variable of concern is unclear. The statistical analysis for adult males indicates that persons with residency periods greater than 6 years have higher weighted ^{137}Cs results than the rest of the male population. For adult females, the group residing on Bikini for 3-6 years have lower weighted ^{137}Cs results than the rest of the adult female population. Residency once past 1 year, was expected to have no effect on the ^{137}Cs body burden. This expectation was based on the mathematical models used by ICRP Publication 10A (ICRP 71) which indicate that equilibrium with the environment would be reached within the first 2 years of exposure to a constant uptake of ^{137}Cs.

Data for these analyses were grouped in age and residency intervals that would provide a minimum sample size of five data points per sample interval. The small sample size and large variance of the grouped data cast serious doubt as to the significance of the results generated by our statistical analysis.

The last variable considered was the impact of the social structure in the Marshallese society. This factor seems to be highly significant. Table 42 lists the ^{137}Cs body burden results ordered by family ranking. The family rank was accomplished by assigning the family placement number to the adult male's ^{137}Cs body burden. Examination of this table reveals that the family follows the pattern set by the adult male. This pattern does not follow a direct one to one relationship; however, the trend is apparent.

There are several possible reasons for this trend. First, individuals from the same family have a similar philosophy regarding the quantity of indigenous food crops that they want to consume each day. Second, the family only uses locally grown food products that are obtainable from that family's land. The family wato is also listed in Table 35. Finally, the significance of processed food on the family diet will be a function of the first two items listed above and the willingness of the family to purchase food.

The whole-body counting data also indicates that previous estimates of the type of food and amount of various components in the Bikini diet did not adequately describe the dietary patterns that existed between 1974 and 1978. As certain local food crops, coconuts, became available in 1976, they were incorporated into the diet in the form of jekaru (the water sap of the coconut tree), jekomai (a syrup concentrate made from jekaru) and waini (drinking coconuts). The maturation time of the coconut tree is 5-7 years. Consequently, one would expect to observe a steady increase in the ^{137}Cs body burden through 1978 at which time an equilibrium body burden would be reached. Comparison of the observed reduction in the ^{137}Cs body burden from April 25, 1978 to January 24, 1979 with the expected reduction in the body burdens from September 1, 1978 to January 24, 1979 yields almost identical results for the adult male and adult female groups as shown in Tables 7 and 8. This implies that the Bikini population could have attained equilibrium and that the body burdens on September 1, 1978 were not significantly different than those measured in April 1978. The child data do not agree with the expected value; however, the difference is not beyond the range of half-times listed in NCRP Report 52 (NCRP 77). Although NCRP Report 52 lists a mean half-time for children ages 5 through 15, it does not specify the age distribution of the sample. Most of the Bikini children were in the 5-10 year category; hence, one would expect the observed reduction factor for this group to be somewhat higher than the expected value.

Although the data indicates that the ^{137}Cs body burdens may not have increased between April and September 1978, this is not assurance that the body burdens would not have increased when new dietary items like pandanus and breadfruit became available for daily consumption.

Furthermore, while the population may have been near equilibrium with their April dietary uptake, individuals within the population may not have been. This was apparent in the adult male ^{137}Cs body burden data where two individuals show no decline in activity between the April 1978 and January 1979 whole body count. In one case, the individual was present on Bikini for only 5 months prior to the April 1978 count. This places the individual at approximately 60% of his equilibrium body burden value. In the second case, there seems to be no clear explanation for the lack of any reduction in the body burden, however

1. the individual may have lived away from Bikini prior to the April count; hence, equilibrium was not established at the time of counting, or

2. the individual changed his diet pattern between April and September.

These deviations from the norm do not alter the conclusion that equilibrium or near equilibrium may have been reached for the population as a whole for ^{137}Cs. Indeed, they illustrate variations about a mean value.

Data collected between January 1979 and August 1980 also indicate that certain individuals have been ingesting ^{137}Cs at a rate which exceeds that of the sample population. This could in large part be due to visits to Bikini or other contaminated atolls between measurement dates.

The individual dosimetric data presented here clearly illustrates that at least 19% of the Bikini residents would have received a dose equivalent in excess of 5 mSv (0.5 rem) due to the ingestion of ^{137}Cs had the April 1978 activity ingestion rate of ^{137}Cs continued. This dose equivalent level does not include the dose equivalent from external radiation or other internally deposited radioactive material. Removal of the Bikini population from Bikini Atoll eliminated the ^{137}Cs source term from the diet and limited the dose equivalent received by this population.

The contribution of ^{90}Sr to the bone marrow dose equivalent commitment was small relative to the contribution from external exposure and ^{137}Cs. As residence intervals increased, and food products with higher ^{90}Sr concentrations became more available, then the body burdens and bone marrow dose equivalents would have correspondingly increased.

The total body and bone marrow total dose equivalent commitments have a standard deviation of 40% in the adult subgroups. For residence periods between the years 1969 and 1978, a maximally exposed person received a total dose equivalent commitment of 30 mSv (3 rem) and the population average total dose equivalent commitment was 12 mSv (1.2 rem) due to man-made radioactivity on Bikini Island.

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Appendix A

Urine Bioassay Chemistry Procedures

^{137}Cs and ^{90}Sr Assay of Urine in the Absence of Fresh Fission Products

A. Reagents

Strontium carrier solution: 20 mg Sr/ml

Yttrium carrier solution: 20 mg Y/ml

Calcium chloride: 0.1 M

Diethylhexylphosphoric acid: 20% in toluene

Nitric Acid: 16N

Hydrochloric: 0.08 N

Ammonium hydroxide: 15 N

Ammonium hydroxide wash solution: 1 ml 15 N in 500 ml H 0

Sodium hydroxide: 6 M

B. Sample Preparation for ^{137}Cs Analysis

1. Loosen cap on sample bottle and place into ultrasonic cleaner for approximately 10 minutes to loosen and disperse solids.
2. Pour suspended sample into a 2 liter graduated cylinder and record total sample volume.
3. Measure 300 ml of sample into an aluminum can. Seal on lid.
4. Analyze sample with Ge(Li) detector system. Count for 4000 seconds.
5. When gamma analysis is completed and data is verified, return sample to analytical laboratory.

C. Procedure for ^{90}Sr Analysis

1. Remove urine from aluminum can and pour into 2 liter beaker. Rinse can and cover and add rinses to beaker.

2. Pour remaining sample from bottle into the 2 liter beaker, add 50 ml concentration HNO to bottle to rinse walls, add to beaker. Rinse with water and add to sample.

3. Adjust pH to approximately 1 and heat sample to 80°C. Stir.

4. Add to sample

   Strontium carrier: 40 mg

   Yttrium carrier: 40 mg

   ^{90}Sr tracer: 1 ml (X10,000 dpm)

   CaCl 0.1 M: 50 ml

5. Digest sample at 80°C for 30 minutes while stirring.

6. Adjust pH = 4.

7. Add 40 ml saturated oxalic acid solution and mix well.

8. Drop add 6 M NaOH to adjust pH = 4.

9. Digest (with stirring) for 30 minutes.

10. Remove from heat, remove stirring bar, let settle overnight.

11. Filter entire sample through a 2 inch Whatman 42 filter paper mounted in filter assembly. Wash the precipitate once with ammonia wash solution.

12. Transfer filter paper and precipitate to a 150 ml beaker. Dry at 125°C in a muffle furnace. Slowly raise the temperature (over an eight hour period) to a maximum of 500°C. Continue heating at 500°C overnight.

13. Cool the sample and add small volumes of concentrated HNO. Evaporate slowly to dryness. Dissolve residue in 60 ml of 0.08 N HCl. Adjust pH = 1.

14. Transfer sample solution to a 125 ml separatory funnel and extract the yttrium with 60 ml of 20% HDEHP solution. Note time of extraction. Save aqueous phase for possible future reanalysis.

15. Wash the organic phase twice with 60 ml of 0.08 N HCl. Save the first wash and combine the aqueous phase from step 14.

16. Extract the yttrium from the organic phase with 2, 60 ml volumes of 3 N HNO_3. Shake for 2 minutes for each extraction and then combine 3 N HNO_3 solutions in a 150 ml beaker.

17. Evaporate the sample solution to a volume of approximately 3 ml and quantitatively transfer to a 50 ml centrifuge tube with several volumes of water.

18. Adjust the pH to 8-10 with NH_4OH to precipitate $Y(OH)_3$.

19. Centrifuge, decant and discard supernatant liquid.

20. Wash the precipitate with water, centrifuge, discard wash.

21. Dissolve the precipitate in 1:1 HCl (a few drops), slurry and add 25 ml water.

22. Add saturated oxalic acid (2-3 ml), then 2-3 drops of NH_4OH. Digest at 85°C for 1 hour.

23. Filter through a preweighed glass fiber filter disc, wash with water and ethyl alcohol. Dry at 110°C for 15 minutes.

24. Weigh the dried precipitate and filter paper. Mount on nylon disc, cover with 0.25 ml mylar and beta count for 60 minutes using low background anti-coincidence counters.

25. Correct for gravimetric yttrium yield and yttrium decay single separation.

26. Report data in pci/l urine at time of collection.

Appendix 3

<u>Symbols, constants and equations used to calculate $^{90}Sr-^{90}Y$ bone marrow dose equivalent during the uptake interval and the committed dose equivalent</u>

The following definition, symbols, constants and equations describe the mathematical model used to calculate dose equivalent during and post the uptake interval. Intermediate steps can be used to determine body burdens or daily activity ingestion rates. The equations were developed with the assumption that the measured quantity from a bioassay program would be the urine activity concentration. Constant continuous uptake of $^{90}Sr-^{90}Y$ through the ingestion pathway was assumed for the entire residence period. For ^{90}Sr, the uptake interval equals the residency period. As indicated previously ^{90}Sr disintegrations are divided equally between cortical and trabecular bone.

Mathematical Model

Symbols, Definitions and Units of Physical Quantities

N_i^o ≡ the number of atoms of species of concern present at time zero in compartment i, atoms,

N_i ≡ the instantaneous number of atoms of species of concern present at time t in compartment i, atoms,

P_i ≡ atom intake rate into compartment i from blood, atoms day^{-1},

K_i ≡ the instantaneous fraction of atoms removed from compartment i per unit time by physiological mechanisms, day^{-1},

λ ≡ the instantaneous fraction of atoms removed from compartment i per unit time by radiological mechanisms, day^{-1},

q_i ≡ the instantaneous activity in compartment i at time t, Becquerels,

E_i ≡ the instantaneous activity excretion rate from compartment i at time t, Becquerels day^{-1},

f_u ≡ the fraction of body activity excreted in urine,

f_1 ≡ the fraction of GI tract activity entering blood,

q ≡ the instantaneous activity in the body, Becquerels,

P ≡ the atom ingestion rate, atoms day^{-1},

X_i ≡ the fraction of atoms entering blood deposited in compartment i,

t ≡ uptake interval, day,

U ≡ instantaneous urine activity concentration, Becquerels $liter^{-1}$,

U_m ≡ male urine excretion rate, liters day^{-1},

U_f ≡ female urine excretion rate, liters day^{-1},

Q ≡ quality factor,

D_C ≡ disintegrations due to ^{90}Sr remaining in body following uptake interval, Becquerel days,

D ≡ disintegrations due to ^{90}Sr in the body during uptake interval, Becquerel days,

H_M ≡ the dose equivalent to red marrow during uptake interval, mrem,

H_{BN} ≡ the dose equivalent to bone during uptake interval, mrem,

H_M^C ≡ the dose equivalent to red marrow post uptake, mrem,

H_{BN}^C ≡ the dose equivalent to bone post uptake, mrem,

S_i ≡ the absorbed dose to red marrow per disintegration of ^{90}Sr in cortical bone, rads dis^{-1},

S_1 ≡ the absorbed dose to red marrow per disintegration of ^{90}Sr in trabecular bone, rads dis^{-1},

S_2 ≡ the absorbed dose to red marrow per disintegration of ^{90}Y in cortical bone, rads dis^{-1},

S_3 ≡ the absorbed dose to red marrow per disintegration of ^{90}Y in trabecular bone, rads dis^{-1},

S_4 ≡ the absorbed dose to bone per disintegration of ^{90}Sr in cortical bone, rads dis^{-1},

S_5 ≡ the absorbed dose to bone per disintegration ^{90}Sr in trabecular bone, rads dis^{-1},

S_6 ≡ the absorbed dose to bone per disintegration of ^{90}Y in cortical bone, rads dis^{-1},

S_7 ≡ the absorbed dose to bone per disintegration of ^{90}Y in trabecular bone, rads dis^{-1}.

EQUATIONS

$$\frac{dN_i}{dt} = -(\lambda + K_i)\, N_i + P_i, \qquad (1)$$

$$N_i = N_i^o\, e^{-(\lambda + K_i)t} + \frac{P_i}{\lambda + K_i}\,(1 - e^{-(\lambda + K_i)t}), \qquad (2)$$

$$q_i = \lambda N_i, \qquad (3)$$

$$E_i = K_i N_i \lambda, \qquad (4)$$

$$\lambda P = \frac{UU_m}{f_1\; f_u}\,\Big(\frac{K_1 X_1}{\lambda + K_1}\,(1 - e^{-(\lambda + K_1)t}) +$$

$$\frac{K_2 X_2}{\lambda + K_2}\,(1 - e^{-(\lambda + K_2)t}) +$$

$$\frac{K_3 X_3}{\lambda + K_3}\,(1 - e^{-(\lambda + K_3)t})\Big)^{-1} \qquad (5)$$

$$q = f_1 \lambda P \left(\frac{X_1}{\lambda+K_1}(1-e^{-(\lambda+K_1)t}) + \right.$$

$$\frac{X_2}{\lambda+K_2}(1-e^{-(\lambda+K_2)t}) +$$

$$\left.\frac{X_3}{\lambda+K_3}(1-e^{-(\lambda+K_3)t})\right), \tag{6}$$

$$D = \frac{f_1 \lambda P X_1}{\lambda+K_1}\left(t - \frac{(1-e^{-(\lambda+K_1)t})}{\lambda+K_1}\right) +$$

$$\frac{f_1 \lambda P X_2}{\lambda+K_2}\left(t - \frac{(1-e^{-(\lambda+K_2)t})}{\lambda+K_2}\right) +$$

$$\frac{f_1 \lambda P X_3}{\lambda+K_3}\left(t - \frac{(1-e^{-(\lambda+K_3)t})}{\lambda+K_3}\right), \tag{7}$$

$$D_C = \frac{f_1 \lambda P X_1}{(\lambda+K_1)^2}(1-e^{-(\lambda+K_1)t}) +$$

$$\frac{f_1 \lambda P X_2}{(\lambda+K_2)^2}(1-e^{-(\lambda+K_2)t}) +$$

$$\frac{f_1 \lambda P X_3}{(\lambda+K_3)^2}(1-e^{-(\lambda+K_3)t}), \tag{8}$$

$$H_M = 4.32 \times 10^7 \, D \, Q \, (S_1 + S_2 + S_3 + S_4), \quad (9)$$

$$H_{BN} = 4.32 \times 10^7 \, D \, Q \, (S_5 + S_6 + S_7 + S_8), \quad (10)$$

$$H_M^C = 4.32 \times 10^7 \, D_C Q \, (S_1 + S_2 + S_3 + S_4), \quad (11)$$

$$H_{BN}^C = 4.32 \times 10^7 \, D_C Q \, (S_5 + S_6 + S_7 + S_8), \quad (12)$$

Values for Constants

Symbol	Value	Reference
K_1	$3.33 \times 10^{-1}\ d^{-1}$	W. S. Snyder, M. J. Cook and M. R. Ford, Health Physics, 10, 171 (1964).
K_2	$2.27 \times 10^{-2}\ d^{-1}$	"
K_3	$2.5 \times 10^{-4}\ d^{-1}$	"
X_1	0.73	"
X_2	0.10	"
X_3	0.17	"
λ	$6.54 \times 10^{-5}\ d^{-1}$	12th Edition, Chart of the Nuclides (1977).
f_u	0.85	ICRP 10 (1967).
f_1	0.20	ICRP 73/C2-34; ICRP 20 (1972).
U_m	$1.4\ \ell\ d^{-1}$	ICRP Reference Man
U_f	$1.0\ \ell\ d^{-1}$	ICRP Reference Man
Q	1.0	NCRP

Values for Constants (Cont'd)

Symbol	Value	Reference
S_1	9.8×10^{-15} rads dis^{-1}	MIRD 11
S_2	7.3×10^{-13} rads dis^{-1}	MIRD 11
S_3	2.5×10^{-13} rads dis^{-1}	MIRD 11
S_4	4.3×10^{-12} rads dis^{-1}	MIRD 11
S_5	6.3×10^{-13} rads dis^{-1}	MIRD 11
S_6	4.1×10^{-13} rads dis^{-1}	MIRD 11
S_7	3.0×10^{-12} rads dis^{-1}	MIRD 11
S_8	1.7×10^{-12} rads dis^{-1}	MIRD 11

Appendix C

<u>Symbols, constants and equations used to calculate the ^{137}Cs - ^{137m}Ba total body dose equivalent during the uptake interval and the committed dose equivalent</u>

The following definitions, symbols, constants and equations describe the mathematical model used to calculate the dose equivalent and the committed dose equivalent. Intermediate steps can be used to determine urine activity concentrations or daily ingestion rates. The equations were developed with the assumption that the body burden as determined from whole body counting, would be the measured quantity from the bioassay program. Three intervals of monotonically increasing, but constant and continuous uptake throughout an interval were assumed. Consequently, the equations must be repeated 3 times in order to obtain the total dose equivalent during the uptake interval. For ^{137}Cs, the uptake interval corresponds to the number of days out of the residence period that an individual maintained the proposed daily activity ingestion rate.

Mathematical Model

Symbols, Definitions and Units of Physical Quantities

N_i^o $\equiv$ the number of atoms of species of concern present at time zero in compartment i, atoms,

N_i $\equiv$ the instantaneous number of atoms of species of concern present at time t in compartment i, atoms,

P_i $\equiv$ atom intake rate into compartment i from blood, atoms day^{-1},

K_i $\equiv$ the instantaneous fraction of atoms removed from compartment i per unit time by physiological mechanisms, day^{-1},

λ ≡ the instantaneous fraction of atoms removed from compartment i per unit time by radiological mechanisms, day^{-1},

q_i ≡ the instantaneous activity in compartment i at time t, Becquerels,

E_i ≡ the instantaneous activity excretion rate from compartment i at time t, Becquerels day^{-1},

f_u ≡ the fraction of body activity excreted in urine,

f_1 ≡ the fraction of GI tract activity entering blood,

q ≡ the instantaneous activity in the body, Becquerels,

q^o ≡ the initial activity in the body, Becquerels,

P ≡ the atom ingestion rate, atoms day^{-1},

X_i ≡ the fraction of atoms entering blood deposited in compartment i,

t ≡ uptake interval, day,

Q ≡ quality factor,

D_C ≡ committed disintegrations due to ^{137}Cs remaining in body following uptake interval, Becquerel days,

M ≡ mass of individual, kg,

D ≡ disintegrations due to ^{137}Cs in the body during uptake interval, Becquerel days,

H_{RB} ≡ the dose equivalent to the total body during the uptake interval, mRem,

H_{PB} ≡ the dose equivalent to the total body post uptake interval, mRem,

X'_i ≡ the fraction of radioactive atoms in the total body remaining in compartment i at the end of the uptake interval,

S ≡ the absorbed dose to the total body per disintegration of ^{137}Cs-^{137m}Ba in the total body, rads dis^{-1},

EQUATIONS

$$\frac{dNi}{dt} = (\lambda + K_i)N_i + P_i, \tag{1}$$

$$N_i = N_i^o e^{-(\lambda+K_i)t} + \frac{P_i}{\lambda+K_i}(1-e^{-(\lambda+K_i)t}), \tag{2}$$

$$q_i = \lambda N_i, \tag{3}$$

$$E_i = K_i N_i \lambda_i \tag{4}$$

$$X_i' = \frac{\frac{X_i}{(Ki+\lambda)}\left(1-e^{-(K_i+\lambda)t}\right)}{\sum_i \frac{X_i}{(K_i+\lambda)}\left(1-e^{-(K_i+\lambda)t}\right)} \tag{5}$$

$$q = \lambda P\Big(\frac{X_1 f_1}{(K_1+\lambda)}(1-e^{-(K_1+\lambda)t}) +$$

$$\frac{X_2 f_1}{(K_2+\lambda)}(1-e^{-(K_3+\lambda)t})\Big) +$$

$$\overset{o}{q}\left(X_1' e^{-(K_1+\lambda)t} + X_2' e^{-(K_2+\lambda)t}\right) \tag{6}$$

$$D = \frac{\lambda P X_1 f_1}{K_1+\lambda}\left(t - \frac{(\lambda e^{-(\lambda+K_1)t})}{K_1+\lambda}\right) +$$

$$\frac{\lambda P X_2 f_1}{K_2+\lambda}\left(t - \frac{(1-e^{-(\lambda+K_2)t})}{K_2+\lambda}\right) \tag{7}$$

$$D_C = \frac{X_1' q^o}{K_1+\lambda} (1-e^{-(\lambda+K_1)t}) +$$

$$\frac{X_2' q^o}{K_2+\lambda} (1-e^{-(\lambda+K_2)}) , \quad (8)$$

$$H_{RB} = 8.64 \times 10^7 \; DQS , \quad (9)$$

$$H_{PB} = 8.64 \times 10^7 \; D_C QS . \quad (10)$$

Values for Constants

Symbol	Value	Reference
K_1	$0.7\ d^{-1}$	ICRP
K_2	$0.006\ d^{-1}$	ICRP 10
X_1	0.15	ICRP 10
X_2	0.85	ICRP 10
X_1'	0.002	Uptake interval >> 140 days
X_2'	0.998	Uptake interval >> 140 days
λ	$6.33 \times 10^{-5}\ d^{-1}$	Nuclear data tables
f_1	1.0	ICRP 10
Q	1.0	ICRP 26
S	1.05×10^{-13} rads dis^{-1}	MIRD 11

Table 1

Pooled or Mean Urine Activity Concentration for ^{90}Sr and ^{137}Cs

Year of Collection	^{90}Sr Urine Conc pCi/ℓ	^{137}Cs Urine Conc nCi/ℓ	Comment
1970	1.2	0.10	3640 ml - pooled
1970	1.3	0.13	3365 ml - pooled
1970	2.2	-	1100 ml - pooled
1970	1.9	-	930 ml - pooled
1971	0.96	0.22	3920 ml - pooled
1971	0.89	0.20	2960 ml - pooled
1971	1.2	0.21	3300 ml - pooled
1971	3.9	0.11	500 ml - pooled
1972	4.2	0.91	2700 ml - pooled
1973	6.7	1.3	mean of 14 people
1974	2.3	1.3	mean of 21 people
1975	7.3	1.8	pooled
1975	3.1	1.3	pooled
1976	5.3	2.2	mean of 26 people
1977	3.9	7.7	mean of 4 people
1978	6.1	14.	mean of 35 people
1979	2.6	1.3	January, mean of 50 people
1979	2.8	.87	May, mean of 40 people
1980	NA	NA	August

NA = Not Analyzed

Table 2

Urine Activity Concentrations for Former Adult Male Bikini Island Residents

1970 - 1980

ID #	1973		1974		1976		1977		1978		1979 - Jan.		1979 - May		1980 - Aug.	
	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ
Tonne (A)	8.9	2.1	$\leq$0.4	0.40												
Jawel (A)	5.7	1.1														
Acme (A)	5.5	2.6														
Aprizi (A)	2.0	0.40														
Santos (A)	1.9	0.40														
Jormea (A)	7.8	2.0	-	-												
Enlik (A)			2.4	0.80												
Boas (A)					2.7 ± 0.2	3.9 ± 0.2	NA	0.58								
863									8.7 ± 2.6	20. ± 0.45						
6070			1.2	1.0	10. ± 0.6	3.0 ± 0.2			11 ± 1.6	16 ± 0.41	2.8 ± 0.70	6.3 ± 0.14				
6119*									NA	16 ± 0.44						

Table 2 (Cont'd)

ID #	1973 ^{90}Sr Urine Conc. pCi/ℓ	1973 ^{137}Cs Urine Conc. nCi/ℓ	1974 ^{90}Sr Urine Conc. pCi/ℓ	1974 ^{137}Cs Urine Conc. nCi/ℓ	1976 ^{90}Sr Urine Conc. pCi/ℓ	1976 ^{137}Cs Urine Conc. nCi/ℓ	1977 ^{90}Sr Urine Conc. pCi/ℓ	1977 ^{137}Cs Urine Conc. nCi/ℓ	1978 ^{90}Sr Urine Conc. pCi/ℓ	1978 ^{137}Cs Urine Conc. nCi/ℓ	1979 - Jan. ^{90}Sr Urine Conc. pCi/ℓ	1979 - Jan. ^{137}Cs Urine Conc. nCi/ℓ	1979 - May ^{90}Sr Urine Conc. pCi/ℓ	1979 - May ^{137}Cs Urine Conc. nCi/ℓ	1980 - Aug. ^{90}Sr Urine Conc. pCi/ℓ	1980 - Aug. ^{137}Cs Urine Conc. nCi/ℓ
6033									12 ± 1.2	NA						
6018			3.0	0.60	7.1± 0.6	2.8 ± 0.2			7.6 ± 0.91	NA						
6069*									NA	16 ± 0.44			1.2 ± 1.2	1.2 ± .12		
6068					2.3± 0.2	0.29± 0.06			2.9 ± 1.6	9.1 ± 0.31						
6067					5.6± 0.6	1.9 ± 0.2			2.3 ± 0.73	NA	0.54± 0.25	5.2 ± 0.10	0.51± 0.95	2.0 ± 0.09		
6067					2.8± 0.4	1.0 ± 0.2										
6017	6.2	0.90							12 ± 2.7	37 ± 0.61			4.6 ± 2.0	1.4 ± 0.13		
6019					1.6± 0.2	1.1 ± 0.2			10 ± 1.3	NA	3.1 ± 1.2	2.7 ± 0.17				
6001					4.8± 0.8	2.9 ± 0.2										
					12 ± 1.2	6.9 ± 0.4					0.56± 0.01	4.1 ± 0.21				

Table 2 (Cont'd)

ID #	1973 ^{90}Sr Urine Conc. pCi/ℓ	1973 ^{137}Cs Urine Conc. nCi/ℓ	1974 ^{90}Sr Urine Conc. pCi/ℓ	1974 ^{137}Cs Urine Conc. nCi/ℓ	1976 ^{90}Sr Urine Conc. pCi/ℓ	1976 ^{137}Cs Urine Conc. nCi/ℓ	1977 ^{90}Sr Urine Conc. pCi/ℓ	1977 ^{137}Cs Urine Conc. nCi/ℓ	1978 ^{90}Sr Urine Conc. pCi/ℓ	1978 ^{137}Cs Urine Conc. nCi/ℓ	1979 - Jan. ^{90}Sr Urine Conc. pCi/ℓ	1979 - Jan. ^{137}Cs Urine Conc. nCi/ℓ	1979 - May ^{90}Sr Urine Conc. pCi/ℓ	1979 - May ^{137}Cs Urine Conc. nCi/ℓ	1980 - Aug. ^{90}Sr Urine Conc. pCi/ℓ	1980 - Aug. ^{137}Cs Urine Conc. nCi/ℓ
6073			≤0.2	1.5												
6005									2.0 ± 1.3	6.9 ± 0.26			-1.2 ± 16	1.3 ± 0.045		
6008					5.5 ± 1.4	1.7 ± 0.2					1.3 ± 0.62	6.1 ± 0.25				
6086	5.4	0.50	4.6	1.2	5.5 ± 0.4	0.9 ± 0.2			9.4 ± 1.6	16 ± 0.40	0.71 ± 0.52	2.9 ± 0.17	5.9 ± 1.3	2.1 ± 0.095		
6071*									NA	16 ± 0.44	0.55 ± 1.0	4.5 ± 0.21				
6076					1.2 ± 0.2	1.2 ± 0.2			0.93 ± 2.0	18 ± 0.43	0.37 ± 0.80	6.2 ± 0.25				
6072*			2.5	0.50					NA	16 ± 0.44						
813							NA	7.8			2.5 ± 1.0	2.9 ± 0.11				
6118									1.8 ± 0.70	NA	1.4 ± 0.59	3.5 ± 0.085	0.67 ± 1.1	0.46 ± 0.076		
6126					4.1 ± 0.4	3.2 ± 0.2			6.1 ± 2.6	11 ± 0.15						

Table 2 (Cont'd)

ID #	1973 ^{90}Sr Urine Conc. pCi/ℓ	1973 ^{137}Cs Urine Conc. nCi/ℓ	1974 ^{90}Sr Urine Conc. pCi/ℓ	1974 ^{137}Cs Urine Conc. nCi/ℓ	1976 ^{90}Sr Urine Conc. pCi/ℓ	1976 ^{137}Cs Urine Conc. nCi/ℓ	1977 ^{90}Sr Urine Conc. pCi/ℓ	1977 ^{137}Cs Urine Conc. nCi/ℓ	1978 ^{90}Sr Urine Conc. pCi/ℓ	1978 ^{137}Cs Urine Conc. nCi/ℓ	1979 - Jan. ^{90}Sr Urine Conc. pCi/ℓ	1979 - Jan. ^{137}Cs Urine Conc. nCi/ℓ	1979 - May ^{90}Sr Urine Conc. pCi/ℓ	1979 - May ^{137}Cs Urine Conc. nCi/ℓ	1980 - Aug. ^{90}Sr Urine Conc. pCi/ℓ	1980 - Aug. ^{137}Cs Urine Conc. nCi/ℓ
6003									9.8 ± 1.9	17 ± 0.41						
6117					4.3± 0.4	1.9 ± 0.2	<0.62	NA	8.4 ± 1.0	NA	1.4 ± 0.57	4.3 ± 0.21	1.2 ± 1.1	2.3 ± 0.16		
6128					3.3± 0.4	2.7 ± 0.2	4.2 ± 2.0	NA	23.0 ± 6.0	5.1 ± 0.23	0.37± 0.41	1.5 ± 0.13				
6125							4.1 ± 1.5	8.3	1.2 ± 0.64	NA			-0.4 ± 1.4	1.7 ± 0.059		
6007									4.8 ± 1.1	10 ± 0.32	1.2 ± 0.69	1.4 ± 0.12				
											0.04± 0.68	8.0 ± 0.29				
6066											1.5 ± 11	1.3 ± 0.16				
864					13 ± 1.4	5.1 ± 0.2	NA	12								
966					6.8± 0.6	-	6.6 ± 1.8	16								
6135									2.4 ± 0.88	NA						

Table 2 (Cont'd)

ID #	1973 ^{90}Sr Urine Conc. pCi/ℓ	1973 ^{137}Cs Urine Conc. nCi/ℓ	1974 ^{90}Sr Urine Conc. pCi/ℓ	1974 ^{137}Cs Urine Conc. nCi/ℓ	1976 ^{90}Sr Urine Conc. pCi/ℓ	1976 ^{137}Cs Urine Conc. nCi/ℓ	1977 ^{90}Sr Urine Conc. pCi/ℓ	1977 ^{137}Cs Urine Conc. nCi/ℓ	1978 ^{90}Sr Urine Conc. pCi/ℓ	1978 ^{137}Cs Urine Conc. nCi/ℓ	1979 - Jan. ^{90}Sr Urine Conc. pCi/ℓ	1979 - Jan. ^{137}Cs Urine Conc. nCi/ℓ	1979 - May ^{90}Sr Urine Conc. pCi/ℓ	1979 - May ^{137}Cs Urine Conc. nCi/ℓ	1980 - Aug. ^{90}Sr Urine Conc. pCi/ℓ	1980 - Aug. ^{137}Cs Urine Conc. nCi/ℓ
6096									4.3 ± 1.6	6.1 ± 0.25	0 ± 0.72	4.0 ± 0.20	1.1 ± 1.1	2.1 ± 0.15		
6002					1.1± 0.2	0.9 ± 0.2			1.1 ± 0.39	NA						
6161	2.2	0.60									0.86± 0.40	0.33 ± 0.030				
6166											0.29± 0.52	ND	0.39± 0.9	ND		
6184											0.22± 0.53	0.10 ± 0.049	2.8 ± 3.0	0.099± 0.037		
6210			3.2	1.7	2.0± 0.2	3.0 ± 0.2							0 ± 1.95	1.4 ± 0.12		
6190																
6205													0.4 ± 1.6	ND		
6211													1.5 ± 5.3	ND		
6218													0.9 ± 2.5	ND		
6219													3.8 ± 5.4	ND		

Table 2 (Cont'd)

ID #	1973		1974		1976		1977		1978		1979 Jan.		1979 - May		1980 Aug.	
	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ
6220													0.25 ± 1.3	ND		
6221													-.06 1.0	ND		
6136											2.9 ± 1.6	0.079 0.043				
6138											0.25 ± 0.47	2.6 ± 0.66				
6153											0 ± 1.6	0.11 ± 0.043	-0.06 ± 1.6	ND		
6168													3.7 ± 5.6	ND		
6180											1.3 ± 0.53	0.16 ± 0.047				
6182											0.36 ± 0.39	3.2 ± 0.19				
80													12 ± 1.3	ND		
Isaw							NA	1.3								
Steve							NA	7.8								

Table 2 (Cont'd)

ID #	1973		1974		1976		1977		1978		1979 - Jan.		1979 - May		1980 - Aug.	
	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ
6004*									NA	16 ± 0.44						
Sample Size	9	9	8	8	19	18	4	7	21	17	24	22	22	12		
Mean	5.1	1.2	2.2	0.96	5.0	2.5	3.9	7.7	6.7	15	1.0	3.3	1.9	1.4		
Stnd Dev	2.5	0.84	1.5	0.47	3.5	1.7	2.5	5.5	5.4	7.3	0.95	2.2	2.9	0.74		
Low	1.9	0.4	0.2	0.5	1.1	0.29	.62	0.58	0.93	5.1	0	0.10	-1.2	0.099		
High	8.9	2.6	4.6	1.7	13	5.1	6.6	16	23	37	3.1	6.3	12	2.3		

Table 3

Urine Activity Concentrations for Former Adult Female Bikini Island Residents

1973 - 1980

	1973		1974		1976		1978		1979 - Jan.		1979 - May		1980 - Aug.	
ID #	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ
Ruth	11.6	2.1	3.8	3.2	-	-								
Pelapel	4.8	1.2	-	-	-	-								
Wanna	-	-	≤0.1	1.0	-	-								
Wenar	-	-	-	-	2.3 ± 0.4	1.4 ± 0.2								
Kobaje	-	-	-	-	9.6 ± 7.0	1.4 ± 0.2								
6045							3.6± 1.9	17 ± 0.42						
6112							3.9± 2.0	18 ± 0.42	0.082± 0.89	6.5 ± 0.13	2.5 ± 1.1	1.3 ± 0.076		
6114							6.0± 2.7	NA	1.1 0.69	0.77 0.095				
6111							3.9± 3.4	19 ± 0.50	0.39 ± 1.3	4.9 ± 0.23				

Table 3 (Cont'd)

ID #	1973		1974		1976		1978		1979 - Jan.		1979 - May		1980 - Aug.	
	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ
6122							3.8 ± 2.4	8.9 ± 0.40	0 ± 0.54	1.3 ± 0.12	1.8 ± 1.4	0.66 ± 0.089		
6123									3.8 ± 2.3	5.0 ± 0.23				
6059							4.8 ± 2.2	7.6 ± 0.29						
6063					1.5 ± 0.4	1.6 ± 0.2								
6032*							2.0 ± .91	16 ± 0.44	0 ± 0.51	2.8 ± 0.17	7.5 ± 3.4	0.61 ± 0.069		
6185											0.26 ± 0.99	0.046 ± 0.035		
6108					7.6 ± 1.8	0.9 ± 0.2	4.5 ± 2.9	7.0 ± 0.27	2.3 ± 0.89	4.8 ± 0.23				
6206											-0.06 ± 1.2	ND		
6113							2.0 ± 1.2	6.7 ± 0.26	4.5 ± 5.4	2.6 ± 0.18	0.8 ± 1.8	0.57 ± 0.083		
6065							13 ± 2.0	3.6 ± 0.19	2.4 ± 2.4	2.8 ± 0.23				

Table 3 (Cont'd)

ID #	1973 ^{90}Sr Urine Conc. pCi/ℓ	1973 ^{137}Cs Urine Conc. nCi/ℓ	1974 ^{90}Sr Urine Conc. pCi/ℓ	1974 ^{137}Cs Urine Conc. nCi/ℓ	1976 ^{90}Sr Urine Conc. pCi/ℓ	1976 ^{137}Cs Urine Conc. nCi/ℓ	1978 ^{90}Sr Urine Conc. pCi/ℓ	1978 ^{137}Cs Urine Conc. nCi/ℓ	1979 - Jan. ^{90}Sr Urine Conc. pCi/ℓ	1979 - Jan. ^{137}Cs Urine Conc. nCi/ℓ	1979 - May ^{90}Sr Urine Conc. pCi/ℓ	1979 - May ^{137}Cs Urine Conc. nCi/ℓ	1980 - Aug. ^{90}Sr Urine Conc. pCi/ℓ	1980 - Aug. ^{137}Cs Urine Conc. nCi/ℓ
6097*							NA	16 ± 0.44	0.38 ± 0.98	0.33 0.064	0.81 ± 1.1	0.83 ± 0.097		
6109*							NA	16 ± 0.44			1.9 ± 1.3	0.11 ± 0.043		
6046							5.6 ± 1.2	13 ± 0.37			1.9 ± 1.3	0.11 ± 0.043		
6098									0.71 ± 0.69	0.69 ± 0.20				
6060									1.2 ± 0.82	1.7 ± 0.20	1.9 ± 1.4	0.59 ± 0.085		
6222											0.58 ± 1.3	ND		
6110											4.4 ± 1.8	0.61 ± 0.088		
525							2.2 ± 0.82	NA			3.7 ± 1.6	0.17 ± 0.059		
6064*							NA	16 ± 0.44	0.91 ± 0.45	2.0 ± 0.066	2.7 ± 0.91	1.8 ± 0.088		
6061							4.6 ± 0.91	14 ± 0.38						

Table 3 (Cont'd)

ID #	1973		1974		1976		1978		1979 - Jan.		1979 - May		1980 - Aug.	
	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ	^{90}Sr Urine Conc. pCi/ℓ	^{137}Cs Urine Conc. nCi/ℓ
6051											0.99 ± 0.84	0.20 ± 0.034		
934					5.4 ± 0.4	NA	8.2 ± 1.4	NA			2.6 ± 1.5	2.1 ± 0.16		
6062											10 ± 4.1	1.5 ± 0.13		
6035							9.9 ± 2.0	14 ± 0.37	4.3 ± 2.9	2.7 ± 0.13				
6115					5.1 ± 0.8	3.2 ± 0.2	6.0 ± 2.3	10 ± 0.33	0.61 ± 1.0	4.2 ± 0.21				
6034*							NA	16 ± 0.44			1.7 ± 1.6	0.57 ± 0.082		
865					4.0 ± 0.4	1.4 ± 0.2					1.4 ± 1.1	0.71 ± 0.059		
6036*							NA	16 ± 0.44						
6137									0.31 ± 0.87	0.36 ± 0.17				
6139									1.1 ± 12.3	ND				

Table 3 (Cont'd)

ID #	1973 ^{90}Sr Urine Conc. pCi/ℓ	1973 ^{137}Cs Urine Conc. nCi/ℓ	1974 ^{90}Sr Urine Conc. pCi/ℓ	1974 ^{137}Cs Urine Conc. nCi/ℓ	1976 ^{90}Sr Urine Conc. pCi/ℓ	1976 ^{137}Cs Urine Conc. nCi/ℓ	1978 ^{90}Sr Urine Conc. pCi/ℓ	1978 ^{137}Cs Urine Conc. nCi/ℓ	1979 - Jan. ^{90}Sr Urine Conc. pCi/ℓ	1979 - Jan. ^{137}Cs Urine Conc. nCi/ℓ	1979 - May ^{90}Sr Urine Conc. pCi/ℓ	1979 - May ^{137}Cs Urine Conc. nCi/ℓ	1980 - Aug. ^{90}Sr Urine Conc. pCi/ℓ	1980 - Aug. ^{137}Cs Urine Conc. nCi/ℓ
6140									5.7 ± 6.9	0.17 ± 0.11				
6144									0.82 ± 0.76	0.13 ± 0.050				
6148									0.33 ± 0.73	0.13 ± 0.051	0.22 ± 0.98	0.10 ± 0.050		
6151									3.1 ± 1.5	0.96 ± 0.11	1.7 ± 1.0	1.9 ± 0.091		
6152									2.1 ± 2.5	ND	-0.35 1.2	ND		
6155					3.4 ± 0.6	0.50 ± 0.10			1.7 ± 0.73	2.5 ± 0.16	3.9 ± 1.2	0.82 ± 0.94		
6159					2.4 ± 0.2	1.2 ± 0.2			0.17 ± 0.23	0.13 ± 0.022	0 ± 1.33	0.059 ± 0.027		
6160									5.7 ± 0.95	2.8 ± 0.17	0.27 ± 0.81	0.33 ± 0.066		
6163									0.38 ± 0.42	0.16 ± 0.054				
6165									0.85 ± 0.89	0.075 ± 0.011				

Table 3 (Cont'd)

ID #	1973 ^{90}Sr Urine Conc. pCi/ℓ	1973 ^{137}Cs Urine Conc. nCi/ℓ	1974 ^{90}Sr Urine Conc. pCi/ℓ	1974 ^{137}Cs Urine Conc. nCi/ℓ	1976 ^{90}Sr Urine Conc. pCi/ℓ	1976 ^{137}Cs Urine Conc. nCi/ℓ	1978 ^{90}Sr Urine Conc. pCi/ℓ	1978 ^{137}Cs Urine Conc. nCi/ℓ	1979 - Jan. ^{90}Sr Urine Conc. pCi/ℓ	1979 - Jan. ^{137}Cs Urine Conc. nCi/ℓ	1979 - May ^{90}Sr Urine Conc. pCi/ℓ	1979 - May ^{137}Cs Urine Conc. nCi/ℓ	1980 - Aug. ^{90}Sr Urine Conc. pCi/ℓ	1980 - Aug. ^{137}Cs Urine Conc. nCi/ℓ
6167									0.02± 0.52	0.081± 0.045	1.5 ± 1.2	ND		
6175											2.7 ± 1.4	ND		
6181											8.2 ± 11.3	ND		
Sample Size	2	2	1	2	9	8	16	18	28	26	27	21		
Mean	8.2	1.7	3.8	2.1	6.0	1.5	5.3	13	1.6	2.1	2.4	0.74		
Stnd. Dev.	4.8	0.64	-	1.6	5.2	0.79	3.0	4.6	1.7	1.9	2.6	0.63		
Low	4.8	1.2	-	1.0	1.5	0.50	2.0	3.6	0	.075	-0.35	0.046		
High	11.6	2.1	-	3.2	9.6	3.2	13	19	5.7	6.5	10	2.1		

Table 4

Urine Activity Concentrations for Former Adolescent Residents of Bikini Atoll

1978, 1979, and 1980

		1978		Jan. 1979		May 1979		August 1980	
ID #	Sex	^{90}Sr pCi/ℓ	^{137}Cs nCi/ℓ	^{90}Sr pCi/ℓ	^{137}Cs nCi/ℓ	^{90}Sr pCi/ℓ	^{137}Cs nCi/ℓ	^{90}Sr pCi/ℓ	^{137}Cs nCi/ℓ
6127	M	1.7±0.54	NA	2.2 ±0.77	0.66±0.037	1.4 ± 1.5	0.28±0.066		
6132	M	11 ±2.4	30 ± .55						
6011	M	29 ±3.1	18 ±0.43			33 ± 3.9	0.53±0.083		
6065	M					3.0 ± 1.2	0.18±0.052		
6169	M					0.78± 0.96	ND		
6178	M					1.3 ± 1.3	ND		
6183	M					4.4 ± 5.0	ND		
6200	M					4.6 ± 1.5	1.1 ±0.11		
6131*	M	NA	16 ±0.44			1.9 ± 1.2	0.79±0.095		
6207	M					-1.0 ±18	ND		
Sample Size		3	3	1	1	9	5		
Mean		14	21	2.2	0.66	5.5	0.58		
Stnd. Dev.		14	7.6	-	-	11	0.38		
Low		1.7	16	-	-	-1.0	0.18		

Table 4 (Cont'd)

ID #	Sex	1978 ^{90}Sr pCi/ℓ	1978 ^{137}Cs nCi/ℓ	Jan. 1979 ^{90}Sr pCi/ℓ	Jan. 1979 ^{137}Cs nCi/ℓ	May 1979 ^{90}Sr pCi/ℓ	May 1979 ^{137}Cs nCi/ℓ	August 1980 ^{90}Sr pCi/ℓ	August 1980 ^{137}Cs nCi/ℓ
High		29	30	-	-	13	1.1		
6129	F			0.47±4.3	3.2 ±0.24				
6091	F					17 ±14	0.57±0.11		
6173	F					5.5 ± 2.0	ND		
6048	F					-0.11±10	0.18 ±0.13		
6212	F					-0.04± 1.5	ND		
Sample Size				1	1	4	2		
Mean				0.47	3.2	5.6	0.38		
Stnd Dev				-	-	8.0	0.28		
Low				-	-	0.11	0.18		
High				-	-	17	0.57		

Body Burdens & Dose Assessm't for Bikini Is. Residents-Draft

DRAFT - March 10, 1981

Body Burdens and Dose Assessment for Bikini Island Residents - 1969-1980

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^{137}Cs and ^{90}Sr body burden measurements were conducted on the residents of Bikini Atoll from 1970 to 1980. During this time, the mean adult ^{90}Sr body burden rose to 78 Bq while the mean adult ^{137}Cs body burden rose to 78 kBq. Following the departure of the residents from Bikini Atoll, body burden measurements were conducted in January and May 1979 and August 1980 to determine the elimination rate of ^{137}Cs and ^{90}Sr for the Marshallese population. Using these data, the dose equivalents during and post the residence period on Bikini Atoll (committed dose equivalent) have been calculated. The mean adult total body dose equivalent from internal and external sources of radiation was approximately 10 mSv (1000 mRem). The mean adult total body committed dose equivalent was 11 mSv (1100 mRem).

INTRODUCTION

Bikini Atoll was one area used by the U.S. government to test nuclear weapons from 1946 to 1958. Prior to commencement of the testing program, all

Table 5

Urine Activity Concentrations for Former Children

Residents of Bikini Atoll - 1979, 1980

		May 1979		August 1980
ID #	Sex	^{90}Sr pCi/ℓ	^{137}Cs nCi/ℓ	
6172	M	3.9 ± 1.5	N.D.	
6156	M	2.7 ± 1.3	N.D.	
6009	M	6.8 ± 3.8	0.15 ±0.052	
6012	M	11 ± 3.4	0.31 ±0.060	
6014	M	3.5 ± 2.2	0.093±0.030	
6043	M	22 ±23	N.D.	
6202	M	6.8 ± 9.4	0.071±0.049	
6208	M	-.43± 1.1	N.D.	
Sample Size		8	4	
Mean		7.0	0.16	
Stnd. Dev.		6.9	0.11	
Low		-0.43	0.071	
High		22	0.31	
6203	F	-.32±15	N.D.	
6204	F	-.22± 1.7	1.0 ±0.11	
6213	F	-.15± 1.8	N.D.	
6217	F	-.08± 3.7	N.D.	
Sample Size		4	1	
Mean		-0.19	1.0	

Table 5 (Cont'd)

ID #	Sex	May 1979 ^{90}Sr pCi/ℓ	May 1979 ^{137}Cs nCi/ℓ	August 1980
Stnd. Dev.		.10	-	
Low		-0.33	-	
High		-0.08	-	

Table 6

Transuranic Urine Activity Concentrations at Bikini Atoll Residents: 1975-1977

ID #	Name	EML 1970 ^{239}Pu fCi/ℓ	EML 1971 ^{239}Pu fCi/ℓ	EML 1974 ^{239}Pu fCi/ℓ	EML 1975 Fall ^{239}Pu fCi/ℓ	EML 1976 Spring ^{239}Pu fCi/ℓ	EML 1976 Fall ^{239}Pu fCi/ℓ	BNWL 1977 Spring ^{239}Pu fCi/ℓ	BNWL 1977 Spring ^{239}Pu fCi/ℓ	LASL 1977 Spring ^{239}Pu fCi/ℓ	LASL 1977 Fall ^{239}Pu fCi/ℓ
No ID	Boas	-	-	-	-	-	-	-	-	<10	-
6159	Edwila	-	-	60	-	-	-	-	-	-	-
813	Jerry Joel	-	-	-	-	-	-	.73±0.53	0.48 ±0.45	<10	<10
6166	Aldji	-	-	10	-	-	-	-	-	-	-
6125	Harold J.	-	-	-	-	-	-	.73±0.53	0.48 ±0.45	<10	
No ID	Tatus	-	-	10	-	-	-	-	-	-	-
966	Joji	-	-	10	-	-	-	-.01±0.64	-0.50 ± .53	-	<10
6167	Rosa	-	-	10	-	-	-	0.73±0.53	0.48 ±0.45	-	-
864	Bero	-	-	9	-	-	6.2± 1.4	1.02±0.63	0.51 ±0.43	-	<10
No ID	Joimea	-	-	10	-	-	-	-	-	-	-
No ID	Iaaw	-	-	-	-	-	-	-	-	<10	-
6161	Bima	-	-	4	-	-	-	-	-	-	-
No ID	Steve	-	-	-	-	-	-	-	-	<10	-
934	Libwe	-	-	20	-	-	-	-	-	-	-
6117	Rinton	-	-	-	-	-	-	0.73±0.53	0.48 ±0.45	-	-

Table 6 (Cont'd)

ID #	Name	EML 1970 ^{239}Pu fCi/ℓ	EML 1971 ^{239}Pu fCi/ℓ	EML 1974 ^{239}Pu fCi/ℓ	EML 1975 Fall ^{239}Pu fCi/ℓ	EML 1976 Spring ^{239}Pu fCi/ℓ	EML 1976 Fall ^{239}Pu fCi/ℓ	BNWL 1977 Spring ^{239}Pu fCi/ℓ	BNWL 1977 Spring ^{239}Pu fCi/ℓ	LASL 1977 Spring ^{239}Pu fCi/ℓ	LASL 1977 Fall ^{239}Pu fCi/ℓ
6128	Tatac	-	-	-	-	-	-	0.73±0.53	0.48 ±0.45	-	-
							7.2± 7.2	0.46±0.27	-0.041±0.093	-	-
6067	Widkaj	-	-	-	-	-	3.9± 0.7	-	-	-	-
6001	Andrew Jakeo	-	-	20	-	-	3.7± 3.7	-	-	-	-
6067	Jambo	-	-	-	-	-	21. ±21.	-	-	-	-
6210	Bear	-	-	-	-	-	19. ±19.	-	-	-	-
6126	Jandrik	-	-	-	-	-	12. ±12.	-	-	-	-
No ID	Kelsa Joash	-	-	-	-	-	3.4± 3.4	-	-	-	-
	Pooled	3	4	-	11±2	9±2	3.2± 2.1	-	-	-	-
		2	4	-	12±2	-	-	-	-	-	-
	Urine G	20	-	-	-	-	-	-	-	-	-
	Urine H	24	-	-	-	-	-	-	-	-	-
Controls											
	Ebeye	-	-	-	-	-	1.0± 0.6	-	-	-	-
	Wotje	-	-	-	-	-	1.4± 1.4	-	-	-	-
	Majuro Hospital	-	-	-	-	-	3.5± 3.5	-	-	-	-
	Majuro Polio Wing	-	-	-	-	-	2.0± 2.0	-	-	-	-
	BNL	-	-	-	-	-	1.7± 1.7	-	-	-	-

Table 7

Five Day Consecutive Urine Concentrations for ^{137}Cs and ^{90}Sr: January 1979

	^{137}Cs					^{90}Sr				
		Standard Deviation of	Counting Error of	Range			Standard Deviation of	Counting Error of	Range	
ID #	Mean nCi/ℓ	Mean nCi/ℓ	Mean nCi/ℓ	Low nCi/ℓ	High nCi/ℓ	Mean pCi/ℓ	Mean pCi/ℓ	Mean pCi/ℓ	Low pCi/ℓ	High pCi/ℓ
55	0.32	0.13	0.015	0.21	0.50	0.41	0.41	0.12	0.12	1.1
58	0.40	0.16	0.016	0.21	0.60	-0.03	0.35	0.12	-0.41	0.50
6159	0.13	0.039	0.011	0.064	0.16	0.17	0.47	0.12	-0.19	0.92
6118	3.5	1.0	0.043	2.1	4.9	1.4	1.6	0.30	0.48	4.2
57	0.18	0.039	0.012	0.12	0.23	0.27	0.65	0.17	-0.86	0.78
6066	1.3	1.1	0.082	0.41	3.1	1.5	2.5	5.5	-0.30	5.8
6112	6.5	2.9	0.064	2.0	9.8	.082	0.57	0.45	-0.71	0.73
6060	1.7	0.49	0.10	1.2	2.5	1.2	0.47	0.41	0.86	1.86
6064	2.0	0.36	0.033	1.5	2.4	0.91	1.4	0.22	0.14	3.2
6067	5.2	0.47	0.052	4.5	5.8	0.54	0.42	0.13	0	1.2
6070	6.3	1.1	0.070	5.0	7.0	2.8	0.90	0.35	2.1	3.8
6035	2.7	0.19	0.069	2.5	2.9	4.3	2.1	1.4	2.4	6.5
6161	0.33	0.11	0.015	0.23	0.48	0.86	0.79	0.20	0.12	2.1
254	0.26	0.067	0.013	0.19	0.34	0.16	0.21	0.14	-.060	0.45

Table 7 (Cont'd)

ID #	Mean nCi/ℓ	^{137}Cs Standard Deviation of Mean nCi/ℓ	Counting Error of Mean nCi/ℓ	Range Low nCi/ℓ	Range High nCi/ℓ	Mean pCi/ℓ	^{90}Sr Standard Deviation of Mean pCi/ℓ	Counting Error of Mean pCi/ℓ	Range Low pCi/ℓ	Range High pCi/ℓ
255	0.23	0.11	0.013	0.10	0.39	-0.20	0.46	0.37	-0.81	0.43
257	0.19	0.044	0.010	0.13	0.25	-0.26	0.22	0.18	-0.02	.49
N	16									
$\bar{X}$	2.0	0.52	0.064	9.8	1.7	1.1	0.25	0.64	0.12	2.1

Table 8

Summary of System Efficiency and MDLS for Field WBC System

Nuclide	Energy	Efficiency	MDL	Time
^{137}Cs	662 KeV	8.7×10^{-3}	37 Bq (1 nCi)	900 sec
^{60}Co	1173 & 1334 KeV	6.7×10^{-3}	37 Bq (1 nCi)	900 sec
^{40}K	1460 KeV	7.0×10^{-3}	222 Bq (6 nCi)	900 sec

Table 9

Body Burden Data for Medically Registered Adult Males Relocated from Bikini Atoll

				1974[1]		1977[2]		1978			January 1979			May 1979			August 1980		
Medical ID	Weight in Kilograms	Age (Yr)	Years on Bikini	Potassium grams	^{137}Cs μCi	Potassium grams	^{137}Cs μCi	Potassium grams	^{60}Co nCi	^{137}Cs μCi	Potassium grams	^{60}Co nCi	^{137}Cs μCi	Potassium grams	^{60}Co nCi	^{137}Cs μCi	Potassium grams	^{60}Co nCi	^{137}Cs μCi
80	61	69	0.75	-	-	-	-	97.6	1.42	1.14	-	-	-	133	-	0.12	-	-	-
6006	63	37	0.75	-	-	-	-	141	2.39	1.47	-	-	-	123*	-	0.163*	134	-	.037
863	67	27	4	-	-	146	0.729	156	4.93	2.34	179	2.5	1.1	-	-	-	204	1.2	.087
6070	85	28	10	170	0.093	167	1.51	152	8.17	3.92	137	3.0	1.6	-	-	-	-	-	-
6004	95	28	0.25	-	-	-	-	167	1.88	1.33	-	-	-	-	-	-	-	-	-
6033	79	27	6	148	0.095	136	1.52	132	8.65	3.84	-	-	-	-	-	-	127	-	.035
6018	89	34	6	198	0.22	-	-	180	14.3	5.88	-	-	-	-	-	-	-	-	-
6069	61	32	8	-	-	-	-	132	4.01	1.17	-	-	-	166	2.0	0.38	-	-	-
6068	79	56	6	165	0.051	144	0.778	141	6.17	3.07	-	-	-	-	-	-	139	-	.029
6067	74	56	7	-	-	-	-	151	5.91	2.99	137	2.4	1.0	169	1.2	0.63	164	1.2	.088
6066	94	32	3	-	-	-	-	168	2.04	0.820	171	1.2	0.48	197	-	0.45	-	-	-
6017	80	49	8	-	-	-	-	153	13.9	5.72	-	-	-	165	1.5	0.52	145	-	.042
6019	60	48	5	-	-	119	0.791	107	3.95	1.03	135	2.9	0.39	-	-	-	139	1.5	.0066
6001	85	66	7	143	0.078	-	-	126	3.33	1.73	132	1.9	0.77	-	-	-	160	-	.055
6073	85	24	7	-	-	132	0.775	127	4.19	2.18	-	-	-	134	-	0.12	160	1.4	.16
6005	70	58	1.5	-	-	-	-	133	3.40	2.08	-	-	-	177	1.1	0.16	154	-	.0070
6008	55	32	4	-	-	153	1.99	125	5.00	1.94	148	3.2	1.3	-	-	-	152	1.5	.10
6086	78	46	8	170	0.17	149	2.14	151	7.92	3.51	179	2.8	0.86	161	1.9	0.40	186	1.0	.029
6071	78	32	0.75	-	-	-	-	136	2.26	1.72	136	1.2	0.93	-	-	-	185	-	.058
6076	69	39	3	-	-	-	-	163	6.64	3.44	171	2.9	2.4	-	-	-	232	1.1	.15
6072	55	20	0.67	-	-	-	-	128	2.96	1.75	-	-	-	-	-	-	-	-	-
813	58	23	4	-	-	143	0.995	138	3.65	1.69	154	1.8	0.61	-	-	-	-	-	-
6118	55	22	6	126	0.77	-	-	108	1.92	0.631	144	1.6	0.75	126	0.9	0.41	111	-	.028
6126	55	35	2	-	-	149	2.21	137	7.79	3.30	-	-	-	-	-	-	141	-	.032
6003	77	22	8	168	0.076	161	0.923	139	5.60	2.44	-	-	-	-	-	-	-	-	-
6117	80	22	6	-	-	169	1.15	148	6.09	2.68	172	2.9	0.90	168	1.5	0.44	177	-	.022
6128	52	31	7	-	-	149	1.29	119	4.79	1.85	155	2.7	0.92	-	-	-	138	1.0	.042
6125	64	35	9	159	0.10	150	1.54	144	5.65	2.52	-	-	-	164	2.0	0.33	169	1.4	.021
6007	82	35	0.58	-	-	-	-	127	2.58	1.49	144	0.67	0.32	-	-	-	175	-	.018
6130	69	29	0.42	-	-	-	-	143	2.20	1.46	156	1.5	1.5	134	-	0.97	111	-	.065
6119	54	17	7	-	-	138	0.641	124	4.58	2.13	-	-	-	-	-	-	-	-	-
864	90	51	7	163	0.29	133	3.23	136	5.99	3.05	-	-	-	-	-	-	-	-	-
966	75	56	7	-	-	162	2.22	174	14.8	5.71	-	-	-	149	2.5	0.48	155	-	.021
6135	81	35	1	-	-	-	-	142	3.30	2.12	-	-	-	-	-	-	190	-	.10
6096	66	48	3	-	-	145	1.93	146	4.12	1.91	146	2.5	1.3	156	0.9	0.7	120	-	.053
6002	66	65	2	-	-	130	1.04	116	2.21	1.26	-	-	-	-	-	-	-	-	-
6161[3,4]	64	34	5	130	0.081	-	-	-	-	-	142	-	0.109	126	-	0.048	-	-	-
6166[3,4]	64	58	7	150	0.072	-	-	-	-	-	146	-	0.023	146	-	0.011	146	-	.0028
6184[4]	50	59	5	160	0.043	-	-	-	-	-	130	-	0.067	144	-	0.025	148	-	.0073
6210[4]	85	35	10	156	0.124	141	0.74	-	-	-	-	-	-	160	-	0.29	145	-	.029

[1]Conard, R.A., BNL 50424.

[2]Personal communication with S. Cohn.

[3]Individuals left Bikini Atoll 8 months prior to the August 1978 Relocation Program.

[4]Individuals received sick call medical care prior to April 1978 but were not officially registered.

*Data obtained August 1979.

Table 22 (Cont'd)

Comparison Adult Females from Kili

Name	ID#	Age	August 1980	
			^{137}Cs uCi	Potassium Grams
	2119	45	$2.5x10^{-3}$	99

PRIVACY ACT MATERIAL REMOVED

Table 10

Body Burden Data for Medically Registered Adult Females Relocated from Bikini Atoll

Medical ID	Weight in Kilograms	Age (Yr)	Years on Bikini	1974[1] Potassium grams	1974[1] ^{137}Cs μCi	1977[2] Potassium grams	1977[2] ^{137}Cs μCi	1978 Potassium grams	1978 ^{60}Co nCi	1978 ^{137}Cs μCi	January 1979 Potassium grams	January 1979 ^{60}Co nCi	January 1979 ^{137}Cs μCi	May 1979 Potassium grams	May 1979 ^{60}Co nCi	May 1979 ^{137}Cs μCi	August 1980 Potassium grams	August 1980 ^{60}Co nCi	August 1980 ^{137}Cs μCi
6045	83	28	0.75	-	-	-	-	95	1.79	1.15	-	-	-	116*	-	0.075*	130	-	.019
6112	90	35	1	-	-	-	-	96	2.18	1.76	94	1.6	0.98	118	-	0.46	109	-	.023
6114	54	32	0.75	-	-	-	-	79	1.40	0.818	102	-	0.12	-	-	-	119	-	.0055
6111	84	32	0.5	-	-	-	-	100	2.11	1.31	107	1.2	0.53	-	-	-	108	-	.021
6122	73	70	10	94	0.033	-	-	86	3.20	1.34	93	1.9	0.31	90	1.1	0.11	96	-	.0050
6123	77	50	4	-	-	107	1.53	99	3.81	1.41	126	2.5	0.62	97	-	0.25	104	1.3	.011
6059	45	19	1	-	-	-	-	80	1.33	0.861	-	-	-	-	-	-	105	-	.0033
6063	49	24	4	-	-	89.6	0.799	81	3.16	1.52	-	-	-	-	-	-	-	-	-
6032	63	32	3	-	-	96.4	1.88	100	5.49	3.07	94	1.7	0.77	109	1.0	0.26	93	-	.0044
6124	53	54	0.58	-	-	-	-	71	1.27	0.957	-	-	-	-	-	-	85	-	.0064
6108	86	24	4	94	0.029	98.0	0.706	93	2.48	0.729	114	1.6	0.53	-	-	-	112	-	.022
6058	66	18	5	106	0.077	88.8	0.690	92	4.63	2.08	-	-	-	-	-	-	-	-	-
6113	54	25	4	-	-	91.7	0.534	91	2.33	1.03	107	1.1	0.30	107	-	0.11	97	-	.0064
6065	52	19	4	-	-	101	0.734	93	2.39	1.06	96	1.3	0.36	-	-	-	112	-	.0080
6097	53	19	4	86	0.036	88.9	0.468	90	2.15	1.27	95	1.0	0.34	86	-	0.16	99	-	.017
6109	50	15	4	-	-	110	0.621	88	1.49	0.411	106	-	0.060	116	-	0.018	92	-	.0013
6046	88	43	1.75	-	-	94.3	0.833	100	3.81	2.10	-	-	-	104	1.2	0.36	88	-	.022
6098	60	16	3	-	-	91.4	0.706	93	2.38	.891	66	1.2	0.47	92	-	0.18	101	-	.0030
6060	55	22	2	-	-	-	-	81	2.00	1.39	105	-	0.18	115	-	0.059	-	-	-
6036	56	27	0.34	-	-	-	-	73	1.54	1.53	-	-	-	-	-	-	-	-	-
6110	77	32	8	111	0.11	-	-	94	3.98	1.50	-	-	-	110	-	0.11	116	1.4	.0083
525	78	37	0.75	-	-	-	-	106	2.96	2.36	-	-	-	109	-	0.32	98	-	.014
6064	60	30	7	-	-	-	-	83	2.55	0.907	74	1.6	0.42	88	-	0.22	87	-	.011
6061	65	32	6	-	-	-	-	81	3.62	2.22	-	-	-	-	-	-	-	-	-
6051	50	19	5	-	-	95.9	0.545	88	2.25	1.44	-	-	-	83	-	0.045	92	-	.19
934	74	43	6	-	-	98.8	2.23	110	10.8	5.48	-	-	-	104	2.1	0.48	108	-	.022
6062	54	21	4	-	-	96.8	0.840	79	2.53	1.44	-	-	-	100	-	0.088	97	-	.0035
6035	77	20	6	-	-	113	0.573	100	4.94	2.78	100	2.3	0.65	-	-	-	-	-	-
6115	56	43	7	95	0.058	85.9	1.15	80	4.16	2.28	84	1.8	0.48	95	2.0	0.17	93	-	.0068
6034	76	46	7	102	0.12	93.7	0.995	92	6.92	3.89	-	-	-	104	-	0.15	86	1.2	.0075
865	54	45	7	59	0.018	89.4	0.558	78	1.70	1.31	-	-	-	82	1.0	0.13	-	-	-
6050	62	22	2	-	-	112	1.14	81	3.42	1.40	-	-	-	-	-	-	89	-	.014
6167[3,4]	60	59	7	89	0.030	-	-	-	-	-	92	-	0.015	97	-	0.0079	88	-	.0032
6159[3,4]	111	27	4	124	0.073	-	-	-	-	-	115	-	0.028	125	-	0.012	127	-	.023
6148[3]	94	42	3	60	0.018	-	-	-	-	-	90	-	0.037	96	-	0.015	96	-	.0055
6163[3,5]	84	38	-	-	-	142	0.570	-	-	-	136	-	0.061	-	-	-	-	-	-
6151[3]	82	31	2	-	-	102	0.971	-	-	-	87	-	0.121	77	-	0.059	-	-	-

[1] Conard, R.A., BNL 50424.
[2] Personal communication with S. Cohn.
[3] Individuals received sick call medical care prior to April 1978 but were not officially registered.
[4] Individuals left Bikini Atoll 8 months prior to the August 1978 Relocation Program.
[5] Individuals left Bikini Atoll 14 months prior to the August 1978 Relocation Program.
*Data obtained August 1979.

Table 11

Body Burden Data for Medically Registered Adolescents Relocated from Bikini Atoll

Medical ID	Weight in Kilograms	Age (Yr)	Years on Bikini	1977 Potassium grams	1977 ^{137}Cs μCi	1978 Potassium grams	1978 ^{60}Co nCi	1978 ^{137}Cs μCi	January 1979 Potassium grams	January 1979 ^{60}Co nCi	January 1979 ^{137}Cs μCi	May 1979 Potassium grams	May 1979 ^{60}Co nCi	May 1979 ^{137}Cs μCi	August 1980 Potassium grams	August 1980 ^{137}Cs μCi
Males																
6147	36	12	4.5	84	0.959	-	-	-	53	-	0.204	94	-	0.075	95	.0035
6132	33	12	2	-	-	58	3.45	1.85	-	-	-	-	-	-	82	.0038
6131	38	14	6	96	1.33	69	3.40	1.69	108	2.1	0.76	133	1.4	0.32	139	.015
6011	40	11	6	-	-	53	1.34	0.830	59	1.0	0.055	74	-	0.017	99.7	.0009
6127	32	13	7	91	0.824	53	2.17	0.732	95	2.0	0.21	60	-	0.053	92	.0033
6133	27	11	7	-	-	53	3.42	2.09	-	-	-	55	1.0	0.022	59	-
6015	29	11	1.42	-	-	57	1.18	1.28	37	-	0.071	60	-	0.016	-	-
Females																
6129	48	13	4	91	0.682	69	1.32	.744	73	1.2	0.27	89	-	0.076	100	.0044
6048	40	13	0.25	-	-	70	2.61	2.05	-	-	-	121	-	0.074	108	.0014
6091	43	13	6	-	-	69	2.20	1.17	103	1.4	0.15	86	-	0.037	-	-

Table 12

Body Burden Data for Medically Registered Children Relocated from Bikini Atoll

Medical ID	Weight in Kilograms	Age (Yr)	Years on Bikini	1978 Potassium grams	1978 ^{60}Co nCi	1978 ^{137}Cs μCi	January 1979 Potassium grams	January 1979 ^{137}Cs μCi	May 1979 Potassium grams	May 1979 ^{137}Cs μCi	August 1980 Potassium grams	August 1980 ^{137}Cs μCi
Males												
6009	20	6	4	36	0.98	1.26	-	-	59	0.007	88	.0010
6049	23	8	2	47	2.7	1.71	-	-	-	-	59	.0032
6042	23	7	0.25	43	1.0	1.07	-	-	-	-	-	-
6014	20	5	1.34	41	1.7	1.50	-	-	69	0.012	46	-
6012	24	7	7	41	1.7	1.27	-	-	63	0.022	58	.0025
6023	28	8	4	52	1.7	1.28	43	0.16	-	-	71	-
6016	27	10	7	53	2.5	1.43	-	-	51	0.039	62	.0014
6013	18	5	2	33	1.3	1.00	-	-	-	-	-	-
6031*	20	5	3	-	-	-	-	-	35	0.0028	37	-
6029	20	6	5	-	-	-	-	-	25	0.0047	48	.0009
6100*	17	5	4.3	-	-	-	-	-	24	0.015	43	-
6021*	19	5	4.3	-	-	-	NC	0.046	51	0.0062	49	-
6020	20	6	2	-	-	-	72	0.056	37	0.0074	38	-
6107*	15	5	4.3	-	-	-	46	0.016	40	0.0026	37	-
6074*	20	5	4.3	-	-	-	34	.009	25	-	-	-
6116*	14	5	3	-	-	-	-	-	-	-	33	-
Females												
6094	34	10	6	51	2.3	2.02	-	-	-	-	-	-
6092	29	8	6	52	2.8	2.25	-	-	-	-	-	-
6080	34	7	0.58	50	-	0.543	-	-	-	-	-	-
6010	29	8	7	56	1.8	1.41	50	0.17	-	-	71	.0021
6038	21	6	2	42	1.3	1.00	-	-	-	-	53	.0019
6105	22	5	3	31	1.2	0.967	65	0.053	29	0.0074	51	-
6103	-	9	3	48	1.4	1.40	-	-	-	-	99	.0046
6028	25	7	5	52	1.4	1.26	-	-	49	0.015	75	.0011
6030	34	10	3	54	3.0	2.38	34	0.26	70	0.064	63	.0018
6027	22	6	3	36	5.6	1.16	58	0.042	-	-	56	-
6044	18	6	5	35	6.4	1.15	-	-	36	0.0062	-	-
6025	21	5	3	44	0.97	1.03	45	0.13	67	0.028	52	-
6081	26	9	0.67	49	-	1.02	-	-	-	-	-	-
6106	22	6	3	32	-	0.622	37	0.077	44	0.013	53	-
6078*	17	5	-	-	-	-	28	0.0030	-	-	-	-
6088*	15	5	4.3	-	-	-	-	-	33	0.0030	-	-
6090	25	6	5	-	-	-	-	-	31	0.0049	47	-
6101	19	6	5.3	-	-	-	12	0.051	15	0.0069	36	-
6056*	17	6	4.3	-	-	-	NC	0.046	49	0.0074	41	-
6057	26	7	1	-	-	-	-	-	66	0.0058	33	-
6079*	19	5	3	-	-	-	-	-	-	-	33	-

NC = Not calculated
*Individuals less than 5 years of age on 4/27/78

Table 11

Summary of ^{137}Cs Body Burdens for Bikini Inhabitants, 1974 to 1979

Population	Number Counted 1974(5)	Range of ^{137}Cs Results 1974(5)	Mean ^{137}Cs Results 1974(5)	Number Counted 1977(5)	Range of ^{137}Cs Results 1977(5)	Mean ^{137}Cs Results 1977(5)	Number Counted 1978	Range of ^{137}Cs Results 1978	Mean ^{137}Cs Results 1978
Adult Male	18	1.6 kBq (0.043 μCi) to 15 kBq (0.40 μCi)	4.7 kBq (0.13 μCi) ± 3.4 kBq (.093 μCi)	22	21 kBq (0.57 μCi) to 120 kBq (3.2 μCi)	48 kBq (1.3 μCi) ± 27 kBq (0.73 μCi)	36(1)	23 kBq (0.63 μCi) to 220 kBq (5.9 μCi)	90 kBq (2.4 μCi) ± 49 kBq (1.3 μCi)
Adult Female	13	0.67 kBq (0.018 μCi) to 9.3 kBq (0.25 μCi)	2.7 kBq (0.073 μCi) ± 2.3 kBq (0.063 μCi)	20	20 kBq (0.53 μCi) to 81 kBq (2.2 μCi)	34 kBq (0.93 μCi) ± 17 kBq (0.47 μCi)	32	15 kBq (0.41 μCi) to 200 kBq (5.5 μCi)	62 kBq (1.7 μCi) ± 37 kBq (1.0 μCi)
Male Children 11-15 yrs	0	ND	ND	3	24 kBq (0.65 μCi) to 39 kBq (1.0 μCi)	30 kBq (0.82 μCi) ± 7.6 kBq (0.21 μCi)	6(2)	27 kBq (0.73 μCi) to 77 kBq (2.1 μCi)	53 kBq (1.4 μCi) ± 21 kBq (0.56 μCi)
Female Children 11-15 yrs	0	ND	ND	3	20 kBq (0.56 μCi) to 35 kBq (0.94 μCi)	25 kBq (0.68 μCi) ± 8.5 kBq (0.23 μCi)	3	28 kBq (0.76 μCi) to 76 kBq (2.1 μCi)	46 kBq (1.3 μCi) ± 25 kBq (0.66 μCi)
Male Children 5-10 yrs	0	ND	ND	0	ND	ND	8(3)	37 kBq (1.0 μCi) to 64 kBq (1.7 μCi)	50 kBq (1.3 μCi) ± 7.6 kBq (0.21 μCi)
Female Children 5-10 yrs	0	ND	ND	0	ND	ND	14	20 kBq (0.54 μCi) to 92 kBq (2.4 μCi)	47 kBq (1.3 μCi) ± 21 kBq (0.56 μCi)
All Adults	31	0.67 kBq (0.018 μCi) to 15 kBq (0.40 μCi)	3.9 kBq (0.11 μCi) ± 3.1 kBq (0.085 μCi)	42	20 kBq (0.53 μCi) to 120 kBq (3.2 μCi)	42 kBq (1.1 μCi) ± 24 kBq (0.64 μCi)	68	15 kBq (0.41 μCi) to 220 kBq (5.9 μCi)	77 kBq (2.1 μCi) ± 46 kBq (1.2 μCi)

Population	Number Counted Jan. 1979	Range of ^{137}Cs Results Jan. 1979	Mean ^{137}Cs Results Jan. 1979	Number Counted May 1979	Range of ^{137}Cs Results May 1979	Mean ^{137}Cs Results May 1979	Number Counted Aug. 1980	Range of ^{137}Cs Results Aug. 1980	Mean ^{137}Cs Results Aug. 1980
Adult Male	17	12 kBq (0.32 μCi) to 89 kBq (2.4 μCi)	37 kBq (1.0 μCi) ± 19 kBq (0.51 μCi)	18	0.41 kBq (0.011 μCi) to 36 kBq (0.97 μCi)	13 kBq (0.36 μCi) ± 9.5 kBq (0.26 μCi)	27	0.10 kBq (0.0028 μCi) to 5.9 kBq (0.16 μCi)	1.8 kBq (0.049 μCi) ± 1.5 kBq (0.041 μCi)
Adult Female	16	2.2 kBq (0.060 μCi) to 36 kBq (0.98 μCi)	16 kBq (0.44 μCi) ± 8.9 kBq (0.24 μCi)	23	0.29 kBq (0.0079 μCi) to 18 kBq (0.48 μCi)	6.1 kBq (0.16 μCi) ± 5.1 kBq (0.14 μCi)	28	0.048 kBq (0.0013 μCi) to 7.0 kBq (0.19 μCi)	0.44 kBq (0.012 μCi) ± 1.2 kBq (0.033 μCi)
Male Children 11-15 yrs	4	2.0 kBq (0.055 μCi) to 28 kBq (0.76 μCi)	10 kBq (0.27 μCi) ± 12 kBq (0.33 μCi)	6	0.59 kBq (0.016 μCi) to 12 kBq (0.32 μCi)	3.1 kBq (0.084 μCi) ± 4.4 kBq (0.12 μCi)	5	0.033 kBq (0.0009 μCi) to 0.56 kBq (0.015 μCi)	0.20 kBq (0.0053 μCi) ± 0.21 kBq (0.0055 μCi)
Female Children 11-15 yrs	2	5.6 kBq (0.15 μCi) to 10 kBq (0.27 μCi)	7.8 kBq (0.21 μCi) ± 3.1 kBq (0.084 μCi)	3	1.4 kBq (0.037 μCi) to 2.8 kBq (0.076 μCi)	2.3 kBq (0.062 μCi) ± 0.81 kBq (0.022 μCi)	2	0.052 kBq (0.0014 μCi) to 0.16 kBq (0.0044 μCi)	0.11 kBq (0.0029 μCi) ± 0.076 kBq (0.0021 μCi)
Male Children 5-10 yrs	1	5.9 kBq (0.16 μCi)	5.9 kBq (0.16 μCi)	10	0.10 kBq (0.0026 μCi) to 1.4 kBq (0.039 μCi)	0.44 kBq (0.012 μCi) ± 0.42 kBq (0.011 μCi)	5	0.033 kBq (0.0009 μCi) to 0.12 kBq (0.0032 μCi)	0.067 kBq (0.0018 μCi) ± 0.037 kBq (0.0010 μCi)
Female Children 5-10 yrs	6	1.6 kBq (0.042 μCi) to 9.6 kBq (0.26 μCi)	4.4 kBq (0.12 μCi) ± 3.0 kBq (0.080 μCi)	11	0.11 kBq (0.003 μCi) to 2.4 kBq (0.066 μCi)	0.56 kBq (0.015 μCi) ± 0.66 kBq (0.018 μCi)	5	0.041 kBq (0.0011 μCi) to 0.17 kBq (0.0046 μCi)	0.085 kBq (0.0023 μCi) ± [illegible] kBq (0.0017 μCi)
All Adults	33	2.2 kBq (0.060 μCi) to 89 kBq (2.4 μCi)	27 kBq (0.73 μCi) ± 18 kBq (0.49 μCi)	41	0.29 kBq (0.0079 μCi) to 36 kBq (0.97 μCi)	9.3 kBq (0.25 μCi) ± 8.1 kBq (0.22 μCi)	55	0.048 kBq (0.0013 μCi) to 7.0 kBq (0.19 μCi)	1.2 kBq (0.033 μCi) ± 1.5 kBq (0.041 μCi)

Table 13 (Cont'd)

Summary of ^{137}Cs Body Burdens for Bikini Inhabitants, 1974 to 1979

Population	Number Counted 1974(5)	Range of ^{137}Cs Results 1974(5)	Mean ^{137}Cs Results 1974(5)	Number Counted 1977(5)	Range of ^{137}Cs Results 1977(5)	Mean ^{137}Cs Results 1977(5)	Number Counted 1978	Range of ^{137}Cs Results 1978	Mean ^{137}Cs Results 1978
All Children	0	ND	ND	6	20 kBq (0.56 µCi) to 39 kBq (1.0 µCi)	28 kBq (0.75 µCi) ± 7.8 kBq (0.21 µCi)	31	20 kBq (0.56 µCi) to 92 kBq (2.5 µCi)	50 kBq (1.4 µCi) ± 18 kBq (0.49 µCi)
Total Average	31	0.67 kBq (0.018 µCi) to 15 kBq (0.40 µCi)	3.9 kBq (0.11 µCi) ± 3.1 kBq (0.085 µCi)	49	20 kBq (0.53 µCi) to 120 kBq (3.2 µCi)	40 kBq (1.1 µCi) ± 22 kBq (0.61 µCi)	99	15 kBq (0.41 µCi) to 220 kBq (5.9 µCi)	68 kBq (1.8 µCi) ± 38 kBq (1.0 µCi)

Population	Number Counted Jan. 1979	Range of ^{137}Cs Results Jan. 1979	Mean ^{137}Cs Results Jan. 1979	Number Counted May 1979	Range of ^{137}Cs Results May 1979	Mean ^{137}Cs Results May 1979	Number Counted Aug. 1980	Range of ^{137}Cs Results Aug. 1980	Mean ^{137}Cs Results Aug. 1980
All Children	11	1.6 kBq (0.042 µCi) to 28 kBq (0.76 µCi)	8.3 kBq (0.22 µCi) ± 7.8 kBq (0.21 µCi)	30	0.10 kBq (0.0026 µCi) to 12 kBq (0.32 µCi)	1.2 kBq (0.032 µCi) ± 2.2 kBq (0.059 µCi)	17	0.033 kBq (0.0009 µCi) to 0.56 kBq (0.015 µCi)	0.11 kBq (0.0031 µCi) ± 0.17 kBq (0.0046 µCi)
Total Average	46	1.6 kBq (0.042 µCi) to 89 kBq (2.4 µCi)	22 kBq (0.59 µCi) ± 18 kBq (0.49 µCi)	71	0.10 kBq (0.0026 µCi) to 36 kBq (0.97 µCi)	5.9 kBq (0.16 µCi) ± 7.4 kBq (0.20 µCi)	72	0.033 kBq (0.0009 µCi) to 7.0 kBq (0.19 µCi)	0.96 kBq (0.026 µCi) ± 1.5 kBq (0.040 µCi)

ND - No Data available for the specific column.

(1) One adult, counted at Bikini, was a visitor from Rongelap Atoll. He remained on ship with our staff while at Bikini and returned at Ebeye with us. His body count was not used in this table.

(2) One male child in this age group was counted twice to determine what effect showering prior to the body count had on the final result. Only one result was used for this individual since both results were similar.

(3) A six month old child's data has not been included in this table and category due to the difference in geometry between a baby and our calibration phantom.

(4) The 1978 mean value for all individual count includes the > 10 year age group while the 1977 mean value has no representation in this sample section and the 1974 mean value has no child representation.

(5) The 1974 (CO 75) and 1977 ^{137}Cs body burden data were obtained from S. Cohn, Brookhaven National Laboratory, Medical Department.

Table 14

Comparison of Observed
Versus Expected Reduction Factors

Description	# of Persons	Mean Reduction Factor
Expected Reduction Factor for Adult Males[1]	NA	2.4
Observed Reduction Factor for Adult Bikini Males	17	2.3
Expected Reduction Factor for Adult Females[2]	NA	3.5
Observed Reduction Factor for Adult Bikini Females	16	3.8
Expected Reduction Factor for Children Ages 5-14[2]	NA	5.9
Observed Reduction Factor for Children Ages 5-14	12	12.

NA = Data Not Available

(1) Effective half time obtained from ICRP Publication 10A (ICRP 71).

(2) Effective half time obtained from NCRP Report 52 (NCRP 77).

Table 15

^{137}Cs Biological Removal Rate Constants for Marshallese Adult Males

ID#	Date	^{137}Cs μCi	Date	^{137}Cs μCi	Date	^{137}Cs μCi	K d^{-1}	K d^{-1}	K d^{-1}
863	1/23/79	1.1	8/2/80	8.6×10^{-2}			4.7×10^{-3}		
6067	1/24/79	1.0	5/17/79	.63	8/1/80	8.8×10^{-2}	4.0×10^{-3}	4.5×10^{-3}	4.6×10^{-3}
6066	1/24/79	.48	5/18/79	.45			NA		
6017	5/21/79	.52	7/31/80	4.2×10^{-2}			6.2×10^{-3}		
6019	1/22/79	.39	7/31/80	6.8×10^{-3}			NA		
6001	1/22/79	.77	7/31/80	5.5×10^{-2}			5.0×10^{-3}		
6073	5/15/79	.12	8/1/80	1.6×10^{-1}			NA		
6005	5/21/79	.16	7/31/80	7.8×10^{-3}			NA		
6008	1/23/79	1.3	8/1/80	1.0×10^{-1}			4.7×10^{-3}		
6086	1/23/79	.86	5/16/79	.40	7/30/80	2.9×10^{-2}	6.7×10^{-3}	6.7×10^{-3}	6.7×10^{-3}
6071	1/23/79	.93	8/3/80	5.8×10^{-2}			5.2×10^{-3}		
6076	1/22/79	2.4	7/31/80	1.5×10^{-1}			5.0×10^{-3}		
6118	1/24/79	.75	5/17/79	.41	8/1/80	2.8×10^{-2}	5.3×10^{-3}	6.6×10^{-3}	6.9×10^{-3}
6117	1/24/79	.90	5/16/79	.44	7/31/80	2.2×10^{-2}	6.3×10^{-3}	7.6×10^{-3}	7.9×10^{-3}
6128	1/25/79	.92	8/4/80	4.2×10^{-2}			5.9×10^{-3}		
6125	5/18/79	.33	8/5/80	2.1×10^{-2}			7.4×10^{-3}		
6007	1/23/79	.32	8/4/80	1.8×10^{-2}			6.3×10^{-3}		
6130	1/22/79	1.5	5/15/79	.97	7/31/80	6.5×10^{-2}	3.8×10^{-3}	5.8×10^{-3}	6.4×10^{-3}
966	5/15/79	.48	7/31/80	2.1×10^{-2}			8.3×10^{-3}		
6096	1/22/79	1.3	5/16/79	.70	7/31/80	5.3×10^{-2}	5.4×10^{-3}	6.0×10^{-3}	6.2×10^{-3}
6161	1/24/79	.109	5/17/79	.048			7.4×10^{-3}		
6166	1/24/79	.023	5/16/79	.011	7/31/80	2.8×10^{-3}	7.3×10^{-3}	NA	NA

Table 15 (Cont'd)

^{137}Cs Biological Removal Rate Constants for Marshallese Adult Males (Cont'd)

ID#	Date	^{137}Cs μCi	Date	^{137}Cs μCi	Date	^{137}Cs μCi	K d^{-1}	K d^{-1}	K d^{-1}
6184	1/25/79	.067	5/17/79	.025	8/1/80	7.3×10^{-3}	9.1×10^{-3}	NA	NA
6210	5/21/79	.290	7/11/80	2.9×10^{-2}			6.0×10^{-3}		
6190	5/16/79	6.0×10^{-3}	7/31/80	7.1×10^{-3}			NA		
6223	5/21/79	99×10^{-3}	8/4/80	1.5×10^{-2}			6.3×10^{-3}		
6226	5/21/79	MDL	8/4/80	4.4×10^{-3}			NA		
6153	1/23/79	5.8×10^{-3}	5/16/79	5.4×10^{-3}			NA		
6168	1/24/79	2.4×10^{-3}	5/16/79	MDL	7/31/80	MDL	NA	NA	NA
6180	1/25/79	34×10^{-3}	7/30/80	5.9×10^{-3}			NA		
6182	1/25/79	1220×10^{-3}	5/16/79	620×10^{-3}			6.0×10^{-3}		

Table 15 (Cont'd)

^{137}Cs Biological Removal Rate Constants for Marshallese Adult Females

ID#	Date	^{137}Cs μCi	Date	^{137}Cs μCi	Date	^{137}Cs μCi	K d^{-1}	K d^{-1}	K d^{-1}
6112	1/24/79	.98	5/16/79	.46	7/30/80	2.3×10^{-2}	6.7×10^{-3}	7.1×10^{-3}	7.2×10^{-3}
6114	1/23/79	.12	8/3/80	5.5×10^{-3}			8.7×10^{-3}		
6111	1/23/79	.53	8/4/80	2.1×10^{-2}			6.1×10^{-3}		
6122	1/22/79	.31	5/16/79	.11	7/31/80	5.0×10^{-3}	9.1×10^{-3}	1.19×10^{-2}	1.26×10^{-2}
6123	1/22/79	.62	5/17/79	.25	7/31/80	1.1×10^{-2}	7.86×10^{-3}	8.15×10^{-3}	8.21×10^{-3}
6032	1/22/79	.77	5/16/79	.26	7/31/80	4.4×10^{-3}	9.5×10^{-3}	NA	
6108	1/23/79	.53	8/1/80	2.2×10^{-2}			6.07×10^{-3}		
6113	1/23/79	.30	5/16/79	.11	8/2/80	6.4×10^{-3}	8.9×10^{-3}	9.1×10^{-3}	9.2×10^{-3}
6065	1/22/79	.36	8/2/80	8.0×10^{-3}			8.3×10^{-3}		
6097	1/23/79	.31	5/16/79	.16	7/31/80	1.7×10^{-2}	5.8×10^{-3}	NA	
6109	1/23/79	.060	5/16/79	.018	7/31/80	1.3×10^{-3}	1.2×10^{-2}	NA	
6046	5/15/79	.36	8/2/80	2.2×10^{-2}			6.7×10^{-3}		
6098	1/22/79	.47	5/17/79	.18	7/31/80	3.0×10^{-3}	8.3×10^{-3}	NA	
6060	1/24/79	.18	5/17/79	.059			9.8×10^{-3}		
6110	5/21/79	.11	7/31/80	8.3×10^{-3}			7.7×10^{-3}		
525	5/21/79	.32	8/4/80	1.4×10^{-2}			7.9×10^{-3}		
6064	1/24/79	.42	5/15/79	.22	7/31/80	1.1×10^{-2}	5.8×10^{-3}	7.5×10^{-3}	7.9×10^{-3}
6051	5/15/79	.045	7/31/80	1.9×10^{-1}			NA		
934	5/15/79	.48	7/31/80	2.2×10^{-2}			7.4×10^{-3}		
6062	5/16/79	.088	7/31/80	3.5×10^{-3}			NA		
6115	1/23/79	.48	5/16/79	.17	7/30/80	6.8×10^{-3}	9.2×10^{-3}	9.6×10^{-3}	9.8×10^{-3}
6034	5/21/79	.15	8/1/80	7.5×10^{-3}			8.9×10^{-3}		

Table 15 (Cont'd)

^{137}Cs Biological Removal Rate Constants for Marshallese Adult Females (Cont'd)

ID#	Date	^{137}Cs μCi	Date	^{137}Cs μCi	Date	^{137}Cs μCi	K d^{-1}	K d^{-1}	K d^{-1}
6167	1/24/79	.015	5/16/79	.0079	7/31/80	3.2×10^{-3}	6.7×10^{-3}	NA	
6159	1/24/79	.028	5/17/79	.012	8/2/80	2.3×10^{-2}	8.2×10^{-3}	NA	
6148	1/23/79	.037	5/16/79	.015	7/31/80	5.5×10^{-3}	8.5×10^{-3}	6.6×10^{-3}	6.1×10^{-3}
6151	1/23/79	.121	5/17/79	.059			6.4×10^{-3}		
6137	1/22/79	3.8×10^{-3}	5/17/79	1.7×10^{-3}	8/1/80	2.4×10^{-3}	2.7×10^{-2}	NA	
6140	1/22/79	27×10^{-3}	5/17/79	8.6×10^{-3}	7/31/80	5.6×10^{-4}	1.1×10^{-2}	NA	
6144	1/22/79	37×10^{-3}	5/17/79	13×10^{-3}	8/1/80	2.0×10^{-3}	9.8×10^{-3}	NA	
6152	1/23/79	2.4×10^{-3}	5/16/79	3.9×10^{-3}	8/2/80	4.8×10^{-3}		NA	
6155	1/23/79	390×10^{-3}	5/16/79	150×10^{-3}	8/2/80	7.3×10^{-3}	8.4×10^{-3}	8.9×10^{-3}	9.0×10^{-3}
6160	1/24/79	360×10^{-3}	5/17/79	140×10^{-3}			8.4×10^{-3}		
6175	1/24/79	11×10^{-3}	5/17/79	5.2×10^{-3}			8.4×10^{-3}		
6181	1/25/79	8.5×10^{-3}	5/17/79	4.6×10^{-3}			7.4×10^{-3}	NA	
6185	1/25/79	2.7×10^{-3}	5/16/79	3.4×10^{-3}				NA	

Table 15 (Cont'd)

^{137}Cs Biological Removal Rate Constants for Marshallese Adolescents

ID#	Date	^{137}Cs µCi	Date	^{137}Cs µCi	Date	^{137}Cs µCi	K d^{-1}	K d^{-1}	K d^{-1}
Males									
6147	1/23/79	.204	5/16/79	.075	7/31/80	3.5×10^{-3}	8.9×10^{-3}	NA	
6131	1/23/79	.76	5/16/79	.32	8/1/80	1.5×10^{-2}	7.6×10^{-3}	7.7×10^{-3}	7.7×10^{-3}
6011	1/23/79	.055	5/16/79	.017	7/31/80	9.0×10^{-4}	1.1×10^{-2}	NA	
6127	1/22/79	.21	5/16/79	.053	8/1/80	3.3×10^{-3}	1.2×10^{-2}	NA	
6133	5/16/79	.022	7/31/80	6.6×10^{-4}			NA		
6015	1/24/79	.071	5/17/79	.016			1.4×10^{-2}		
6178	1/24/79	2.0×10^{-3}	5/17/79	1.7×10^{-3}			NA		
Females									
6129	1/22/79	.27	5/17/79	.076	7/31/80	4.4×10^{-3}	1.1×10^{-2}	NA	
6048	5/21/79	.074	8/5/80	1.4×10^{-3}			NA		
6091	1/24/79	.15	5/17/79	.037			1.3×10^{-2}		
6173	1/24/79	4.0×10^{-3}	8/1/80	2.2×10^{-3}			NA		
6170	1/24/79	2.8×10^{-3}	5/17/79	1.8×10^{-3}	7/31/80	9.7×10^{-4}	NA		
6141	1/22/79	2.7×10^{-3}	5/16/79	1.5×10^{-3}			NA		

Table 15 (Cont'd)

^{137}Cs Biological Removal Rate Constants for Marshallese Children

ID#	Date	^{137}Cs µCi	Date	^{137}Cs µCi	Date	^{137}Cs µCi	K d^{-1}	K d^{-1}	K d^{-1}
Males									
6031	5/15/79	2.8×10^{-3}	8/1/80	7.6×10^{-4}			NA		
6029	5/15/79	4.7×10^{-3}	7/31/80	9.0×10^{-4}			NA		
6100	5/15/79	15×10^{-3}	8/1/80	6.0×10^{-4}			NA		
6021	1/24/79	46×10^{-3}	5/16/79	6.2×10^{-3}	7/30/80	3.0×10^{-4}	2.0×10^{-2}	NA	
6020	1/22/79	56×10^{-3}	5/16/79	7.4×10^{-3}	7/31/80	5.0×10^{-4}	1.9×10^{-2}	NA	
6107	1/23/79	16×10^{-3}	5/16/79	2.6×10^{-3}	8/1/80	3.2×10^{-4}	2.4×10^{-2}	NA	
6023	1/22/79	.16	7/31/80	7.5×10^{-4}			NA		
6016	5/15/79	1.3	7/31/80	1.4×10^{-3}			1.9×10^{-2}		
6156	1/24/79	2.0×10^{-3}	5/17/79	3.4×10^{-3}	8/1/80	1.9×10^{-3}	NA	NA	
6172	1/24/79	2.8×10^{-3}	5/16/79	1.9×10^{-3}	7/31/80	1.0×10^{-3}	NA	NA	
Females									
6171	1/24/79	4.0×10^{-3}	5/16/79	1.1×10^{-3}	7/31/80	4.7×10^{-4}	NA	NA	
6157	1/24/79	7.2×10^{-3}	8/3/80	3.4×10^{-3}			1.5×10^{-3}		
6158	1/24/79	3.5×10^{-3}	5/18/79	1.2×10^{-3}	8/3/80	6.5×10^{-3}	NA	NA	
6150	1/23/79	4.0×10^{-3}	5/16/79	1.5×10^{-3}	8/1/80	9.5×10^{-4}		NA	
6101	1/24/79	51×10^{-3}	5/15/79	6.9×10^{-3}			2.0×10^{-2}		
6056	1/24/79	46×10^{-3}	5/16/79	7.4×10^{-3}			1.8×10^{-2}		
6057	5/21/79	5.8×10^{-3}	8/5/80	5.4×10^{-4}			NA		
6010	1/23/79	.17	7/31/80	2.1×10^{-3}			9.2×10^{-3}		
6105	1/23/79	.053	5/16/79	7.4×10^{-3}	7/30/80	3.4×10^{-4}	1.9×10^{-2}	NA	

Table 15 (Cont'd)

^{137}Cs Biological Removal Rate Constants for Marshallese Children (Cont'd)

ID#	Date	^{137}Cs μCi	Date	^{137}Cs μCi	Date	^{137}Cs μCi	K d^{-1}	K d^{-1}	K d^{-1}
Females (Cont'd)									
6028	5/15/79	.015	7/31/80	$1.1x10^{-3}$					
6030	1/22/79	.26	5/16/79	.064	7/31/80	$1.8x10^{-3}$	$1.2x10^{-2}$	$1.1x10^{-2}$	$1.0x10^{-2}$
6025	1/23/79	.13	5/16/79	.028			$1.4x10^{-2}$		
6160	1/23/79	.077	5/16/79	.013	7/31/80	$2.7x10^{-4}$	$1.7x10^{-2}$	NA	
6142	1/22/79	$2.3x10^{-3}$	5/16/79	$1.0x10^{-3}$	7/31/80	$1.0x10^{-3}$	NA	NA	

Table 16

Comparison of Mean Long Term ^{137}Cs Biological Removal Rate Constants for the Former Bikini Atoll Population

Population Description	Group Size	K, d^{-1} 1/79-5/79	Group Size	K, d^{-1} 1/79-8/80	Group Size	K, d^{-1} 5/79-8/80	Group Size	Average K, d^{-1}
Adult Males (22-59a)	10	$.0061 \pm .0017$	13	$.0057 \pm .00094$	12	$.0068 \pm .0010$	35	$.0062 \pm .0012$
Adult Females (19-70a)	21	$.0084 \pm .0016$	13	$.0082 \pm .0017$	12	$.0084 \pm .0016$	46	$.0083 \pm .0016$
Adolescents (11-15a)	7	$.011 \pm .0022$	1	.0077	1	.0077	9	$.010 \pm .0024$
Juveniles (5-10a)	9	$.018 \pm .0035$	2	$.0072 \pm .0050$	3	$.015 \pm .0064$	14	$.016 \pm .004$

Table 17

Body Burden Data for Non-Medically Registered Adult Male Prior Residents of Bikini Atoll

						January		May		August	
ID #	Age (yr)	Height (cm)	Weight (kg)	Yrs. On Bikini	Yrs. Off Bikini	1979 ^{137}Cs Result nCi	1979 Potassium Result Gram	1979 ^{137}Cs Result nCi	1979 Potassium Result Gram	1980 ^{137}Cs Result nCi	1980 Potassium Result Gram
6136	48	150	58	--	4	8.5	144	--	--	--	--
6138	20	163	57	--	3	2.8	165	--	--	--	--
6153	23	160	65	1	1.42	5.8	170	5.4	146	--	--
6168	16	150	44	7	1.0	2.4	101	--	100	--	104
6174	52	174	84	--	6	17	158	--	--	--	--
6180	22	173	67	4	1	34	141	--	--	5.9	153
6182	18	161	53	6	0.42	1220	122	620	131	--	--
6190	19	166	57	0.25	2	--	--	6.0	161	7.1	153
6205	42	170	81	4	4.5	--	--	--	159	--	--
6211	19	163	55	1	3	--	--	--	134	--	--
6218	56	158	72	2	10	--	--	--	169	--	--
6219	30	173	60	2	9	--	--	--	143	--	--
6220	26	166	66	2	9	--	--	--	165	--	--
6221	53	175	82	2	9	--	--	4.2	139	--	--

Table 17 (Cont'd)

Body Burden Data for Non-Medically Registered Adult Male Prior Residents of Bikini Atoll

						January		May		August	
ID #	Age (yr)	Height (cm)	Weight (kg)	Yrs. On Bikini	Yrs. Off Bikini	1979 ^{137}Cs Result nCi	1979 Potassium Result Gram	1979 ^{137}Cs Result nCi	1979 Potassium Result Gram	1980 ^{137}Cs Result nCi	1980 Potassium Result Gram
6223	66	152	65	2 days May 14, 15, 1979	.016	--	--	99	127	15	135
6224	45	158	55	2 days May 14, 15, 1979	.016	--	--	120	146	--	--
6226	18	164	58	2	3	--	--	—	137	4.4	152

Table 18

Body Burden Data for Non-Medically Registered Adult Female Prior Residents of Bikini Atoll

						January		May		August	
ID #	Age (yr)	Height (cm)	Weight (kg)	Yrs. On Bikini	Yrs. Off Bikini	1979 ^{137}Cs Result nCi	1979 Potassium Result Gram	1979 ^{137}Cs Result nCi	1979 Potassium Result Gram	1980 ^{137}Cs Result nCi	1980 Potassium Result Gram
6137	38	161	64	0.33	4	3.8	113	1.7	112	2.4	99
6139	22	140	38	--	3	2.1	89	--	--	--	--
6140	16	146	46	0.17	0.42	27	94	8.6	94	--	69
6144	21	150	44	1	0.42	37	105	13	89	2.0	--
6152	20	157	59	1	1.42	2.4	123	3.9	117	4.8	148
6155	24	155	66	6	0.42	390	120	150	96	7.3	88
6160	65	153	55	6	0.67	360	67	140	87	--	--
6165	36	142	60	--	1.5	6.6	76	--	--	--	--
6175	24	155	63	--	--	11	90	5.2	92	--	--
6181	44	151	55	4	1	8.5	105	4.6	105	--	--
6185	21	144	41	3	2.5	2.7	74	3.4	79	--	69
6187	21	152	54	0.019	1	--	--	1.6	107	--	--
6189	21	155	--	2.5	1	--	--	1.9	114	--	--
6206	32	151	73	3	5.5	--	--	--	116	--	--
6222	39	156	66	2.5	3	--	--	--	98	--	--

Table 19

Body Burden Data for Non Medically Registered Adolescents Prior Residents of Bikini Atoll

						January		May		August	
ID #	Age (yr)	Height (cm)	Weight (kg)	Yrs. On Bikini	Yrs. Off Bikini	1979 ^{137}Cs Result nCi	1979 Potassium Result Gram	1979 ^{137}Cs Result nCi	1979 Potassium Result Gram	1980 ^{137}Cs Result nCi	1980 Potassium Result Gram
Males											
6169	14	167	46	7	1.0	1.2	108	--	120	--	--
6178	12	157	33	4	1.0	2.0	46	1.7	70	--	--
6183	12	139	35	--	1.67	1.0	36	--	74	--	--
6200	14	155	43	1	.71	--	--	110	111	--	--
6225	11	125	25	5	1.33	--	--	--	53	--	--
6207	12	138	35	4	4.5	--	--	--	78	--	--
Females											
6173	13	142	47	3	0.42	4.0	33	--	48	2.2	74
6170	13	140	45	7	1.0	2.8	58	1.8	77	.97	100
6162	12	147	50	--	1.5	5.0	36	--	--	--	--
6212	14	151	50	1	3	--	--	--	73	--	--
6141	12	138	33	0	--	2.7	63	1.5	112	--	60
6188	14	146	49	0	--	--	--	2.9	107	--	--

Table 20

Body Burden Data for Non-Medically Registered Children Prior Residents of Bikini Atoll

						January		May		August	
ID #	Age (yr)	Height (cm)	Weight (kg)	Yrs. On Bikini	Yrs. Off Bikini	1979 ^{137}Cs Result nCi	1979 Potassium Result Gram	1979 ^{137}Cs Result nCi	1979 Potassium Result Gram	1980 ^{137}Cs Result nCi	1980 Potassium Result Gram
Males											
6156	9	130	34	6	1.0	2.0	53	3.4	59	1.9	75
6164	5	85	15	--	1.5	8.0	40	--	--	--	--
6172	10	130	30	7	1.0	2.8	40	1.9	74	1.0	73
6202	6	100	19	5.3	.72	--	--	1.8	53	--	--
6208	10	136	33	4	4.5	--	--	--	76	--	--
6145	5	110	21	--	--	1.0	46	--	--	--	--
6186	5	104	20	--	--	--	--	--	22	--	--
Females											
6179	8	115	22	4	1	1.2	--	--	59	--	--
6177	6	103	18	--	6	--	--	--	36	--	--
6176	8	144	24	--	6	--	--	--	38	--	--
6171	6	96	15	2.67	1.0	4.0	16	1.1	47	--	29
6157	5	106	20	4	1.0	7.2	32	--	54	3.4	44
6158	6	103	20	4	1.0	3.5	32	1.2	46	6.5	53

Table 20 (Cont'd)

ID #	Age (yr)	Height (cm)	Weight (kg)	Yrs. On Bikini	Yrs. Off Bikini	January 1979 ^{137}Cs Result nCi	January 1979 Potassium Result Gram	May 1979 ^{137}Cs Result nCi	May 1979 Potassium Result Gram	August 1980 ^{137}Cs Result nCi	August 1980 Potassium Result Gram
Females (cont'd)											
6150	8	120	25	4	0.42	4.0	42	1.5	40	.95	45
6149	5	99	19	4.3	0.42	1.6	37	--	32	--	42
6203	5	92	15	4.3	.72	--	--	--	54	--	--
6204	5	104	21	1	.72	--	--	1.1	57	--	--
6142	10	126	26	0	--	2.3	52	1.0	72	1.0	67
6143	4	104	19	0	--	1.2	41	--	35	--	--
6191	6	113	23	0	--	--	--	1.1	61	--	--
6213	10	121	25	1	3	--	--	--	56	--	--
6217	10	126	25	2	9	--	--	--	44	--	--

Table 21

Comparison Adult Males from Kili

Name	ID#	Age	August 1980 ^{137}Cs µCi	August 1980 Potassium Grams
	2102	30	$1.2x10^{-2}$	164
	2103	20	$1.3x10^{-2}$	173
	2104	37	$1.1x10^{-2}$	166
	2105	38	$9.5x10^{-3}$	170
	2107	38	$1.5x10^{-2}$	177
	2114	35	$6.2x10^{-3}$	172
	2116	45	$8.1x10^{-3}$	134
	2117	49	$7.2x10^{-3}$	158
	2118	27	$7.3x10^{-3}$	162
	2100	50	$9.4x10^{-3}$	152
PRIVACY ACT MATERIAL REMOVED	2101	54	$9.1x10^{-3}$	156
	1109	22	$1.3x10^{-2}$	176
	1111	34	$1.5x10^{-2}$	191
	1098	34	$8.4x10^{-3}$	191
	1101	37	$1.6x10^{-2}$	188
	1102	39	$3.1x10^{-3}$	112
	1103	55	$6.5x10^{-3}$	121
	1104	26	$5.7x10^{-3}$	135
	1105	22	$3.9x10^{-3}$	136
	1107	36	$2.8x10^{-3}$	180
	1106	26	$1.4x10^{-3}$	184
	1108	23	$7.5x10^{-3}$	189

Table 21 (Cont'd)

Comparison Adult Males from Kili (Cont'd)

Name	ID#	Age	August 1980 ^{137}Cs µCi	August 1980 Potassium Grams
	1110	40	1.3×10^{-2}	156
	2120	34	6.0×10^{-3}	158
	2121	46	5.4×10^{-3}	152
	2122	56	9.4×10^{-3}	138
	2123	25	1.7×10^{-2}	180
	2124	22	$3.7\times10^{-}$	143
	2125	28	3.4×10^{-3}	147

PRIVACY ACT MATERIAL REMOVED

Table 21 (Cont'd)

Comparison Adult Males from Majuro

Name	ID#	Age	August 1980 ^{137}Cs uCi	August 1980 Potassium Grams
	1047	31	6.1×10^{-3}	184
	2084	32	8.3×10^{-3}	168
	2085	55	3.2×10^{-2}	112
	2087	62	1.7×10^{-2}	134
	2089	21	3.5×10^{-3}	149
	2019	26	1.4×10^{-2}	152
	2060	50	3.0×10^{-2}	122
	2065	44	1.2×10^{-2}	137
	1048	70	9.1×10^{-3}	144
	1056	62	8.2×10^{-3}	131
	1074	34	5.2×10^{-3}	143
	1076	35	8.2×10^{-3}	174
	1084	80	6.3×10^{-3}	155
PRIVACY ACT MATERIAL REMOVED	1088	19	4.4×10^{-3}	191
	1089	21	5.4×10^{-3}	168
	1090	27	1.6×10^{-2}	179
	1091	34	3.2×10^{-3}	169
	1092	29	8.5×10^{-3}	183
	1004	44	4.8×10^{-3}	136
	2028	17	2.2×10^{-3}	136
	2050	17	2.5×10^{-3}	133

Table 22

Comparison Adult Females from Majuro

Name	ID#	Age	August 1980 ^{137}Cs uCi	Potassium Grams
	2015	36	2.3×10^{-3}	97
	2091	40	4.0×10^{-3}	117
	2055	38	4.7×10^{-3}	98
	2059	32	9.6×10^{-3}	86

PRIVACY ACT MATERIAL REMOVED

Table 26

Whole Body Counting Census

Date Counted	Total Counted	Medically Registered Population Total in April '78	Bikinians Medically Registered[1] in April '78	Number of Medically Registered Population Total Counted	Number of Relocated Bikini Residents Counted	Number of Non-relocated Residents Counted
April 1978	99	143	135	99	99	--
January 1979	101	143	135	53	64	33
May 1979	129	143	135	63	79	44
January plus May 1979 Non Duplicate Counts	---	---	---	82	98	50

[1] Bikini Medical Registry included 34 persons under 5 years of age and not eligible for whole body counting in April 1978.

Table 27

Census of Medically Registered, Whole Body Counted, Relocated Bikini Residents

Date Counted	Adult Males	Adult Females	Male Adolescents Ages 11-15	Female Adolescents Ages 11-15	Male Children Ages 5-10	Female Children Ages 5-10	Total Persons Counted	Medically Registered Population Total in April 1978*	% of Medically Registered Population Counted
April 1978	36	32	6	3	8	14	99	143	69
January 1979	17	16	4	2	1	6	46	143	32
May 1979	14	19	5	3	4	6	51	143	36
January plus May 1979 Duplicate Counts	7	11	4	2	0	4	28	143	20

*Bill Scott-Medical Dept-BNL

Table 28

Census of Non-Medically Registered Persons and Medically Registered Children Whole Body Counted Only in 1979

Date Counted/ Classification	Adult Males	Adult Females	Male Adolescents Ages 11-15	Female Adolescents Ages 11-15	Male Children Ages 5-10	Female Children Ages 5-10	Total Persons Counted
January 1979/							
Non-relocated residents.	8	11	3	2	3	6	33
Relocated residents, not medically registered.	2	5	1	1	0	2	11
Relocated residents medically registered.	0	0	0	0	4	3*	7*
Non-residents.	0	0	0	1	1	2	4
TOTAL	10	16	4	4	8	13	55

Table 28 (Cont'd)

Date Counted/ Classification	Adult Males	Adult Females	Male Adolescents Ages 11-15	Female Adolescents Ages 11-15	Male Children Ages 5-10	Female Children Ages 5-10	Total Persons Counted
May 1979/							
Non-relocated residents.	12	12	5	2	3	8	42
Relocated residents not medically registered.	3	5	2	1	1	4	16
Relocated residents medically registered.	0	0	0	0	7	5	12
Transient.	2	0	0	0	0	0	2
Non-resident.	0	0	0	2	1	3	6
TOTAL	17	17	7	5	12	20	78
January and May 1979 Duplicate Counts	6	13	4	3	6	12	44

*All but one individual in this classification recounted in May 1979.

Table 29

Summary of Residence Location for Persons Whole Body Counted in

January and May 1979

Group/Class		Residence Atolls - Islands: Majuro- Ejit	Majuro- Rita	Kili	Jaluit-Jabor	Total Counted
Relocated Marshallese/	Jan	26	37	1	0	64
Residents of Bikini Atoll	May	34	30	15	0	79
Nonrelocated Marshallese/	Jan	4	29	0	0	33
Residents of Bikini Atoll	May	3	24	0	17	44
Controls	Jan	1	3	0	0	4
	May	3	3	0	0	6

Table 30

Frequency Distribution of Residence Location in January 1979

	Residence Atolls - Islands				
	Majuro- Ejit	Majuro- Rita	Kili	Jaluit-Jabor	Total Counted
Relocated Medically Registered:					
Adult Males	8	8	1	0	17
Adult Females	8	8	0	0	16
Adolescent Males	1	3	0	0	4
Adolescent Females	1	1	0	0	2
Male Children	1	0	0	0	1
Female Children	3	3	0	0	6
Relocated Nonmedically Registered:					
Adult Males	0	2	0	0	2
Adult Females	2	3	0	0	5
Adolescent Males	0	1	0	0	1
Adolescent Females	0	1	0	0	1
Male Children	1	3	0	0	4
Female Children	1	4	0	0	5
Other Nonmedically Registered:					
Adult Males	2	6	0	0	8
Adult Females	2	9	0	0	11
Adolescent Males	0	3	0	0	3
Adolescent Females	0	3	0	0	3
Male Children	1	3	0	0	4
Female Children	0	8	0	0	8

Table 31

Frequency Distribution of Residence Location in May 1979

	Residence Atolls - Islands				
	Majuro- Ejit	Majuro- Rita	Kili	Jaluit-Jabor	Total Counted
Relocated Medically Registered:					
Adult Males	6	5	3	0	14
Adult Females	9	7	3	0	19
Adolescent Males	3	2	0	0	5
Adolescent Females	1	1	1	0	3
Male Children	1	0	3	0	4
Female Children	3	3	0	0	6
Relocated Nonmedically Registered:					
Adult Males	1	1	1	0	3
Adult Females	3	2	0	0	5
Adolescent Males	1	1	0	0	2
Adolescent Females	0	1	0	0	1
Male Children	3	4	1	0	8
Female Children	3	3	3	0	9
Other Nonmedically Registered:					
Adult Males	1	4	0	9	14
Adult Females	2	8	0	2	12
Adolescent Males	0	3	0	2	5
Adolescent Females	1*	2**	0	1	4
Male Children	1*	2	0	1	4
Female Children	1*	8**	0	2	11

*individual is part of the control population.
**one or more individuals participated in the program as a control.

Table 32

Medically Registered Relocated Adult Male ID Number,

Name and Residence Location

		January 1979		May 1979	
ID#	Name	Count Date	Residence Atoll-Island	Count Date	Residence Atoll-Island
80		---	---	5/21	Kili
6006		---	---	---	Kwajalein-Ebeye
863		1/23	Majuro-Rita	---	Majuro-Ejit
6070		1/24	Majuro-Rita	---	Maloelap
6004		---	---	---	Jaluit
6033		---	---	---	Majuro - (Rita?)
6018		---	---	---	Wotje
6069		---	---	5/15	Majuro-Rita
6068		---	---	---	Majuro - (?)
6067		1/24	Majuro-Rita	5/17	Majuro-Rita
6066	e	1/24	Majuro-Rita	5/18	Majuro-Rita
6017		---	---	5/21	Kili
6019		1/22	Majuro-Ejit	---	Majuro-Ejit
6001	eo	1/22	Majuro-Ejit	---	Majuro-Ejit
6073		---	---	5/15	Majuro-Ejit
6005		---	---	5/21	Kili
6008		1/23	Majuro-Rita	---	Majuro-Ejit
6086	l	1/23	Majuro-Ejit	5/16	Majuro-Ejit
6071		1/23	Majuro-Ejit	---	Kili
6076		1/22	Majuro-Ejit	---	Majuro-Ejit
6072		---	---	---	Kili

Table 32 (Cont'd)

Medically Registered Relocated Adult Male ID Number,

Name and Residence Location (cont'd)

813	1/22	Majuro-Rita	---	Kili
6118	1/24	Majuro-Rita	5/17	Majuro-Rita
6126	---	---	---	Kili
6003	---	---	---	Ugelang
6117	1/24	Majuro-Rita	5/16	Majuro-Rita
6128	1/25	Kili	---	Kili
6125	---	---	5/18	Majuro-Ejit
6007	1/23	Majuro-Ejit	---	Kili
6130	1/22	Majuro-Ejit	5/15	Majuro-Ejit
6119	---	---	---	Majuro- (Rita?)
864	---	---	---	Majuro-Ejit
966	---	---	5/15	Majuro-Ejit
6135	---	---	---	Lib
6096	1/22	Majuro-Ejit	5/16	Majuro-Ejit
6002	---	---	---	Kili

Table 23

Medically Registered Relocated Adult Female ID Number,

Name and Residence Location

ID#	Name	January 1979 Count Date	January 1979 Residence Atoll Island	May 1979 Count Date	May 1979 Residence Atoll-Island
6045		---	---	---	Kwajalein-Ebeye
6112		1/24	Majuro-Rita	5/16	Majuro-Rita
6114		1/23	Majuro-Ejit	---	Kili
6111		1/23	Majuro-Ejit	---	Kili
6122		1/22	Majuro-Ejit	5/16	Majuro-Ejit
6123		1/22	Majuro-Ejit	5/17	Majuro-Ejit
6059		---	---	---	Kili
6063		---	---	---	Deceased
6032		1/22	Majuro-Ejit	5/16	Majuro-Ejit
6124		---	---	---	Kili
6108		1/23	Majuro-Rita	---	Majuro-Rita
6058		---	---	---	Kili
6113		1/23	Majuro-Rita	5/16	Majuro-Rita
6065		1/22	Majuro-Ejit	---	Kili
6097		1/23	Majuro-Rita	5/16	Majuro-Rita
6109		1/23	Majuro-Rita	5/16	Majuro-Rita
6046		---	---	5/15	Majuro-Ejit
6098		1/22	Majuro-Ejit	5/17	Majuro-Ejit
6060		1/24	Majuro-Rita	5/17	Majuro-Rita
6036		---	---	---	Jaluit
6110		---	---	5/21	Kili

PRIVACY ACT MATERIAL REMOVED

Table 33 (Cont'd)

Medically Registered Relocated Adult Female ID Number,

Name and Residence Location (cont'd)

525	---	---	5/21	Kili
6064	1/24	Majuro-Rita	5/15	Majuro-Rita
6061	---	---	---	Wotje
6051	---	---	5/15	Majuro-Ejit
934	---	---	5/15	Majuro-Rita
6062	---	---	5/16	Majuro-Ejit
6035	1/24	Majuro-Rita	---	Maloelap
6115	1/23	Majuro-Ejit	5/16	Majuro-Ejit
6034	---	---	5/21	Kili
865	---	---	5/15	Majuro-Ejit
6050	---	---	---	Kili

PRIVACY ACT MATERIAL REMOVED

Table 34

Medically Registered Adolescents (Ages 11-14) ID Number,

Name and Residence Location

ID#	Name	January 1979 Count Date	January 1979 Residence and Island	May 1979 Count Date	May 1979 Residence Atoll-Island
Males:					
6132		---	---	---	Kili
6131		1/23	Majuro-Rita	5/16	Majuro-Ejit
6011		1/23	Majuro-Rita	5/16	Majuro-Rita
6127		1/22	Majuro-Ejit	5/16	Majuro-Ejit
6133		---	---	5/15	Majuro-Ejit
6015		1/24	Majuro-Rita	5/17	Majuro-Rita
Females					
6129		1/22	Majuro-Ejit	5/17	Majuro-Ejit
6048		---	---	5/21	Kili
6091		1/24	Majuro-Rita	5/17	Majuro-Rita

PRIVACY ACT MATERIAL REMOVED

Table 25

Medically Registered Children (Ages 5-10) ID Number.

Name and Residence Location

ID#	Name	January 1979 Count Date	January 1979 Residence Atoll-Island	May 1979 Count Date	May 1979 Residence Atoll-Island
Males:					
6009		---	---	5/21	Kili
6049		---	---	---	Kili
6042		---	---	---	Jaluit
6014		---	---	5/21	Kili
6012		---	---	5/21	Kili
6023		1/22	Majuro-Ejit	---	Majuro-Ejit
6016		---	---	5/15	Majuro-Ejit
6013		---	---	---	Kili
Females:					
6094		---	---	---	Wotje
6092		---	---	---	Wotje
6080		---	---	---	Kili
6010		1/23	Majuro-Ejit	---	Majuro-Ejit
6038		---	---	---	Kili
6105		1/23	Majuro-Ejit	5/16	Majuro-Ejit
6103		---	---	---	Maloelap
6028		---	---	5/15	Majuro-Ejit
6030		1/22	Majuro-Ejit	5/16	Majuro-Ejit
6027		1/23	Majuro-Rita	---	Majuro-Rita
6044		---	---	5/15	Majuro-Rita
6025		1/23	Majuro-Rita	5/16	Majuro-Rita
6081		---	---	---	Majuro-Ejit
6106		1/23	Majuro-Rita	5/16	Majuro-Rita

PRIVACY ACT MATERIAL REMOVED

Table 36

Nonmedically Registered Adult Female ID Number,

Name and Residence Location

		January 1979		May 1979	
ID#	Name	Count Date	Residence Atoll-Island	Count Date	Residence Atoll-Island
6137		1/22	Majuro-Ejit	5/17	Majuro-Ejit
6139		1/22	Majuro-Ejit	---	Majuro-Ejit
6140		1/22	Majuro-Ejit	5/17	Majuro-Ejit
6144		1/22	Majuor-Ejit	5/17	Majuro-Ejit
6148		1/23	Majuro-Rita	5/16	Majuro-Ejit
6151		1/23	Majuro-Rita	5/17	Majuro-Rita
6152		1/23	Majuro-Rita	5/16	Majuro-Rita
6155		1/23	Majuro-Rita	5/16	Majuro-Rita
6159		1/24	Majuro-Rita	5/17	Majuor-Rita
6160		1/24	Majuor-Rita	5/17	Majuro-Rita
6163		1/24	Majuro-Rita	---	Majuro-Rita
6165		1/24	Majuro-Rita	---	Majuro-Rita
6167		1/24	Majuro-Rita	5/16	Majuro-Rita
6175		1/24	Majuro-Rita	5/17	Majuro-Rita
6181		1/25	Majuro-Rita	5/17	Majuro-Rita
6185		1/25	Majuro-Rita	5/16	Majuro-Rita
6187		---	---	5/16	Majuro-Ejit
6189		---	---	5/16	Majuro-Rita
6206		---	---	5/21	Jaluit-Jabor
6222		---	---	5/21	Jaluit-Jabor

PRIVACY ACT MATERIAL REMOVED

Table 37

Nonmedically Registered Adult Male ID Number,

Name and Residence Location

ID#	Name	January 1979 Count Date	January 1979 Residence Atoll-Island	May 1979 Count Date	May 1979 Residence Atoll-Island
6136		1/22	Majuro-Ejit	---	Majuro-Ejit
6138		1/22	Majuro-Ejit	---	Majuro-Ejit
6153		1/23	Majuro-Rita	5/16	Majuro-Rita
6161		1/24	Majuro-Rita	5/17	Majuro-Rita
6166		1/24	Majuro-Rita	5/16	Majuro-Rita
6168		1/24	Majuro-Rita	5/16	Majuro-Rita
6174		1/24	Majuro-Rita	---	Majuro-Rita
6180		1/25	Majuro-Rita	---	Enewetak-Enewetak
6182		1/25	Majuro-Rita	5/16	Majuro-Rita
6184		1/25	Majuro-Rita	5/17	Majuro-Ejit
6190		---	---	5/16	Majuro-Ejit
6205		---	---	5/21	Jaluit-Jabor
6210		---	---	5/21	Kili
6211		---	---	5/21	Jaluit-Jabor
6218		---	---	5/21	Jaluit-Jabor
6219		---	---	5/21	Jaluit-Jabor
6220		---	---	5/21	Jaluit-Jabor
6221		---	---	5/21	Jaluit-Jabor
6223		---	---	5/21	Jaluit-Jabor
6224		---	---	5/21	Jaluit-Jabor
6226		---	---	5/21	Jaluit-Jabor

PRIVACY ACT MATERIAL REMOVED

Table 38

Nonmedically Registered Adolescent ID Number.

Name and Residence Location

ID#	Name	January 1979 Count Date	January 1979 Residence Atoll-Island	May 1979 Count Date	May 1979 Residence Atoll-Island
6200		---	---	5/17	Majuro-Rita
6207		---	---	5/21	Jaluit-Jabor
6225		---	---	5/21	Jaluit-Jabor
6188		---	---	5/16	Majuro-Ejit
6212		---	---	5/21	Jaluit-Jabor
6147		1/23	Majuro-Rita	5/16	Majuro-Ejit
6169		1/24	Majuro-Rita	5/16	Majuro-Rita
6178		1/24	Majuro-Rita	5/17	Majuro-Rita
6183		1/25	Majuro-Rita	5/16	Majuro-Rita
6173		1/24	Majuro-Rita	5/17	Majuro-Rita
6170		1/24	Majuro-Rita	5/17	Majuro-Rita
6162		1/24	Majuro-Rita	---	Aur
6141		1/22	Majuro-Rita	5/16	Majuro-Rita

PRIVACY ACT MATERIAL REMOVED

Table 39

Nonmedically Registered Juvenile ID Number,

Name and Residence Locations

		January 1979		May 1979	
ID#	Name	Count Date	Residence Atoll-Island	Count Date	Residence Atoll-Island
6186		---	---	5/16	Majuro-Ejit
6202		---	---	5/21	Kili
6208		---	---	5/21	Majuro-Ejit
6191		---	---	5/16	Majuro-Ejit
6203		---	---	5/21	Kili
6204		---	---	5/21	Kili
6213		---	---	5/21	Jaluit-Jabor
6217		---	---	5/21	Jaluit-Jabor
6156		1/24	Majuro-Rita	5/17	Majuro-Rita
6164		1/24	Majuro-Rita	---	Aur
6172		1/24	Majuro-Rita	5/16	Majuro-Rita
6179		1/24	Majuro-Rita	5/17	Majuro-Rita
6177		1/24	Majuro-Rita	5/17	Majuro-Rita
6176		1/24	Majuro-Rita	5/17	Majuro-Rita
6171		1/24	Majuro-Rita	5/16	Majuro-Rita
6157		1/24	Majuro-Rita	5/17	Majuro-Rita
6158		1/24	Majuro-Rita	5/18	Majuro-Rita
6150		1/23	Majuro-Rita	5/16	Majuro-Rita
6149		1/23	Majuro-Rita	5/16	Majuro-Rita
6142		1/22	Majuro-Rita	5/16	Majuro-Rita
6143		1/22	Majuro-Rita	5/17	Majuro-Rita

PRIVACY ACT MATERIAL REMOVED

Table 39 (Cont'd)

Nonmedically Registered Juvenile ID Number,

Name and Residence Locations

		January 1979		May 1979	
ID#	Name	Count Date	Residence Atoll-Island	Count Date	Residence Atoll-Island
6145		1/22	Majuro-Ejit	---	Majuro-Ejit
6031		---	---	5/15	Majuro-Ejit
6029		---	---	5/15	Majuro-Ejit
6100		---	---	5/15	Majuro-Rita
6021		1/24	Majuro-Rita	5/16	Majuro-Rita
6020		1/22	Majuro-Ejit	5/16	Majuro-Ejit
6107		1/23	Majuro-Rita	5/16	Majuro-Rita
6074		1/24	Majuro-Rita	5/17	Majuro-Rita
6078		1/23	Majuro-Ejit	---	Kili
6088		---	---	5/15	Majuro-Ejit
6090		---	---	5/15	Majuro-Ejit
6101		1/24	Majuro-Rita	5/15	Majuro-Rita
6056		1/24	Majuro-Rita	5/16	Majuro-Ejit
6057		---	---	5/21	Kili

PRIVACY ACT MATERIAL REMOVED

Table 40

Medically Registered Relocated Bikini Atoll Residents

Not Whole Body Counted Since 1978

ID #	Age	Name	Sex	Location
6132	12		M	Kili
6049	8		M	Kili
6042	7		M	Jaluit
6013	5		M	Kili
6094	10		F	Wotje
6092	8		F	Wotje
6080	7		F	Kili
6038	6		F	Kili
6103	9		F	Maloelap
6081	9		F	Majuro, Ejit
6006	37		M	Kwajalein, Ebeye
6004	28		M	Jaluit
6033	27		M	Majuro
6018	34		M	Wotje
6068	56		M	Majuro
6072	20		M	Kili
6126	35		M	Kili
6003	22		M	Enewetak
6119	17		M	Majuro
864	51		M	Majuro, Ejit
6135	35		M	Lib
6002	65		M	Kili

PRIVACY ACT MATERIAL REMOVED

Table 40 (Cont'd)

Medically Registered Relocated Bikini Atoll Residents

Not Whole Body Counted Since 1978 (cont'd)

ID #	Age	Name	Sex	Location
6045	28		F	Kwajalein, Ebeye
6059	19		F	Kili
6124	54		F	Kili
6058	18		F	Majuro, Ejit
6036	27		F	Jaluit (Rongelap)
6061	32		F	Wotje
6050	22		F	Kili

Total Missed = 30

PRIVACY ACT MATERIAL REMOVED

Table 41

Individual Dosimetry Data for Bikinians -

Explanation of Column Headings

Column	Item or Derived Quality	Measured Quantity	Comments
1	Name	-	Personal Interview
2	ID Number	-	BNL Medical Dept. & S&EP Div. Records
3	Residence Inverval	-	Personal Interviews
4	^{90}Sr and ^{90}Y Bone Marrow Dose Equivalent During and Post Residence Interval	Urine Activity Concentration	Three Compartment Model, Constant Continuous Uptake
5	^{137}Cs + ^{137m}Ba Dose Equivalent During and Post Residence Interval	Body Burden Measurements	Two Compartment Model, Monotonically Increasing Uptake
6	Net External Dose Equivalent During Residence Interval	External Exposure Rate Measurements	Assumed Living Patterns
7	Total Body Dose Equivalent	-	Sum of Columns 5 & 6
8	Total Bone Marrow Dose Equivalent During and Post Residence Interval	-	Sum of Columns 4, 5, and 6

INDIVIDUAL DOSIMETRY DATA FOR BIKINIANS

Name	ID Number	Residence Interval a	^{90}Sr & ^{90}Y Bone Marrow Dose Equiv. During & Post Residence Int. mRem	^{137}Cs + ^{137m}Ba Dose Equiv. During & Post Residence Int. mRem	Net External Dose Equiv. During Residence Interval mRem	Total Body Dose Equiv. During & Post Residence Int. mRem	Total Bone Marrow Dose Equiv. During and Post Residence Interval mRem
	6001	7.3	130*	480	950	1400	1600
	6127	7.3	39	580	950	1500	1600
	6130	.72	49	200	94	300	300
	6076	3.3	9.9	900	430	1300	1300
	813	4.3	77*	600	560	1200	1200
	6019	5.3	190	420	690	1100	1300
	6111	.80	7.7	150	100	250	260
	6097	4.3	51*	430	520	950	1000
	6115	7.3	97	760	880	1600	1700
	6109	4.3	51*	240	520	760	810
	6091	6.3	74*	550	760	1300	1400
	6132	2.3	62	1200	300	1500	1600
	6046	2.0	27	400	240	600	700
	6061	6.3	65	630	760	1400	1500

INDIVIDUAL DOSIMETRY DATA FOR BIKINIANS (Cont'd)

Name	ID Number	Residence Interval y	^{90}Sr & ^{90}Y Bone Marrow Dose Equiv. During & Post Residence Int. mRem	^{137}Cs + ^{137m}Ba Dose Equiv. During & Post Residence Int. mRem	Net External Dose Equiv. During Residence Interval mRem	Total Body Dose Equiv. During & Post Residence Int. mRem	Total Bone Marrow Dose Equiv. During and Post Residence Interval mRem
	6066	3.3	59*	400	430	830	890
	6070	10.3	185*	870	1300	2200	2400
	6118	6.3	42	420	820	1200	1300
	6117	6.3	110*	610	820	1400	1500
	6128	7.3	130*	810	950	1800	1900
	6122	10.3	86	380	1200	1600	1700
	6015	1.7	31*	650	220	870	900
	6030	3.3	39*	1200	400	1600	1600
	6129	4.3	51*	330	520	850	900
	6027	3.3	39*	760	400	1200	1200
	6010	7.3	86*	1100	900	2000	2100
	6105	3.3	39*	1100	400	1500	1500
	6033	8.3	150*	900	1100	2000	2100
	6007	.88	15	190	110	300	310
	6008	4.3	77*	850	560	1400	1500

INDIVIDUAL DOSIMETRY DATA FOR BIKINIANS (Cont'd)

Name	ID Number	Residence Interval a	^{90}Sr & ^{90}Y Bone Marrow Dose Equiv. During & Post Residence Int. mRem	^{137}Cs + ^{137m}Ba Dose Equiv. During & Post Residence Int. mRem	Net External Dose Equiv. During Residence Interval mRem	Total Body Dose Equiv. During & Post Residence Int. mRem	Total Bone Marrow Dose Equiv. During and Post Residence Interval mRem
	6071	1.0	18*	220	130	350	370
	863	4.3	120	620	600	1200	1300
	6086	8.3	240	990	1100	2100	2300
	6069	8.3	150*	580	1100	1700	1900
	6073	7.3	130*	490	950	1400	1600
	6072	1.0	18*	330	130	460	480
	6119	7.3	130*	730	950	1700	1800
	864	7.3	130*	960	950	1900	2000
	966	7.3	130*	1400	950	2300	2500
	6059	1.3	15*	240	160	400	410
	6124	.88	10*	180	110	390	400
	6058	5.3	63*	550	600	1200	1300
	6036	.64	7.6*	260	77	340	340
	6110	8.3	98*	450	1000	1400	1500
	6051	5.3	63*	520	600	1200	1200

INDIVIDUAL DOSIMETRY DATA FOR BIKINIANS (Cont'd)

Name	ID Number	Residence Interval (y)	^{90}Sr & ^{90}Y Bone Marrow Dose Equiv. During & Post Residence Int. mRem	^{137}Cs + ^{137m}Ba Dose Equiv. During & Post Residence Int. mRem	Net External Dose Equiv. During Residence Interval mRem	Total Body Dose Equiv. During & Post Residence Int. mRem	Total Bone Marrow Dose Equiv. During and Post Residence Interval mRem
Mer··	6092	6.3	74*	1600	800	2400	2400
	6080	.88	10*	200	110	310	320
	6038	2.3	27*	1100	280	1400	1400
	6103	3.3	39*	1200	400	1600	1600
	6028	5.3	63*	1200	600	1800	1900
	6044	5.3	63*	1600	600	2200	2300
	6062	4.3	51*	540	520	1100	1100
	6034	7.3	86*	880	900	1800	1900
	865	7.3	86*	430	900	1300	1400
	6050	2.3	27*	410	300	710	740
	6009	4.3	77*	1600	600	2200	2300
	6049	2.3	41*	1600	300	1900	1900
	6042	.55	10*	510	72	580	590
	6014	1.6	29*	1300	210	1500	1500
	6012	7.3	130*	1500	950	2400	2600
	6016	7.3	130*	1500	950	2400	2600

INDIVIDUAL DOSIMETRY DATA FOR BIKINIANS (Cont'd)

Name	ID Number	Residence Interval a	^{90}Sr & ^{90}Y Bone Marrow Dose Equiv. During & Post Residence Int. mRem	^{137}Cs + ^{137m}Ba Dose Equiv. During & Post Residence Int. mRem	Net External Dose Equiv. During Residence Interval mRem	Total Body Dose Equiv. During & Post Residence Int. mRem	Total Bone Marrow Dose Equiv. During and Post Residence Interval mRem
	6013	2.3	41*	1300	300	1600	1600
	6094	6.3	74*	1300	800	2100	2200
	6005	1.8	12	470	230	700	710
	6135	1.3	11	330	170	500	510
	6125	9.3	45	890	1200	2100	2100
	6067	7.3	54	780	950	1700	1800
	6002	2.3	7.7	370	300	670	680
	6006	1.0	9.5	260	230	490	500
	6112	1.3	12	260	160	420	430
	6035	6.3	140	600	760	1400	1500
	6113	4.3	19	360	520	880	900
	6060	2.3	27*	510	280	790	820
	6032	3.3	39*	860	400	1400	1400
	6123	4.3	50*	480	520	1000	1100
	6098	3.3	39*	320	400	720	760

Table 42

1978 ^{137}Cs Body Burden of Bikinians Ordered by Family Group

Rank	Medical ID	WATO	Status of Family Member	Body Burden kBq
1	6018	unknown	H	220.0
	6061		W	82.0
	6094		C(F)	75.0
	6092		C(F)	83.0
2	966	ELAK	H	210.0
	934		W	200.0
	6016		C(M)	53.0
	6044		C(F)	43.0
3	6017	MWEN ELAP	H	210.0
	6034		W	140.0
	6009		C(M)	47.0
4	6070	unknown	H	150.0
	6035		W	100.0
5	6033	unknown	H	140.0
	6058		W	77.0
6	6126	unknown	H	120.0
	6050		W	50.0
	6132		C(M)	68.0
	6038		C(F)	37.0
	6049		C(M)	63.0
	6013		C(M)	37.0
7	864	BATITEN	H	110.0
	865		W	49.0
	6119		C(M)	79.0
	6133		C(M)	78.0
	6028		C(F)	47.0
	6091		C(F)	43.0
	6090		C( )	
8	6068	MANIBOT	H	110.0
	6112		W	65.0
	6118		C(M)	23.0
9	6117	JANAI	H	99.0
	6063		W	56.0
10	6125	BATITEN	H	93.0
	6062		W	53.0

INDIVIDUAL DOSIMETRY DATA FOR BIKINIANS (Cont'd)

Name	ID Number	Residence Interval a	^{90}Sr & ^{90}Y Bone Marrow Dose Equiv. During & Post Residence Int. mRem	^{137}Cs + ^{137m}Ba Dose Equiv. During & Post Residence Int. mRem	Net External Dose Equiv. During Residence Interval mRem	Total Body Dose Equiv. During & Post Residence Int. mRem	Total Bone Marrow Dose Equiv. During and Post Residence Interval mRem
	6065	4.3	130	390	520	910	1000
	6004	.55	10*	130	72	200	210
	6018	6.3	150	1100	820	1900	2100
	6126	2.3	45	1100	300	1400	1400
	6003	8.3	250	580	1100	1700	1900
	6114	1.0	12*	170	120	290	300
	6096	3.3	46	680	430	1100	1100
	80	1.0	18*	200	130	330	350
	6017	8.3	330	1200	1100	2300	2700
	6045	1.0	9.0	150	120	270	280
	6108	4.3	43	210	520	730	770
	6063	4.3	19	620	520	1100	1100
	525	1.0	5.6	350	120	470	480
	934	6.3	120	1300	760	2100	2200
	6068	6.3	60	630	820	1500	1600
	6106	3.3	39*	750	400	1100	1200

INDIVIDUAL DOSIMETRY DATA FOR BIKINIANS (Cont'd)

Name	ID Number	Residence Interval [illegible]	^{90}Sr & ^{90}Y Bone Marrow Dose Equiv. During & Post Residence Int. mRem	^{137}Cs + ^{137m}Ba Dose Equiv. During & Post Residence Int. mRem	Net External Dose Equiv. During Residence Interval mRem	Total Body Dose Equiv. During & Post Residence Int. mRem	Total Bone Marrow Dose Equiv. During and Post Residence Interval mRem
	6025	3.3	39*	900	400	1300	1300
	6064	7.3	86*	400	900	1300	1400
	6023	4.3	77*	990	560	1500	1600
	6131	6.3	110*	950	820	1800	1900
	6011	6.3	170	550	820	1400	1600
	6081	.97	12*	490	120	610	620
	6133	7.3	130*	1900	950	2800	3000
	6048	.55	6.5*	590	72	660	670

*These values were derived from average male or average female daily activity ingestion rates for Sr-90.

Table 42 (Cont'd)

Rank	Medical ID	WATO	Status of Family Member	Body Burden kBq
11	6003		H	90.0
	6097		W	47.0
12	863		H	87.0
	6113		W	38.0
	6025		C(F)	38.0
13	6073		H	80.0
	6051		W	53.0
14	6005		H	77.0
	6046		W	78.0
	6014		C(M)	56.0
15	6008		H	72.0
	6108		W	27.0
	6027		C(F)	43.0
16	6128		H	69.0
	6131		C(M)	63.0
	6011		C(M)	31.0
17	6072		H	65.0
	6059		W	32.0
18	6001		H	64.0
	6122		W	49.0
	6076		C(M)	130.0
19	6071		H	64.0
	6111		W	49.0
	6081		C(F)	38.0
20	813		H	62.0
	6065		W	39.0
21	6007		H	55.0
	6114		W	30.0
	6080		C(F)	20.0
22	6130	K	H	54.0
	6098		W	33.0
23	6006		H	54.0

Table 42 (Cont'd)

Rank	Medical ID	WATO	Status of Family Member	Body Burden kBq
24	6004		H	49.0
	6036		W	57.0
	6042		C(M)	39.0
25	6069		H	43.0
	6064		W	34.0
	6103		C(F)	52.0
26	80		H	42.0
	525		W	87.0
	6048		C(F)	76.0
	6012		C(M)	47.0
27	6019		H	38.0
	6123		W	52.0
	6065		C(F)	39.0
	6023		C(M)	47.0
28	6066		H	30.0
	6060		W	51.0
29	6110		W	56.0
	6127		C(M)	27.0
	6010		C(F)	52.0

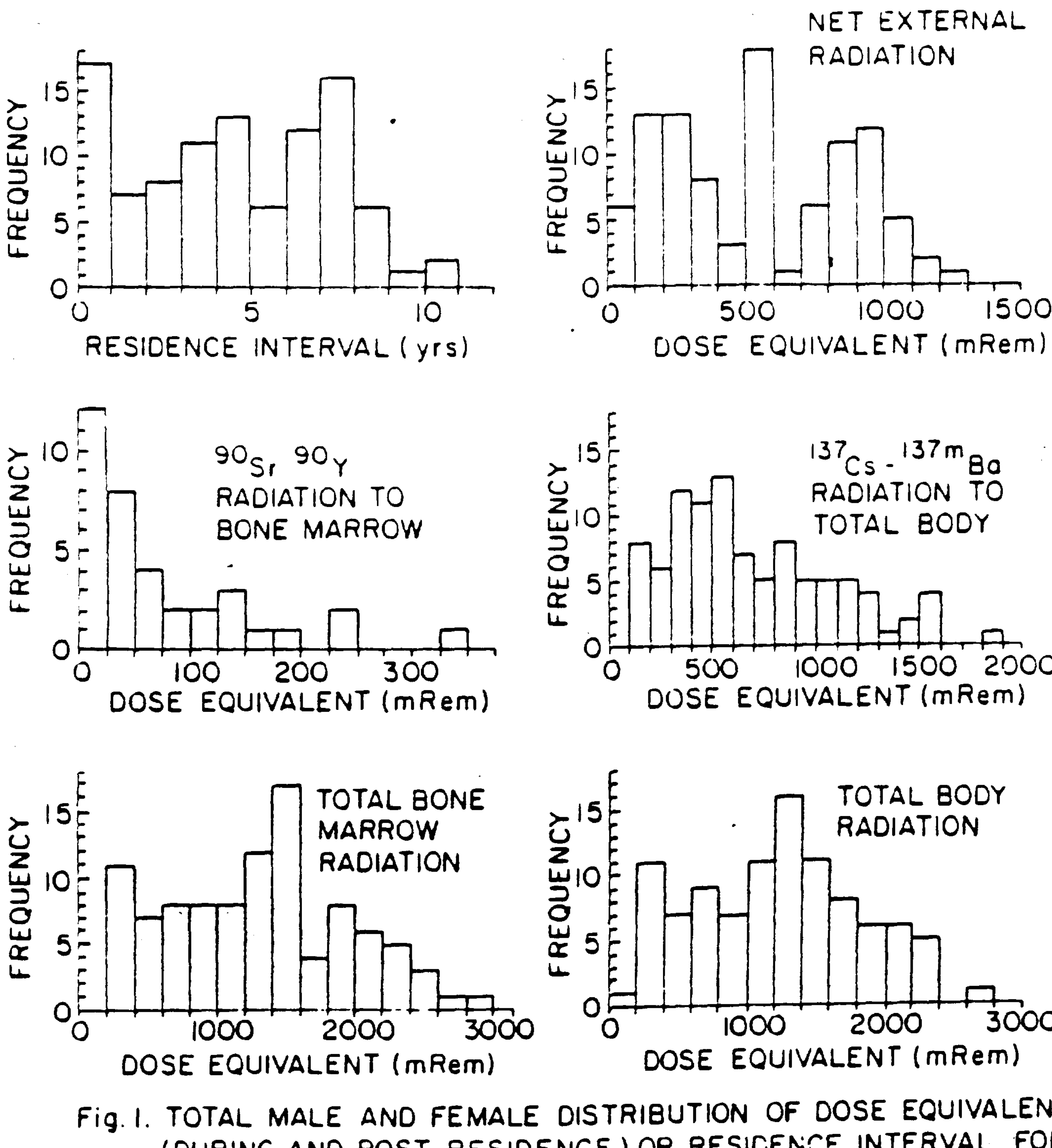


Fig. 1. TOTAL MALE AND FEMALE DISTRIBUTION OF DOSE EQUIVALENT (DURING AND POST RESIDENCE) OR RESIDENCE INTERVAL FOR INHABITANTS OF BIKINI ISLAND, BIKINI ATOLL

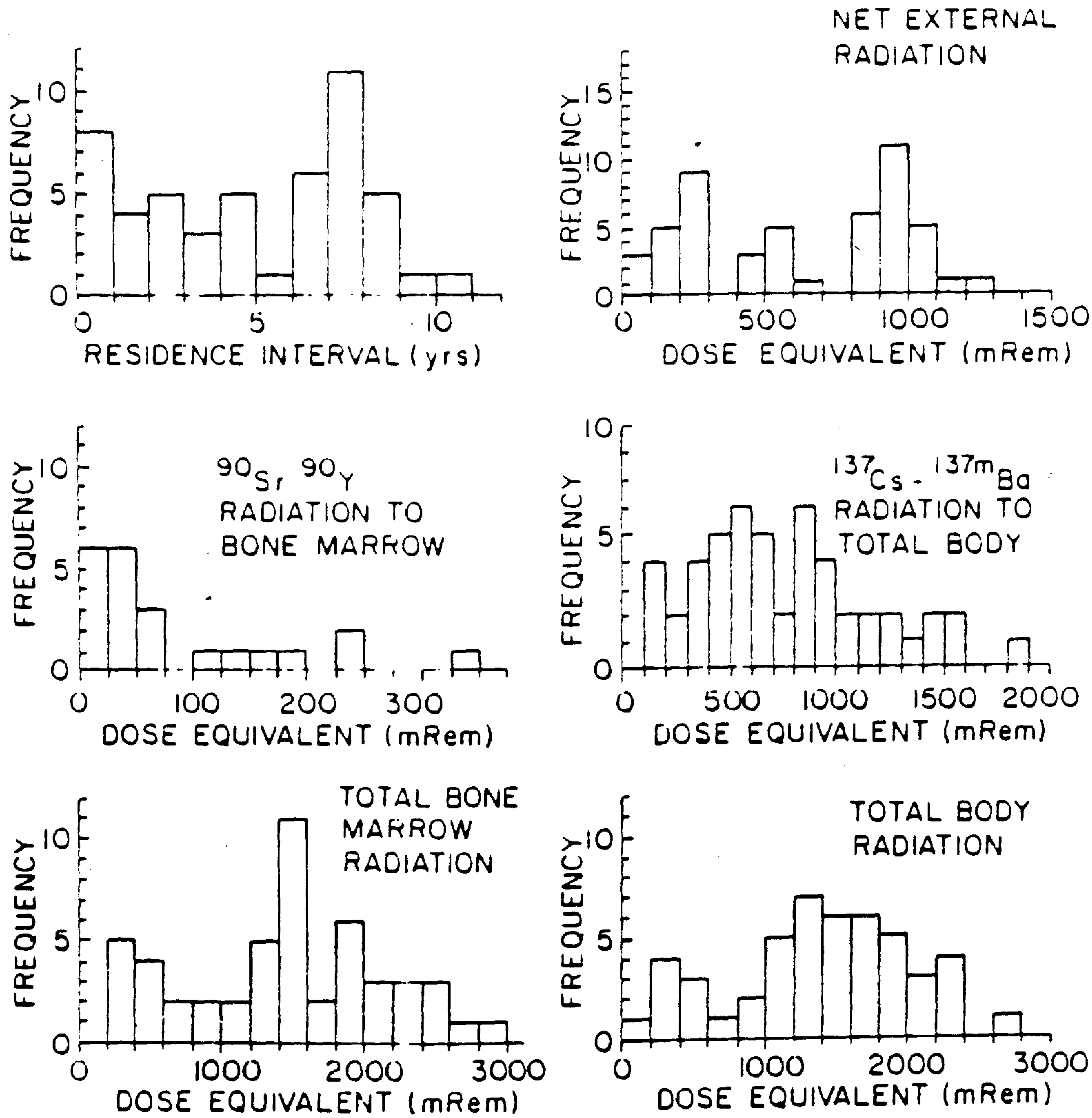


Fig. 2 TOTAL MALE DISTRIBUTION OF DOSE EQUIVALENT (DURING AND POST RESIDENCE) OR RESIDENCE INTERVAL FOR INHABITANTS OF BIKINI ISLAND, BIKINI ATOLL

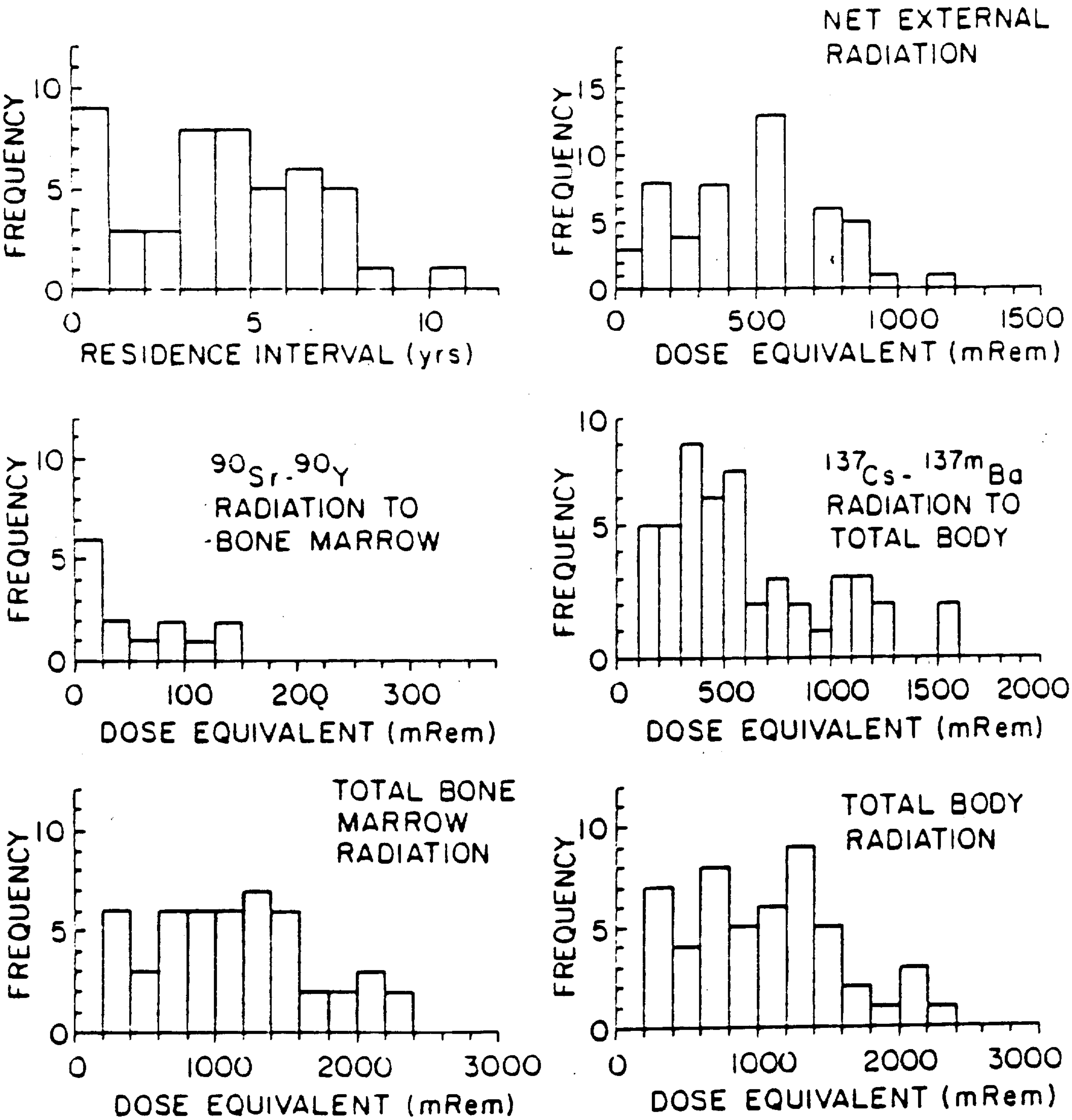


Fig. 3. TOTAL FEMALE DISTRIBUTION OF DOSE EQUIVALENT (DURING AND POST RESIDENCE) OR RESIDENCE INTERVAL FOR INHABITANTS OF BIKINI ISLAND, BIKINI ATOLL

Review of Quality Assurance Data-M.I. Radiological Safety Program-Draft

DRAFT

REVIEW OF QUALITY ASSURANCE DATA

MARSHALL ISLANDS RADIOLOGICAL SAFETY PROGRAM

The quality assurance program for the Marshall Islands Radiological Safety program consists of replicate sampling, participation of inter-laboratory comparisons and repetitive activity determinations of calibrated sources. The following report summarizes the results of the first two activities since the inception of the program. Calibrated source determinations are recorded in the data logbooks. An example of this data is presented in Figure 1.

I. Environmental and Biological Samples

A. Replicate Sampling: bioassay and environmental samples are split processed and analyzed. The results listed in Tables 1 and 2 define the error associated in the sample analyses due to random fluctuations in analytical technique. Individual 5-day, 24 hour urine samples were collected to determine the biological fluctuation associated with repetitive single urine sample results in the same individual. Table 3 describes these results.

B. Inter-laboratory Comparisons: Other laboratories have participated in this quality assurance program since 1974. Samples are split at BNL and then forwarded to each laboratory. Samples may be genuine or purposely spiked with a known amount of radionuclide before processing (Tables 4 and 5).

II. Whole Body Counting

A. Replicate Sampling: Replicate sampling commenced in 1978. Currently 5% of the sample population are repetitively examined. Replicate results are presented in Tables 7 and 8.

Inter-laboratory Comparisons: BNL personnel and Marshallese visiting BNL are counted using the field equipment and the whole-body counter of the BNL Medical Department. Tables 8 and 9 summarize these results.

Table 1

Replicate Sample Summary of Quality Control Data for Marshall Islands Radiological Safety Program

Sample Type: Location	Sample ID	Collection Date	K-40 pCi/g	Sr-90 pCi/g	Cs-137 pCi/g	Pu-239 Pu-240 pCi/g	Pu-238 pCi/g	Co-60 pCi/g
Sludge: Bikini-Bikini from House 15	Sludge 5A	4/5/76	-	-	42.8±1.09	-	-	-
	Sludge 5B	"	-	7.84 ±0.31	36.3±1.21	4.39±1.19	0.099±0.10	-
Soil: Bikini-Bikini, Series L, Pit J	L-9	4/17/75	-	0.36 ±0.02	-	-	-	-
	L-9	"	-	0.57 ±0.04	-	-	-	-
Soil: Eneu-Bikini, Series C, Pit 2	C-3	4/14/75	-	3.82 ±0.07	-	-	-	-
	C-3	"	-	3.84 ±0.13	-	-	-	-
	C-4	"	-	3.00 ±0.08	-	-	-	-
	C-4	"	-	4.12 ±0.14	-	-	-	-
	C-5	"	-	3.91 ±0.07	-	-	-	-
	C-5	"	-	4.30 ±0.16	-	-	-	-
	C-6	"	-	10.4 ±0.12	-	-	-	-
	C-6	"	-	9.78 ±0.18	-	-	-	-
	C-7	"	-	8.38 ±0.15	-	0.009± -	-	-
	C-7	"	-	5.38 ±0.12	-	0.008± -	-	-
	C-8	"	-	4.12 ±0.08	-	-	-	-
	C-8	"	-	4.46 ±0.13	-	-	-	-
	C-9	"	-	6.21 ±0.11	-	-	-	-
	C-9	"	-	5.37 ±0.13	-	-	-	-
Soil: Eneu-Bikini, Series D, Pit #1	D-1	"	-	-	-	0.345±0.30	-	-
	D-1	"	-	-	-	0.210± -	-	-
	D-7	4/14/75	-	10.5 ±0.17	-	-	-	-
	D-7	"	-	6.39 ±0.15	-	-	-	-
Soil: Nam-Bikini, 6" Core near W-2	S-8	4/7/76	-	53.9 ±0.53	-	-	-	-
	S-8	"	-	55.7 ±0.79	-	-	-	-
Soil: Nam-Bikini, 0-50cm Profile at Pit W-1	S-15	"	-	48.6 ±0.79	-	-	-	-
	recount	"	-	51.7 ±0.79	-	-	-	-
	S-15	"	-	49.5 ±0.50	-	-	-	-
Soil: Nam-Bikini, 6" Core East Transect	S-20	"	-	184. ±1.00	-	-	-	-
	recount	"	-	187. ±1.45	-	-	-	-
Soil: Nam-Bikini, 0-70cm Profile, Station #2	S-27	4/8/76	-	83.8 ±1.41	-	-	-	-
	recount	"	-	77.0 ±0.64	-	-	-	-
	S-27	"	-	75.3 ±0.62	-	-	-	-
Soil: Nam-Bikini, 6" Core Station #2	S-25	"	-	75.3 ±0.64	-	-	-	-
	recount	"	-	84.2 ±1.02	-	-	-	-

Table 1 (Cont'd)

Replicate Sample Summary of Quality Control Data for Marshall Islands Radiological Safety Program

Sample Type: Location	Sample ID	Collection Date	K-40 pCi/g	Sr-90 pCi/g	Cs-137 pCi/g	Pu-239 Pu-240 pCi/g	Pu-238 pCi/g	Co-60 pCi/g
Soil: Rongelap-Rongelap, 12" Profile	S-1	4/3/76	-	46.4 ±0.75	-	-	-	-
	S-1	"	-	47.2 ±1.32	-	-	-	-
Animal: Eneu-Bikini, Fish Scales	F-3A	4/14/75	11.9 ±2.35	-	-	-	-	1.43 ±0.288
	F-3A	"	11.5 ±2.17	-	-	-	-	1.32 ±0.266
Animal: Nam-Bikini, Mullet Fish	F-1A	12/8/74	9.34 ±1.97	-	-	-	-	2.39 ±0.349
	F-1A	"	10.1 ±2.14	-	-	-	-	2.61 ±0.381
Animal: Nam-Bikini, Mullet Skin	F-1D	12/8/74	4.05 ±1.62	0.433 ±0.161	-	-	-	3.32 ±0.480
	F-1D	"	4.38 ±1.76	0.481 ±0.170	-	-	-	3.06 ±0.440
Animal: Nam-Bikini, Snapper Viscera	F-4C	"	7.22 ±1.68	-	-	-	-	4.52 ±0.445
	F-4C	"	6.67 ±1.55	-	-	-	-	4.17 ±0.411
Range of Ratios of Replicate Samples	--	--	1.03-1.08	1.00-1.58	1.18	1.-1.64	-	1.08-1.09

Table 2

Sr-90 Replicate Sampling in Soil, Vegetation and Urine

Date	Type	ID	First Run[(a)]	Second Run[(a)]	Ratio First Run / Second Run	Comment
1976	Soil	S-1	21 ± .34	21 ± .59	1.0	1976 Soil
1976	Soil	S-8	54 ± .53	56 ± .79	.96	Mean
1976	Soil	S-15	50 ± .50	49 ± .49	1.0	Ratio = .98±.052
1976	Soil	S-20	180 ± .99	140 ±1.5	.95	
1976	Soil	S-25	75 ± .64	84 ±1.0	.89	
1976	Soil	S-27	77 ± .64	75 ± .62	1.0	
1977	Soil	S-51	.67± .15	.90± .14	.74	
1977	Soil	S-53	10 ± .35	9.3 ± .33	1.1	
1977	Soil	S-55	5.4 ± .29	6.0 ± .31	.90	
1977	Soil	S-57	7.1 ± .33	7.0 ± .32	1.0	
1977	Soil	S-59	21 ± .52	22 ± .54	.95	
1977	Soil	S-61	12 ± .43	12 ± .41	1.0	1977 Soil
1977	Soil	S-63	22 ± .52	23 ± .52	.96	Mean
1977	Soil	S-65	1.1 ± .16	1.2 ± .17	.92	Ratio = .98±.10
1977	Soil	S-75	79 ±1.2	78 ± .87	1.0	
1977	Soil	S-85	11 ± .35	10 ± .36	1.1	
1977	Soil	S-95	2.7 ± .19	2.3 ± .20	1.2	
1977	Soil	S-105	18 ± .44	18 ± .48	1.0	
1977	Soil	S-108	1.3 ± .26	1.5 ± .28	.87	
1977	Soil	S-115	7.0 ± .30	6.8 ± .26	1.0	
1977	Soil	S-125	11 ± .40	12 ± .35	.92	
1976	Veg	V-3	170 ±1.1	170 ±1.3	1.0	1976 Veg
1976	Veg	V-9	320 ±1.5	320 ±1.8	1.0	Mean
1976	Veg	V-11	260 ±1.8	260 ±2.0	1.0	Ratio = 1.00±.011
1976	Veg	V-14	89 ± .98	87 ± .92	1.0	
1976	Veg	V-21	84 ± .72	85 ±1.1	.99	
1978	Urine	22	6.7 ± .83	6.5 ±1.0	1.0	
1978	Urine	23	8.2 ±1.0	9.8 ±1.4	.84	
1978	Urine	24	10 ±1.1	10 ±1.3	1.0	
1978	Urine	25	8.3 ± .91	9.0 ±1.0	.92	1978 Urine
1978	Urine	26	5.0 ±1.1	3.6 ±1.1	1.4	Mean
1978	Urine	27	3.3 ±1.2	3.8 ± .89	.87	Ratio = .93±.28
1978	Urine	28	3.4 ± .67	3.8 ± .81	.89	
1978	Urine	29	3.2 ± .82	3.0 ±1.2	1.07	
1978	Urine	30	.41± .82	1.2 ± .68	.34	

(a) pCi per gram analyzed for soil and vegetation, pCi per amount analyzed for urine.

Table 3

Mean, One Standard Deviation, Counting Error and Ranges of Cs-137 and Sr-90

Individual Urine Activity Concentrations in Samples Collected Sequentially During January 1979

	Cs-137*					Sr-90*				
		Standard Deviation	Counting Error	Range			Standard Deviation	Counting Error	Range	
ID #	Mean nCi/ℓ	± nCi/ℓ	± nCi/ℓ	Low nCi/ℓ	High nCi/ℓ	Mean pCi/ℓ	± pCi/ℓ	± pCi/ℓ	Low pCi/ℓ	High pCi/ℓ
55	0.32	0.13	0.015	0.21	0.50	0.41	0.41	0.12	0.12	1.1
58	0.40	0.16	0.016	0.21	0.60	-0.03	0.35	0.12	-0.41	0.50
6159	0.13	0.039	0.011	0.064	0.16	0.17	0.47	0.12	-0.19	0.92
6118	3.5	1.0	0.043	2.1	4.9	1.4	1.6	0.30	0.48	4.2
57	0.18	0.039	0.012	0.12	0.23	0.27	0.65	0.17	0.86	0.78
6066	1.3	1.1	0.082	0.41	3.1	1.5	2.5	5.5	0.30	5.8
6112	6.5	2.9	0.064	2.0	9.8	.082	0.57	0.45	-0.71	0.73
6060	1.7	0.49	0.10	1.2	2.5	1.2	0.47	0.41	0.86	1.
6064	2.0	0.36	0.033	1.5	2.4	0.91	1.4	0.22	0.14	3.2
6067	5.2	0.47	0.052	4.5	5.8	0.54	0.42	0.13	0.00	1.2
6035	2.7	0.19	0.069	2.5	2.9	4.3	2.1	1.4	2.4	6.5
6161	0.33	0.11	0.015	0.23	0.48	0.86	0.79	0.20	0.12	2.1
254	0.26	0.067	0.013	0.19	0.34	0.16	0.21	0.14	-0.60	0.45
255	0.23	0.11	0.013	0.10	0.39	-.20	0.46	0.37	-0.81	0.48
257	0.19	0.044	0.010	0.13	0.25	-.26	0.22	0.18	-0.02	0.49
6070	6.3	1.1	0.070	5.0	7.0	2.8	0.90	0.35	2.1	3.8
Average of all samples	2.3	.74	0.039	1.3	2.6	0.88	0.85	0.64	0.29	2.13

*Based on five sequential daily voids.

Table 4

April 1976 Summary of Intercomparison Data for the Marshall Islands Radiological Safety Program

Sample Description	Location	Laboratory	Sr-90 nCi/kg	Sr-90 Ratio BNL/HASL*	Cs-137 nCi/kg	Cs-137 Ratio BNL/HASL*
Pig Skin	Bikini	BNL	0.38 ± .050		120 ± 2.0	
Pig Skin	Bikini	HASL	0.48 ± .050	0.79	130 ± 6.0	0.92
Pig Meat	Bikini	BNL	0.44 ± .060		230 ± 3.0	
Pig Meat	Bikini	HASL	0.39 ± .050	1.1	220 ± 9.0	1.0
Pig Bone	Bikini	BNL	25. ± .34		63. ± 1.0	
Pig Bone	Bikini	HASL	65. ± 2.0	0.38	69. ± 3.0	0.91
Pig Nose	Bikini	BNL	1.3 ± .090		210 ± 4.0	
Pig Nose	Bikini	HASL	2.1 ± .20	0.62	170 ± 9.0	1.2
Pig Brains	Bikini	BNL	2.1 ± .14		180 ± 5.0	
Pig Brains	Bikini	HASL	2.6 ± .20	0.81	140 ± 7.0	1.3
Pig Muscle	Bikini	BNL	0.45 ± .060		66. ± 2.0	
Pig Muscle	Bikini	HASL	0.86 ± .10	0.52	150 ± 8.0	0.44
Coconut Crab Shell	Wotje	BNL	1.1 ± .11		0.40 ± .20	
Coconut Crab Shell	Wotje	HASL	1.1 ± .10	1.0	0.80 ± .20	0.50
Coconut Crab Meat	Wotje	BNL	0.10 ± .060		2.8 ± .29	
Coconut Crab Meat	Wotje	HASL	0.080 ± .010	1.3	1.5 ± .10	1.9
Coconut Crab Viscera	Wotje	BNL	0.030 ± .060		0.25 ± .070	
Coconut Crab Viscera	Wotje	HASL	0.13 ± .010	0.23	0.70 ± .10	0.36
Coconut Crab Shell	Kabelle	BNL	210 ± 3.0		17. ± 1.0	
Coconut Crab Shell	Kabelle	HASL	140 ± 14.	1.5	18. ± 1.0	0.94
Coconut Crab Meat	Kabelle	BNL	7.4 ± .31		66. ± 1.2	
Coconut Crab Meat	Kabelle	HASL	6.7 ± .50	1.1	74. ± 4.0	0.89
Coconut Crab Viscera	Kabelle	BNL	10. ± .23		44. ± 1.0	
Coconut Crab Viscera	Kabelle	HASL	11. ± .50	0.91	47. ± 2.0	0.94
Coconut Crab Shell	Arbor	BNL	92. ± 1.4		4.7 ± .10	
Coconut Crab Shell	Arbor	HASL	58. ± 3.0	1.6	6.0 ± .50	0.78
Coconut Crab Meat	Arbor	BNL	3.0 ± .15		25. ± .70	
Coconut Crab Meat	Arbor	HASL	2.8 ± .30	1.1	16. ± 1.0	1.6
Coconut Crab Viscera	Arbor	BNL	8.6 ± .78		11. ± .50	
Coconut Crab Viscera	Arbor	HASL	7.4 ± .70	1.2	29. ± 1.0	0.38
Average Ratio ± Standard Deviation				0.94 ±0.39		0.94 ±0.44

*Currently the Health and Safety Laboratory (HASL) is named the Environmental Measurements Laboratory (EML)

Table 5

Laboratory Intercomparison of Soil, Air, Vegetation, Tissue and Water Radiochemical Analyses

Date Yr Mo	Type	Nuclide	BNL* Value	EML** Value	Ratio BNL/EML
76 10	Air	Be 7	0.170E 04	0.187E 04	0.91
76 10	Air	Mn 54	0.500E 03	0.145E 03	3.5
76 10	Air	Co 57	0.187E 03	0.252E 03	0.74
76 10	Air	Co 60	0.810E 02	0.838E 02	0.97
76 10	Air	Fe 59	0.240E 03	0.279E 03	0.86
76 10	Air	Sr 90	0.370E 01	0.300E 01	1.2
76 10	Air	Zr 95	0.157E 03	0.179E 03	0.88
76 10	Air	Cs 134	0.105E 03	0.103E 03	1.0
76 10	Air	Cs 137	0.258E 03	0.286E 03	0.90
76 10	Air	Pu 238	0.450E-01	0.600E-01	0.75
76 10	Air	Pu 239	0.150E-01	0.600E-01	0.25
77 01	Air	Be 7	0.540E 04	0.590E 04	0.95
77 01	Air	Na 22	0.420E 03	0.505E 03	0.83
77 01	Air	Mn 54	0.430E 03	0.473E 03	0.91
77 01	Air	Co 58	0.460E 03	0.509E 03	0.90
77 01	Air	Co 60	0.380E 03	0.427E 03	0.89
77 01	Air	Fe 59	0.700E 03	0.725E 03	0.97
77 01	Air	Sr 90	0.110E 02	0.982E 01	1.1
77 01	Air	Nb 95	0.560E 03	0.581E 03	0.96
77 01	Air	Ru 103	0.580E 03	0.550E 03	1.1
77 01	Air	Ru 106	0.490E 04	0.541E 04	0.91
77 01	Air	Sb 125	0.500E 04	0.541E 04	0.93
77 01	Air	Cs 134	0.500E 03	0.500E 03	1.0
77 01	Air	Cs 137	0.980E 03	0.982E 03	1.0
77 01	Air	Ce 144	0.874E 04	0.987E 04	0.89
77 01	Air	Pu 238	0.220E 01	0.990E 00	2.2
77 01	Air	Pu 239	0.200E 01	0.110E 01	1.8
77 04	Air	Mn 54	0.255E 03	0.252E 03	1.0
77 04	Air	Co 60	0.244E 03	0.264E 03	0.92
77 04	Air	Sr 90	0.170E 02	0.122E 02	1.3
77 04	Air	Zr 95	0.220E 03	0.232E 03	0.95
77 04	Air	Ru 103	0.289E 03	0.275E 03	1.1
77 04	Air	Cs 137	0.213E 03	0.203E 03	1.1
77 04	Air	Pu 239	0.220E 00	0.590E 00	0.37
77 07	Air	Na 22	0.134E 03	0.142E 03	0.94
77 07	Air	Co 57	0.146E 03	0.158E 03	0.92
77 07	Air	Zn 65	0.223E 03	0.218E 03	1.0

*BNL Brookhaven National Laboratory
**EML Environmental Measurements Laboratory

Table 5 (cont'd)

Date Yr Mo	Type	Nuclide	BNL Value	EML Value	Ratio BNL/EML
77 07	Air	Cs 134	0.193E 03	0.196E 03	0.99
77 07	Air	Cs 137	0.191E 03	0.178E 03	1.1
77 07	Air	Ce 141	0.576E 03	0.606E 03	0.95
77 07	Air	Pu 239	0.125E 01	0.162E 01	0.77
76 10	Soil	K 40	0.210E 00	0.810E 00	0.26
76 10	Soil	Sr 90	0.280E 00	0.234E 00	1.2
76 10	Soil	Cs 137	0.410E 00	0.473E 00	0.87
76 10	Soil	Pu 238	0.500E-02	0.600E-02	0.83
76 10	Soil	Pu 239	0.330E-01	0.450E-01	0.73
77 01	Soil	K 40	0.130E 01	0.221E 01	0.59
77 01	Soil	Co 60	0.730E 00	0.860E 00	0.85
77 01	Soil	Sr 90	0.620E 01	0.263E 01	2.4
77 01	Soil	Cs 137	0.490E 02	0.586E 02	0.84
77 01	Soil	Pu 238	0.230E-01	0.270E-01	0.85
77 01	Soil	Pu 239	0.359E 00	0.550E 00	0.65
77 04	Soil	K 40	0.240E 01	0.223E 01	1.1
77 04	Soil	Co 60	0.680E 00	0.780E 00	0.87
77 04	Soil	Sr 90	0.460E 01	0.263E 01	1.8
77 04	Soil	Cs 137	0.530E 02	0.586E 02	0.90
77 04	Soil	Pu 238	0.230E-01	0.270E-01	0.85
77 04	Soil	Pu 239	0.500E 00	0.610E 00	0.82
77 07	Soil	K 40	0.152E 01	0.245E 01	0.62
77 07	Soil	Co 60	0.793E 00	0.870E 00	0.91
77 07	Soil	Sr 90	0.258E 01	0.264E 01	0.98
77 07	Soil	Cs 137	0.595E 02	0.637E 02	0.93
77 07	Soil	Pu 238	0.230E-01	0.320E-01	0.72
77 07	Soil	Pu 239	0.472E 00	0.600E 00	0.79
76 10	Tissue	Sr 90	0.320E 01	0.419E 01	0.76
77 01	Tissue	K 40	0.230E 01	0.173E 01	1.3
77 01	Tissue	Sr 90	0.220E 01	0.286E 01	0.77
77 04	Tissue	K 40	0.400E 01	0.860E 00	4.7
77 04	Tissue	Sr 90	0.440E 01	0.297E 01	1.5
77 07	Tissue	K 40	0.820E 00	0.560E 00	1.5
77 07	Tissue	Sr 90	0.300E 01	0.331E 01	0.91
77 07	Tissue	Cs 137	0.960E-01	0.370E-01	2.6
76 10	Veg	Sr 90	0.170E 00	0.176E 00	0.97
76 10	Veg	Cs 137	0.320E 00	0.252E 00	1.3
77 04	Veg	K 40	0.186E 03	0.205E 03	0.91
77 04	Veg	Cs 137	0.220E 00	0.230E 00	0.96
76 10	Water	H 3	0.530E 02	0.406E 02	1.3
76 10	Water	Mn 54	0.140E 01	0.139E 01	1.0
76 10	Water	Co 57	0.150E 01	0.157E 01	0.96
76 10	Water	Co 60	0.580E 00	0.650E 00	0.89
76 10	Water	Fe 59	0.170E 01	0.160E 01	1.1
76 10	Water	Sr 90	0.600E-01	0.500E-01	1.2

Table 5 (cont'd)

Date Yr Mo	Type	Nuclide	BNL Value	EML Value	Ratio BNL/EML
76 10	Water	Cs 134	0.870E 00	0.920E 00	0.95
76 10	Water	Cs 137	0.100E 01	0.100E 01	1.0
76 10	Water	Ce 144	0.840E 00	0.910E 00	0.92
76 10	Water	Pu 238	0.800E-04	0.400E-03	0.20
76 10	Water	Pu 239	0.300E-03	0.860E-03	0.35
77 01	Water	H 3	0.268E 02	0.406E 02	0.66
77 01	Water	Mn 54	0.177E 01	0.178E 01	0.99
77 01	Water	Co 58	0.220E 01	0.232E 01	0.95
77 01	Water	Co 60	0.550E 01	0.572E 01	0.96
77 01	Water	Fe 59	0.250E 01	0.228E 01	1.1
77 01	Water	Sr 90	0.164E 01	0.216E 01	0.76
77 01	Water	Cs 134	0.230E 01	0.232E 01	0.99
77 01	Water	Cs 137	0.250E 01	0.252E 01	0.99
77 01	Water	Ce 144	0.460E 01	0.518E 01	0.89
77 01	Water	Pu 238	0.120E-02	0.240E-02	0.50
77 01	Water	Pu 239	0.800E-03	0.230E-02	0.35
77 04	Water	H 3	0.407E 02	0.406E 02	1.0
77 04	Water	Mn 54	0.114E 01	0.113E 01	1.0
77 04	Water	Co 57	0.140E 01	0.177E 01	0.79
77 04	Water	Co 60	0.180E 01	0.189E 01	0.95
77 04	Water	Fe 59	0.190E 01	0.201E 01	0.95
77 04	Water	Cs 137	0.200E 01	0.204E 01	0.98
77 04	Water	Pu 238	0.400E-03	0.122E-02	0.33
77 04	Water	Pu 239	0.400E-03	0.150E-02	0.27
77 07	Water	H 3	0.430E 02	0.406E 02	1.1
77 07	Water	Be 7	0.427E 02	0.403E 02	1.1
77 07	Water	Na 22	0.978E 00	0.118E 01	0.83
77 07	Water	Zn 65	0.499E 01	0.523E 01	0.95
77 07	Water	Sr 90	0.115E 01	0.113E 01	1.0
77 07	Water	Cs 137	0.170E 01	0.174E 01	0.98
77 07	Water	Ce 141	0.459E 01	0.518E 01	0.89
77 07	Water	Pu 239	0.298E-02	0.450E-02	0.66
77 10	Air	Be 7	0.171E 04	0.171E 04	1.0
77 10	Air	Co 57	0.755E 02	0.856E 02	0.88
77 10	Air	Co 60	0.139E 03	0.149E 03	0.93
77 10	Air	Sb 125	0.153E 04	0.208E 04	0.73
77 10	Air	Cs 134	0.230E 03	0.115E 03	2.0
77 10	Air	Cs 137	0.165E 03	0.144E 03	1.2
77 10	Air	Pu 238	0.270E-01	0.140E-01	1.9
77 10	Air	Pu 239	0.826E 00	0.126E 01	0.66
77 10	Soil	Pu 238	0.330E-01	0.800E-01	0.41
77 10	Soil	Pu 239	0.230E 01	0.356E 01	0.65
77 10	Tissue	K 40	0.199E 01	0.135E 01	1.5
77 10	Tissue	Sr 90	0.374E 01	0.364E 01	1.0
77 10	Tissue	Cs 137	0.182E 00	0.140E 00	1.3

Table 5 (cont'd)

Date Yr Mo	Type	Nuclide	BNL Value	EML Value	Ratio BNL/EML
77 10	Veg	K 40	0.159E 02	0.175E 02	0.91
77 10	Veg	Co 60	0.569E 01	0.507E 01	1.1
77 10	Veg	Cs 137	0.140E 02	0.125E 02	1.1
77 10	Water	H 3	0.444E 03	0.460E 03	0.97
77 10	Water	Co 60	0.303E 00	0.310E 00	0.98
77 10	Water	Sr 90	0.361E 00	0.390E 00	0.93
77 10	Water	Pu 238	0.260E-03	0.340E-03	0.76
77 10	Water	Pu 239	0.197E-03	0.160E-03	1.2
78 01	Air	Na 22	0.755E 02	0.766E 02	0.99
78 01	Air	Mn 54	0.194E 03	0.137E 03	1.4
78 01	Air	Co 60	0.127E 03	0.105E 03	1.2
78 01	Air	Zn 65	0.263E 03	0.183E 03	1.4
78 01	Air	Sr 90	0.538E 02	0.450E 02	1.2
78 01	Air	Sr 90	0.542E 02	0.450E 02	1.2
78 01	Air	Cs 137	0.144E 03	0.102E 03	1.4
78 01	Air	Cf 144	0.433E 04	0.330E 04	1.3
78 01	Soil	K 40	0.185E 02	0.214E 02	0.86
78 01	Soil	Cs 137	0.350E 00	0.480E 00	0.73
78 01	Soil	Ra 226	0.240E 01	0.130E 01	1.9
78 01	Soil	Am 241	0.230E 00	0.350E 00	0.66
78 01	Tissue	K 40	0.221E 01	0.140E 01	1.6
78 01	Tissue	Sr 90	0.131E 01	0.365E 01	0.36
78 01	Tissue	Sr 90	0.146E 01	0.365E 01	0.40
78 01	Tissue	Cs 137	0.104E 00	0.140E 00	0.74
78 01	Veg	K 40	0.212E 03	0.177E 02	12.
78 01	Veg	Co 60	0.603E 01	0.505E 01	1.2
78 01	Veg	Sr 90	0.161E 02	0.150E 02	1.1
78 01	Veg	Sr 90	0.156E 02	0.150E 02	1.0
78 01	Veg	Cs 137	0.157E 02	0.125E 02	1.3
78 01	Veg	Th 228	0.154E 01	0.970E 00	1.6
78 01	Water	H 3	0.213E 02	0.215E 02	0.99
78 01	Water	H 3	0.223E 02	0.215E 02	1.0
78 01	Water	Mn 54	0.133E 01	0.127E 01	1.1
78 01	Water	Co 58	0.270E 01	0.253E 01	1.1
78 01	Water	Co 60	0.430E 01	0.392E 01	1.1
78 01	Water	Sr 90	0.490E 00	0.450E 00	1.1
78 01	Water	Sr 90	0.530E 00	0.450E 00	1.2
78 01	Water	Cs 137	0.115E 01	0.113E 01	1.0
79 04	Air**	Sr 89	0.811E 01	0.815E 01	1.0
79 04	Air**	Be 7	0.152E 04	0.160E 04	0.95
79 04	Air**	Na 22	0.123E 03	0.177E 03	1.1
79 04	Air**	Zr 95	0.896E 02	0.878E 02	1.0
79 04	Air**	Cs 137	0.126E 03	0.132E 03	0.95
79 04	Water**	Sr 89	0.112E 00	0.120E 00	0.93
79 04	Water**	Co 60	0.116E 01	0.121E 01	0.97

Table 5 (cont'd)

Date Yr Mo	Type	Nuclide	BNL Value	EML Value	Ratio BNL/EML
79 04	Water**	Cs 134	0.121E 01	0.117E 01	1.0
79 04	Water**	Cs 137	0.116E 01	0.121E 01	0.96
79 04	Water**	Ce 144	0.196E 02	0.204E 02	0.96
79 04	Soil**	Sr 90	0.20 E 00	0.225E 00	0.89
79 04	Soil**	Cs 137	0.592E 00	0.577E 00	1.0
79 04	Soil**	K 40	0.312E 01	0.280E 01	1.1
79 04	Tissue**	Sr 90	0.397E 01	0.337E 01	1.2
79 04	Tissue**	Cs 137	0.300E 01	0.310E 01	0.96
79 04	Tissue**	K 40	0.846E 01	0.833E 01	1.0
79 04	Veg**	Sr 90	0.110E 01	0.108E 01	1.0
79 04	Veg**	Cs 137	0.232E 00	0.205E 00	1.1
79 04	Veg**	K 40	0.204E 01	0.167E 01	1.2
80 10*	Water	H 3	0.140E 02	0.149E 02	0.94
80 10*	Water	Co 60	0.125E 01	0.197E 01	0.63
80 10*	Water	Sr 89	0.205E 00	0.218E 00	0.94
80 10*	Water	Sr 90	0.160E-01	0.216E-01	0.74
80 10*	Water	Cs 134	0.159E 01	0.244E 01	0.65
80 10*	Water	Cs 137	0.145E 01	0.226E 01	0.64
80 10*	Air	Be 7	0.294E 04	0.230E 04	1.3
80 10*	Air	Co 60	0.237E 03	0.200E 03	1.2
80 10*	Air	Sr 90	0.994E 01	0.107E 01	0.93
80 10*	Air	Cs 134	0.254E 04	0.247E 04	1.0
80 10*	Air	Ce 141	0.435E 03	0.404E 03	1.1
80 10*	Air	Ce 144	0.338E 04	0.346E 04	0.98
80 10*	Soil	Sr 90	0.434E 00	0.490E 00	0.94
80 10*	Veg	Sr 90	0.126E 02	0.138E 02	0.91
80 10*	Veg	Sr 90	0.963E 02	0.138E 02	7.0***
80 10*	Veg**	K 40	0.735E 01	0.225E 02	0.33
80 10*	Soil**	K 40	0.135E 01	0.207E 02	0.65
80 10*	Soil**	Co 60	0.073E 00	0.10 E 00	0.73
80 10*	Soil**	Cs 137	0.775E 01	0.110E 02	0.70
80 10*	Soil**	Ra 226	0.44 E 00	0.66 E 00	0.67
80 10*	Soil**	Th 228	0.66 E 00	0.66 E 00	1.0
80 10*	Tissue**	K 40	0.231E 01	0.17 E 01	1.4
80 10*	Tissue**	Cs 137	0.195E 02	0.275E 02	0.71
80 10*	Tissue**	Co 60	0. 60E 01	0.874E 01	0.69
80 10*	Tissue**	Sr 90	0.358E 02	0.387E 02	0.93

*Reanalyzed on 81 03.
**BNL Result Not Reported to EML.
***Result erroneously reported as vegetation instead of tissue.

Table 5 (cont'd)

SUMMARY

Year	Type	Mean BNL/EML Ratio	Standard Deviation of Ratio	Number of Samples
1976	Air	1.1	0.8	11
1977	Air	1.1	0.4	38
1978	Air	1.3	0.15	8
1979	Air	1.0	0.06	5
1981	Air	1.1	0.14	6
1976	Soil	0.78	0.34	5
1977	Soil	0.92	0.43	20
1978	Soil	1.0	0.56	4
1979	Soil	1.0	0.11	3
1981	Soil	0.78	0.15	6
1976	Tissue	0.76	-	1
1977	Tissue	1.7	1.2	10
1978	Tissue	0.77	0.57	4
1979	Tissue	1.1	0.13	3
1981	Tissue	0.93	0.33	4
1976	Veg	1.1	0.21	2
1977	Veg	1.0	0.11	5
1978	Veg	3.0	4.4	6
1981	Veg	3.4	4.3	2
1976	Water	0.90	0.33	11
1977	Water	0.87	0.23	32
1978	Water	1.1	0.058	7
1979	Water	0.96	0.03	5
1981	Water	0.76	0.15	6

Table 6

^{90}Sr Urine Intercomparison Data - 1981

Sample ID#	Spiked ^{90}Sr Conc. pCi/ℓ	BNL[a] ^{90}Sr Report Conc. pCi/ℓ	EML[b] ^{90}Sr Report Conc. pCi/ℓ
1056	0.51	1.2 ± 0.60	1.6 ± 0.06
1074	10	10 ± 0.7	13 ± 0.13
2085	31	32 ± 1.5	37 ± 0.24
Pooled Urine[c]	-	0.37 ± 0.11[d] 0.58 ± 0.21[e]	0.57 ± 0.01
Spike Assay	$11x10^3$[f]	$11x10^3$	-

[a] Brookhaven National Laboratory
[b] Environmental Measurements Laboratory
[c] Kili Composite, 10 Liters
[d] 2x Background Variations at Time of Count
[e] Based on Decay Count 2-3 Days Later
[f] Amersham Searle Ampoule S3/67/51

Table 7

Replicate Results of Marshallese

Description	ID #	^{137}Cs nCi	Potassium Grams	Ratio ^{137}Cs	Ratio K
April 1978 Survey	6132	2.3 2.3	74 71	1.0	1.0
May 1979 Survey	6069	0.43 ± 0.0013 0.38 ± 0.0015	170 ± 6.0 170 ± 6.0	1.1	1.0
	966	0.51 ± 0.0013 0.48 ± 0.0016	140 ± 6.0 150 ± 6.0	1.1	0.93
September 1979 Survey	911	0.14 ± 0.00099 0.14 ± 0.00098	120 ± 5.0 120 ± 5.0	1.0	1.0
	939	0.21 ± 0.0012 0.21 ± 0.0012	150 ± 5.0 150 ± 5.0	1.0	1.0
	8022	0.057 ± 0.00068 0.057 ± 0.00068	140 ± 5.0 140 ± 5.0	1.0	1.0
	2125	0.060 ± 0.00070 0.059 ± 0.0069	160 ± 4.8 160 ± 4.7	1.0	1.0
	2248	0.069 ± 0.00072 0.069 ± 0.00072	130 ± 5.0 130 ± 4.0	1.0	1.0
	882	0.12 ± 0.0009 0.12 ± 0.001	150 ± 5.0 140 ± 5.0	1.0	1.1
		nCi	Grams		
January 1980 Survey	1021	15 ± .48 13 ± .45	230 ± 6.2 700 ± 5.7	1.2	1.2
	1045	21 ± .49 20 ± .49	170 ± 5.7 170 ± 5.6	1.1	1.0
	1057	4.3 ± .37 4.1 ± .36	180 ± 5.8 170 ± 5.9	1.1	1.1
	1081	8.3 ± .33 8.1 ± .34	63 ± 4.0 68 ± 4.0	1.0	0.93
	1101	14 ± .45 15 ± .46	190 ± 5.7 200 ± 5.8	0.93	0.95

Table 7 (cont'd)

Description	ID #	^{137}Cs nCi	Potassium Grams	Ratio ^{137}Cs	Ratio K
January 1980 Survey (cont'd)	1119	36 ± .62	190 ± 6.2	1.0	1.0
		36 ± .62	190 ± 6.2		
	1139	14 ± .49	140 ± 5.7	1.0	1.0
		14 ± .49	140 ± 5.7		
	1160	19 ± .52	120 ± 5.6	1.1	0.92
		18 ± .51	130 ± 5.7		
	1181	12 ± .47	190 ± 6.2	0.86	0.95
		14 ± .49	200 ± 6.2		
	1200	11 ± .47	150 ± 6.0	1.0	1.0
		11 ± .46	150 ± 6.0		
	1221	4.4 ± .30	54 ± 3.8	1.1	1.2
		4.0 ± .30	47 ± 3.7		
	1239	20 ± .53	170 ± 6.0	0.95	1.0
		21 ± .53	170 ± 6.0		
	2021	11.4 ± 3.8	130 ± 4.3	-	-
		Data Lost	Data Lost		
	2035	6.0 ± 0.37	100 ± 6.0	0.98	1.0
		6.1 ± 0.36	180 ± 5.9		
	2046	24 ± 0.58	61 ± 6.3	1.0	1.0
		23 ± 0.58	61 ± 6.2		
	2059	27 ± 0.35	180 ± 5.7	0.90	1.1
		30 ± 0.35	160 ± 5.7		
	2081	5.8 ± 0.35	89 ± 4.4	0.97	0.94
		6.0 ± 0.35	95 ± 4.4		
	2103	21 ± 0.48	110 ± 5.5	1.1	1.2
		20. ± 0.47	94 ± 5.5		
	2121	4.8 ± 0.29	35 ± 4.0	0.94	0.97
		5.1 ± 0.29	36 ± 4.0		
	2141	11 ± 0.45	170 ± 6.4	1.1	1.0
		9.7 ± 0.44	170 ± 6.5		

Table 7 (cont'd)

Description	ID #	^{137}Cs nCi	Potassium Grams	Ratio ^{137}Cs	Ratio K
January 1980 Survey (cont'd)	2162	11 ± 0.44	93 ± 5.8	1.1	1.2
		10. ± 0.44	81 ± 5.7		
	2183	13 ± 0.47	100 ± 6.0	1.1	1.0
		12 ± 0.47	100 ± 6.0		
	2202	10. ± 0.41	66 ± 4.5	1.0	0.81
		10. ± 0.41	81 ± 4.7		
	2222	8.4 ± 0.44	120 ± 6.2	0.98	1.0
		8.6 ± 0.44	120 ± 6.1		
	2240	14 ± 0.47	140 ± 5.8	1.1	1.3
		13 ± 0.47	110 ± 6.1		
August 1980 Survey	6090	Spectrum Not Analyzed			
		-	47 ± 3.5	-	-
	6028	1.1 ± 0.26	75 ± 4	0.85	1.1
		1.3 ± 0.27	70 ± 4		
	1048	9.1 ± 0.40	140 ± 6	0.97	0.93
		9.4 ± 0.40	150 ± 6		
	6114	5.5 ± 0.50	120 ± 5.0	0.95	1.0
		5.8 ± 0.38	120 ± 5.2		
	6073	160 ± 1.0	160 ± 4.3	1.0	0.94
		160 ± 1.0	170 ± 6.8		
	6173	2.2 ± 0.29	74 ± 4.2	0.96	1.0
		2.3 ± 0.30	73 ± 4.2		
	2107	15 ± 0.46	180 ± 5.9	0.94	1.0
		16 ± 0.47	180 ± 5.8		
January 1981 Survey	1133	4.5 ± 0.38	110 ± 5.1	0.94	1.0
		4.8 ± 0.38	110 ± 5.1		
	2088	1.2 ± 0.26	57 ± 3.7	1.4	1.0
		0.86 ± 0.26	57 ± 3.7		
	1147	0.35 ± 0.23	51 ± 3.4	0.39	0.89
		0.89 ± 0.25	57 ± 3.5		

Table 7 (cont'd)

Description	ID #	^{137}Cs ηCi	Potassium Grams	Ratio ^{137}Cs	K
January 1981 Survey (cont'd)	1124	11 ± 0.43	120 ± 5.6	1.0	1.0
		11 ± 0.43	120 ± 5.5		
	2025	17 ± 0.5	170 ± 5.5	1.1	0.94
		16 ± 0.4	180 ± 0.4		
	1119	24 ± 0.5	170 ± 5.4	1.0	1.0
		24 ± 0.5	170 ± 5.4		
	1232	1.8 ± 0.31	68 ± 4.1	0.82	1.1
		2.2 ± 0.32	61 ± 4.1		
	1036	17 ± 0.46	110 ± 5.0	0.94	1.0
		18 ± 0.48	110 ± 5.6		
	2101	-	55 ± 3.3	-	1.1
		0.29 ± 0.24	50 ± 3.5		
	2194	4.4 ± 0.34	63 ± 4.1	0.92	0.90
		4.8 ± 0.30	70 ± 3.9		
	1220	3.9 ± 0.37	130 ± 5.6	0.85	1.0
		4.6 ± 0.38	130 ± 5.7		
	2193	7.3 ± 0.38	170 ± 5.4	0.94	0.94
		7.8 ± 0.39	180 ± 5.4		
	2054	8.1 ± 0.39	180 ± 5.4	1.1	1.1
		7.5 ± 0.41	160 ± 5.7		
	1265	7.6 ± 0.41	140 ± 5.6	0.96	0.93
		7.9 ± 0.38	150 ± 5.2		
	2268	5.8 ± 0.36	120 ± 5.0	1.1	1.1
		5.5 ± 0.37	110 ± 5.0		
	2184	7.3 ± 0.40	94 ± 5.4	1.0	1.1
		7.3 ± 0.40	87 ± 5.3		
	2235	3.8 ± 0.33	110 ± 4.9	1.6	1.1
		2.4 ± 0.35	100 ± 5.2		
	1074	4.2 ± 0.38	130 ± 5.5	0.70	0.87
		6.0 ± 0.36	150 ± 5.2		

Table 8

Whole Body Counter Intercomparison Results

Name	Date	S&EP Results ^{137}Cs µCi	S&EP Results K grams	Medical Results ^{137}Cs µCi	Medical Results K grams	S&EP/Medical Ratio ^{137}Cs	S&EP/Medical Ratio K
	6/29/79	0.017	93	0.017	72	1.0	1.3
	6/29/79	0.043	177	0.043	135	1.0	1.3
	6/29/79	0.019	160	0.019	114	1.0	1.4
	6/29/79	0.017	71	0.020	73	0.85	0.97
	6/29/79	0.072	103	0.062	75	1.2	1.4
	6/29/79	0.040	153	0.037	128	1.1	1.2
	6/29/79	0.018	106	0.022	78	0.82	1.4
	6/29/79	0.17	93	0.17	75	1.0	1.2
	6/29/79	0.059	117	0.055	103	1.1	1.1
	10/23/79	0.0021	115	.0039	100	0.54	1.2
	10/23/79	0.0021	96	0.0044	89	0.48	1.1
	10/23/79	0.0015	110	0.0019	77	0.79	1.4
	10/23/79	0.0015	106	0.0025	82	0.60	1.3
	10/23/79	0.0016	94	0.0041	104	0.39	0.9
	9/26/80	0.014	72	0.014	71	1.0	1.0
	1/8/81	.0030	98	0.0026	92	1.2	1.1
	1/8/81	.0030	96	0.0024	71	1.3	1.4
	1/8/81	.0030	124	0.0029	97	1.0	1.3

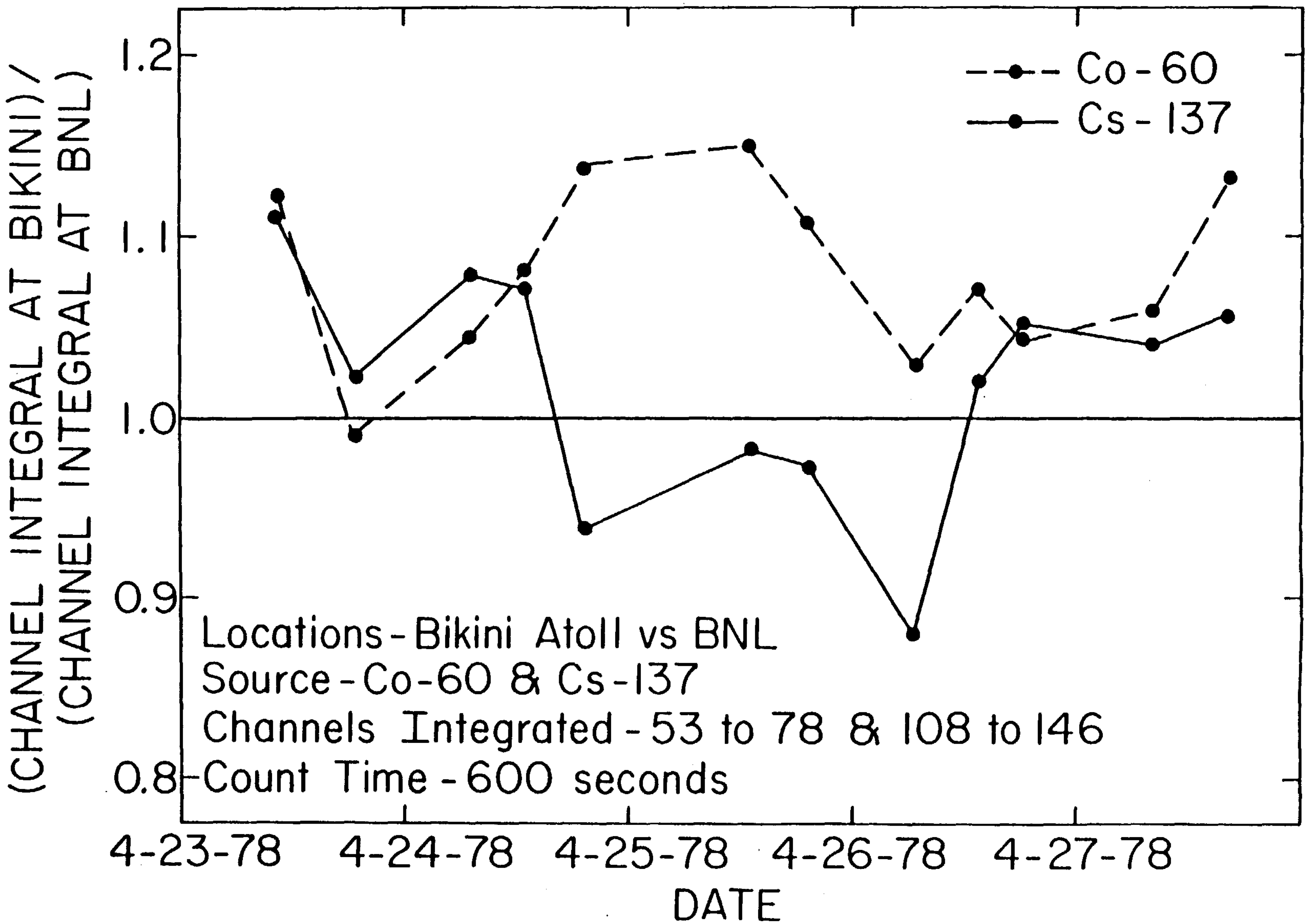
Table 9

	S&EP Results			Medical Results			S&EP/Medical Ratio	
Name	Date	^{137}Cs µCi	K Grams	Date	^{137}Cs µCi	K Grams	^{137}Cs	K
	10/6/77	0.001	110	10/77	0.002	110	0.5	1.0
	4/25/78	-	110					
	4/24/78	-	120	2/16/78	0.003	150	-	0.80
	3/14/78	0.002	130	3/14/78	0.0049	120	0.41	1.1
	3/14/78	-	150	5/18/78	0.0021	150	-	1.0
	4/23/78	-	150					
	5/15/79	0.00078	180					
	5/16/79	-	170					
	5/18/79	0.0014	170					
	8/22/79	-	120					
	9/2/79	0.0024	190					
	9/2/79	0.0022	150					
	3/14/78	-	140	5/23/78	0.0022			
	4/15/78	-	120					
	1/20/79	0.0015	140					
	1/25/79	0.0015	130					
	5/15/79	0.0013	140					
	5/16/79	0.00034	140					
	5/18/79	0.0019	140					
	8/26/79	0.002	160					
	1/31/80	0.0027	150					
	2/6/80	-	180					
	2/8/80	0.0019	170					
	2/12/80	0.0008	160					
	2/13/80	0.0009	150					
	1/27/81	0.0021	150	1/13/81	0.0013	130	1.67	1.2
	1/21/81	0.0005	150					
	1/20/79	0.002	140					
	1/25/79	0.0013	150					
	1/31/80	0.0014	190					
	2/1/80	0.0016	180					
	2/6/80	0.0016	190					
	2/8/80	0.0014	170					
	2/12/80	0.0023	160					
	8/1/80	0.0017	160					
	8/5/80	0.0014	120					
	8/9/80	0.002	130					

Table 9 (cont'd)

Name	S&EP Results Date	S&EP Results ^{137}Cs µCi	S&EP Results K Grams	Medical Results Date	Medical Results ^{137}Cs µCi	Medical Results K Grams	S&EP/Medical Ratio ^{137}Cs	S&EP/Medical Ratio K
	9/2/79	0.0026	200					
	9/2/79	0.013	170					
	1/31/80	0.012	190					
	8/1/80	0.022	150					
	9/2/79	0.0011	160					
	1/31/80	0.0027	120					
	8/1/80	0.0031	130					
	9/2/79	0.0031	120					
	1/31/80	0.0028	64					
	10/77							
	9/2/79	0.0067	200					
	1/31/80	0.0064	170					
	8/1/80	0.0095	210					
	1/31/80	-	140					
	1/26/81	0.0025	150					
		0.0027						
as	1/31/80	-	110					
	2/6/80	-	130					
	1/31/80	0.0023	200					
	2/1/80	0.0019	200					
	2/12/80	0.0016	190					
i	1/20/79	0.003	110					
	5/18/79	0.0019	120					
	7/30/80	0.007	120					
	8/1/80	0.007	130					
	8/5/80	0.0013	150					
	8/1/80	0.0005	130					
	1/21/81	0.0016	170	1/31/81	0.0024	160	0.67	1.1
	1/21/81	0.0014	200	1/13/81	0.0016	160	0.88	1.3
	1/26/81	15.9	210					

FIGURE ONE: WHOLE BODY COUNTING CONTROL CHART -- THE FIGURE INDICATES THE RELATIVE RESPONSE OF THE SAME SYSTEM USED AT TWO LOCATIONS



JOURNAL ARTICLES

Dosimetric Results for the Bikini Population

Dietary Radioactivity Intake from Bioassay Data: A Model Applied to Cs-137 Intake by Bikini Island Residents

Whole Body Counting Results from 1974 to 1979 for Bikini Island Residents

Co-60 and Cs-137 Long Term Biological Removal Rate Constants for the Marshallese Population-Pre-publication copy

Cs-137 in Human Milk and Dose Equivalent Assessment-Draft

Table 1. Distribution of acceptable doses preferred to bodily injuries

Bodily injury	Whole body dose (rads) 0.5	5	25	50	100	150	200	300
	Percentage of replies %	%	%	%	%	%	%	%
Loss of small finger	0.67	8.8	25.2	19.7	22.5	12.2	4.8	6.1
Loss of index finger		4.0	22.2	14.1	27.5	15.4	8.1	8.7
Loss of thumb		2.0	18.0	15.3	22.0	13.3	18.0	11.3
Loss of hand		2.0	3.3	17.3	12.7	20.0	17.3	27.3
Loss of arm			2.8	7.6	17.9	13.8	22.1	35.9
Loss of leg			2.8	4.2	15.4	13.3	25.2	39.2
Loss of two limbs			2.8	2.8	4.9	7.8	19.7	62.0

The bar graph (Fig. 1) shows the average equivalent exposure the respondents were willing to accept instead of the specified bodily injury.

In general, the data collected indicates a reasonable trend with an expected increase of acceptable equivalent exposure as the severity of the bodily injury increases. Most respondents would prefer an exposure greater than 200 rad rather than accept the loss of a limb.

The extremes in some of the replies are disquieting and may indicate significant problems in the credibility or a lack of knowledge of the generally accepted risk coefficients. The respondent who would rather lose a finger than receive a dose of 0.5 rad may not realize that many diagnostic procedures involve this order of whole body dose (UN77). A significant number (6–9%) of respondents would rather be exposed to 300 rad than lose a finger. Using published experimental data (Ki61; Hu78), the risk of fatality from an acute exposure of 300 rem may be deduced to be between 15 and 25%. The persons concerned either are not aware of the risk or do not accept the value. Either of these possibilities seems more reasonable than the assumption that the individuals would prefer a one in five chance of losing one's life than the loss of a finger.

The authors intend to extend this work to determine responses of a broader segment of professionals involved in radiation and also to survey the rationale leading to some of the replies.

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Dosimetric Results for the Bikini Population

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During the mid 1940s through 1958, the U.S. conducted high yield weapons tests at Bikini and Enewetak Atolls. These areas were contaminated with fallout from the tests. A restoration program, concentrating on the main residence islands of Bikini and Eneu Islands at Bikini Atoll, began in 1969. Approximately 30 Trust Territory residents including some former Bikini Atoll inhabitants participated in the initial cleanup and redevelopment of the Atoll. During subsequent years, the Bikini population increased to some 140 individuals at the time of their departure in August 1978.

Between 1969 and 1974, scrub vegetation on Bikini and Eneu Islands was cleared and indigenous food crops were planted. These crops consisted mainly of coconut, pandanus and breadfruit trees but included a garden development where squash, papaya, bananas and other crops were grown (Ro77). During the maturation interval for most of the tree crops (5–7 yr), the majority of the food consumed on Bikini Island was imported by Trust Territory supply vessels. As the local vegetation developed, the diet became less restricted to imported foods so that by 1978, the diet contained substantial quantities of locally grown items.

Bioassay and external exposure monitoring programs were initiated for Bikini Island residents in anticipation of the changing dietary situation, and with the realization that it was essential to do personnel monitoring on those individuals living on Bikini Island.

Extensive external radiation monitoring was performed in 1975 through the joint efforts of Brookhaven National Laboratory and Lawrence Livermore Laboratory. Data were collected using an environmental ionization chamber to quantify exposure rates, portable NaI scintillation survey meters to map the external radiation fields, a portable gamma spectroscopy system to define the major energy components of the external field and to determine energy dependence correction factors for the ion chamber, and LiF thermoluminescent dosimeters to measure long term integral exposures. External exposure estimates were developed based on these measurements and an assumed living pattern (Gu76; Gr79).

Urine samples for radionuclide bioassay were collected during BNL medical field trips to Bikini between 1970 and 1976 (Co75, unpublished results). This program was reinstated by BNL Safety and Environmental Protection Division in 1978 with systematic 24-hr urine collections from all adult Bikinians. Urine bioassay results were used to calculate ^{90}Sr-^{90}Y and ^{137}Cs-^{137m}Ba body burdens and resultant radiation dose equivalents for all Bikinians from whom a satisfactory urine sample was obtained.

Whole body counting was performed in 1974 and 1977 by the BNL Medical Department (Co75; Co77), and the program continued in 1978 under the BNL Safety and Environmental Protection Division along with the follow-up whole body counting of former Bikini Island residents currently residing on Ejit or Majuro Islands, Majuro Atoll and on Kili Island (Mi80). Field measurement of γ-emitting radionuclide body burdens was accomplished with a trailer-mounted shadow-shield whole body counter. Dose commitments were calculated from the measured body burdens for many persons residing at Bikini Island during the years 1969–78.

In addition to retrospective dose equivalents, whole body counting and bioassay techniques provided the data base from which dose equivalent commitments were calculated. These calculations, together with external radiation measurements, provided a complete assessment of dose to the Bikini population from chronic exposure to important fallout radionuclides in their home atoll environment.

Results

In the following tables, the dose equivalent during the residency interval and dose equivalent commitments to bone, bone marrow and the total body are presented. The means for the dose equivalent and dose equivalent commitment were determined from individual data points which represent a wide distribution of residence intervals. The mean value corresponds to residence interval (years) for the population described. Residence intervals were determined through verbal interrogation of participants in the personnel monitoring program.

Tables 1 and 2 represent the bone and bone marrow mean doses and ranges in mrem which were the result of ingesting ^{90}Sr-^{90}Y during the residency interval. These data were derived from measured urine activity concentrations during the uptake period. Constant continuous ingestion of

Table 1. ^{90}Sr-^{90}Y Bone dosimetric averages for Bikinians

			Dose Equivalent During Residence Interval, mRem			Dose Equivalent Commitment, mRem		
				Range			Range	
Population Description	Number of Persons	Mean Residence Interval, Years	Mean	High	Low	Mean	High	Low
Adult males	19	4.2	28	120	.59	68	230	7.3
Adult females	15	4.1	15	42	.35	42	110	5.8
Male children (11-15 years of age)	3	5.3	47	120	13	130	310	29

Table 2. ^{90}Sr-^{90}Y Bone marrow dosimetric averages for Bikinians

Population Description	Number of Persons	Mean Residence Interval, Years	Dose Equivalent During Residence Interval, mRem			Dose Equivalent Commitment, mRem		
			Mean	Range High	Range Low	Mean	Range High	Range Low
Adult males	19	4.2	27	120	.57	61	210	6.7
Adult females	15	4.1	14	41	.34	38	98	5.3
Male children (11-15 years of age)	3	5.3	47	120	13	120	290	26

Table 3. Net external total body dosimetric average for Bikinians

Population Description	Number of Persons	Mean Residence Interval, Years	Dose Equivalent During Residence Interval, mRem Mean
Adult males	17	4.9	600
Adult females	16	4.3	500
Children (5-14 years)	12	4.4	500

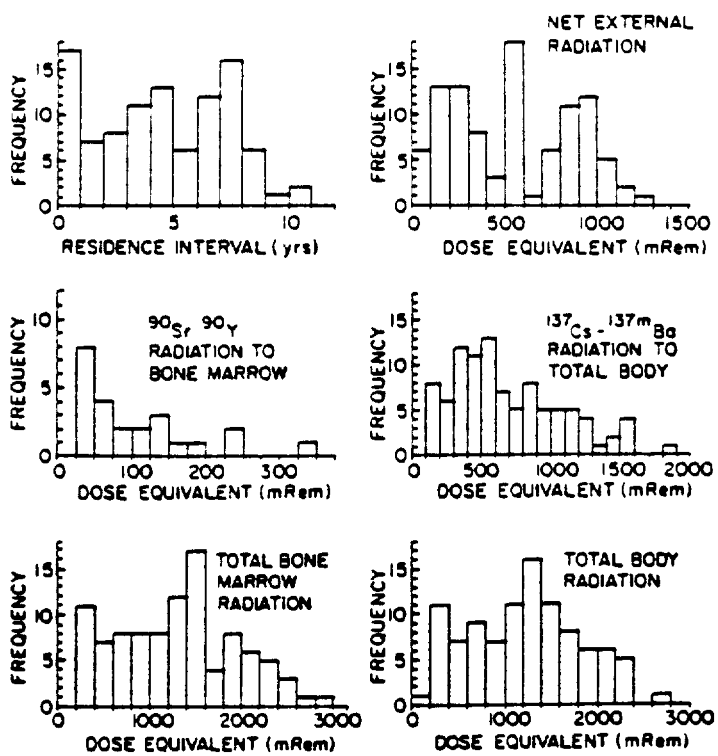

FIG. 1. Total male and female distribution of dose equivalent (during and post residence) or residence interval for inhabitants of Bikini Island, Bikini Atoll.

Table 4. ^{137}Cs–^{137m}Ba Total body dosimetric averages for Bikinians

Population Description	Number of Persons	Mean Residence Interval, Years	Dose Equivalent During Residence Interval, mRem: Mean	Range: High	Range: Low	Dose Equivalent Commitment, mRem: Mean	Range: High	Range: Low
Adult males	17	4.9	470	810	120	110	200	43
Adult females	16	4.3	330	770	91	85	190	29
Children (5-14 years of age)	12	4.4	670	920	270	140	270	57

activity was assumed in the models used to calculate the dose equivalents and dose equivalent commitments.

Table 3 depicts the net external dose equivalent resulting from living on Bikini Island. The dose equivalent during the residency interval varies for subgroups within the population acording to the assumed living pattern selected. Since these values were obtained from ion chamber measurements and hypothetical living patterns, no range of results has been provided. In this report, 1 Roentgen is assumed equal to 1 rem.

Table 4 presents the average whole body doses due to the ingestion of ^{137}Cs. Data were derived from whole body counting measurements made in 1974, 1977 and 1978. Constant continuous uptake of ^{137}Cs in the diet was not assumed. For these calculations, the uptake period was divided into three intervals during which the ^{137}Cs activity ingestion rate for a given interval remained constant, but increased stepwise with time to account for observed increases in ^{137}Cs body burdens.

Table 5 summarizes the total body dose equivalent during the residency period from in-

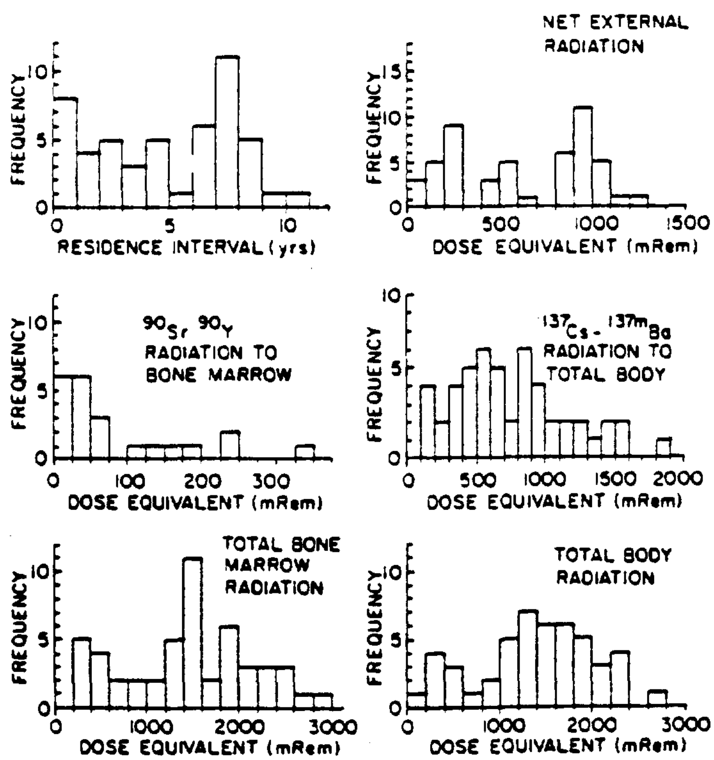

FIG. 2. Total male distribution of dose equivalent (during and post residence) or residence interval for inhabitants of Bikini Island, Bikini Atoll.

Table 5. Total body dosimetric average for external plus internal sources for former Bikini residents

Population Description	Number of Persons	Mean Residence Interval, Years	Dose Equivalent During Residence Interval, mRem	Dose Equivalent Commitment, mRem
Adult males	17	4.9	1100	110
Adult females	16	4.3	830	85
Children (5-14 years)	12	4.4	1200	140

ternal ^{137}Cs and man-made external radiation, and the total body dose equivalent commitment upon departure from Bikini Atoll in August 1978. A standard deviation for these quantities of approx. ±40% of the mean was observed in adult subgroups. Internal dose equivalent distributions in Figs. 1–3 were constructed by first calculating mean daily activity ingestion rates for different subgroups of the Bikini Island population based on the individual measurement data from which Tables 1, 2 and 4 were derived. Secondly, these mean activity ingestion rates and individual residence internal values we used as input data to mathematical models applied to inhabitants who did not participate in our personnel monitoring programs. The models describe various regimes for the uptake, retention and excretion of internally deposited radionuclides. Finally, dosimetric models which allow for constant continuous uptake of ^{90}Sr and stepwise increasing uptake for ^{137}Cs were chosen to determine the internal dose equivalent and dose equivalent commitment for all inhabitants. Thus for residence periods between the years 1969 and 1978, these figures evince a maximally exposed person receiving a whole body dose equivalent and commitment of 3 rem, and a

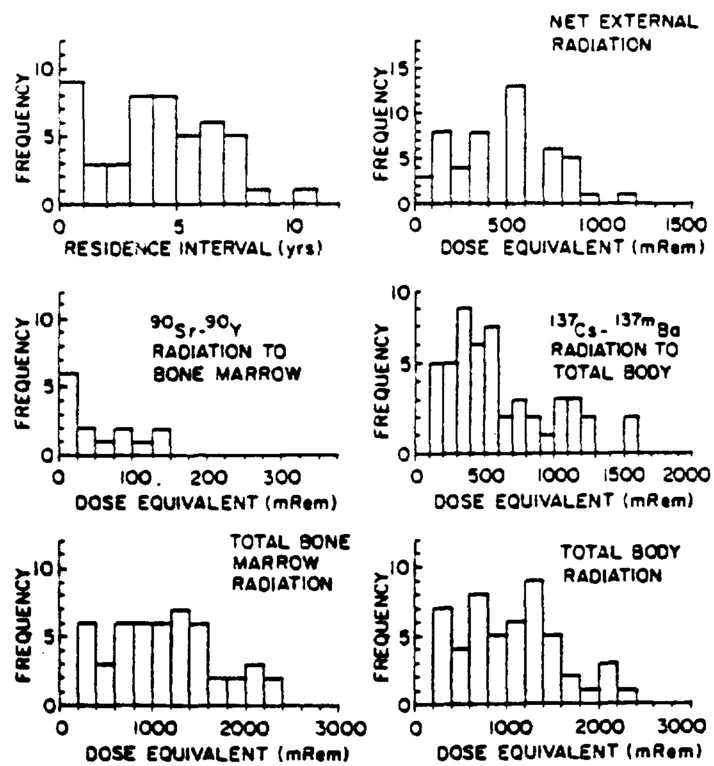

FIG. 3. Total female distribution of dose equivalent (during and post residence) or residence interval for inhabitants of Bikini Island, Bikini Atoll.

population average dose equivalent and commitment of 1.2 rem from man-made radioactivity on Bikini Island.

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Neutron Quality Factor Measurements at the Oak Ridge National Laboratory's Dosimetry Applications Research Facility*

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THE Oak Ridge National Laboratory's (ORNL) Dosimetry Applications Research (DOSAR) facility is used for a wide range of dosimetry studies by the staff. Research in cooperation with experimenters from medical centers, the academic community and industry is also an integral part of the DOSAR facility mission. The primary research tool at the facility in the Health Physics Research Reactor (HPRR). The HPRR is a small, unmoderated fast reactor which may be operated in the steady state or the pulse mode (Au65). Since the HPRR is frequently used for personnel dosimetry applications research, the effective neutron quality factor (QF) of the reactor spectrum is of interest. Quality factors calculated by Monte Carlo methods for the HPRR have been published in this journal (Mu74; Si78). The effective neutron QF has recently been measured for the HPRR in the unshielded condition as well as behind each of three of the most commonly used shields: 12-cm thick Lucite, 13-cm thick steel and 20-cm thick concrete. The measurements are described and the results are presented below. Three types of detectors were used in the QF measurements:

(1) *SNOOPY*—This remmeter is the commercial† version of the Andersson–Braun portable neutron monitor (An64). The sensor is a BF_3 counter surrounded by a boron-loaded polyethylene moderator. Details are available in the literature (Ha75; Te75). The SNOOPY was calibrated using the DOSAR NSD-60 ^{252}Cf source which produced 6.45 mrem/hr at 1 m. This dose rate was determined from the well-known source flux using a conversion factor of 3×10^{-9} rad · cm^2/neutron (St70) and a QF of 9.6‡ for the ^{252}Cf.

(2) *RD*-1—The RD-1 sensor is a 7.3-cm-diameter spherical ionization chamber filled with tissue equivalent (TE) gas and having 0.16-cm-thick walls made of Shonka A-150 TE plastic (Go78). The sensor is part of a new on-line dosimetry system§ installed at the DOSAR facility to monitor experimental irradiations at the HPRR. It has been calibrated using standard gamma sources as well as with the accurately known HPRR mixed radiation fields. The RD-1 sensor measures total

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*Research sponsored by the Division of Pollutant Characterization and Safety Research, U.S. Dept. of Energy under Contract W-7405-ENG-26 with Union Carbide Corp.

†Manfactured by Tracerlab (Richmond, California).

‡The QF for ^{252}Cf was determined by multiplying the fractional fluence in various energy intervals (St70) by the average QF for neutrons of those energies as reported in Table 2 of NCRP Report 38 (NCRP71).

§Manufactured by Digital Data Dosimetry (Tulsa, OK).

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DIETARY RADIOACTIVITY INTAKE FROM BIOASSAY DATA: A MODEL APPLIED TO ^{137}Cs INTAKE BY BIKINI ISLAND RESIDENTS*

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Abstract—Several publications of the ICRP and NCRP (ICRP59; ICRP68; ICRP71; NCRP77) describe mathematical models relating total radionuclide body burden, urinary activity excretion rate and uptake interval. This paper presents an equation with which the constant daily activity ingestion rate may be calculated from sequentially obtained whole body counting and urine bioassay data. The model was developed to relate whole body counting results to urinary activity excretion data for ^{137}Cs in the Marshallese population at Bikini Island for whom accurate dietary intake and residence interval information were not available. The technique is applicable to radioactivie material whose biological and physical removal mechanisms are linear first order processes described by appropiate rate constants which give the instantaneous fraction of atoms transferred from compartments in the body to urine per unit time, and the instantaneous fraction of atoms decaying per unit time.

INTRODUCTION

ICRP PUBLICATION 10A (ICRP71) specifically describes the mathematical modelling used for several radionuclides. In these models, the constant continuous uptake of radioactive material has been assumed to cease during the acquisition of the bioassay sample. A problem arises in the case of enviromental exposures, such as those which occur in the contaminated atolls of the Northern Marshall Islands, where activity uptake continues during the sampling period.

For at least the past 4 years, the ^{137}Cs body burdens of people living on Bikini Island, Bikini Atoll have been rising (Figs. 1 and 2) to levels which have approached and in some cases exceeded the nonoccupational maximum permissible body burden of 110 kBq (3.0 μCi) (ICRP65). Previous diet studies (Mu54; No77) and ^{137}Cs dose estimates performed by Robison (Ro77) assume a ^{137}Cs dietary intake rate of 1073–1850 Bqd^{-1} (29–50 nCid^{-1}). Current metabolic information for ^{137}Cs predicts that an equilibrium ^{137}Cs body burden would be reached at sufficient time (~ 2 yr) post onset of constant continuous dietary intake (NCRP77).

Figures 1 and 2 depict the 1974–78 male and female ^{137}Cs mean body burdens (Coh75; Coh77; Mi79). The data suggests that the population mean ^{137}Cs body burdens may not have attained an equilibrium value. The food product presumed responsible for the dramatic rise in body burdens, namely, coconut, became available in significant quantities in 1976. Prior to this time, the individual body burdens should have assumed relatively low equilibrium value for residents whose stay time on Bikini was greater than two years. During the April 1978 field trip to Bikini Atoll, whole body counting and urine sampling were performed on 68 adult

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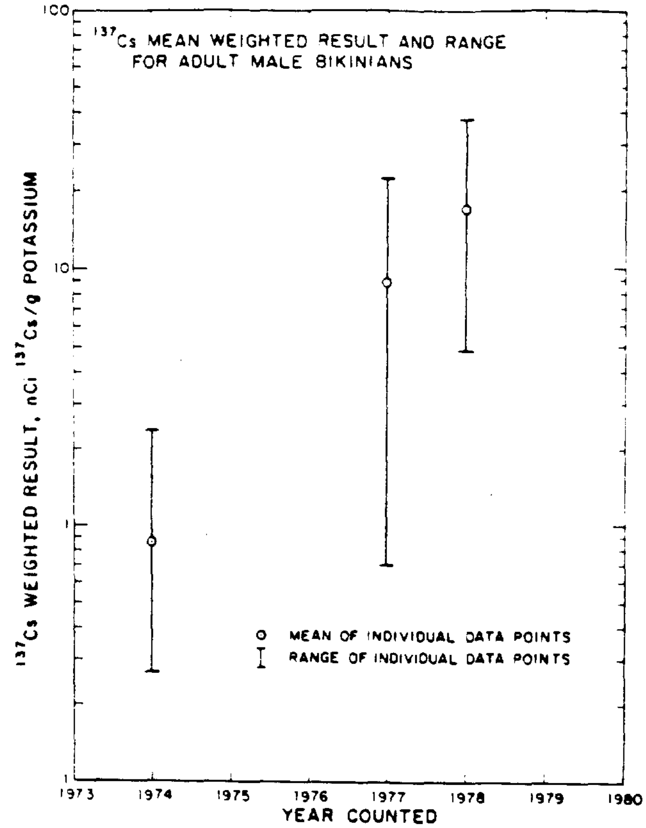

FIG. 1. ^{135}Cs Mean weighted result and range for adult male Bikinians.

subjects. The following section summarizes the development of a mathematical model which relates body burden, urinary activity excretion rate and daily activity ingestion rate. An understanding of this latter parameter is crucial to the predictive modeling of dose commitments to people living in contaminated environments such as that at Bikini Atoll.

METHOD

Appendix A of ICRP Publication 10A (ICRP71) describes the relationship between body burden, $q(t)$ and activity excretion rate $E(t)$ at some time t:

$$E(t) = k\,q(t) \qquad (1)$$

where k = the instantaneous fraction of activity leaving the body per unit time, d^{-1}.

Thus, $E(t)$, the activity excretion rate, is directly proportional to the body burden, $q(t)$. With this equation, either $q(t)$ or $E(t)$ can be calculated from a single bioassay measurement provided that (1) the mean residence time of the radionuclide in the body, which by definition is the inverse of the total removal rate constant for the radionuclide, is known, and (2) the excretion rate can be described by a single rate constant.

Similar equations are developed here to determine the daily activity ingestion rate for ^{137}Cs assuming that two compartments in the body release ^{137}Cs radioactivity to the urine. These equations assume a constant continuous uptake during the whole body count and urinary sampling interval, and relate the constant continuous daily activity ingestion rate, λP, to the measured body burden at time of measurement, and the urinary activity excretion rate one day later.

The equations have been developed using

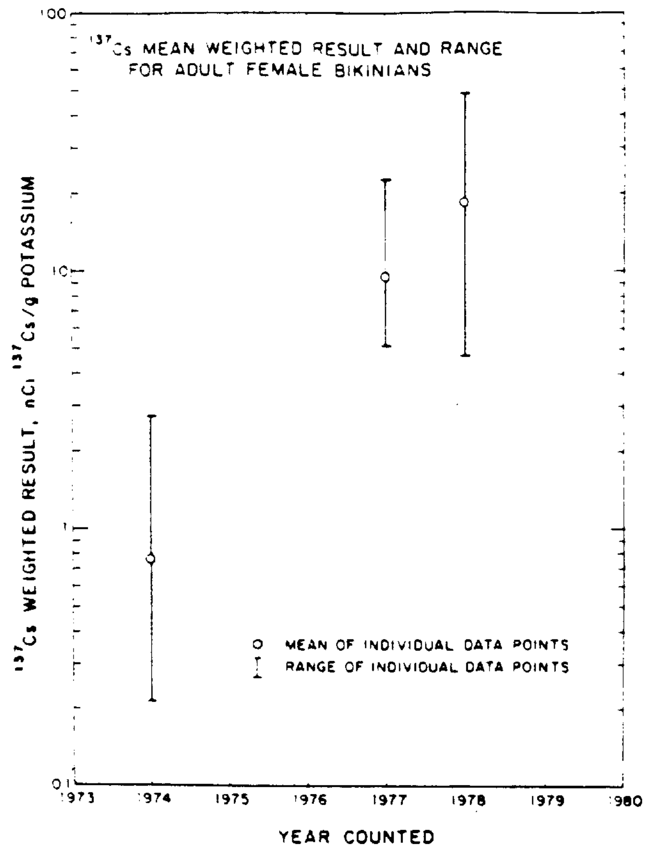

FIG. 2. ^{137}Cs Mean weighted result and range for adult female Bikinians.

the following set of definitions and assumptions:

Definitions

- N^o the number of atoms of species of concern present in the body at time of *in vivo* measurement, atoms
- N_i^o the number of atoms of species of concern present in compartment i at time of *in vivo* measurement, atoms
- $N_i(t)$ the instantaneous number of atoms of the species of concern present at time t in compartment i, atoms
- P_i atom intake rate to the ith compartment, atoms d^{-1}
- k_i the instantaneous fraction of atoms removed per unit time from compartment i to urine by physiological mechanisms, d^{-1}
- λ the instantaneous fraction of atoms removed per unit time by radioactive decay, d^{-1}
- $q_i(t)$ the instantaneous activity in compartment i at time t, Bq
- $E_i(t)$ the instantaneous activity excretion rate from compartment i at time t, Bq d^{-1}
- X_i the fraction of radioactive atoms in blood reaching compartment i
- X_i' the fraction of radioactive atoms in the total body which are in compartment i at the time of *in vivo* measurement
- F_u fraction of atoms eliminated from the total body via the urine

$U(t)$ instantaneous urine activity concentration, Bq l^{-1}
f_1 fraction of atoms in GI tract reaching blood
U_s male or female urine excretion rate, l d^{-1}

Assumptions

$$\frac{dN_i}{dt} = -(\lambda + k_i) N_i + P_i \quad (1)$$

$$q(t) = \Sigma_i q_i(t) \quad (2)$$

$$F_i = \frac{k_i}{k_i + \lambda - \frac{P_i}{N_i}} \quad (3)$$

$$E_i(t) = -F_i \frac{dq_i(t)}{dt} \quad (4)$$

$$E(t) = \Sigma_i E_i(t) \quad (5)$$

$$P = \frac{\Sigma_i P_i}{f_1} \quad (6)$$

$$U(t)\, U_s = F_u E(t) \quad (7)$$

ANALYTICAL SOLUTION

The instantaneous atom rate of change in compartment i is described by assumption 1. Solving the differential equation for an analytical solution yields.

$$N_i(t) = N_i^\circ e^{-(\lambda+k_i)t} + \frac{P_i}{(\lambda + k_i)}(1 - e^{-(\lambda+k_i)t}) \quad (2)$$

and the body burden contribution from the ith compartment is,

$$q_i(t) = \lambda N_i(t) = \lambda N_i^\circ e^{-(\lambda+k_i)t} + \frac{\lambda P_i}{(\lambda + k_i)}(1 - e^{-(\lambda+k_i)t}), \quad (3)$$

From assumptions 3 and 4, the activity excretion rate from the ith compartment is

$$E_i(t) = \frac{k_i}{\lambda + k_i - P_i/N_i}(q_i^\circ(\lambda + k_i) - \lambda P_i)\, e^{-(\lambda+k_i)t}. \quad (4)$$

Assuming a two compartment model for ^{137}Cs, the following values are obtained from ICRP Publication 10A (ICRP71) and ICRP Publication 23 (ICRP75):

$f_1 = 1$
$k_1 = 0.006\ d^{-1}$
$k_2 = 0.7\ d^{-1}$
$X_1 = 0.85$
$X_2 = 0.15$
$\lambda = 6.33 \times 10^{-5}\ d^{-1}$
$U_s = 1.4\ l.d^{-1}$ (male)
$U_s = 1.0\ l d^{-1}$ (female)
$F_u = 0.9$.

Given the previously described assumptions let $t = 1d$, $X_1' = 1 - X_2'$, and $X_2' = 0.002$.

Substituting the above values into equation (4) and summing over two compartments yields an expression which relates the daily activity ingestion rate for ^{137}Cs to the ^{137}Cs body burden and excretion rate at the times of counting and sampling respectively. The daily activity ingestion rate cannot be algebraically isolated from the resulting equation with ease. Therefore the r. h. s. of the equation is evaluated by using an estimate for this quantity. This evaluation is compared to the urine activity excretion rate and if they are unequal the r.h.s. is reevaluated after changing the estimate for the activity ingestion rate. The process is repeated until the evaluation of the r.h.s. and the urine activity excretion rate differ by less than 0.1%. Table 1 lists the individual daily activity ingestion rates as calculated by this method.

RESULTS AND DISCUSSION

If the loss of ^{137}Cs via perspiration and insensible losses is neglected during the counting interval and a 24-hr urine sample is begun immediately after counting, then there exists a mechanism to calculate the uptake during the 24-hr sampling period without full knowledge of the uptake interval.

Of the 68 urine samples collected in April 1978, only 26 samples were determined to be of sufficient volume to be considered 24-hr samples. The measured daily excretion rates, measured body burdens and calculated daily activity ingestion rates are presented in Table 1. The total error on the body burden measurement is estimated to be ±25% while the error on the excretion values exclusive of sample fluctuations is ±10%. The mean daily ingestion rate as calculated from the body burdens and excretion rates in Table 1 is 2100 Bqd^{-1} (57 nCi d^{-1}).

Table 1. *1978 Total body activity, activity excretion and activity ingestion rates*

ID#	Sex	^{137}Cs Body Burden	^{137}Cs Daily Urine Activity Excretion Rate	^{137}Cs Daily Activity Ingestion Rate
6113	F	3.8×10^4 Bq(1.0 μCi)	250 Bq/d (6.8 nCi/d)	310 Bq/d (8.4 nCi/d)
6112	F	6.5×10^4 Bq(1.8 μCi)	650 Bq/d (18 nCi/d)	3600 Bq/d (97 nCi/d)
6046	F	7.8×10^4 Bq(2.1 μCi)	500 Bq/d (14 nCi/d)	470 Bq/d (13 nCi/d)
6005	M	7.7×10^4 Bq(2.1 μCi)	360 Bq/d (9.7 nCi/d)	-- Bq/d (-- nCi/d)
6068	M	11×10^4 Bq(3.0 μCi)	470 Bq/d (13 nCi/d)	-- Bq/d (-- nCi/d)
6007	M	5.5×10^4 Bq(1.5 μCi)	540 Bq/d (15 nCi/d)	2900 Bq/d (76 nCi/d)
6017	M	21×10^4 Bq(5.7 μCi)	1900 Bq/d (51 nCi/d)	8900 Bq/d (240 nCi/d)
6086	M	13×10^4 Bq(3.5 μCi)	810 Bq/d (22 nCi/d)	450 Bq/d (12 nCi/d)
6128	M	6.9×10^4 Bq(1.9 μCi)	270 Bq/d (7.3 nCi/d)	-- Bq/d (-- nCi/d)
6096	M	7.1×10^4 Bq(1.9 μCi)	310 Bq/d (8.4 nCi/d)	-- Bq/d (-- nCi/d)
6070	M	15×10^4 Bq(4.0 μCi)	850 Bq/d (23 nCi/d)	-- Bq/d (-- nCi/d)
6003	M	9.0×10^4 Bq(2.4 μCi)	860 Bq/d (23 nCi/d)	4400 Bq/d (120 nCi/d)
6011	M	3.9×10^4 Bq(1.1 μCi)	950 Bq/d (26 nCi/d)	9900 Bq/d (270 nCi/d)
6132	M	8.7×10^4 Bq(2.4 μCi)	1600 Bq/d (43 nCi/d)	15000 Bq/d (400 nCi/d)
6126	M	12×10^4 Bq(3.2 μCi)	580 Bq/d (16 nCi/d)	-- Bq/d (-- nCi/d)
6061	F	8.2×10^4 Bq(2.2 μCi)	520 Bq/d (14 nCi/d)	400 Bq/d (-- nCi/d)
863	M	8.7×10^4 Bq(2.4 μCi)	1000 Bq/d (27 nCi/d)	6600 Bq/d (180 nCi/d)
6045	F	4.3×10^4 Bq(1.2 μCi)	630 Bq/d (17 nCi/d)	5100 Bq/d (140 nCi/d)
6076	M	13×10^4 Bq(3.5 μCi)	940 Bq/d (25 nCi/d)	2200 Bq/d (60 nCi/d)
6059	F	3.2×10^4 Bq(.86 μCi)	280 Bq/d (7.6 nCi/d)	1200 Bq/d (32 nCi/d)
6115	F	8.4×10^4 Bq(2.3 μCi)	390 Bq/d (11 nCi/d)	-- Bq/d (-- nCi/d)
6111	F	4.9×10^4 Bq(1.3 μCi)	710 Bq/d (19 nCi/d)	5700 Bq/d (150 nCi/d)
6122	F	4.9×10^4 Bq(1.3 μCi)	330 Bq/d (8.9 nCi/d)	510 Bq/d (14 nCi/d)
6108	F	2.7×10^4 Bq(.73 μCi)	260 Bq/d (7.0 nCi/d)	1400 Bq/d (38 nCi/d)
6065	F	3.9×10^4 Bq(1.1 μCi)	130 Bq/d (3.5 nCi/d)	-- Bq/d (-- nCi/d)
6035	F	10×10^4 Bq(2.7 μCi)	500 Bq/d (14 nCi/d)	-- Bq/d (-- nCi/d)
mean	M+F	8.1×10^4 Bq(2.2 μCi)	640 Bq/d (17 nCi/d)	2100 Bq/d (57 nCi/d)
mean	M	10×10^4 Bq(2.7 μCi)	820 Bq/d (22 nCi/d)	3100 Bq/d (84 nCi/d)
mean	F	5.7×10^4 Bq(1.5 μCi)	430 Bq/d (12 nCi/d)	1200 Bq/d (32 nCi/d)

Table 2. 1974 Total body activity: activity excretion and activity ingestion rates

ID #	Sex	^{137}Cs Body Burden	^{137}Cs Daily Urine Activity Excretion Rate	^{137}Cs Daily Activity Ingestion Rate
B1	F	2.2×10^3 Bq(.059 μCi)	19 Bq/d (510 pCi/d)	87 Bq/d (2,400 pCi/d)
B11	M	5.8×10^3 Bq (.16 μCi)	88 Bq/d (2,400 pCi/d)	750 Bq/d (20,000 pCi/d)
B35	M	3.4×10^3 Bq(.092 μCi)	52 Bq/d (1,400 pCi/d)	430 Bq/d (12,000 pCi/d)
B44	F	3.4×10^3 Bq(.092 μCi)	120 Bq/d (3,200 pCi/d)	1400 Bq/d (34,000 pCi/d)
B45	M	6.2×10^3 Bq (.17 μCi)	83 Bq/d (2,200 pCi/d)	630 Bq/d (17,000 pCi/d)
B51	M	8.2×10^3 Bq (.22 μCi)	31 Bq/d (840 pCi/d)	-- Bq/d (— pCi/d)
mean	M+F	4.9×10^3 Bq (.13 μCi)	66 Bq/d (1,800 pCi/d)	500 Bq/d (14,000 pCi/d)

This is greater than the previous estimate of 1073–1850 Bq d^{-1} (29–50 nCi d^{-1})(Ro77) and indicates that the dietary model currently used to predict the dose committment under-estimates the intake of ^{137}Cs by ingestion.

Table 2 shows the mean daily ingestion as calculated from available data for 1974 (Con75). This value indicates the availability of dietary items containing ^{137}Cs at this time. Appropiate changes in the uptake regime used for internal dose calculations have been made to reflect the increasing uptake exhi-

Table 3. Sequential urine activity concentrations for ^{137}Cs and ^{40}K in single void samples

ID #	Sample Date	^{137}Cs	^{40}K
6118	1-23-79	121 Bq/ℓ (3280 pCi/ℓ)	83.4 Bq/ℓ (2250 pCi/ℓ)
"	1-25-79	119 Bq/ℓ (3210 pCi/ℓ)	34.4 Bq/ℓ (930 pCi/ℓ)
"	1-26-79	79.2 Bq/ℓ (2140 pCi/ℓ)	43.3 Bq/ℓ (1170 pCi/ℓ)
"	1-27-79	148 Bq/ℓ (4010 pCi/ℓ)	38.9 Bq/ℓ (1050 pCi/ℓ)
"	1-28-79	182 Bq/ℓ (4910 pCi/ℓ)	57.4 Bq/ℓ (1550 pCi/ℓ)
6112	1-22-79	72.2 Bq/ℓ (1950 pCi/ℓ)	35.8 Bq/ℓ (968 pCi/ℓ)
"	1-23-79	298 Bq/ℓ (8060 pCi/ℓ)	72.9 Bq/ℓ (1970 pCi/ℓ)
"	1-24-79	229 Bq/ℓ (6190 pCi/ℓ)	56.2 Bq/ℓ (1520 pCi/ℓ)
"	1-27-79	179 Bq/ℓ (4850 pCi/ℓ)	109 Bq/ℓ (2950 pCi/ℓ)
"	1-28-79	234 Bq/ℓ (6330 pCi/ℓ)	65.5 Bq/ℓ (1770 pCi/ℓ)
6064	1-22-79	66.2 Bq/ℓ (1790 pCi/ℓ)	54.0 Bq/ℓ (1460 pCi/ℓ)
"	1-23-79	55.1 Bq/ℓ (1490 pCi/ℓ)	43.7 Bq/ℓ (1180 pCi/ℓ)
"	1-25-79	90.7 Bq/ℓ (2450 pCi/ℓ)	41.8 Bq/ℓ (1130 pCi/ℓ)
"	1-27-79	77.7 Bq/ℓ (2100 pCi/ℓ)	54.4 Bq/ℓ (1470 pCi/ℓ)
"	1-28-79	77.7 Bq/ℓ (2100 pCi/ℓ)	38.9 Bq/ℓ (1050 pCi/ℓ)

bited by the Bikinians during their residence interval (Gr79).

Fluctuations in an individual's urine activity concentration will have significant impact on the daily activity ingestion rate determined by this method. A low urine activity concentration will cause the daily activity ingestion rate to have a negative value. This implies that the body burden alone without activity production should be eliminated through the urine pathway at a higher concentration than is measured. The true value for the daily activity ingestion rate for an individual may be estimated with greater accuracy by collecting sequential single void urine samples and averaging. An example of fluctuation in sequential urine activity concentrations for ^{137}Cs and ^{40}K are presented in Table 3. An estimate of the true value for the daily activity ingestion rate for a population can be obtained by using the mean value for body burden and urine activity concentration for a group of similar individuals as done in Tables 1 and 2.

In summary, the equations presented here provide a simple technique to determine the daily ingestion rate of an individual exposed to a constant continuous uptake of radioactive material from direct measurement of the body burden and excretion rate. Once the daily ingestion rate is calculated, it can be used to verify the accuracy of dietary pathway principles. These equations can be applied to any radionuclide whose biological and physical removal mechanisms are linear first order processes.

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WHOLE BODY COUNTING RESULTS FROM 1974 TO 1979 FOR BIKINI ISLAND RESIDENTS*

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Abstract—Three body burden measurements of the Bikini Island population were conducted from 1974 to 1978 at Bikini Island. During this time, the mean ^{137}Cs body burden of the adult Bikini population increased by a factor of 20. This dramatic elevation of the body burden appears to be solely attributable to increased availability of locally grown food products, specifically coconuts and coconut plant products. In January 1979, 45% of the individuals that were whole body counted in April 1978 were recounted approx. 145 days after the Bikini Island population departed from Bikini Atoll. These results show that the adult population ^{137}Cs body burden decreased by a factor of 2.9 between the April 1978 and January 1979 *in vivo* measurements.

INTRODUCTION

BIKINI ATOLL was one area used by the U.S. Government to test nuclear weapons from 1946 to 1958. Prior to commencement of the testing program, all Bikini Atoll inhabitants were moved first to Rongerik Atoll and then finally to Kili Island. On 1 March 1954 a thermonuclear device, code named Bravo, was detonated at Bikini Atoll.

The radioactive cloud from this test moved eastward depositing fallout on several of the Northern Marshall Island Atolls: Bikini Atoll (all Marshallese inhabitants had been moved), Rongelap with 64 people, Ailinginae with 18 people, Rongerik with 28 people and Utirik with 157 people. The Japanese fishing boat Fukurju-Muru (Lucky Dragon) with 23 fishermen aborad was also contaminated (Con75).

The exposure of individuals to radioactive fallout 6–24 hr post detonation of "Bravo" resulted in external total body gamma dose equivalents ranging from 20 to 200 rem (Con 75). This incident initiated the involvement of Conard *et al.* who for the past 24 years has been responsible for the ongoing medical surveillance of the inhabitants living on the contaminated atolls, those Marshallese who were initially exposed to the fallout and have been moved, and to a control Marshallese population.

The medical history by R. A. Conard included total body burden measurements of radioactive material inhaled or ingested by the Marshallese. This work was performed by Cohn *et al.* (Coh63; Con75).

Rehabilitation efforts of Bikini Atoll began in 1969 which required persons to reside on Bikini Island. By April 1978, the population numbered 138 persons and consisted of caretakers and agriculturalists employed by the Trust Territory plus other Bikini families who found their way back via Trust Territory trade ships. This population remained on Bikini Island until they were relocated in August 1978 to Kili Island in the southern Marshalls and to Ejit Island, Majuro Atoll.

During the rehabilitation and repopulation years, the medical services provided by Conard and the Brookhaven Medical Team were expanded to include sick call and body burden measurements. Body burden

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measurements were made in 1974 (Con75) and in 1977 (Coh77). In August 1977, the responsibility for providing body burden measurements was transferred from the Medical Department to the Safety and Environmental Protection Division at Brookhaven National Laboratory. The 1978 and 1979 body burden measurements of the Bikini population were conducted by the latter organization.

In this report, the results of four whole body counting measurements on the Bikini population that were conducted in 1974 and 1977–79 are presented. Because the body burden measurements were performed by two different organizations, the current experimental design included a cross check mechanism to ensure that previous and current results are directly comparable. The approach to the problem was multidirectional. First, key detection components were duplicated. Second, the systems were calibrated in the same manner (Coh63). Third, the operational procedures and counting geometries were basically similar, and an intercomparison study was conducted using Marshallese and Brookhaven personnel to ensure system comparability

EXPERIMENTAL DESIGN

Instrumentation

The detector chosen for field use by both Brookhaven organizations is a 28-cm-diameter, 10-cm-thick, sodium iodide thallium activated scintillation crystal NaI(Tl). It is optically coupled to seven, 7.6-cm-diameter low background magnetically shielded, photomultiplier tubes. In the current system the signal output from each photomultiplier tube is connected in parallel through a summing box with the combined output routed to a preamplifier-amplifier and then to a microprocessor-based computer/pulseheight analyzer (PHA). The PHA data is stored on a magnetic diskette, and the results may be analyzed either in the field or at BNL using a matrix reduction, minimization of the sum of squares technique (TP76).

Calibration

Analysis of NaI(Tl) spectra by the matrix reduction technique requires that the computer library contain a standard for each radionuclide that is expected in the field measurement and that the field measurements and standards have the same geometry.

To accomplish this, a review of the previous whole body counting data (Con75; Coh77) indicated the need to calibrate for ^{40}K, ^{60}Co and ^{137}Cs. The current system was calibrated using an Anderson REMCAL phantom (Coh63). Each radionuclide was introduced into the phantom's organs in an amount equivalent to the fraction in organ of reference of that in total body as defined by the ICRP in Publication 2 (ICRP59). To verify the activity in the phantom prior to use as a standard, an aliquot of the phantom solution was counted on a lithium drifted germanium detector which was calibrated with NBS standard sources.

The phantom was then counted in a shadow whole body counter (WBC) (Pa65). The whole body counting system consists of a stationary crystal and stationary bed. The counter detects radioactive material located principally in the thorax, so positioning of the phantom and the *in vivo* counting subjects must be as similar as possible. To facilitate reproducible counting geometries, each subject and the standard phantom was positioned such that the central axis of the crystal intersected the central axis of the body about 25 cm below the sternal notch. The distance between the surface of the bed and the bottom of the detector is 32.4 cm. The total system efficiencies for ^{40}K, ^{60}Co and ^{137}Cs are listed in Table 1 as are typical minimum detection limits for these nuclides.

Quality control

The quality control (QC) program consisted of a cross comparison of the radionuclide quantities estimated to be in the phantom volume vs NBS calibration standards. Agreement between these two activity concentrations is within ±5% for all radionuclides. Other quality control mechanisms employed were repetitive counting of secondary point source standards, multiple counts of Brookhaven personnel, repetative counting of the Marshallese (blind replicates) and an intercomparison study.

Table 1. Summary of system efficiency and MDLS for field WBC system

Nuclide	Energy	Efficiency	MDL	Time
^{137}Cs	662 KeV	8.7×10^{-3}	37 Bq (1 nCi)	900 sec
^{60}Co	1173 & 1334 KeV	6.7×10^{-3}	37 Bq (1 nCi)	900 sec
^{40}K	1460 KeV	7.0×10^{-3}	222 Bq (6 nCi)	900 sec

Two point sources were used in the QC program. A ^{137}Cs source, which had been used by the BNL medical surveys in previous years, was used to monitor changes in system resolution and efficiency as function of time. A second source, a $^{137}Cs + ^{60}Co$ point source, was used for zero and gain determination.

Replicate counting of Marshallese was conducted on 5% of the subjects. Results indicate that the data obtained from the field whole body counting system is reproducible to within plus or minus 6 percent. Almost all of this error is due to the variability of subject position. When subjects remain stationary, the difference between sequential results is 1%.

An intercomparison of whole body counting systems was conducted between the field system and the whole body counter operated by S. Cohn for the Brookhaven Medical Department. Persons used in the study included nine Marshallese with measurable ^{137}Cs body burdens plus six Brookhaven employees with current whole body counting records at the Medical Department. The results of the study indicate that ^{137}Cs and the potassium body burdens which exceed the minimum sensitivity of both systems are in agreement to within $\pm 5\%$.

RESULTS

Table 2 is a summary of the whole body counting data for ^{137}Cs body burdens. Adult individuals were measured in 1974 (Con75), 1977 (Coh77), 1978 and 1979. It represents the mean, standard deviation and ranges of values obtained from the sample population. There is a general increase in the body burdens of adult males from 1974 to 1977 by a factor of 13.3, and from 1977 to 1978 by a factor of 1.8. The general increase for adult females from 1977 to 1978 was slightly higher than that for males over the same period. In most cases, the 1979 data are significantly lower than the 1978 data with an average reduction in the ^{137}Cs body burden by a factor of 2.9.

It must be noted that data for adults reported in Tables 2–4 are uncorrected for height and weight differences between subjects and the phantom. This will have a minimal effect on adult data ($< 15\%$ possible error) (Mi76). Body burdens of the children and adolescents reported in these tables have been corrected for geometric differences between adult standard man and the average Marshallese child.

Table 3 represents the mean, standard deviation and range of ^{60}Co body burden reported in 1978 and 1979. In prior years, ^{60}Co was detected but body burdens were not computed due to the insignificant contribution of ^{60}Co to the total body burden relative to ^{137}Cs. Table 4 presents the mean, standard deviation and range of body potassium masses reported from 1974 to 1979.

Table 5 compares the observed reduction in ^{137}Cs body burdens from April 1978 to January 1979 with the reduction in ^{137}Cs body burden that was expected as a result of relocating the Bikini Population in late August 1978. Values for the expected biological removal rate constants were obtained from NCRP Report 52 (NCRP77) and ICRP Publication 10A (ICRP71).

RESULTS AND DISCUSSIONS

The whole body counting data indicate that previous estimates of the type of food and amount of various components in the Bikini diet did not adequately describe the dietary patterns that existed between 1974 and 1978.

Table 2. Summary of ^{137}Cs body burdens

Population	Number Counted 1974(5)	Range of ^{137}Cs Results 1974(5)	Mean ^{137}Cs Result 1974(5)	Number Counted 1977(5)	Range of ^{137}Cs Results 1977(5)
Adult Male	18	1.6 kBq (0.043 μCi) to 15 kBq (0.40 μCi)	4.7 kBq (0.13 μCi) ± 3.4 kBq (.093 μCi)	22	21 kBq (0.57 μCi) to 120 kBq (3.2 μCi)
Adult Female	13	0.67 kBq (0.018 μCi) to 9.3 kBq (0.25 μCi)	2.7 kBq (0.073 μCi) ± 2.3 kBq (0.063 μCi)	20	20 kBq (0.53 μCi) to 83 kBq (2.2 μCi)
Male Children 11-15 yrs	0	ND	ND	3	24 kBq (0.65 μCi) to 39 kBq (1.0 μCi)
Female Children 11-15 yrs	0	ND	ND	3	20 kBq (0.56 μCi) to 35 kBq (0.94 μCi)
Male Children 5-10 yrs	0	ND	ND	0	ND
Female Children 5-10 yrs	0	ND	ND	0	ND

for Bikini inhabitants 1974–79

Mean ^{137}Cs Result 1977(5)	Number Counted 1978	Range of ^{137}Cs Results 1978	Mean ^{137}Cs Result 1978	Number Counted 1979	Range of ^{137}Cs Results 1979	Mean ^{137}Cs Result 1979
48 kBq (1.3 µCi) ± 27 kBq (0.73 µCi)	36[1]	23 kBq (0.63 µCi) to 220 kBq (5.9 µCi)	90 kBq (2.4 µCi) ± 49 kBq (1.3 µCi)	17	12 kBq (0.32 µCi) to 89 kBq (2.4 µCi)	37 kBq (1.0 µCi) ± 19 kBq (0.51 µCi)
34 kBq (0.93 µCi) ± 17 kBq (0.47 µCi)	32	15 kBq (0.41 µCi) to 200 kBq (5.5 µCi)	62 kBq (1.7 µCi) ± 37 kBq (1.0 µCi)	16	2.2 kBq (0.060 µCi) to 36 kBq (0.98 µCi)	16 kBq (0.44 µCi) ± 8.9 kBq (0.24 µCi)
30 kBq (0.82 µCi) ± 7.6 kBq (0.21 µCi)	6[2]	27 kBq (0.73 µCi) to 77 kBq (2.1 µCi)	53 kBq (1.4 µCi) ± 21 kBq (0.56 µCi)	4	2.0 kBq (0.055 µCi) to 28 kBq (0.76 µCi)	10 kBq (0.27 µCi) ± 12 kBq (0.33 µCi)
25 kBq (0.68 µCi) ± 8.5 kBq (0.23 µCi)	3	28 kBq (0.74 µCi) to 76 kBq (2.1 µCi)	46 kBq (1.3 µCi) ± 25 kBq (0.66 µCi)	2	5.6 kBq (0.15 µCi) to 10 kBq (0.27 µCi)	7.8 kBq (0.21 µCi) ± 3.1 kBq (0.080 µCi)
ND	8[3]	37 kBq (1.0 µCi) to 64 kBq (1.7 µCi)	50 kBq (1.3 µCi) ± 7.6 kBq (0.21 µCi)	1	5.9 kBq (0.16 µCi)	5.9 kBq (0.16 µCi)
ND	14	20 kBq (0.54 µCi) to 92 kBq (2.4 µCi)	47 kBq (1.3 µCi) ± 21 kBq (0.56 µCi)	6	1.6 kBq (0.042 µCi) to 9.6 kBq (0.26 µCi)	4.4 kBq (0.12 µCi) ± 3.0 kBq (0.080 µCi)

Table 2. (Contd)

Population	Number Counted 1974(5)	Range of ^{137}Cs Results 1974(5)	Mean ^{137}Cs Result 1974(5)	Number Counted 1977(5)	Range of ^{137}Cs Results 1977(5)
All Adults	31	0.67 kBq (0.018 μCi) to 15 kBq (0.40 μCi)	3.9 kBq (0.11 μCi) ± 3.1 kBq (0.085 μCi)	42	20. kBq (0.53 μCi) to 120 kBq (3.2 μCi)
All Children	0	ND	ND	6	20. kBq (0.56 μCi) to 39 kBq (1.0 μCi)
Total Average	31	0.67 kBq (0.018 μCi) to 15 kBq (0.40 μCi)	3.9 kBq (0.11 μCi) ± 3.1 kBq (0.085 μCi)	48	20. kBq (0.53 μCi) to 120 kBq (3.2 μCi)

ND—No Data available for the specific column.

(1) One adult, counted at Bikini, was a visitor from Rongelap Atoll. He remained on ship with our staff while at Bikini and returned to Ebeye with us. His body count was not used in this table.

(2) One male child in this age group was counted twice to determine what effect showering prior to the body count had on the final result. Only one result was used for this individual since both results were similar.

(3) A six month old child's data has not been included in this table and category due to the difference in geometry between a baby and our calibration phantom.

(4) The 1978 mean value for all individual count includes the 5–10 year age group while the 1977 mean value has no representation in this sample section and the 1974 mean value has no child representation.

(5) The 1974 (Con75) and 1977 ^{137}Cs body burden data were obtained from S. Cohn, Brookhaven National Laboratory, Medical Department.

Mean ^{137}Cs Result 1977(5)	Number Counted 1978	Range of ^{137}Cs Results 1978	Mean ^{137}Cs Result 1978	Number Counted 1979	Range of ^{137}Cs Results 1979	Mean ^{137}Cs Result 1979
42 kBq (1.1 μCi) ± 24 kBq (0.64 μCi)	68	15 kBq (0.41 μCi) to 220 kBq (5.9 μCi)	77 kBq (2.1 μCi) ± 46 kBq (1.2 μCi)	33	2.2 kBq (0.060 μCi) to 89 kBq (2.4 μCi)	27 kBq (0.73 μCi) ± 18 kBq (0.49 μCi)
28 kBq (0.75 μCi) ± 7.8 kBq (0.21 μCi)	31	20 kBq (0.54 μCi) to 92 kBq (2.3 μCi)	50 kBq (1.4 μCi) ± 18 kBq (0.49 μCi)	13	1.6 kBq (0.042 μCi) to 28 kBq (0.76 μCi)	8.3 kBq (0.22 μCi) ± 7.8 kBq (0.21 μCi)
40 kBq (1.1 μCi) ± 22 kBq (0.61 μCi)	99	15 kBq (0.41 μCi) to 220 kBq (5.9 μCi)	68 kBq (1.8 μCi) ± 38 kBq (1.0 μCi)	46	1.6 kBq (0.042 μCi) to 89 kBq (2.4 μCi)	22 kBq (0.59 μCi) ± 18 kBq (0.49 μCi)

Table 3. Summary of ^{60}Co body burdens

Population	Number Counted 1978	Range of ^{60}Co Result 1978
Adult Male	36(1)	53 Bq (1.4 nCi) to 550 Bq (15 nCi)
Adult Female	32	47 Bq (1.3 nCi) to 400 Bq (11 nCi)
Male Children 11 - 15 yrs	6(2)	44 Bq (1.2 nCi) to 130 Bq (3.5 nCi)
Female Children 11 - 15 yrs	3	49 Bq (1.3 nCi) to 96 Bq (2.6 nCi)
Male Children 5 - 10 yrs	8(3)	36 Bq (0.98 nCi) to 99 Bq (2.7 nCi)
Female Children 5 - 10 yrs	14	13 Bq (0.35 nCi) to 240 Bq (6.4 nCi)
All Adults	68	47 Bq (1.3 nCi) to 550 Bq (11 nCi)
All Children	31	13 Bq (0.35 nCi) to 240 Bq (6.4 nCi)
Total Average	99	13 Bq (0.35 nCi) to 550 Bq (11 nCi)

(See Table 2 For Explanation of Footnotes) *for Bikini inhabitants* 1978 *and* 1979

Mean ^{60}Co Result 1978	Number Counted 1979	Range of ^{60}Co Result 1979	Mean ^{60}Co Result 1979
190 Bq (5.3 nCi) ± 130 Bq (3.4 nCi)	17	25 Bq (0.67 nCi) to 120 Bq (3.2 nCi)	81 Bq (2.2 nCi) ± 28 Bq (0.77 nCi)
120 Bq (3.2 nCi) ± 71 Bq (1.9 nCi)	16	12 Bq (0.32 nCi) to 93 Bq (2.5 nCi)	52 Bq (1.4 nCi) ± 22 Bq (0.59 nCi)
92 Bq (2.5 nCi) ± 40 Bq (1.1 nCi)	4	19 Bq (0.5 nCi) to 78 Bq (2.1 nCi)	52 Bq (1.4 nCi) ± 29 Bq (0.78 nCi)
76 Bq (2.1 nCi) ± 24 Bq (0.66 nCi)	2	44 Bq (1.2 nCi) to 52 Bq (1.4 nCi)	48 Bq (1.3 nCi) ± 5.2 Bq (0.14 nCi)
63 Bq (1.7 nCi) ± 23 Bq (0.67 nCi)	1		34 Bq (0.91 nCi)
78 Bq (2.1 nCi) ± 68 Bq (1.8 nCi)	4	13 Bq (0.35 nCi) to 22 Bq (0.59 nCi)	17 Bq (0.46 nCi) ± 3.7 Bq (0.1 nCi)
160 Bq (4.3 nCi) ± 110 Bq (3.0 nCi)	33	12 Bq (0.32 nCi) to 120 Bq (3.2 nCi)	67 Bq (1.8 nCi) ± 29 Bq (0.79 nCi)
77 Bq (2.1 nCi) ± 51 Bq (1.4 nCi)	11	13 Bq (0.35 nCi) to 78 Bq (2.1 nCi)	37 Bq (1 nCi) ± 23 Bq (0.62 nCi)
130 Bq (3.6 nCi) ± 100 Bq (2.8 nCi)	44	12 Bq (0.32 nCi) to 120 Bq (3.2 nCi)	60 Bq (1.6 nCi) ± 31 Bq (0.83 nCi)

Table 4. Summary of body Potassium mass for

Population	Number Counted 1974(5)	Range of Potassium Result 1974(5)	Mean Potassium Result 1974(5)	Number Counted 1977(5)	Range of Potassium Result 1977(5)
Adult Male	18	130g to 200g	160g ± 19g	22	120g to 170g
Adult Female	13	59g to 110g	93g ± 16g	20	86g to 110g
Male Children 11 - 15 yrs	0	ND	ND	3	84g to 96g
Female Children 11 - 15 yrs	0	ND	ND	3	84g to 91g
Male Children 5 - 10 yrs	0	ND	ND	0	ND
Female Children 5-10 yrs	0	ND	ND	0	ND
All Adults	31	59g to 200g	130g ± 35g	42	86g to 170g
All Children	0	ND	ND	6	84g to 96g
Total Average	31	59g to 200g	130g ± 35g	48	84g to 170g

See Table 2 for Explanation of Footnotes.

Bikini inhabitants, 1974–79, determined from ^{40}K

Mean Potassium Result 1977 (5)	Number Counted 1978	Range of Potassium Result 1978	Mean Potassium Result 1978	Number Counted 1979	Range of Potassium Result 1979	Mean Potassium Result 1979
150g ± 13g	36 (1)	98g to 180g	140g ± 19g	17	130g to 180g	150g ± 16g
96g ± 7.6g	32	71g to 110g	89g ± 10g	16	66g to 130g	98g ± 15g
90g ± 5.7g	6 (2)	53g to 69g	57g ± 6.2g	4	37g to 110g	75g ± 33g
89g ± 4.3g	3	69g to 70g	69g ± 0.9g	2	73g to 100g	88g ± 21g
ND	8 (3)	33g to 53g	43g ± 7.3g	1	-	43g
ND	14	33g to 56g	45g ± 8.5g	6	34g to 65g	48g ± 12g
120g ± 27g	68	71g to 180g	120g ± 29g	33	66g to 180g	130g ± 32g
89g ± 4.6g	31	33g to 70g	49g ± 11g	13	34g to 110g	62g ± 26g
120g ± 28g	99	33g to 180g	95g ± 40g	46	34g to 180g	110g ± 42g

Table 5. Comparison of observed vs expected reduction factors for ^{137}Cs body burdens

Description	# of Persons	Mean Reduction Factor
Expected Reduction Factor for Adult Males(1)	NA	2.4
Observed Reduction Factor for Adult Bikini Males	17	2.3
Expected Reduction Factor for Adult Females(2)	NA	3.5
Observed Reduction Factor for Adult Bikini Females	16	3.8
Expected Reduction Factor for Children Ages 5-14(2)	NA	5.9
Observed Reduction Factor for Children Ages 5-14	12	12.

NA = Not applicable.

(1) Effective half time obtained from ICRP Publication 10A (ICRP 71).

(2) Effective half time obtained from NCRP Report 52 (NCRP 77).

As certain local food crops, coconuts, became available in 1976, they were incorporated into the diet in the form of *jekaru* (the water sap of the coconut tree) *jekomai* (a syrup concentrate made from *jekaru*) and *ni* (drinking coconuts). The maturation time of the coconut tree is 5–7 yrs. Consequently, one could expect to observe a steady increase in the ^{137}Cs body burden through 1978 at which time a peak body burden would be reached. Comparison of the observed reduction in the ^{137}Cs body burden from 25 April 1978 to 24 January 1979 with the expected reduction in the body burdens from 1 September 1978 to 24 January 1979 yields almost identical results for the adult male and adult female groups as shown in Table 5. This implies that the Bikini population near equilibrium with their environment and that the body burdens on 1 September 1978 were not significantly different than those measured in April 1978. The child data do not agree with the expected values; however, the difference is not beyond the range of half-times listed in NCRP Report 52 (NCRP77). Although the report lists a mean half-time for children ages 5–15, it does not specify the age distribution of the sample. Most of the Bikini children (9) were in the 5–10 yr category; hence, one would expect the observed reduction factor for this group to be somewhat higher than the expected value.

Although the data indicates that the ^{137}Cs body burdens did not increase between April and September 1978, this is not assurance that the body burdens would not have increased when new dietary items like pandanus and breadfruit became available for daily consumption.

Furthermore, while the population may have been near equilibrium with their April–September dietary uptake, individuals within the population may not have been. This was apparent in the adult male. ^{137}Cs body burden data where two individuals show no decline in activity between April 1978 and January 1979 whole body count. In one case, the individual was present on Bikini for only 5 months prior to the April 1978 count. This places the individual at approx. 60% of his equilibrium body burden value. In the second case, there seems to be no clear explanation for the lack of any reduction in the body burden. Several possible explanations include: (1) the individual may have lived away from Bikini prior to the April count; hence, equilibrium was not established at the time of counting, or (2) the individual changed his diet pattern between April and September.

These deviations from the norm do not alter the conclusion that equilibrium or near equilibrium had been reached for the population as a whole for ^{137}Cs. Indeed, they illustrate variations about a mean value.

Finally, the individual data, not presented here, clearly illustrates that at least 19% of the Bikini residents would have received annual dose equivalents in excess of 5 mSv (0.5 rem) due to the ingestion of ^{137}Cs had the April 1978 activity ingestion rate of ^{137}Cs continued. This dose equivalent level does not include the dose equivalent from external radiation or other internally deposited radioactive material. Removal of the Bikini population from Bikini Atoll eliminated the ^{137}Cs source term from the diet and limited the dose equivalent received by this population.

Acknowledgement—We would like to express our sincere appreciation to Stanton H. Cohn, Ph.D., Brookhaven National Laboratory, Medical Department, for his advice and assistance during the initial setup, preliminary operations and transfer of responsibility for bioassay services to our division.

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DRAFT

^{60}CO AND ^{137}CS LONG TERM BIOLOGICAL REMOVAL RATE CONSTANTS FOR THE MARSHALLESE POPULATION

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ABSTRACT

Residents of Bikini Atoll were moved from their home Atoll on 31 August 1978. Since that time, they have been relocated either to Kili Island, or to Majuro and Ejit Islands at Majuro Atoll. Whole body counting and urine bioassay were performed on this population in January and May 1979, and body burdens for nuclides positively identified were determined from both techniques. Data from these measurements have been used to calculate long term biological removal rate constants for ^{137}Cs and ^{60}Co and to relate the long term rate constant for ^{137}Cs to total body mass.

INTRODUCTION

Body burden measurements performed on the Bikini Island population in 1978 (Mi79) and external exposure surveys conducted in 1975 (Gu76, Gr79a) of Bikini Atoll provided data which indicated that many of the individuals living on Bikini Atoll would receive an annual dose equivalent in excess of 5 mSv (.5 rem) (Gr79b).

This information was reported to the United States Departments of Energy and Interior. The decision was made by the latter agency to relocate the Bikini Atoll population. This action was accomplished between August 28-31, 1978. The former Bikini Atoll residents were moved to Kili Island in the southern Marshall Islands, and to Majuro or Ejit Islands in Majuro Atoll. The Department of Energy, responsible for the radiologic follow up of this population, requested that whole body counting and urine bioassay measurements be made on this population at approximately six month intervals for the first year to confirm the elimination rates of radioactive materials in order to accurately assess internal doses and dose commitments for individual Bikinians.

Whole body counting and urine bioassay services were provided to this Marshallese population in January and May, 1979. From these data, long term biological removal rate constants have been measured for ^{137}Cs and ^{60}Co. ^{90}Sr has been measured in both urine sample series; however, additional sampling points in time will be required in order to estimate the intermediate and long term biological removal rate constants for this radionuclide.

EXPERIMENTAL DESIGN

^{137}Cs and ^{60}Co body burdens were measured using a shadow shield whole body counter. The system design, analysis techniques and aspects of the quality control program are described in a previous report (Mi79). Urine bioassay samples were taken to provide ^{90}Sr body burden estimates and an independent estimate of ^{137}Cs body burdens. Cesi um body burdens calculated from urine bioassay data are used for comparison with the whole body counting estimates as an additional parameter of our quality control program. ^{60}Co was rarely detected in the urine thus a similar comparison is not possible for this radionuclide. The mathematical technique used for determination of the body burden can be derived from a previous publication (Le79).

Figures 1 through 4 show relative results between comparisons of paired urine bioassay results, and whole body counting data collected from the Rongelap and Utirik population in 1977 (Co77) and the Bikini population in 1974 (Co75), 1978 and 1979 (Mi79). Figures 1 through 3 have samples plotted randomly; figure 4 has the samples plotted in the same sequence as the urine was analyzed. The results show excellent agreement between the two body burden evaluation techniques. The standard deviation plotted on figures 1 through 4 reflect the fluctuation in the individual's daily urine activity concentration used to calculate the ^{137}Cs body burden.

METHOD

The National Council on Radiation Protection and Measurements in Report 52 (NCRP77) and the International Commission on Radiation Protection report of committee IV publication 10 (ICRP68) suggest that ^{137}Cs has a biological long term compartment with a removal rate constant which is on the order of $6 \times 10^{-3}\ d^{-1}$. ICRP publication 10 suggests that there may be long term biological retention of ^{60}Co (ICRP68), and studies performed on humans report that the retention function for ^{60}Co can be described by multiple compartments with biological mean residence times that range between .37 days and 880 days

(Le72, Sm72). The data presented here provide long term biological removal rate constants for ^{137}Cs and ^{60}Co determined from the Marshallese population exposed to these nuclides primarily through dietary pathways.

When the Bikini population was relocated, their new residence islands were essentially free of radioactive contamination due to the United States weapons testing program. Persons having lived exclusively in contamination free environments were used as controls. Their ^{137}Cs and ^{60}Co body burdens during the May survey were assumed to be representative of the baseline body burden status of the Bikini population prior to their return to Bikini. The equation used to calculate the long term biological removal rate constants for both radionuclides is of the form

$$(A-C) = (B-C)e^{-(k+\lambda)t} \qquad (1)$$

where

A $\equiv$ measured body burden in May, 1979, Bq

B $\equiv$ measured body burden in January, 1979, Bq

C $\equiv$ averaged measured body burden of the control population in May, 1979

k $\equiv$ instantaneous fraction of radioactive atoms removed per unit time by biological mechanisms, d^{-1}

λ $\equiv$ instantaneous fraction of atoms removed per unit time by radioactive decay, d^{-1}

t $\equiv$ elapsed time between measurements, d.

Values of the radiological decay rate constant for each nuclide were obtained from the Atomic Data and Nuclear Data Tables (AD76) and are 6.3×10^{-5} d^{-1} for ^{137}Cs and 3.6×10^{-4} d^{-1} for ^{60}Co.

The baseline mean ^{137}Cs body burden is 60 Bq as determined from 47 measurements with results ranging from the system detection limit (37 Bq) to several hundred bequerels. Cobalt 60 was not detected in the control population. The average ratio between ^{137}Cs and ^{60}Co body burdens in the exposed population was 490. The ^{137}Cs to ^{60}Co activity ratio was assumed to be of the same magnitude for the control population. Because the baseline ^{60}Co body burden was estimated to be well below the MDL, it was assumed to be .2% of the control group body activity for ^{137}Cs in the determination of the long term biological remove rate constant.

Tables 1 through 4 present the January and May 1979 ^{137}Cs body burdens, elapsed time and long term biological removal rate constants as measured in Marshallese adult males, adult females, adolescents and juveniles. Data presented in these tables are for individuals whose body burdens in January and May are significantly above the baseline ^{137}Cs body burden for the control population. A body burden was included in the data set if it exceeded the mean ^{137}Cs body burden of the control population plus three standard deviations of the mean.

Table 5 presents similar data for ^{60}Co. Because ^{60}Co was not detected in the control population, no acceptance criteria were applied to the body burden in this table other than the quantitative presence of two consecutively decreasing ^{60}Co body burdens.

RESULTS

Table 6 summarizes the individual data presented in Tables 1 through 4 for ^{137}Cs and compares the data with values listed in ICRP publication 10 (ICRP68) and NCRP report 52 (NCRP77). The biological removal rate constants for adult male and adult female Marshallese are in agreement with previously reported data. The biological removal rate constant for adolescent Marshallese is similar to the value reported in NCRP report 52 (NCRP77) for juveniles. The long term biological removal rate constant for juvenile Marshallese did not agree with reported data. This appears to occur because of the difference in the age distribution of the juvenile data reported in NCRP report 52 and that of the Marshallese juveniles.

The ^{137}Cs long term biological removal rate constant for the Marshallese population is highly dependent on body mass. This relationship is best described by a simple logarithmic equation of the form

$$k = a + b \ln(m) \qquad (2)$$

The coefficient of determination for this equation is 0.79 for females and 0.89 for males. The regression coefficients a and b are respectively 19 and -3.9 for males, and 14 and -2.6 for females. The units for the quantities mass, m, and biological rate constant, k, are kg and year^{-1} respectively. The impact of mass on the rate constant is greatest for body masses less than 60 kilograms. Similar results were reported in studies by Lloyd (L173) which related body mass to biological half-life for ^{137}Cs.

Several investigators have reported that ^{60}Co exhibits a long term biological removal rate constant for both inhaled insoluble cobalt (Jo65, Si64) and CoCl administered orally or intravenously (Le72, Sm72). These investigators agree that the retention function for cobalt should have several compartments whose retention is characterized by linear first order removal mechanisms. For ingestion, four and five compartment models have been postulated to describe the retention of soluble CoCl.

Using the average of values reported by Smith (Sm 72) and rounding to significant figures, the single intake retention function would be of the form

$$R(t) = 0.5e^{-1.4t} + 0.3e^{-1.2t} + 0.1e^{-0.12t} + 0.1e^{-0.00087t}, \qquad (3)$$

where

$R(t) \equiv$ fraction of initial atoms administered which remain in the body at time t not corrected for radioactive decay.

The fractions of ^{60}Co atoms in each compartment at the end of each individual's residence interval were calculated assuming a constant continuous uptake regime for ^{60}Co. Individuals were assumed not to have an initial body burden at the onset of residence on Bikini Island. The parameters for biological removal rate constants and fractions of activity

distributed to each of the four compartments are obtained from equation 3. For the eight individuals, eighty-four to eighty-eight percent of the total body ^{60}Co atoms would be in the long term compartment, nine to twelve percent in the intermediate compartment and three percent in the two remaining short term compartments.

In January, approximately 140 days after departure from Bikini, two percent of the atoms would have been in the intermediate compartments and 98 per cent in the long term compartment. In May, the relative contribution of atoms from each compartment to the total atom content in the body would have been .7 percent and 99.3 percent respectively. This corresponds to a change in the ^{60}Co body burden between January, 1979 and May, 1979 of 14 percent. The observed decline in the body burden was 44 percent.

The intermediate and long term biological removal rate constants determined by Smith and Letourneau (Sm72, Le72) do not describe the retention of ^{60}Co for the Marshallese population. From the Marshall Islands data, one cannot estimate the number of compartments that should be used in the ^{60}Co retention model, but an estimate of the long term biological removal rate constant was calculated using equation 1.

Table 7 summarizes the long term biological removal rate constants of ^{60}Co as measured in Marshallese adult males, adult females and one adolescent. All values listed are in reasonable agreement with earlier animal study data and fall within the range of results reported for human data (ICRP68, Jo65, Si64, Le72 and Sm72).

SUMMARY AND CONCLUSIONS

From urine bioassay and whole body counting performed for the Marshallese population who had been relocated from Bikini Atoll, long term biological removal rate constants have been calculated for ^{137}Cs and ^{60}Co. The values presented for ^{137}Cs are in agreement with previously reported values for adult males, adult females and adolescents. More data has been added for the 5-10 year old juvenile data base. Our data provides strong evidence that the biological removal rate constant is related to the body mass by a simple logarithmic equation. This is consistent with the concept that the mean residence time of a ^{137}Cs atom in the body is proportional to the (total body mass in which it is present) size of the body it passes through.

Finally, the ^{60}Co long term biological removal rate constants reported here are few in number but indicate that a long term compartment exists for ^{60}Co. This will have an impact on the dose assigned to the ingestion of ^{60}Co. The significance will depend on the number of compartments selected to describe the retention function and the parameters used to describe the biological removal .

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Table 1

Adult Male ^{137}Cs Long Term Biological Removal Rate Constants

ID#	Jan. 1979 ^{137}Cs Body Burden, kBq	May 1979 ^{137}Cs Body Burden, kBq	Elapsed Time, d	Biological Removal Rate Constant, d^{-1}
6067	37	23	113	4.2×10^{-3}
6182	45	23	113	5.9×10^{-3}
6086	32	15	113	6.7×10^{-3}
6118	28	15	113	5.5×10^{-3}
6117	33	16	112	6.4×10^{-3}
6130	56	36	113	3.9×10^{-3}
6096	48	26	114	5.3×10^{-3}
6161	4.0	1.8	113	7.2×10^{-3}
6166	0.85	0.41	112	7.2×10^{-3}
6184	2.5	0.93	112	9.1×10^{-3}

Table 2

Adult Female ^{137}Cs Long Term Biological Removal Rate Constants

ID#	Jan. 1979 ^{137}Cs Body Burden, kBq	May 1979 ^{137}Cs Body Burden, kBq	Elapsed Time, d	Biological Removal Rate Constants, d^{-1}
6112	36	17	112	6.7×10^{-3}
6122	11	4.1	114	8.7×10^{-3}
6123	23	9.3	115	7.8×10^{-3}
6032	28	9.6	114	9.4×10^{-3}
6113	11	4.1	113	8.8×10^{-3}
6097	11	5.9	113	5.5×10^{-3}
6109	2.2	0.67	113	1.1×10^{-2}
6098	17	6.5	115	8.3×10^{-3}
6060	6.7	2.2	113	1.0×10^{-2}
6064	16	8.1	111	6.1×10^{-3}
6115	18	6.3	113	9.3×10^{-3}
6167	0.56	0.29	112	6.9×10^{-3}
6159	1.0	0.44	113	8.0×10^{-3}
6148	1.4	0.56	113	8.7×10^{-3}
6151	4.5	2.2	114	6.3×10^{-3}
6140	1.0	0.32	115	1.1×10^{-2}
6144	1.4	0.48	115	1.0×10^{-2}
6155	15	5.6	113	8.7×10^{-3}
6160	13	5.1	113	8.3×10^{-3}
6175	0.41	0.19	113	8.7×10^{-3}
6181	0.31	0.17	112	7.3×10^{-3}

Table 3

Adolescent ^{137}Cs Long Term Biological Removal Rate Constants

ID#	Jan. 1979 ^{137}Cs Body Burden, kBq	May 1979 ^{137}Cs Body Burden, kBq	Elapsed Time, d	Biological Removal Rate Constants, d^{-1}
M 6147	7.6	2.8	112	9.0×10^{-3}
M 6131	28	12	113	7.5×10^{-3}
M 6011	2.0	0.63	113	1.1×10^{-2}
M 6127	7.8	2.0	114	1.2×10^{-2}
M 6015	2.6	0.60	113	1.4×10^{-2}
F 6129	10	2.8	115	1.1×10^{-2}
F 6091	5.6	1.4	113	1.2×10^{-2}

Table 4

Juvenile ^{137}Cs Long Term Biological Removal Rate Constants

ID#	Jan. 1979 ^{137}Cs Body Burden, kBq	May 1979 ^{137}Cs Body Burden, kBq	Elapsed Time, d	Biological Removal Rate Constant, d^{-1}
M 6021	1.7	0.23	112	2.0×10^{-2}
M 6020	2.1	0.27	114	2.0×10^{-2}
M 6107	0.59	0.096	113	2.4×10^{-2}
F 6101	1.9	0.26	111	2.0×10^{-2}
F 6056	1.7	0.27	112	1.8×10^{-2}
F 6105	2.0	0.27	113	2.0×10^{-2}
F 6030	9.6	2.4	114	1.2×10^{-2}
F 6025	4.8	1.0	113	1.4 x 10-2
F 6106	2.9	.48	113	1.7×10^{-2}

Table 5

Biological Removal Rate Constants for ^{60}Co

ID#	Age Category and Sex	Jan. 1979 ^{60}Co Body Burden, Bq	May 1979 ^{60}Co Body Burden, Bq	Elapsed Time d	Biological Removal Rate Constant d^{-1}
6067	Adult Male	89	44	113	5.9×10^{-3}
6086	Adult Male	100	70	113	3.1×10^{-3}
6118	Adult Male	59	33	113	4.8×10^{-3}
6117	Adult Male	110	56	112	5.4×10^{-3}
6096	Adult Male	93	33	114	8.7×10^{-3}
6131	Adolescent Male	78	52	113	3.2×10^{-3}
6122	Adult Female	70	41	114	4.3×10^{-3}
6032	Adult Female	63	37	114	4.3×10^{-3}

Table 6

Summary of Long Term Biological Removal Rate Constants for ^{137}Cs

Population	Age, a	Group	Number in Sample	Biological Removal Rate Constant, d^{-1}	Standard Deviation, d^{-1}
Adult Males	-	ICRP	-	.006	-
	(23-55)	NCRP	4	.0051	-
	(23-55)	NCRP	26	.0066	0.0016
	(22-59)	BNL	10	.0061	0.0016
Adult Females	(20-51)	NCRP	15	.0082	0.0020
	(19-70)	BNL	21	.0084	0.0016
Adolescents	(11-15)	BNL	7	.011	0.0021
Juveniles	(5-17)	NCRP	7	.012	0.0043
	(5-10)	BNL	9	.018	0.0034

Table 7

Summary of Long Term Biological Removal Rate Constants for ^{60}Co

Population	Age, a	Sample Size	Biological Removal Rate Constant, d^{-1}	Standard Deviation, d^{-1}
Adult Males	(22-59)	5	5.6×10^{-3}	2.0×10^{-3}
Adult Females	(19-70)	2	4.3×10^{-3}	-
Adolescents	(11-15)	1	3.2×10^{-3}	-

Figure One

BIKINI ATOLL 1974 URINE BIO-ASSAY - WHOLE BODY COUNTING BODY BURDEN COMPARISON

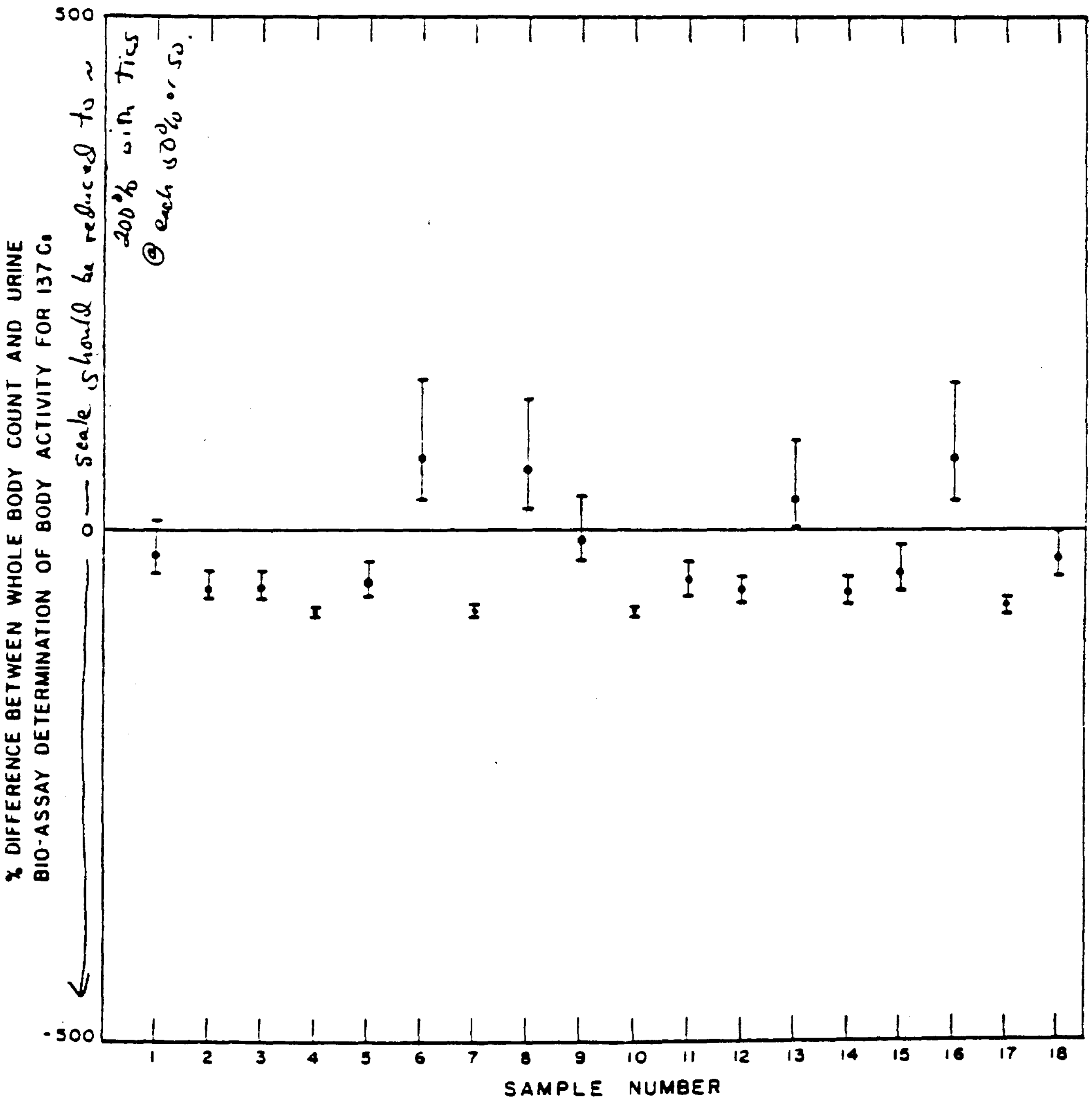


Figure Two

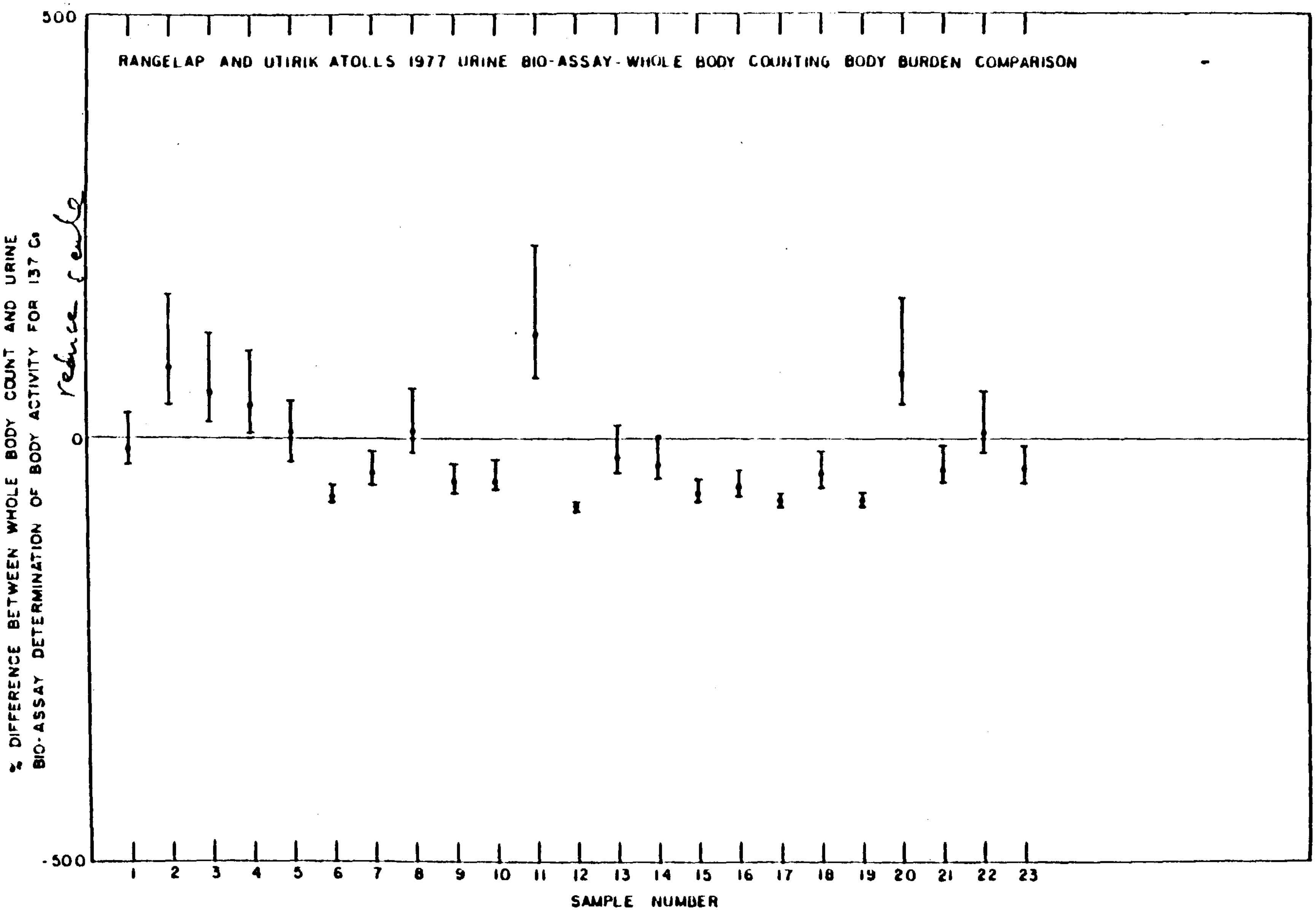

RANGELAP AND UTIRIK ATOLLS 1977 URINE BIO-ASSAY-WHOLE BODY COUNTING BODY BURDEN COMPARISON
% DIFFERENCE BETWEEN WHOLE BODY COUNT AND URINE
BIO-ASSAY DETERMINATION OF BODY ACTIVITY FOR 137 Cs
500
0
-500
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
SAMPLE NUMBER
reduce scale

Figure 7b

BIKINI ATOLL 1978 URINE BIO-ASSAY WHOLE BODY COUNTING BODY BURDEN COMPARISON

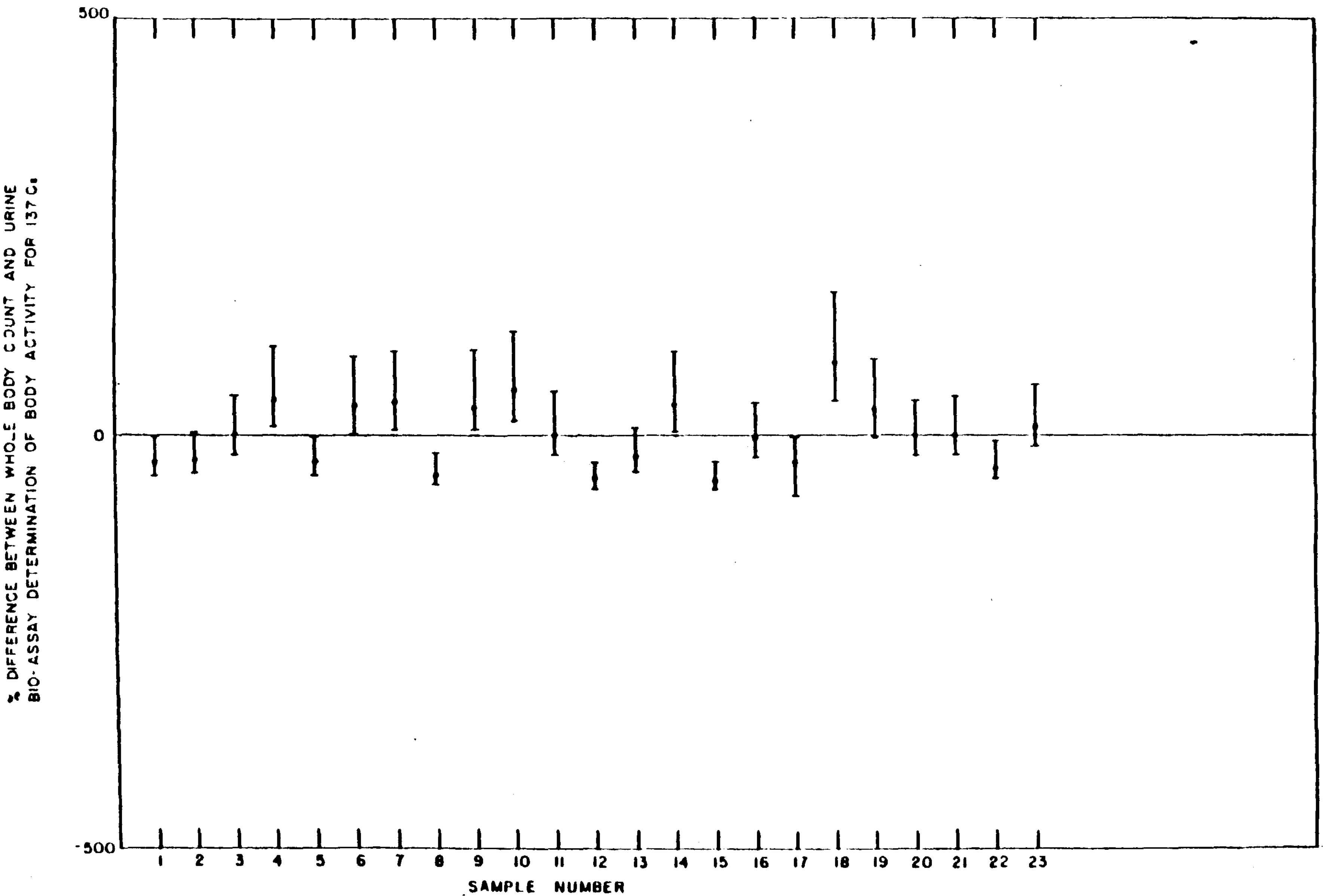
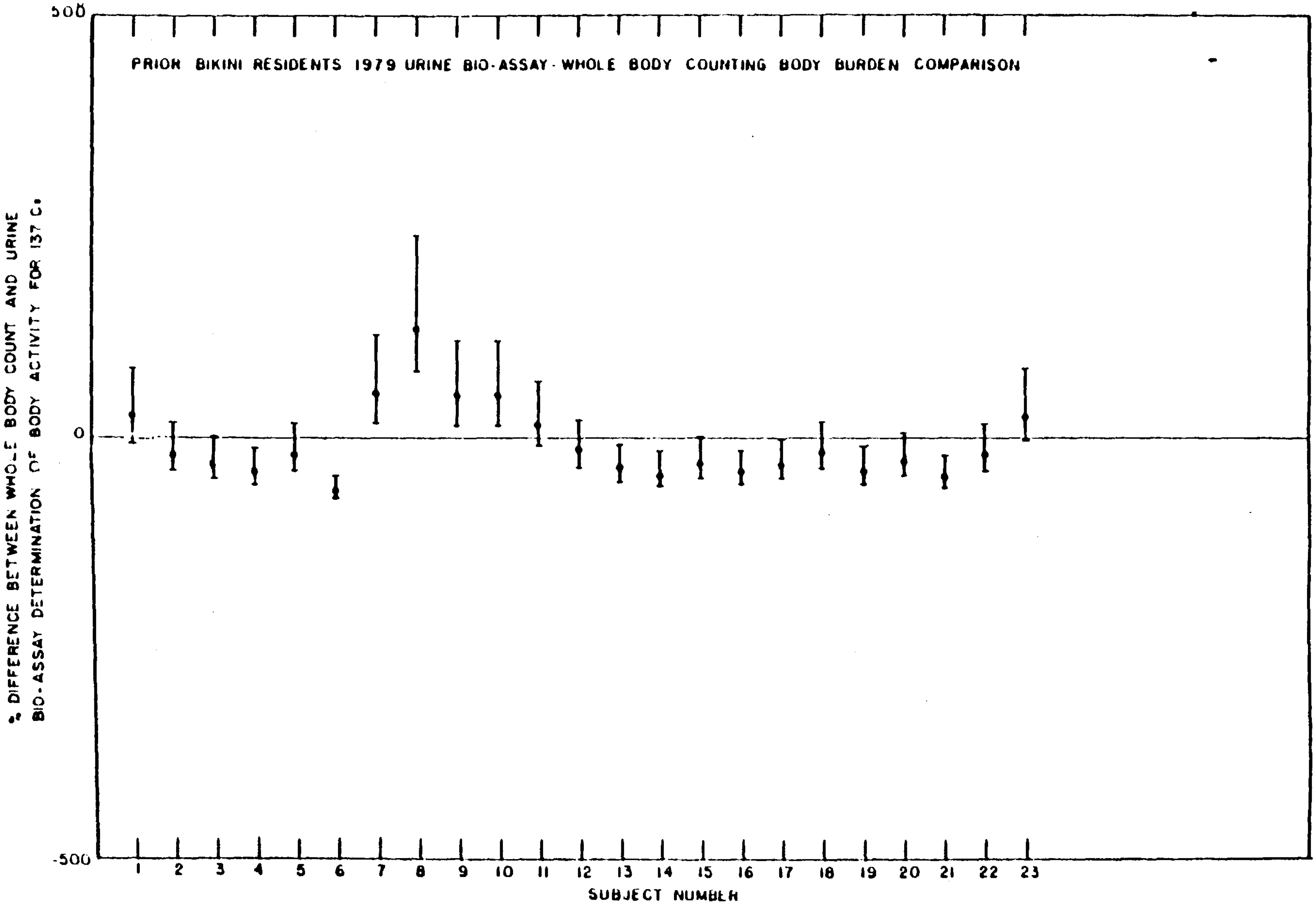


Figure Four



PRIOR BIKINI RESIDENTS 1979 URINE BIO-ASSAY-WHOLE BODY COUNTING BODY BURDEN COMPARISON
500
0
-500
% DIFFERENCE BETWEEN WHOLE BODY COUNT AND URINE BIO-ASSAY DETERMINATION OF BODY ACTIVITY FOR 137 Cs
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
SUBJECT NUMBER

^{137}Cs in Human Milk and Dose-Equivalent Assessment

DRAFT

Abstract

In May 1979, human milk samples were obtained from four lactating adult Marshallese females, whose ^{137}Cs body burden had been defined by whole-body counting and analysis of urine samples. The samples, ranging in volume from 10 ml to 30 ml, were analyzed by gamma spectroscopy and atomic absorption to determine the presence of ^{137}Cs and potassium. Results were used to estimate the daily ingestion rate of ^{137}Cs for Marshallese infants whose primary food supply was human milk. Concentration factors relating adult female ^{137}Cs body burdens to ^{137}Cs activity concentrations in human milk were determined. A range of ^{137}Cs body burdens and dose commitments resulting from ingestion of human milk and/or coconut products (human milk subsitutes) from 1 September 1977 to 31 August 1978 were calculated for a hypothetical infant resident on Bikini Atoll during this final year residence interval of the former Bikini population.

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Introduction

The Marshall Islands Radiological Safety Program at Brookhaven National Laboratory, under contract with the U.S. Department of Energy, provides whole-body counting and urine analysis services to residents of the Marshall Islands whose atolls were affected by radioactive fallout from the U.S. nuclear weapons testing program conducted in the mid-Pacific during the 1950's. Individuals five years of age or older are monitored under the current program. This age limitation was imposed to assure willing participation by informed persons as well as to select individuals whose body burdens of ^{137}Cs and potassium were large enough to be detected in a 15 minute whole-body count. Children under five years of age were not expected to have ^{137}Cs body burdens which exceeded the ^{137}Cs body burdens of the five year old children, based on review of previous whole body counting data (Co57, Co59, Co60, Co62, Co63, Co65, Co67, Co70, Co75).

A retrospective dose assessment prepared for the Rongelap and Utirik residents (Le80) has indicated that individuals who ingested radioactive material as infants (age 0-4 years) received a higher dose-equivalent commitment than other segments of the sample population. In addition, these individuals had the highest daily ingestion rate of ^{137}Cs and other nuclides which were positively identified in the sample program. These data on infants were determined from body burden and urine activity measurements conducted at age five or older and extrapolated to the infant age group. The Bikini Atoll resident dosimetry (Gr 80) demonstrate that the sampled children received higher dose-equivalent commitments and had higher daily ingestion rates for ^{137}Cs than did the adult population.

Dose-equivalent commitment is a function of body mass and radionuclide removal rate constants. Absorbed fractions are different for the adult and child and thus also effect the dose. Consequently, it should not be surprising, that for equal body burdens, a child may receive a different dose or dose rate than an adult due to different values for body mass, absorbed fractions and removal rate constants. The higher daily activity ingestion rate was not anticipated because it requires the infant to consume more ^{137}Cs activity than that ingested by the adults and/or to consume substantially larger quantities of food.

Information concerning diet and living style patterns observed in the Marshall Islands from the mid 1950's to the present (Na81, Sh57, Mu54) indicates two possible sources of ^{137}Cs in the infant diet: human milk and coconut products. This report examines the dose-equivalent, dose-equivalent rate, and ^{137}Cs body burden for a hypothetical infant residing on Bikini Atoll from 1 September 1977 to 31 August 1978 whose principle diet consisted of these sources of ^{137}Cs. Dosimetric projections were determined from human milk collected during May 1979, and from coconut tree sap and coconuts collected in April 1978. A concentration factor relating adult female ^{137}Cs body burdens to ^{137}Cs activity concentrations in human milk has been determined and is reported along with the dosimetric information.

Limited coconut product samples from the Bikini Island camp area were collected in April 1978 (Figure 1). These samples have been analyzed but constitute a sample size large enough to accurately estimate the true mean ^{137}Cs activity concentration with only 70% confidence. Additional sampling of this food source and an assessment of the quantity that an infant typically ingests are questions to be addressed in future field trips.

Sample Collection

A list of participants in the May 1979 whole-body counting and urine collection program was reviewed with the intent of identifying adult women who were currently lactating. Of the population participating in this program, four females were identified as potentially capable of providing the required samples. Whole-body counting results, urine activity concentrations and residence intervals on Bikini Atoll for these individuals are listed in Table 1. Three of the adult females were long term residents with residual ^{137}Cs body burdens, while one individual (No. 6187) was identified as having a baseline ^{137}Cs body burden.

The sample population had been exposed to ^{137}Cs in their diet during their residence at Bikini Atoll from as early as 1970 up to August 1978. By May 1979, they had been relocated from Bikini Atoll for more than 250 days. Residual ^{137}Cs body burdens thus represented activity associated with the long term retention compartment of the body. Although several former Bikini residents have periodically returned to Bikini Island after August 1978, the adult females who participated in the milk sample program had not returned to or eaten food from Bikini Atoll prior to the May sample dates. Consequently, it has been assumed that the diet did not include significant ^{137}Cs contaminated food products during their residence on Majuro Atoll.

The selected individuals were requested to report to a female research associate who was responsible for sample collection. Samples were obtained by either hand expression into a sample container or through the use of a mechanical breast pump. The mechanical pump was thoroughly cleaned after each use to minimize cross contamination of the samples. Once collected, samples were stored in polyethylene bottles which were pretreated with 7.5 ml of 10% thymol solution and then refrigerated until analysis.

Sample Analysis

Prior to preparation for analysis, the four human milk samples had been refrigerated for approximately one year. During this time the samples had coagulated. Therefore, each sample bottle was placed in an ultrasonic bath until the sample was thoroughly homogenized. Samples were then transferred from the original polyethylene bottle into a teflon lined aluminum sample container. The sample bottles were rinsed with distilled water and residual sample removed. The sample plus rinse water was diluted to 150 ml, counted for 50,000 seconds on a 26% relative efficiency lithium drifted germanium detector and analyzed for photon emitting radionuclides which exceeded background levels. The decay corrected results and one sigma counting errors are presented in Table 2 along with specific sample information. ^{137}Cs was the only radionuclide positively identified in three of the four samples.

Using the above technique, no potassium was detected in any of the samples. However, the expected potassium concentration in human milk (ICRP75) as shown in Table 3, is at least a factor of 10 smaller than the minimum detectable potassium concentration for the sample size and selected counting time. The measurement of potassium at the .5 mg/ml concentration would require a minimum counting interval of one week and even then would have a two sigma counting error in excess of 90%.

The potassium values listed in Table 2 were obtained by atomic absorption. An aliquot of the diluted milk sample was used in the evaluation. This analysis technique is more sensitive than gamma spectroscopy and has a lower detection limit of 0.2 μg/ml.

The ratio between the ^{137}Cs activity concentrations in their milk and the ^{137}Cs body burden of the adult lactating female is shown in the last column of

Table 2. This ratio is in good agreement with the ratio of the mean potassium concentration in human milk and the mean adult female potassium body burden at age 30 of 5.5×10^{-6} ml^{-1} (ICRP 75).

Dose Calculations

The ^{137}Cs daily ingestion rate of the infant is related to: the ^{137}Cs activity concentration in human milk (which is dependent on the mother's ^{137}Cs body burden), the milk uptake rate and mass of the infant. Milk uptake for breast fed infants is assumed to equal the milk secretion rate of the lactating female (Me 55). Table 3 lists the mean value and ranges of anatomical and radiological parameters (ICRP75, Ki75) used in the computation of ^{137}Cs body burdens and dose equivalents.

Dose equivalents for the infant were based on dose equivalent per unit cumulated activity for an average infant (mass 7,000 gm, trunk length 23 cm). The absorbed dose per unit cumulated activity was determined from a total body source and target absorbed fraction, Ø, of .17 (Table 3) for the .662 MeV photon (Ya 75) and was calculated for ^{137}Cs as follows

$$S = \frac{51.2}{m} \left(\Sigma F_i E_i + \Sigma G_i H_i \emptyset_i \right) \qquad (1)$$

where

E_i = average energy of the ith particulate radiation MeV,

F_i = average number of ith particulate radiation with energy E_i per disintegration,

G_i = discrete energy of the ith photon, MeV,

H_i = average number of ith photons with discrete energy G_i per disintegration,

m = mass of the target, g.

$$51.2 = \frac{3.2 \times 10^{9} \text{ disintegrations } \mu Ci^{-1} d^{-1} \times 1.6 \times 10^{-6} \text{ erg MeV}^{-1}}{100 \text{ ergs } g^{-1} \text{ Rad}^{-1}}$$

The quality factors and the distribution or other modifying factors were taken as unity for ^{137}Cs in the total body. The dose equivalent per unit cumulated activity total body source to total body target value is 2.4×10^{-3} Rem $\mu Ci^{-1} d^{-1}$ for the male infant and 2.6×10^{-3} Rem $\mu Ci^{-1} d^{-1}$ for the female infant. Formulation of the male and female value requires the assumption that the body organs and tissues of the infant are shrunken versions of an adult. This approach is acceptable for the total body target and total body source configuration but may lead to significant differences from the true value if applied to specific tissues, especially active bone marrow. This is due to large differences in active bone marrow distribution in the infant relative to the adult.

Although human milk samples were not taken while the Marshallese resided on Bikini Atoll, body burden measurements were conducted on the adult population from 1974 to 1978 (Co75, Mi80). The relationship of the mean adult female ^{137}Cs body burden with respect to time can be described by a simple exponential model of the form

$$q = a\, e^{bt}, \qquad (2)$$

where

q = adult female ^{137}Cs body burden, μCi,

t = time post onset of uptake, d,

$a = 1.75 \times 10^{-2}$ μCi,

$b = 2.16 \times 10^{-3}$ d^{-1}.

The values of a and b were determined from a regression analysis of the adult female whole body counting data. The coefficient of determination for this model is 0.99. Equation two was used to estimate the mean adult female ^{137}Cs body burden as of 1 September 1977. This value (1.13 μCi) was then multiplied by the human milk to body burden conversion factor for ^{137}Cs and the average daily consumption rate of human milk to calculate the mean infant ^{137}Cs ingestion rate. A comparison of the mean ^{137}Cs daily ingestion rates for adult males, adult females and infants on April 26, 1978 and September 1, 1977 is shown in Table 4.

The ^{137}Cs body burden at any point in time and number of disintegrations occurring during the uptake interval can be determined from the following equations (Le 80):

$$q = \lambda P^o f_1 \left(\Sigma_i \frac{X_i}{K_i - K_E} \left(e^{-(\lambda+K_E)t} - e^{-(\lambda+K_i)t}\right)\right) + q^o \left(\Sigma_i X_i' e^{-(\lambda+K_i)t}\right) \quad (3)$$

and

$$D = f_1 \lambda P^o \left(\Sigma_i \frac{X_i}{K_i - K_E} \left(\frac{K_i - K_E - (\lambda+K_i)e^{-(\lambda+K_E)t} + (\lambda+K_E)e^{-(K_i+\lambda)t}}{(K_E+\lambda)(K_i+\lambda)}\right)\right) \quad (4)$$

$$+ q^o \Sigma_i \frac{X_i'}{\lambda+K_i} \left(1 - e^{-(\lambda+K_i)t}\right) ,$$

where t = time post onset of uptake, days,

λ = instantaneous fraction of atoms decaying per unit time, day^{-1},

P^o = initial atom ingestion rate, atoms day^{-1},

K_i = instantaneous fraction of atoms removed from compartment i by physiological mechanisms, day^{-1},

X_i = compartment i deposition fraction.

X_i' = the number of atoms in compartment i relative to the number in all compartments at the onset of increasing continuous uptake, (t=0),

f_1 = fraction transferred from GI tract to blood,

K_E = instantaneous fraction of atoms removed (or added if negative) to the atom uptake per unit time, day^{-1}, due to factors other than radioactive decay,

q = instantaneous body burden, μCi,

q° = body burden at the onset of uptake, μCi,

D = the number of disintegrations in all compartments occurring during the uptake interval, μCi days.

The ^{137}Cs infant body burden at onset of uptake, q°, was assumed to be zero in this report. Also, the fraction transferred from the gastrointestinal tract to the blood, f_1, was assigned a value of unity (Ki 75). The environmental removal rate constant, K_E, as listed in table 3 was determined from the adult female Bikini population. The value reflects the addition of ^{137}Cs to the diet (thus the negative sign) between April 1977 and April 1978. The value of K_E for adult males and for adult females were found to be equal. Since K_E appeared to be constant for the adult population, it was assumed to be applicable for the infant population.

The value for the long term ^{137}Cs physiological removal rate constant, K_2 (see Table 3), is variable and a function of body mass and sex. An equation relating these parameters to K_2 was developed for the Bikini population ages 5 to adult (Mi 81) and is of the form:

$$k = a + b \ln (m) \qquad (5)$$

where k = the long term physiological removal rate constant, yr^{-1}, a = regression coefficient equal to 19 for males and 14 for females,

b = regression coefficient equal to -3.9 for males and -2.6 for females,

m = mass of body, kg.

In this report, K_2 was computed using equation 4 and the mean body mass for the infant's first year of life, leading to a mean biological half time of 22 days for male infants and 28 days for female infants at age 6 months. These half time compare well to the value reported in NCRP77 of 19 days ± 8 days for infants ages 17-143 days.

Using equations 3 and 4, the ^{137}Cs body burdens and the total number of disintegrations occurring in the body of the infant during the 365 day uptake interval concluding on 31 August 1978 were calculated. The parameters in Table 3 and the values of K_2 obtained from equation 4 were also used. The total body dose equivalent was then determined, using the result from equation 1. In the adult, red marrow absorbed dose exceeds the total body absorbed dose from ^{137}Cs by a factor of 1.5. This is due to the scattered photon contribution along the midline of the body and due to irradiation of red marrow from all sides. In the infant, the red marrow distribution is significantly different relative to the adult and therefore this factor cannot be applied. Projected ^{137}Cs infant body burdens are reported in Table 5. This table also summarizes the dose equivalent commited during the residence year on Bikini to an infant from the ingestion of ^{137}Cs in human milk.

Discussion of Results

The mean values presented in Table 5 were computed using equations 2 and 3 and the mean values of the quantities listed in Table 3. The ranges were computed by substituting the upper and lower limits of adult female ^{137}Cs body burden on 1 September 1977. In the estimate of a range of dose it may seem reasonable to assume that the extreme masses could be associated with the extreme ingestion rates since there is no relationship between ^{137}Cs ingestion rate and body mass in the Bikini, Rongelap or Utirik data. However, it was reported that the maximum body burden was three times greater than the mean value for population subgroups (adult males, adult females, female children etc.) and the maximum daily activity ingestion rate was 5 times the mean value for population subgroups for Rongelap, Utirik and Bikini measured data (Gr80, Le80). Consequently, the extreme values for body mass and milk ingestion rate which leads to a maximum body burden of 13 times the mean and a maximum dose equivalent of 13 times the mean are not consistent with observations in the field.

As stated earlier, a review of the Rongelap daily activity ingestion rate data (Le80) indicates that the population ages 0 to 4 years, (mean age 2 years) had an average ^{137}Cs ingestion rate which was larger than the adult ingestion rate by a factor of 2. From the Bikini data presented in table 4, this seems possible only if other dietary items are used as a food source for the Marshallese child. For the infant, several sources (Na81, Wi41, Mu54, and Ba77) indicate that natural food supplements are frequently given. Furthermore, Bayliss - Smith (Ba77) suggests that weaning takes place in Pacific cultures between 6 and 12 months of age. Based on the data of table 6, an intake of a liter per day of coconut fluid obtained from Bikini drinking coconuts during April, 1978 could have increased the activity ingestion rate to 160 nCi d^{-1}. Small children drinking fluid from 2 to 3 coconuts each day could have achieved this level of intake. Thus it seems reasonable to assume that the infant's diet consists of human milk and coconut by-products in varying proportions during the first year of life and that the dose estimates should be adjusted upward in proportion to the increased activity ingestion rate that is postulated.

Because of the low soil activity concentration and the uniform contamination of the atolls, individuals residing on these atolls are not requested to shower or change into disposal clothes prior to the whole body count. Tests conducted in the 1978 field survey indicate this practice is acceptable under the environmental conditions present at these atolls.

Persons participating in whole body counting programs should be requested to answer the following questions:

1) Full name (first and last)

2) ID # [some people (Rongelap and Utirik residents) may have been assigned BNL medical ID# and will have medical cards to verify this number. Other individuals will not. Operator should use historic ID# in these cases if person have participated in the program before].

3) Father's full name

4) Mother's full name

5) Residence Wato, Island and Atoll

6) Recent (last two year's) travel history

7) Height

8) Weight

Electronic Setup

These setup procedures have been written with the intent that they could be used in the event that the whole body counter had to be relocated. Operators should disregard steps that obviously do not apply to the routine monitoring application.

Part A Cable Connections and Switch Settings

1. Should the detector need to be installed into the crystal shield, check for physical damage while installing detector.

2. Connect signal cables and HV cable to detector.

3. Connect signal and HV cable from detector to summing/dividing box or cable.

4. Connect HV supply to sum box.

5. Connect preamp to summing cable.

6. Connect preamp power to the back of the ORTEC 485 amplifier.

7. Set preamp capacitance at 0 pf.

8. Connect signal output of preamp to signal input of amplifier.

9. Connect signal output of amp to 10V signal input of ADC.

10. Make sure amplifier switches are initially set as follows:

    Course Gain -16

    Fine Gain - 7

    Input Polarity - Neg.

    Unipolar/Bipolar - Unipolar

Part B - TP-50 Computer Set up

If computer base TP-50 multi channel analyzer has been moved, the operator should execute the first six steps. Otherwise the operator should start at step six or other applicable step.

1. Remove cover of TP-50.

2. Unpack shipping material in computer.

3. Reseat all boards (if necessary).

4. Make sure all connectors are solidly on IC boards.

5. Replace covers.

6. Check to see if unit is plugged into A.C. power. If not, then plug in unit. (110 volts - 15 amp circuit)

7. Push Halt button.

8. Turn power ON.

9. Depress Boot button (the number 173000 should appear on the display screen).

10. Release Halt button. Insert "TPOS I/TP - 50 Master Disk" into mini floppy. Place the diskette into disk reader so that mini floppy label is in the upper right corner and facing towards the ceiling.

11. Depress Boot button. Note: Upon release of the boot button, the mini floppy will start moving and a little red light on the mini floppy will turn on. Boot will halt at a location 50350. This is normal.

12. For ALPHAT use, content of locations 1700 and 1704 should be 3000 and 1000 respectively and the content of locations 32342 and 32350 should be 165240.

Location	Description	Current Content	Correct Content	Comments
17Ø0	Chans (#ADC Channels)	4ØØØ	3ØØØ	These contents can be changed only prior to step B.13 using ODT Emulator language. To change content in a location, type in location number, / CPU types out current location and content. To change content type in new value CR. otherwise, TYPE line feed to look at next location or CR to terminate ODT used.
17Ø2	End core	16ØØØØ	10ØØØØ	
17Ø4	Buffer 2	2ØØØ	1ØØØ	
32342	Allows long	Ø3Ø35Ø	16524Ø	
3235Ø	Data Acq.	3Ø35Ø	16524Ø	

13. TYPE either "P" or "ØG". System will respond with "TPOS-1001V" and the ?00 at 00.00.

14. TYPE "N" CR.

15. Insert "CURMOV" diskette into mini floppy.

16. TYPE "L T 19;L I CURMOV" CR. System will respond with ?28 at ØØ.ØØ. This is normal.

17. TYPE "N" CR.

Should the operator or system ever get confused to the point where nothing seems to work, reinitiate the system starting at step B.8.

18. Move cursors. TYPE X FCUR(2,1024+146);X FCUR(1,1024+66) CR

19) Operation of Functional Control Panel (FCP)

a) **At the end of step B.1Ø, the system is capable of acquiring and displaying data, overlay data and cursor movement. The initial program contents for certain key parameters are:**

Description	**Initial Content**
ADC's	1
ADC Origin	1
ADC Mode	ADD-ONE
Live Time	Infinity
Display Main Origin	1
Display Overlay Origin	1
Display Length	1/2 of Total Chans Alottment
Overlay Offset	1
Overlay and Main Trace Counts Full Scale (CFS)	8192

b) **To change any NON-ODT variable (those noted on FCP) do the following:**

FCP Button	**Allowable Responses**
Map, Main	Both depressed turns on main trace of preset origin for preset length.
Map, Main, Region of Interest (ROI)	Displays main trace and area between cursors.
Map, Overly	Both depressed turns on overlay display at preset origin for length equal to main trace.
Map, Main, Overly	Turns both display traces on. Note: Turning map off will not reset main or overly switches. These must be initialized when map is turned on.
Main or Overly Orig.	CPU types on screen MNORG or OVORG: Operator respons from TTY or key pad with numeric value between Ø - chans followed by CR.

Ovrly Offset	CPU types "OV OFFSET:" On screen. Operator responds from TTY or key pad with desired digital offset followed by CR.
DSP Length, Main CFS, Ovrly CFS	All three buttons work in conjunction with rightmost rotary switch #2. Depressing any of these switches sets length or counts full scale equal to the value represented by the position of rotary switch #2 (see below).
W, X	No function.
Y	Square root display.
Z	Log display.
Start	Starts all ADC's addressed through rotary switch #1 position 12.
Stop	Stops addressed ADC's.
Zero (both buttons)	When main display in on, zeroes what is being displayed. When main trace is off, prompts operator for area to be zeroed. Response is from TTY or key pad.
Rotary Switch #1 & DO button directly below it	See following table for all functions. Basic operation is to select desired command. Position switch. Push DO. Either a statement of execution or question will appear on the screen. Respond from TTY or key pad.
Rotary Switch #2	Selects display length and counts full scale.
DO Beneath Rotary Switch #2	Undefined.

Rotary Switch #1		Rotary Switch #2	
Position	Function	Position	Display Length/Cts full scale Main and overlay Trace
1	ADC ADD 1 Mode	1	128
2	ADC Sub 1 Mode	2	256
3	ADC in MCS Mode	3	512
4	ADC List Mode	4	1024
5	ADC in MSS Mode	5	2048
6	Non-Alter	6	4096
7	Set Live Time	7	8192
8	Set Real Time	8	16384
9	Origin	9	32768
10	Preset Counts	10	65536
11	Level	11	131072
12	Select ADC	12	262144
		13	524288
		14	1048576
15	Exit FCP	15	2097152
16	Exit and Delete	16	4194304

11. Make sure ADC settings are initially as follows:

LLD - 0.1

ULD - 9.99

Group Size - 256

Conversion Gain - 2048

Analyze/off - Analyze

Coinc/Anticoinc - Anticoinc

Zero Level - 0.48

12. Check to make sure that high voltage supply is plugged into A.C. power.

13. Check to make sure that NimBin (if operator uses external nimbin) is plugged in and power to Nimbin in ON.

14. Set HW supply to positive 1000V and turn on HV supply.

Part ~~B~~C Program

There are five programs currently available for use on the TP-50:

1. Alphal
2. Curmov
3. STANDAR3
4. STANDAR4
5. PMADJ

Alphal, CURMOV, STANDAR3 and 4 plus PMADJ are all located on one diskette. Programs can be loaded in the following way:

*L T 19 CR

*L I File Name CR

Alphal and STANDAR 3 and 4 are auto start programs while the other programs must be told to start with a "G" CR.

1. PMADJ

Loaded and started as described above. Program acquires individual spectrum for each pm tube. Waits for operator to compare photopeak. If tubes need adjustment, program loops until adjustment is completed. Program documented. Operator need only to follow instructions in program. See Part E of this section for specific instructions.

2. CURMOV

Loaded as stated in steps B.14 through B.17. Loaded only into buffer #2 and executed when cursor move push button is selected or when button below rotary switch #2 is pressed. After pushing button, system asks "ADC#:". Operator responds with the number 1 or 2 then CR. System will then print out the current live time and preset live time of selected ADC and the channel # plus content of the cursors plus 3 channels above and below cursor.

3. STANDAR3

Program loaded as stated in the introduction to this section. Purpose is to create standards which can be used in the matrix reduction program Alphal from existing spectra. Special instructions for use follow in next section.

4. STANDAR4

Program loaded as stated above. Purpose is to create standard spectrum at time of data acquisition. Program operation is selfexplanatory.

5. ALPHA1

Program is loaded as stated in section instruction. Purpose is to analyze NaI spectra acquired on TP-50. Spectral length cannot exceed 256 channels. Program operation is not well documented. See operation procedures Part C for specific operational instructions.

Part D - System Energy Calibration and Resolution Check

The whole body counting spectra are to be 256 channels in length and have an energy calibration of 10 kev per channel. Energy calibration along with system efficiencies should be checked at least 3 times per 8 hour day. System resolution should be checked each time a component is changed or moved. The operator should type the following command sequence into the computer:

Operator	CPU Response
1) X FORG(1,1) CR	*
2) X FCUR(1,66) CR	*
3) X FCUR(2,133)	*
4) Operator depresses Main Origin button.	MORG:
5) 1 CR	

6) Operator depresses MAP and then MAIN push buttons.

7) Place check ^{60}Co and ^{137}Cs point sources beneath crystal.

8) Depress ADC start button or type X FADC(1,1000) CR.

9) Computer system now displays point source spectrum. The peak channel of ^{137}Cs should appear as the 1st point to the right of the left cursor(cursor #1) while the high energy peak of ^{60}Co (1.33 mev) should appear as the 1st channel to the right of the right cursor (cursor #2). If cursors do not indicate proper location of peak channels, then amplifier fine gain and ADC zero may have to be adjusted. Note: See Section B to learn how to adjust the horizontal and vertical limits of the display screen.

10) Operator should adjust amplifier gain until the 662 kev ^{137}Cs peak is separated from the 1334 kev ^{60}Co peak by 67 channels.

11) When amplifier gain is correct, ADC zero should be adjusted until the 662 kev photopeak is found in channel 66 and the 1334 kev photopeak is found in channel 133. Note: Operator must zero the displayed spectrum after each adjustment to gain or zero.

12) When proper energy calibration has been achieved, check system resolution.

13) Stop ADC acquisition by pushing ADC stop button.

14) Zero spectrum.

15) Place ^{137}Cs point source along the central axis of the detector approximately 0.5 to 1 meter from the detector.

16) Start ADC by depressing ADC Start button or typing X FADC(1,100) CR.

17) Allow data to acquire for about 100 seconds. Stop ADC by depressing ADC stop button or typing X FSTP(1) CR.

18) Move left and right cursors until they are positioned at the channels which are at half the counts of the peak channel.

19) Obtain channel number of each cursor by depressing button under Rotary Switch 2 and responding to CPU question with the ADC number (1 to 4) followed by a carriage return.

20) Compute resolution at full width at half maximum:

$$\% \text{ Resolution} = \frac{(\text{Kev at FWHM}) \times 100}{662 \text{ Kev}}$$

21) Resolutions of 9 to 10% are acceptable. Higher resolutions require that the program PMADJ be run and photomultiplier tube adjustments be made. Design limits of the detector prohibit resolutions of less than 9%.

Part E - <u>Photomultiplier Adjustment</u>

1) Insert the program diskette into mini floppy unit.

2) Type L T 19;L I PMADJ CR.

3) System will respond with ?28 at 00.00.

4) Operator types "G" CR.

5) Disconnect all but one signal cable from the photomultiplier tubes of the detector and follow all instructions in the program.

6) Increase amplifier gain by a factor of 4.

7) Acquire a spectrum of each PM tube output using program.

8) Adjust each PM tube gain so that the ^{137}Cs peaks overlay each other again following instructions as outlined in PMADJ.

9) If peak heights vary once all peaks overlay the adjust, the focus of the PM tubes to get the maximum count rate in the Cs-137 photo peak area.

10) Attach all signal cable to PM tubes, reduce amplifier gain to original position and compute resolution. Repeat until resolution is as close to 9% as possible.

Operational Procedures

Part A - Personnel Demographic Data

1. When a person reports for a whole body count, the operator should obtain the following information:

a. Complete name

b. BNL ID # of person

c. Height

d. Weight

e. Father's full name

f. Mother's full name

g. Residence Wato Island and atoll

h. Recent travel history (prior 2 years)

2. Count individual for 900 seconds. Note: Individual must sit with good posture. Do not permit individual to slouch.

3. After counting period, store data on diskette and analyze data using procedure to analyze data using Alphal.

4. Release person.

5. Record results in log book.

Part B - QC Procedures

The typical QC program should include four parts: background, standards, repetative counts on subjects and counting subjects with known body burdens. All four aspects shall be included in this program.

1. 900 sec-Backgrounds should be taken at least three times per day:

a. Morning prior to counting.

b. Noon (or mid-counting schedule).

c. Evening after counting is done.

2. 60 sec-point source standards should be taken just prior to the backgrounds to verify zero and gain and overall system stability. The integral over a specific energy range should always be constant ±5%.

3. Persons in the operational group who have known body burdens shall be counted during the counting period at least once.

4. 5% of all patients will be recounted.

Part C - Procedure to Analyze Data Using Alphal

Alphal allows the user to acquire data while the previous data acquisition is being analyzed. All data (background QC and samples) must be acquired, stored and analyzed with ALPHA1. There are several basic commands: files, background, analyze, standard and sample. Each command runs a mini program under Alphal. To load Alphal, insert correct diskette and then type L T 19; L I ALPHA1 CR. The program is auto starting so read the initial message; it appears only once. Note: All yes and no response requires the full work to be typed not just the first letter:

1. Initial Startup

a. Set the clock by typing the day of year (1-366) then a space, the hour and a space then the minute of the day CR.

b. Type STANDARD for the next command.

The standard program must be called 2 times before proceeding further with ALPHA1. The first time is set up the standard into a 12 to 250 channel matrix. The next time is to select which standards should be used. Enter standard numbers appropriate to the detector being used. Use standards from the 1,000 series for detector #1 and standards from the 2,000 series for detector #2.

c. Under ST, the next response should be Recall or RE.CR.

d. Computer types | Operator types | Geometry type | Comment Nuclide

Computer types	Operator types	Geometry type	Comment Nuclide
Insert diskette type return when ready	CR		
STD No	1028(2015)	Adult	Co-60
	1020(2007)	Chair	Cs-137
	1010(2001)	Geometry	Potassium
	1026(2017)	Adolescent	Co-60
	1018(2009)	Chair	Cs-137
	1012(2003)	Geometry	Potassium
	1024(2019)	Juvenile	Co-60
	1016(2011)	Chair	Cs-137
	1015(2005)	Geometry	Potassium
	1030(2020)	Point Source Chair	Co-60, Cs-137 Pt Source Geometry
Matrix Full Command	ST		
RECALL, LIST, Select	SE		
Delete Stnds?	NO		
STND#	1028 or 1026 or 1024		
STND#	1020 or 1018 or 1016		
STND#	1010 or 1012 or 1015 or 1030		
STND# Command	CR CR CR CR		

Note: Under standard selection, if detector #2 is used, substitute appropriate Adult, Adolescent or Juvenile standard numbers for those listed above. The following table lists total standards available to user. If above spectra cannot be recalled, substitute with appropriate standard.

Chair Geometry Bottle Phantom	^{137}Cs Det. 1	^{137}Cs Det. 2	^{60}Co Det. 1	^{60}Co Det. 2	Potassium Det. 1	Potassium Det. 2	Point CsCo Det. 1	Point CsCo Det. 2
Adult	1020	2007	1027	2014	1009	2001	1022	2013
	1021	2008	1028	2015	1010	2002	1030	2020
Adolescent	1018	2009	1025	2016	1011	2003	-	-
	1019	2010	1026	2017	1012	2004	-	-
Juvenile	1016	2011	1023	2018	1013	2005	-	-
	1017	2012	1024	2019	1015	2006	-	-

2) a. Background Acquire

CPU Response	Operator Response
Command	BA
Acquire, store or print?	AC
Device #	1
Time	900
Command	

b. Background Store

Command	BA
Acquire, Store or print?	ST
Device #	1
Compress	No
Number	XX

3) Sample

	CPU Response	Operator
a. Acquire	Command	SA
	Acquire, store or print?	AC
	Device #	1
	Time	900
	Command	
b. Store	Command	SA
	Acquire, store or print?	ST
	Input #	1
	Sample #	XXX
	Sample Weight	1
	Days since sampling	0
	Compress	NO

4) Analysis of Sample

CPU	Operator
Is Bkg ok	yes or no if no
Bkground on disk or tape?	yes or no if no program goes to background acq. if yes program asks for number
Bkg number	XX
Sample Spectrum on tape?	yes or no if no and count finished system will analyze just finished count. If yes then;
Sample I.D. #	XX
Compressed	NO
Subtract Bkg	NO
Region to analyze	
Start =	20 (100)
End =	100 (200)

Sample is analyzed and results printed out. For uniform activity samples, start and end can be channels 20-200 respectively.

A typical procedure to follow would be to set up the system, acquire a background and store the results. Next acquire a sample spectrum and store results. Continue to acquire third spectrum. Analyze sample #1, using bkg. #1. One must also remember to deselect and reselect the appropriate standards based on the individual examined.

Part D - Procedure to create standard spectra using STANDAR3 program

1. STANDAR3

To load program insert diskette with STANDAR3 file.

a. Type L T 19 CR
b. Type L I STANDAR3 CR
c. Program is auto starting so it will type out a message when program is running. Read message.
d. Type CNTL C twice. System should respond with ?00 at 76.2
   *
e. Type L T 19; L A File name; X FLR (257,512); L CR
   Note: File name is the name of the appropriate background file.
f. System responses with *. Type L T 19; L A File name; X FLR (1,256); L C CR
   Note: The above statement must be on 1 line. Also the file name is the name of the standard file.
g. Type G CR
h. Answer first question concerning Bkg (Is Bkg correct?) NO CR
i. Answer yes to next question (Bkg on disk or tape?)
j. Answer any four digit number to next question (Bkg number?)
k. Enter acquisition time of Bkg in seconds
l. Enter acquisition time of standard
m. Enter nuclide name, mass number, activity, halflive and days standard is to be decayed. Note: Use space base to terminate data entry.
n. Answer. No to compress standard
o. Assign and I.D. # to standard type CR.
p. System asks if another STD is to be created. Answer yes or no.
q. If yes, system asks if Bkg is okay. If yes, respond YES if no, type CNTL C twice and repeat steps E through p.
r. If Bkg is okay, response YES then type Cntl C twice and repeat steps f through p.

Procedure to Turn off Equipment and Recover Without Loading Programs

At Night

1) Depress HALT button
2) Turn power off to TP 50
3) Turn H.V. supply off
4) Turn voltage to 0 volts

In the Morning

5) Turn on H.V. supply.
6) Increase H.V. to 1,000 volts.
7) Allow H.V. to stabilize for at least 30 minutes before acquiring standards or backgrounds.
8) Turn TP 50 on.
9) Depress then--release BOOT button.
10) Release HALT button.
11) Type Ø G. Computer responds with ? 00 at a line number.
12) Push MAP button on. (If it was on when operator started procedure, turn it off then back on).
13) Push main trace button on. (If it was on at step 8, turn it off then back on again).
14) Type Ø G (CR).
15) Computer responds with COMMAND:
16) Operator is now running the ALPHA 1 program.

NOTE: If the computer doesn't respond as indicated in step 11, the system must be rebooted from TPOS-I.

An investigation of the available information about the nutritional requirements of infants revealed a 1954 Marshall Islands study by Murai (Mu54). Intakes of breast milk were not recorded, however her data for three infants indicated 81 gd^{-1} of coconut fluid for a 3 month old, 56 gd^{-1} of coconut sap for a 6 month old and 100 gd^{-1} of coconut fluid plus 150 gd^{-1} of coconut embryos for an 11 month old. This information and the observed coconut product activity concentration shown in Table 6 provided an estimated coconut product mean and range of infant daily activity ingestion rate for ^{137}Cs. It is also known that certain components of the diet, such as doughnuts and rice, are made with coconut fluid, however, this source of ^{137}Cs has not been quantified. Dose equivalent commitment and body burden estimates from coconut product ingestion of ^{137}Cs are also listed in Table 5.

Finally, one whole body count of a four month old infant was attempted in April 1978 at the parent's request. Although the infant would not remain stationary during the counting interval and a calibration geometry had to be estimated for such a small subject, the infant's ^{137}Cs body burden of 0.20 μCi falls within the range of expected ^{137}Cs body burdens as reported in Table 5.

Summary

Human milk and coconut products have been examined to determine their dosimetric significance as a dietary source term for the infant residing on Bikini Atoll. The data indicates that a hypothetical maximum ^{137}Cs body burden in the mother could not cause an infant of this atoll to ingest sufficient ^{137}Cs activity from human milk alone to yield an annual dose equivalent commitment that would exceed 500 mRem. However, the additional ingestion of other ^{137}Cs contaminated material such as coconut sap or the fluid of the nut increases the projected dose equivalent commitment estimates such that the hypothetical average infant exceeds an annual dose equivalent of 500 mRem. The data indicate that a wide range of ^{137}Cs daily activity ingestion rates are possible and that human milk is most likely not the major dietary item contributing to the infant population ^{137}Cs daily activity ingestion rates.

In addition to the dose equivalent commitment calculated for the ingestion of ^{137}Cs, the external dose equivalent for the residence interval must be added to determine the total dose equivalent commitment. Based on ionization chamber measurements conducted from 1975 through 1977 (GR79), an infant (age 0-4 years) would have been exposed to a net average external exposure rate of 10.1 μR/hr during the residence interval 1 September 1977 to 31 August 1978. This corresponds to a dose of 77 mrem due to external exposure.

Finally, through use of the methods presented here, it is possible to evaluate the expected body burden and dose equivalent commitments that infants, age 0 to 12 months, will or have received through adequate sampling of the adult female population and the food products to be consumed.

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Table 1

May 1979 ^{137}Cs Body Burden and Urine Activity Concentrations for Lactating Female Population

ID#	Residence Interval on Bikini Atoll, Year	Date Relocated to Majuro Atoll	^{137}Cs May 1979 Body Burden μCi	May 1979 Urine Activity Concentration nCi/l
6062	3	8/31/78	0.088	2.0
6098	4	8/31/78	0.18	N.D.
6110	8	8/31/78	0.11	N.D.
6187	.08	8/31/78	0.0016	N.D.

N.D. = No data available. Urine sample not provided in May 1979 or sample too small for analysis.

Table 2

Radionuclide Concentrations in Marshallese Human Milk Samples

ID#	Sample Volume, ml	Sample Date	Potassium Concentration, mg/ml	^{137}Cs Activity Concentration, pCi/ml	^{137}Cs Activity Concentration in Human Milk to ^{137}Cs Body Burden Ratio, ml^{-1}
6062	18	5/16/79	0.69	0.40±10%	4.6×10^{-6}
6098	30	5/17/79	0.51	0.53±6.4%	2.9×10^{-6}
6110	10	5/21/79	0.41	0.26±21%	2.4×10^{-6}
6187	27	5/16/79	0.45	<0.057	N.A.

N.A. = Not applicable. Control human milk sample contained no measurable quantity of ^{137}Cs.

Table 3

Physiological and Radiological Parameters Used to Determine ^{137}Cs Body Burdens and Dose Equivalents

Quantity	Symbol	Mean	Parameters Range	Units
Infant Milk Ingestion Rate	-	350	500 to 3000	ml/d
Potassium in Human Milk	-	0.51	0.37 to 0.63	mg/ml
Mass of Male at Birth	M	3.5	2.3 to 4.7	kg
Mass of Female at Birth	M	3.4	2.2 to 4.6	kg
Mass of Male at Age One	M	10.4	9.1 to 11.8	kg
Mass of Female at Age One	M	9.5	8.2 to 10.8	kg
Radiological Removal Rate Constant	λ	$6.3x10^{-6}$	$6.2x10^{-5}$ to $6.5x10^{-5}$	d^{-1}
Environmental Removal Rate Constant	K_E	$-1.67x10^{-3}$	$-4.68x10^{-4}$ to $9.97x10^{-4}$	d^{-1}
Compartment Deposition Fractious	X_1 X_2	.13 .87	.02 to .22 .78 to .97	No Units No Units
Physiological Removal Rate Constants, Males Females	K_1 K_2 K_2	.5 .031 .025	.33 to 1.4 .026 to .043 .021 to .033	d^{-1} d^{-1} d^{-1}
Adult Female ^{137}Cs Body Burden on 9/1/77	q	1.13	0.27 to 3.66	μCi
^{137}Cs Activity Concentration in Human Milk to ^{137}Cs Lactating Female Body Burden Ratio	-	$3.28x10^{-6}$	$2.36x10^{-6}$ to $4.55x10^{-6}$	ml^{-1}
Absorbed Fraction in Total Body for ^{137}Cs .6616 MeV Photon Emission in Infants	Ø	.175	.15 to .20	No Units

Table 4

Instantaneous ^{137}Cs Activity Ingestion Rate on 1 September 1977 and 26 April 1978

Population	1 September 1977 ^{137}Cs Activity Ingestion Rate nCi/d Mean	High	Low	26 April 1978 ^{137}Cs Activity Ingestion Rate nCi/d Mean	High	Low
Adult Male	58	270	8.2	85	400	12
Adult Female	22	100	5.7	32	150	8.4
Infants ingesting only human milk	3.2	10.	0.75	4.7	15	1.1
Infants ingesting only coconut products	9.6	18	0.82	14	27	1.2

Table 5

Total Body Dose Equivalent Commitment and Body Burden at the End of Residence from 1 September 1977 to 31 August 1978 for Hypothetical Bikini Island Infant

	^{137}Cs Body Burden, μCi			^{137}Cs Total Dose Equivalent Commitment, Rem		
Human Milk Consumption Only						
	Mean	Low	High	Mean	Low	High
Male Infants	0.15	0.036	0.49	0.11	0.025	0.34
Female Infants	0.19	0.045	0.62	0.14	0.034	0.45
Coconut Product Consumption Only						
	Mean	Low	High	Mean	Low	High
Male Infants	0.46	0.040	0.87	0.32	0.028	0.61
Female Infants	0.57	0.049	1.1	0.43	0.037	0.81
Total Milk Plus Coconut Product Consumption[a]						
	Mean	Low	High	Mean	Low	High
Male Infants	0.62	0.076	1.4	0.43	0.053	0.94
Female Infants	0.76	0.094	1.7	0.58	0.071	1.3

[a] Does not include contribution to dose equivalent from food products made with coconut fluid, meat or sap.

Table 6

April 1978 ^{137}Cs Average Activity in Coconut Products at Bikini Island

	Coconut Fluid	Coconut Meat	Coconut Sap
Activity per unit mass or volume	160 pCi ml^{-1}	70 pCi gm^{-1}	22 pCi ml^{-1}
Sample Size	12 coconuts from 3 trees	12 coconuts from 3 trees	2 liters from 2 trees

PROTOCOLS

Whole Body Counting Operations Manual

Standard Procedure for Air Sampling

Protocol for Radiochemical Analysis of Urine, Teeth and Milk

Radiochemical Analysis and Analytical Procedures for Determination of I-129 in Soil

Whole Body Counting Operations Manual

Introduction

The enclosed material is designed to provide basic information concerning the routine whole body counting program at Brookhaven National Laboratory (BNL). The document is divided into several sections: selection criteria, participant notification and preparation, electronic set-up, operational procedure, program error diagnostics, results-records, and system calibration. Each section has been written to permit system evaluation and operation under normal conditions. Limited discussion is given to unusual occurrences in the following sections: participant preparation and program error diagnostics.

Selection Criteria

The whole body counting and urine analytical service programs are conducted under contract with the U.S. Department of Energy for individuals living on atolls or islands in the Marshall Islands chain which were radiologically contaminated by the U.S. Mid Pacific Nuclear Weapon Testing Program. Individuals currently participating in the program are residents of Enewetak, Ujelang, Rongelap and Utirik Atolls plus former residents of Bikini Atoll currently residing on Majuro Atoll, Jaluit Atoll and Kili Island.

Each atoll is monitored differently. At Rongelap and Utirik, the size of the population participating in the program is approximately 20 individuals per age and sex subgroup. There are six subgroups consisting of male adults, adolescents and juveniles plus female adults, adolescents and juveniles. The number 20 is the number of individuals required in the sample to provide an estimate of the mean body burden at the 90% confidence limit. Normally, the same population is sample overtime to determine any trends in the data.

For the former Bikini Atoll population, individuals who resided on Bikini Island during the final two year residence interval were monitored until July 1980 to follow the decline of ^{137}Cs in their bodies. Special interest was given to individuals present on Bikini Island during the BNL April 1978 field survey and to individuals who were present at the time of the Bikini population resettlement in September 1978. It is unlikely that these individuals will be monitored again relating to the Bikini experience 1969-1978. However, persons participating in the repatriation of Eneu Island which is to commence in 1981 will be monitored initially on a six month basis which is to coincide with the proposed six month residency period on Eneu Island for the former Bikini Islanders. The precise monitoring frequency of the Eneu population subgroup will be determined from the initial body burden levels by the Department of Energy.

At Enewetak and Ujelang Atolls, the entire population is monitored. The frequency of monitoring is once per year and this monitoring schedule is expected to continue at least until the indigenous food products mature.

Participant Notification and Preparation

The BNL Marshall Islands Radiolgical Safety Program advises DOE and DOI as to the frequency that persons residing on contaminated atolls should be monitored. Once the frequency is decided, the program is implemented. The following table lists the atoll, frequency of monitoring and number of individuals in the population that are monitored.

Table 1

Atoll	Frequency	Number in Atoll
Enewetak-Ujelang	Yearly	400
Rongelap	Bi-yearly	100
Utirik	Bi-yearly	100
Bikini	Semi-annual	Number not determined but would consist of population residing on Eneu Island

The normal procedure to initiate a mission is to register the proposed trip plan to the Pacific Area Support Office of the Department of Energy. Once informed of the proposed schedule, PASO will notify the appropriate local and federal authorization of the Marshall Islands government. If changes in scheduling are necessary, they are usually accomplished at this time. The PASO representative is always the official link between BNL and the Marshall Islands people and government both prior to and during a field trip.

Upon arrival at the designated atoll, a local meeting with atoll authorities is required to inform the local personel of the field trip plans and scheduling. This serves as a question and answer period for the people participating in the monitoring program and is an important aspect of the successful completion of the field trip.

Procedure to Copy Data or Program Diskettes

The operators have been provided with 2 copies of all program and standards diskettes. These diskettes or all data diskettes can be copied using the following procedure. Data diskettes should be filled with 65 spectra before requiring duplication (the physical limit is 72 spectra). A complete explanation of the disk duplication process can be found in text, "TPOS II/TP50 Basic Use," Appendix E Disk duplication:

1) Depress HALT button
2) Insert TPOS II diskette
3) Release HALT button
4) Depress BOOT button then immediately release button
5) Wait for TPOS II to read into the computer
6) After disk unit has been addressed twice (red light goes on and off twice) type Control C twice
7) Computer responds with MON >
8) Operator types: SET PAR = 18 (CR)
9) Disk unit is addressed twice
10) When disk light goes off for the second time, type Control C twice
11) Computer responds MON >
12) Operator types: ICOPY (CR)
13) The computer now reads in the program to copy information
14) Operator now follows this sequence

CPU	Operator
ICOPY >	TX: = TX: (CR)
INSRT INPUT	[Operator inserts data or program diskette which is to be copied and then types (CR).]
INSRT OUTPUT	[Operator inserts a zeroed diskette and types CR)
INSRT INPUT	[Operator inserts diskette to be copied and types (CR).]
INSRT OUTPUT	[Operator inserts zeroed diskette a second time and then type (CR).]
INSRT INPUT	[Operator inserts diskette to be copied and types (CR).]
INSRT OUTPUT	[Operator inserts zeroed diskette for third time and types (CR).]
ICOPY >	

15) The ICOPY program takes 3 passes to copy one diskette to another.
16) The operator can copy another diskette with ICOPY by just repeating the process in step 14.
17) When finished, operator can either power the unit down or load in TPOS I, CURMOV, ALPHA 1 and standards.

NOTE: Any diskette which is to be copied should be write protected. A second comment is that the diskette which shall be used as the copy must be <u>zeroed</u> but <u>not</u> <u>formated</u>.

Formated diskettes are used exclusively by the ALPHA 1 program while zeroed diskettes are used by ICOPY or ...

Procedure to Move Cursors

The procedure permits the operator to move the cursors large distances quickly and should be used prior to loading ALPHA 1.

1) With computer in the interactive mode (computer has responded with an asterisk) type the following series of commands:

CPU	Operator
*	X FCUR (2, 1157) (CR)
*	X FCUR (1, 1090) (CR)
*	

2) Continue loading ALPHA 1 program. If ALPHA 1 was running when the operator decided to move the cursors using these commands then type: G (CR). This returns the operator to ALPHA 1 at the COMMAND position.

Note: The general format to move cursors is X FCUR (CN, CH) (CR)
where CN = cursor number (1 = left, 2 = right)
CH = memory location where operator wants the cursor.
Cursor 2 can never be to the left to cursor 1. Likewise, cursor 1 can never be to the right of cursor 2. If the operator accidentally positions the cursors illegally, the operator will receive an error code.

Procedure to Format Diskettes

This procedure must be executed before TIL programs or data can be stored on the diskette:

1) With computer in the interactive mode-(If operator is running ALPHA 1, the operator can get into the interactive mode by typing Control C several times. When the operator gets an asterisk instead of the word command, the computer is in the interactive mode). The operator inserts a zeroed diskette into the disk drive then types the following command sequence:

CPU	Operator
*	L T 19 (CR)
*	L F M (CR)

disk drive turns

*

2) Repeat process to format as many diskettes as desired.

3) To return to program, type: G (CR)

Procedure to Zero New Diskettes

This procedure is necessary to allow new diskettes to be used for copying or formating with TIL programs or data:

1) Press HALT button on computer.
2) Insert TPOS II diskette into the disk unit.
3) Release HALT button.
4) Press boot button. (This is a momentary switch. Press it in, then release it).
5) Wait for computer to instruct operator to type Control C twice.
6) Type CNTL C twice.
7) Computer response with MON >.
8) Type the following sequence (For a complete description, see TPOS II/TP-50,Basic use manual Appendix F).

CPU		Operator
MON >		ZER (CR)
ZER >	(Operator now inserts diskette to be zeroed then type). TX:/CLR/DSZ:2/FOR (CR).	
ZER >	(Operator now inserts the next diskette to be zeroed). TX:/CLR/DSZ:2/FOR (CR).	
ZER >		

9) The process is repeated until all diskettes are zeroed.
10) When finished, type CNTL C twice.
11) Computer responds with MON >.
12) Operator may now run other TPOS II programs or reBoot the system with TPOS I.

1.5 TPOS ERROR MESSAGES

Error numbers for TPOS are organized in groups. Errors Ø through 19 are TIL errors, errors 2Ø through 29 are Library errors, and errors 3Ø and up are TPOS errors. (For discussion of TIL and Library errors, see sections 3.8.1.1 and 3.8.1.2, respectively, of the TIL User Manual.) TPOS errors are:

?3Ø	Illegal numerical argument (too large, too small, or wrong base).
?31	Illegal "U" command (may also cause ?Ø4). May be caused by an attempt to issue the "U E n" command while list mode is turned on.
?32	ADD-1 ADC error.
?33	"UZ" command not understood.
?34	More than 2Ø FDLY's pending.
?35	Isotype table exceeded.

When an error is encountered in a FOCAL program, an error message is typed on the teletype in the following format:

?01 AT 3.52

The first number given is the error diagnostic. The second number is the line number at which the error was encountered. The following is a list of the standard FOCAL error diagnostics, followed by diagnostics for the HYCCUPS extensions and the Library. Note that diagnostic numbers 23 through 27 are used in both the Library software and the HYCCUPS software.

FOCAL-11 Standard Error Diagnostics

?00	Manual restart from location 0 or by CTRL/C
?01	Illegal line number
?02	Illegal variable or function name
?03	Unmatching parantheses
?04	Illegal command
?05	Non-existent line number
?06	Non-existent group or line number in *DO*
?07	Illegal format in *SET* or *FOR*
?08	Double or missing operators in expression
?09	Stack overflow or non-existent device
?10	Core filled by text or command line too long (o)

FOCAL-11 Standard Error Diagnostics

?11	Core filled by variables or no room for variables (o)
?12	Exponent range greater than E± 38 (o)
?13	Disallowed bus address in "FX" (o)
?14	Division by zero attempted (r)
?15	Attempt to exponentiate to a negative power or power too large (r)
?16	Too many characters in input data (r)
?17	Square root of negative number (r)
?18	Input buffer overflow

(o) indicates operational error

(r) indicates a run-time error

HYCCUPS Diagnostics

?23	Cursor number not 1 or 2
?24	Unrealistic arguments in "FZER"
?25	Illegal thumbwheel or rotary switch
?26	Run time given too large for 25 bits
?27	Origin given is too large or ADC input not 1 to 8

Library Diagnostics

?10	Attempt to read a program line longer than allowed
?20	Non-existent library function.
?21	Open or store with previously used file name
?22	Open, store, ask, or in command when a file is already open for outpu
?23	Library function containing non-existent file
?24	Attempt to kill or write when file is not open for output
?25	File name missing on library function
?26	Directory full (no more opens or stores allowed)
?27	Hardware error on read or write
?28	No more storage space, or attempt to read beyond end of file (normal entry for "in" on file not terminated with an asterisk)
?29	Hardware error on write, or attempt to write beyond end of medium

SUMMARY OF ERROR CODES

Error Code	Interpretation and suggested response.
? 00 at	Manual restart from 0 or by CTRL/C. If operator exited Alpha 1, return to program by typing C (CR).
? 01 at	Illegal line number. Operator has tried to write a program line at an illegal line number. Check available line numbers in TPOS manuals.
? 02 at	Illegal variable or function name. Operator has used an non-existent function. Check function table TPOS manual.
? 03 at	Unmatching parenthesis. Operator has not closed all open parenthesis in arithematic or function statement. Try again.
? 04 at	Illegal command. Operator should try intended command again.
? 05 at	Non-existent line number. Operator has told program to execute a line that does not exist. Check line number. If line number should be there and is not, reload program.
? 06 at	Non-exist group or line number in "DO" loop. Check for line number. If present, try "DO" statement again otherwise reload program.
? 07 at	Illegal format in "set" or "for" statement. Operator has not followed programming format. Check FOCAL program book for format.
? 08 at	Double or missing operators in expression. Operator should check program line for program errors.
? 09 at	Stack overflow or non-existent device. There are only 2 error codes which should cause major concern. This is one of them. There are infinite possibilities when this could occur. The more like ones are listed below: a) When this error occurs at step 14 of the startup instructions it means a device (ADC, mini-Floppy or memory) is not responding to the unibus signal. Usually you know if the mini-Floppy is working since that is how TPOS I was loaded or if core memory is being addressed (TPOS I won't load if the memory does not respond to the unibus signal). Also the display and TTY pad work or again you would not have loaded TPOS I. This leaves the ADC. When ? 09 occurs at step 14, check the variable dip switches on the 1505 and 1506 boards. If these are set incorrectly or if the 1504 through 1506 boards are bad, you get the ? 09 at this step.

? 09 at

b) A memory board, controller board, ADC board, etc., fails and then the device is addressed will also cause a ? 09. Concentrate repair efforts on the device selected that gave ? 09.

c) A non-destructive and acceptable ? 09 occurs when you manually zero ADC memory from channel 1281 to 1536 using the zero button and the visual display. Return to the program by typing G (CR).

? 10 at

Core filled by text or command line too long. This error occurs frequently due to operator errors. If the operator fails to execute step 18 in the instruction maual before loading in Alpha 1, an error 10 will occur. The only way to correct this problem is to start over again at step 8. The other occurrence of the error is when memory fails during execution of Alpha 1. Replace bad memory board.

? 11 at through ? 19

These are standard errors not normally encountered. If encountered, they would occur during analysis of data under the Alpha 1 program. The problem would most likely be that the spectrum being analyzed is composed of all zeros. This would occur if the operator stored the spectrum from Input #2 instead of Input #1. The solution is to verify the existence of a valid spectrum. If one exists analyze spectrum on second system. If you get the same error code then the spectrum is faulty. Acquire a new one. If the spectrum is correct, reload TPOS I, CURMOV, ALPHA1 and standards on system where error occurred.

? 20 at

Non-existent Library function. You should never encounter this error.

? 21 at

Open or store with previously used file name. This is a common error and simply means that the operator has attempted to store 2 separate data files (spectra) with the same 4 digit ID numbers. Solution: 1st, the operator should type C (CR). This will put the operator back into the Alpha 1 program at the COMMAND: location. The operator can now type "Files" (CR) and determine when the duplicate number occurred or type "SAMPLE" or "BACKGROUND" (CR) and attempt to "STORE" the data file again, but with a different number.

? 22 at

Open, store, ask or in command when a file is already open for input. Operator will not see this error.

? 23 at

Library function containing non-existent file name. This is a common error made by all operators. The error code simply means: a) the diskette in the disk drive is the wrong one or b) the operator never stored a file with the specified number on it. Solution: First check to determine if the correct diskette has been inserted in the tape drive.

? 23 at	This is the most common operator mistake. Insert the correct diskette then type "G (CR)." This will place the operator back in Alpha 1 COMMAND: mode. The operator then tries to recall the spectrum again. If the correct diskette is in the disk drive, then either the operator entered the wrong file number or never recorded the file. Check to see if the file exists on the diskette by typing "G (CR)" (which places operator back in the COMMAND: mode) and then FILES (CR):.
? 24 at	Attempt to KILL or WRITE when on file is open for output. This error should not be experienced.
? 26 at	Directory is full. The operator may encounter this error if he(she) attempts to store more than 72 files (spectra) on a diskette. Normally, this error means that the file which the operator tried to store has not been stored and must be stored on the new diskette.
? 27 at	Hardware error indicated on read or write. This error occurs under several cases: 1) Operator tried to store data on write protected diskette. Place unprotected diskette in disk unit. Type "G (CR)" and try to store or recall data again. 2) Operator has inserted disk with wrong orientation. Remove diskette and insert properly. Type "G (CR)" and try to store or recall data again. 3) The disk controlled is malfunctioning (board by [illegible] bin). Operator should type "G (CR)" and try to store or recall data again. The controller board occasionally malfunctioning on its own. There is no real significance to the problem unless it becomes a nuisance. (For example, one or two error 27s per 14 hr day is normal). The first solution is to open the TP-50 top and allow more air flow to the controller. If this does not solve the problem, replace controller board. Note: An error 27 means no data was stored or recalled.
? 28 at	Attempt to read file beyond last character or program file not auto starting. Operator should see this error when reading in PMADJ and CURMOV programs.
? 29 at	Hardware error or write or attempt to write beyond the end of medium. Operator will see this error if he(she) tries to store more than 72 data files on a diskette.
? 30	Illegal numerical argument. Operator will frequently see this error in Program PMADJ. Error code just indicates that several DMA devices required data transfer simultaneously and one device received errant data. To continue type "G (CR)".
? 31 to ? 35	Error codes not applicable to current use.

Results

The results generated by the computer indicate the microcurie quantities of the radionuclides that are present in/on the individual. The computer analysis technique used to resolve photo peaks from a NaI (Tl) detector is a weighed least squares fitting technique. This approach has been chosen over manual spectrum stripping or photo peak regression analysis because the technique provides operator independent results, sufficient information to determine if a significant radionuclide has been missed and accurate results for positively identified radionuclides when all nuclides present in the sample are not present in the nuclear library.

There are limitations of this analysis software (Alpha T). It is a nuclide specific analysis technique with a limited nuclide library (12 nuclides). This means that to properly analyze a spectrum, the operator must first know what are the possible components of the spectrum, have calibration standards for those nuclides, and then select the proper nuclides to be part of the analysis package. The system is also somewhat geometry sensitive. No geometric corrections are applied to the data other than those made by selection of proper calibration phantom size. Consequently, individuals who significantly differ from the standard man, adolescent or juvenile phantom used for system calibration may have their body burdens be in error by several percent. This error is not included in the counting error which is reported with each result.

In addition, under routine operation, any positively identified nuclide is assumed to have entered the body by the ingestion pathway. For purpose of dosimetry, the exposure is assumed to follow a constantly increasing or decreasing uptake scenario and the committed dose equivalent is computed based on the measured body burden, retention functions and cumulated activity values (S) found in MIRD 11 or ORNL/NUREG/TM-190.

Records

Whole body conting results are reported to the Department of Energy within 45 days following a field trip. Dose equivalent commitments are reported periodically as the need arises.

Whole body counting results are recorded in the daily equipment operations log, in an individual record log and in the personnel dosimetry data base. All results are to be considered as private, but are avaiable to the individual upon request.

Standard Procedure for Air Sampling

2. Portable Hi Vol Samples

These samples will be used to assess local resuspension mediated by human activity. The air sampling equipment is usually operated at selected sites in the field while the survey team is on station, and removed when the survey team leaves. The equipment consists of A. C. operated high-volume blower coupled to 8 x 10 inch filter media (usually glass fiber).

The samplers should be installed as close as possible to people working in a defined area, and they should be biased toward the downwind side of the work area. If possible, the samples should be operated only during periods of human activity. Flow rates and operating times must be logged to determine the total volumes of air samples. This equipment must be powered by portable electric generators in the field.

3. Aerosol Particle Sizing Samples

Two high-volume Andersen cascade impactors are available for particle size-selective air sampling. These samples will be used for assessments of the respirable fractions of resuspended aerosols. Two cascade impactors are available: a 4-stage unit coupled to a standard Hi Vol blower, and a 5-stage sampling head which must be operated with a positive displacement pump (such as the Roots blower, in the fixed-station sampling equipment). The specifications for the cascade impactors are listed in the table below:

Jet Place No.	Effective Cut-off (μm-MMAD)
1-1	7.0
2-3	3.3
3-4	2.0
4-5	1.1
"Special" (5-stage only)	0.43
5-8	Collection Plate Only
Backup Filter	1.1 (4-stage) or 0.43 (5-stage)

The 4-stage unit must be operated as a portable air sampler while the survey team is on-station; and it is generally operated in association with the portable Hi Vols. The 5-stage impactor has anodized jet plates, and may be operated in the field for extended periods of time. Long-term sampling is desirable to perform radioassays of aerosols at very low activity concentrations.

C. Setup and Calibration of Instruments

1. Andersen Cascade Impactor

(a) Cleaning of the Orifice Collection Plates

i. clean each plate with a mild detergent and warm water
ii. rinse the plates with acetone or alcohol to remove the water
iii. handle the plates at all times by the edges to prevent getting skin oil on the orifice and collection plates; make sure the holes are not plugged

Standard Procedure for Air Sampling
Marshall Island's Radiological Safety Program

A. Purpose

An air sampling program has been established to identify and quantify radioactive aerosols on the village islands of Bikini, Rongelap and Utirik Atolls. It is felt that these aerosols are generated primarily through resuspension of radioactive materials in local soils; and that resuspension processes are mediated by the wind and by human activities. The program is designed to characterize seasonal variations in airborne radioactivity, and to determine annual average concentrations from which dose commitments via the inhalation pathway can be derived.

B. Sample Types

Three types of air samples and associated sampling equipment will be used in the air sampling program. They are (1) fixed station high-volume samples, (2) portable high-volume samples and (3) aerosol particle sizing samples. Each of these is discussed below:

1. Fixed Station Hi Vol (or "HASL") Samples

These samples will be used to assess time averaged concentrations of down-coming fallout and wind mediated resuspended aerosols. The sampling equipment consists of a Roots positive displacement blower and a 1 hp motor powered by 110 VAC line sources, or by D.C. battery banks charged by wind-powered electric generators This equipment is an adaptation of the HASL designed air sampler used for world-wide fall-out monitoring. The sampling head consists of an 8" x 10" inch filter holder coupled to four parallel Unico cyclone preseparators which remove particulates greaters than about 5 μm MMAD. A dry gas meter in the sampling line integrates the total flow during the sampling periods. The samplers are designed to run semicontinuously for 1 to 3 months between sample changes

As of October 1977, fixed station samplers were installed at the following field stations:

Location	Purpose	Power Source
Kwajalein Is., Bldg. 835	Control	A.C.
Roi-Namur Is., LOCB	Control	A.C.
Bikini Is., Community Center	Expt'l	D.C.
Rongelap Is., Athletic Field	Expt'l	D.C.
Utirik Is., Athletic Field	Expt'l	D.C.

A sixth air sampler modified for aerosol particle sizing is available to be operated as a temporary fixed-station sampler. This A.C. unit is powered by a diesel electric generator.

(b) Arranging the Assembly

i. Place a circular gasket on the interface; place dusting talc on the top and bottom side of all gasket to minimize adherence to the collection paper.
ii. Place plate 5 on top of the gasket.
iii. Next place a tared collection disc (configuration #2) on plate 5. Be sure all collection substances are placed on the plates with the rough side up. Next, place another gasket, plate 4, a tared collection disc (configuration #1), and so on until plate 1 is in place.
iv. Next, place the thick washer, recessed side down on the bolt. On top of this washer, place the thin flat washer and then the speedball handle.
v. The sampler is now ready to be interfaced with the standard High Volume Sampler.
vi. Place a tared 8 x 10 backup filter in the high volume holder, place the rectangular gasket on top of the filter and interface with the impactor.
vii. Hand tighten all four corners of the interface plate with the wing nuts so that no leakage occurs.

(c) Adjustment to 20 cfm

i. Open both ends of the manometer and connect one end to the brass fitting on the interface plate with the rubber tubing applied.
ii. Adjust the manometer reading to 6.0 inches (verify) by the use of the variac. This pressure differential corresponds to 20 cfm

2. High Volume Air Sampler

(a) Calibration at the Shop

i. The manufacturer calibration curve may differ by as much as ± 10% from calibration curves generated by using the calibrator set at BNL.
ii. The field flowmeter previously used will be changed to a magnehelic pressure gauge with range from 0-2 in Hg. A calibration curve will be generated for will be generated for the latter.

(b) Out in the field, just observe the pressure reading once in the morning and once in the afternoon daily. This is to record the effect of loading. If there reason to doubt the flowrate due to special occurrences, e.g. power shut-off, read the pressure reading again.

(c) The power to be used out in the field will be either the gas fired generator, ship power, or conventional A.C. outlets. Be sure the necessary cables and adaptors are present.

(d) The fuel for the gas fired generator is supplied by two 5 gallon tanks of gasoline; it was found that this 10 gallons of fuel could provide the generator with power for approximately 16 hours. Note: Check daily oil level; make sure the oil is clean; and that the generator is not overheating, etc.

(e) The Hi Vol is equipped with an elapsed time meter to indicate the amount of time the sampler was run. Note that after each operation.

(f) From preliminary data, it was found that continuous Hi Vol sampling at the indicated time for each island could provide the necessary amount of Pu activity in the filters.

Bikini--at least 2.5 days total
Rongelap--at least 4 days total

If the filters are only to be analyzed gravimetrically, 2.5 day samples at each island would be sufficient.

3. HASL Sampler

(a) Record the reading on the Dry Gas Meter. Also record the pressure gauge reading and fill out the information asked for in the index card, e.g. date, oil change, etc. AFTER REMOVING A USED FILTER AND UPON PLACING A NEW FILTER.

(b) The filter to be used is microsorban with a backing paper between the filter and the screen of the blower unit. It has a plastic frame to prevent adherence of the filter paper to the gasket. Upon removal of a used filter, carefully remove the plastic frame and fold the filter in half then in quarter and place in a preweighed glassine envelope. Attach the index card with the necessary information and place in a plastic bag.

(c) To verify optimum time for HASL sampling, the caretakers at Rongelap, Bikini and Utirik will have to be requested to note the pressure gauge reading once a week. This information plus the requirements of minimum detection limits will decide optimum sampling time.

(d) Tentatively, HASL samples will be left at the following places for this length of time for both the cyclone separator

Bikini	1-3 months
Rongelap	2-3 months
Utirik	3 months
Kwajalein	1-3 months

and the filter papers. Place the contents of the cyclone separators in separate glassine envelopes.

D. Air Filters

Only the glass fiber filters are weighed. They are assayed gravimetrically for mass loading as well as chemically for Pu activity. The microsorban filters are just evaluated radiochemically for Pu activity.

Weighing Procedures:

1. Place the air filters on the racks and heat overnight in the large oven in Joe Steimers' lab (set at 80°C).

2. Let oven cool for at least 4 hours with dessicant at the bottom before weighing the filters.

3. Use the baffles attached to both side windows of the Mettler balance in Joe Steimers' lab. Weigh the filter, the necessary glassine envelopes.

4. Make sure to weigh and store in a safe and clean place CONTROL samples of all types of filters and glassine envelopes.

Note: The rationale for the glassine envelope is as follows:

Should the sample flake off from the filter while handling and shipping in sizable amount, the envelopes are analyzed along with the filter.

5. The same procedure is used for analysis of filters after use in the field.

E. Soil Sampling Associated with the Air Sampling Program

1. HASL Sampling

Take two 2.5 cm downwind and in front of the sampler for soil moisture determination. Label with date, location, etc. Package sample securely in a plastic bag. Place bagged sample and label in a second plastic bag.

2. Hi Vol Sampling

(Same as above).

3. Andersen Cascade Impactor

Do the same as above only if the ACI will be sampling for an adequate amount of time for radioassay for Pu activity.

F. Criteria for Location: (Tentative--before F.C. comes up with her extensive design of experiment)

1. High Activity

2. Where People Are: Human Activity

3. Downwind of Highly Contaminated Areas

G. Suggestion for Hi Vol and ACI sampling for this March trip

Bikini--see LLL soil activity data sheet (esp. Pu activity) Area 4 and Area 1 interface will give high Pu activity and high human activity. Make sure sampler is downwind of highly contaminated area.

Rongelap--Northern Island if possible or else Rongelap Island where the women bring their clothes to wash while they chat.

Utirik--place where the church and council building and where people live is located

Kwajalein--anywhere there except the first sampling site--by the Reef Bachlor/s quarter

Protocol for Urine Bioassay Sample Collections

Marshall Island's Radiological Safety Program

A. Purpose

Radiochemical analyses of urine are used to determine the excretion rates of radionuclides from individuals living in areas affected by the Pacific Testing Programs. The results of these analyses will be used to:

(1) estimate body burdens of ^{90}Sr, $^{239,240}Pu$, and other radionuclides which cannot be determined with in vivo counting techniques,

(2) provide independent estimates of body burdens of gamma emitters (such as ^{137}Cs) which can be determined by in vivo counting, and

(3) provide an indication of the extent to which restrictions on certain local food items are being followed.

B. Sample Types

Three types of urine samples will be used in the bioassay program. They are (1) single void "grab samples", (2) 24-hour urine samples, and (3) large-volume samples comprised of several 24-hour samples. Each of these is discussed below.

(1) Single-void "grab sample"

This is the least desirable type, but it is also the easiest type to collect. Grab samples are useful for estimates of Sr and Cs excretion rates, but 24-hour samples are definitely preferred. Laboratory limits of detection are, in part, a function of sample volume (total activity per sample). A practical minimum sample volume is 200 ml. Attempts should be made to collect more than one voiding, if possible.

(2) 24-hour urine sample

This is the preferred type of sample for routine urine bioassay (except for alpha-emitters). The sample volume (500 to 1500 ml) should be adequate for Sr and Cs radio-assay, and analytical results can be directly compared with published excretion rate data for estimation of body burdens.

(3) Large-volume sample

Because of the limitations of radiochemical and counting procedures, large-volume samples (>5000 ml) must be collected for bioassay of transuranic nuclides. Typically, these samples will consist of five or more days of aggregate 24-hour urine collections. Special precautions must be followed to minimize the possibility of sample contamination with extraneous material (primarily "local" dust and dirt).

C. Sample Collection Procedure

(1) 24-hour urine samples and single-void samples

Provide subject with a one-liter or larger plastic bottle which has been pre-treated with thymol preservative. Note subjects name, location, date and time on sample bottle. Instruct subject to void and empty bladder just before beginning sample collection, and to wash hands before each successive voiding into the sample container. Collect all urine for the next 24 hours in the sample container, including a final voiding to empty the bladder just before returning the container to the field-trip team or its representative. Note date and time of final voiding.

The same container may be used for single-void samples. Ask subject to wait until he or she has to urinate, wash hands, then void into container until bladder is empty.

(2) Large-volume samples

Provide subject with a 2½ gallon or 5 gallon "cubitainer" or similar plastic container which has been pre-treated with thymol. Note subject's name, location, date and time on container. Instruct subject to void and empty bladder just before beginning sample collection, and to wash hands before each successive voiding into the sample container. Collect all urine for the next 120 hours (5 days) or longer if possible (maximum: 10 days). Just before returning the container to the field-trip team at the end of the sampling period, the bladder should be emptied in one final voiding. Note the date and time of the end of the sampling period on the container.

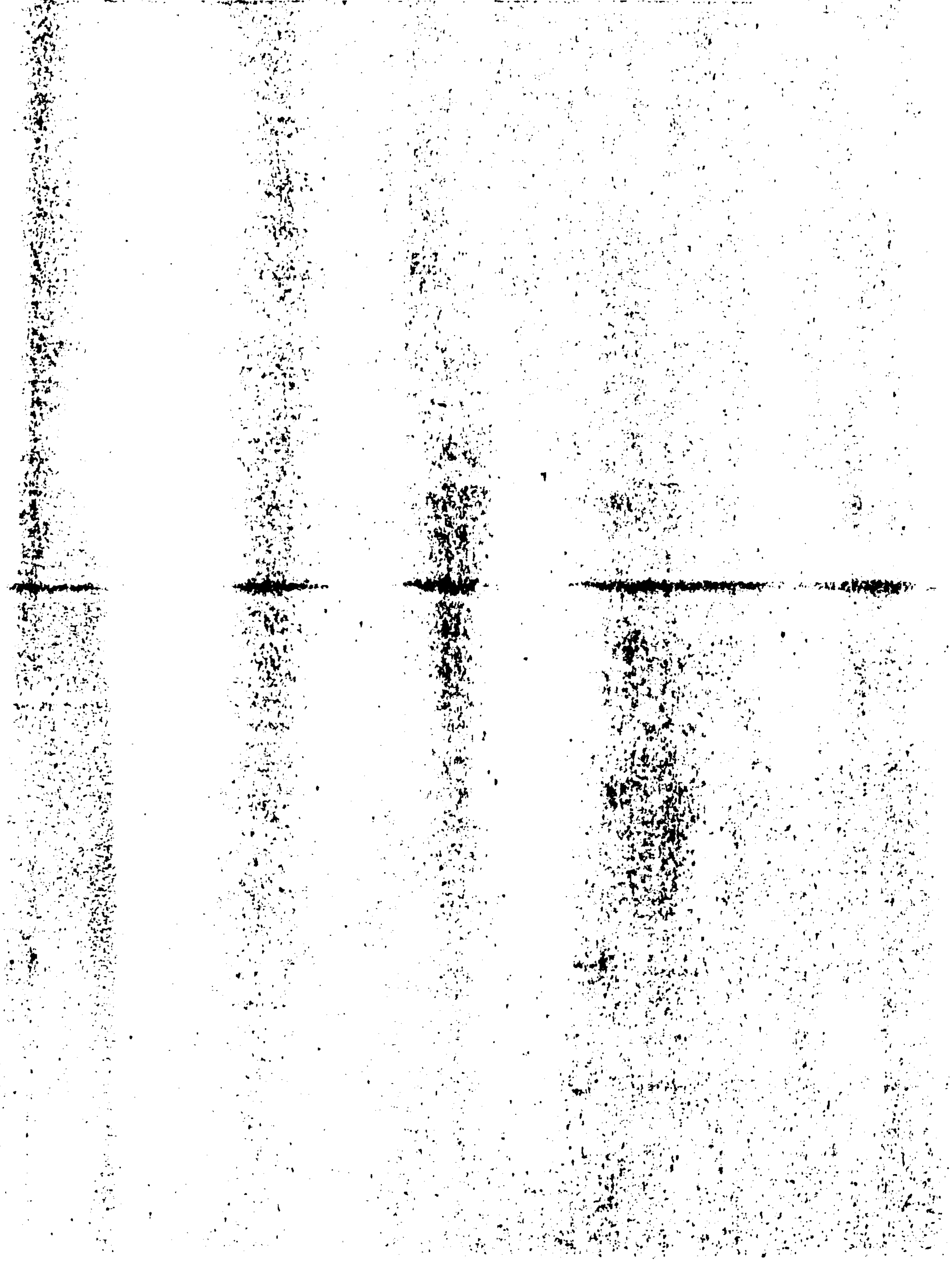
D. Sample Container Preparation, and Post-Collection Treatment

All sample containers should be "pre-treated" by adding 15 ml of 10% thymol solution in alcohol. The solution should be swirled in the container to completely coat the sides, and the top should be left off until the alcohol evaporates leaving a dry thymol residue coating its inner surfaces.

After sample collection, 10 ml of concentrated HNO_3 should be added to each container per liter of urine collected. Sample volume may be estimated The amount (volume) of HNO_3 added and date should be noted on the sample container. The container may then be sealed and packed for shipment to BNL.

Upon arrival at BNL, the sample volume and pH should be measured, and additional concentrated HNO_3 added to adjust the pH to ~2.0. The samples may then be submitted for analysis.

Protocol for Radiochem. Analysis of Urine, Teeth & Milk



PROTOCOL FOR RADIOCHEMICAL ANALYSIS

of

URINE, TEETH AND MILK

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DRAFT

CONTENTS

RADIOCHEMICAL ANALYSIS OF URINE, TEETH AND MILK

URINE BIOASSAY SAMPLE COLLECTION AND RECEIVING

Radiochemical analyses of urine are used to determine the excretion rates of radionuclides from individuals living in areas affected by the Pacific Testing Programs. The results of these analyses will be used to:

1. estimate body burdens of ^{90}Sr, ^{239}Pu, ^{240}Pu, and other radionuclides which cannot be determined with in vivo counting techniques,
2. provide independent estimates of body burdens of gamma emitters (such as ^{137}Cs) which can be determined by in vivo counting,
3. provide an indication of the extent to which restrictions on certain local food items are being followed.

Sample Types

Three types of urine samples used in the bioassay program are:

1. single-void "grab sample". This is the least desirable type, but it is also the easiest type to collect. Grab samples are useful for estimates of Sr and Cs excretion rates, but 1 liter samples are definitely preferred. Laboratory limits of detection are, in part, a function of sample volume (total activity per sample). A practical minimum sample volume is 200 ml and attempts should be made to collect more than one voiding if possible,
2. one liter urine sample. This is the preferred type of sample for routine urine bioassay (except for alpha-emitters). The 1 liter sample volume is required for Sr and Cs radioassay and analytical results can

be directly compared with published excretion rate data for estimation of body burdens,

3. large-volume sample. Because of the limitations of radiochemical and counting procedures, large-volume samples (>5000 ml) must be collected for bioassay of transuranic nuclides. Typically, these samples will consist of five or more ys of 1 liter urine collections. Special precautions must be followed to minimize the possibility of sample contamination with extraneous material, primarily "local" dust and dirt.

Sample Collection and Receiving

Provide the subject with a clean 1 liter polyethylene bottle. Instruct him/her to empty the bladder just prior to sample collection, to wash his/her hands before each successive voiding into the sample container and to collect all urine passed until the sample container is filled.

The 1 liter container may also be used for single-void samples. Instruct the subject to wait until he/she has to urinate, then give instructions to wash hands and void into the container until bladder is empty. For large-volume samples provide the subject with 5 or more 1 liter bottles, using the collection procedure as indicated above. The subject must collect all urine voided for the next 5 - 10 days until all of the bottles are filled.

After samples are submitted to the field trip team 15 grams (1 Tablespoon) of boric acid are added to each liter.

Large-volume samples intended for plutonium analysis must be acidified with 10 ml of concentrated HNO_3 per liter of urine and the date noted on the bottle.

Containers are to be labeled with the following information at the time of collection:

1. name of individual submitting specimen,
2. date of collection,
3. person's identification number,
4. location of sampling,
5. sex.

Prior to laboratory analysis, all sample information must be entered in the bioassay log and samples are to be assigned a sample analysis identification number.

URINE SAMPLE PREPARATION FOR PHOTON SPECTROSCOPY

Sample volumes and pH are measured and recorded. The pH should be adjusted to 2.0 with concentrated nitric acid. If sample volume is sufficient then 300 ml of each sample is to be placed in a 300 ml capacity sealable can (8 cm diameter x 6 cm height), labeled and gamma scanned. If sample is less than 300 ml, dilute premeasured volume to capacity with distilled water and scan.

Samples are counted on a large volume lithium-drifted germanium detector. Data output for each sample is processed, stored and analyzed using a computer based multichannel analyzer. Sample counting time, usually 6,000 to 10,000 seconds is determined by the sample activity concentration. Data are analyzed by standard nuclide identification software for photon emitting radionuclides. Data analyzed prior to 1981 used a peak search routine as developed by Cast of LASL and Aebersold of Tennecomp Systems. Subsequent data have been analyzed using software developed by Nuclear Data (Report #48-0004). The MLD's for a

10,000 second count for ^{137}Cs and ^{40}K are 2.5 and 35.0 pCi respectively. Potassium-40 is a naturally occurring radionuclide and is normally found in urine at concentrations of 1500 pCi/ℓ ± 30% (one standard deviation). Following gamma analysis, sample aliquots are returned to the original sample for ^{90}Sr and/or ^{239}Pu analyses.

SAMPLE PREPARATION FOR ^{90}SR ANALYSIS OF TEETH AND MILK

Reagents

^{85}Strontium Tracer	
Strontium Carrier	
Yttrium Carrier	
Cation Exchange Resin	50W x 8
Nitric Acid	Conc.
Nitric Acid	8N
Hydrogen Peroxide	30%
Hydrochloric Acid	Conc.
Hydrochloric Acid	0.08N

Care should be taken to record all fresh and dry weights on all samples from which water is removed. The following procedure is to be performed on milk samples:

1. to a 1 liter sample of milk add 1 ml of ^{85}Sr tracer, 40 mg of strontium carrier, 40 mg yttrium carrier and stir,
2. add 60 grams of washed 50W x 8 cation exchange resin and stir for at least 30 minutes,
3. allow the resin to settle overnight,
4. remove the milk with suction, taking care not to disturb the resin,
5. wash the resin with 400 ml of distilled water and remove it with suction, discard the milk and wash water,

6. add 400 ml of 8N HNO_3 to the resin and stir for at least 30 minutes,

7. filter the acid through a Whatman #42 paper and wash the resin with three 50 ml volumes of 8N HNO_3,

8. evaporate the acid solution to dryness, add 50 ml of 30% H_2O_2 and evaporate to dryness,

9. cool and dissolve in 50 ml of 1:1 HCl; if any insoluble material remains at this point filter through a double glass fiber filter paper, transfer to a 150 ml beaker and evaporate to dryness,

10. dissolve in 60 ml of 0.08N HCl and proceed to step #1 of the HDEHP procedure.

The following procedure is for the preparation of teeth samples for radiochemical analysis:

1. due to the small sample size and the fact that in most cases strontium and plutonium results are requested add both ^{242}Pu and ^{85}Sr tracers, 40 mg strontium carrier and 40 mg yttrium carrier to the sample,

2. dissolve sample in 1:1 HNO_3 and wet ash to yield a clean white residue,

3. dissolve residue in dilute HNO_3 and proceed to plutonium alkaline earth phosphate method, strontium analysis is performed by the HDEHP method on the column effluent.

SEPARATION OF ^{90}STRONTIUM FROM URINE SAMPLES 1 LITER OR LESS

Reagents

^{85}Strontium Tracer	
Octyl Alcohol	
Nitric Acid	Conc.
Strontium Carrier	20 mg/ml
Yttrium Carrier	20 mg/ml
Calcium Chloride	0.1M
Oxalic Acid	Saturated Solution
Sodium Hydroxide	6M
Hydrochloric Acid	Conc.
Hydrochloric Acid	0.08N

The procedure is as follows:

1. measure sample into a 1.5 liter beaker,
2. place beaker on a stirring hot plate and heat slowly to 80-85°C,
3. acidify sample to pH 1 with nitric acid (add acid in small amounts to prevent excessive foaming, use a few drops of octyl alcohol if necessary),
4. add 40 mg each Sr carrier and Y carrier, 1 ml ^{85}Sr tracer and 50 ml 0.1M $CaCl_2$,
5. digest with stirring at 80-85°C for 30 minutes,
6. adjust to pH 4 with 6M NaOH,
7. add 40 ml saturated oxalic acid solution and mix well,
8. readjust to pH 4 with 6M NaOH and digest, with stirring, at 80-85° for 30 minutes,
9. remove from heat, remove stirring bar and let settle overnight,
10. filter sample through a Whatman #42 ashless filter paper using dilute NH_4OH wash solution to rinse beaker and precipitate,

11. transfer filter paper and precipitate to a 150 ml pyrex beaker and dry at 125°C for 1-2 hours,

12. place sample beaker in a muffle furnace and slowly raise the temperature, over an eight hour period, to 500°C and muffle at 500°C overnight,

13. remove from furnace and allow to cool,

14. dissolve residue in 1:1 HNO_3 and wet ash to a clean white ash,

15. convert to chloride by the addition of 10-15 ml conc. HCl and bake dry,

16. dissolve residue in 60 ml 0.08N HCl and stir 10-15 minutes,

17. proceed with Step 1 of HDEHP procedure.

SEPARATION OF ^{90}SR FROM URINE SAMPLES 7.5 TO 15 LITERS

Reagents

^{85}Strontium Tracer	
Octyl Alcohol	
Hydrochloric Acid	0.08N
Hydrochloric Acid	Conc.
Nitric Acid	8N
Phosphoric Acid	6M
Strontium Carrier	20 mg/ml
Yttrium Carrier	20 mg/ml
Calcium Chloride	0.1M
Ammonium Hydroxide	58%
HDEHP	20% & 5% in Toluene by weight

This procedure is designed for ^{90}Sr analysis on composite urine samples. It is usually a batched sample obtained from persons who have been relocated away from contaminated atolls. The contribution of ^{90}Sr to urine from the diet to blood to bladder pathway is eliminated. Thus, the ^{90}Sr passed to urine is contributed only from bone at the rate of .05% of the bone burden per day. For typical bone burdens in the Marshallese, this means the levels in urine would be between 0.1 to 1.0 pCi/liter. The samples are grouped for analysis according to age, sex, and location. A ten liter sample is often required to obtain results greater than the system's minimum detectable limits.

The procedure is as follows:

1. measure sample aliquots of 2.5 liters into a 4 liter beaker,
2. add conc. HCl to the sample to make the urine 0.2N in HCl and yield a clean solution,
3. heat sample, with stirring, to a temperature of 85-90°C,
4. add 40 mg strontium carrier, 40 mg yttrium carrier, 1 ml ^{85}SR tracer, 40 ml of 0.1M $CaCl_2$ and 8 ml of H_3PO_4,
5. continue stirring for 30 minutes,
6. slowly add ammonium hydroxide until a basic phosphate precipitate is visible. Continue the addition until the solution is basic to a pH of 9 or greater,
7. allow the precipitate to settle overnight,
8. aspirate the supernatant liquid to the lowest possible level such that the precipitate is not disturbed,
9. filter the sample through a Whatman #42 ashless filter paper using dilute NH_4OH wash solution to rinse the beaker and precipitate,
10. transfer the filter paper and precipitate to a 150 ml pyrex beaker and dry at 125°C for 1-2 hours,
11. place sample beaker in a muffle furnace and slowly raise the temperature, over an eight hour period, to 500°C and muffle at 500°C overnight,
12. remove from furnace and allow to cool,

13. dissolve residue in 1:1 HNO_3 and wet ash to a clean white ash,

14. convert to chloride form by the addition of 10-15 ml conc. HCl and bake dry,

15. dissolve residue in 40-50 ml of 0.08N HCl and stir for 10-15 minutes,

16. adjust the pH to 1.1 ± 0.1,

17. if any solids remain at this point, filter sample through a glass fiber paper using 0.08N HCl as a wash solution,

18. transfer sample solution into a 125 ml separatory funnel,

19. rinse the sample container with 60 ml of 20% HDEHP and add to separatory funnel,

20. extract the sample by shaking vigorously for 2 minutes. Allow the phases to separate and drain off the lower aqueous phase into a second 125 ml separatory funnel containing 60 ml of 20% HDEHP,

21. extract the sample again by shaking for 2 minutes and allow phases to separate,

22. drain off the aqueous phase. The aqueous phases of 3 to 6 samples may be combined to make a composite sample of 7.5 to 15 liters,

23. evaporate the combined sample slowly until salting out occurs. Dilute to 40-50 ml with distilled H_2O and adjust pH to 1.1 ± 0.1,

24. if any solids remain at this point, filter sample through glass fiber paper using 0.08N HCl as a wash solution,

25. transfer sample solution to a 100 ml polyethylene bottle, add 40 mg of yttrium carrier, gamma count for ^{85}Strontium recovery and store for 18 days for ^{90}Yttrium ingrowth,

26. proceed to Step 6 of the HDEHP procedure.

^{90}STRONTIUM DETERMINATION BY HDEHP [DI-(2-ETHYLHEXYL) PHOSPHORIC ACID] METHOD

Reagents

Hydrochloric Acid	0.08N
HDEHP	20% in Toluene by weight
HDEHP	5% in Toluene by weight
Nitric Acid	3N
Yttrium Carrier (Purified)	20 mg/ml
Ammonium Hydroxide	58%
Oxalic Acid	Saturated Solution

If preliminary results are desired, steps 6 through 9 can be carried out on the two 60 ml aliquots of 10% HDEHP.

The procedure is as follows:

1. transfer 60 ml of 0.08N HCl sample solution into a 125 ml separatory funnel, add 20 mg yttrium carrier,
2. rinse sample container with 60 ml of 20% HDEHP and add to separatory funnel,
3. extract the sample by shaking vigorously for 2 minutes, allowing phases to separate, then drain off the lower aqueous phase into a second 125 ml separatory funnel containing 60 ml of 20% HDEHP,
4. extract the sample again by shaking for 2 minutes, allowing phases to separate and recording the time of second extraction,
5. drain off the lower aqueous phase into a 100 ml polyethylene bottle, add 1 ml of yttrium carrier, gamma count for ^{85}Strontium recovery and store 18 days for ^{90}Yttrium ingrowth,
6. transfer sample to 125 ml separatory funnel and extract with 60 ml of 5% HDEHP. Note the time of extraction. Save the aqueous phase for future extractions if necessary,
7. wash the organic phase by shaking with 60 ml of 0.08N HCl,

8. repeat step 7,

9. extract ^{90}Yttrium from the 5% HDEHP with two 60 ml volumes of 3N HNO_3. Shake 2 minutes for each extraction and combine the 3N HNO_3 solutions in a 250 ml beaker,

10. evaporate the 3N HNO_3 solution to a volume of a few ml and quantitatively transfer to a 50 ml centrifuge tube with several small volumes of distilled H_2O,

11. place centrifuge tube in a hot water bath and adjust pH to 8-10 with NH_4OH to precipitate yttrium hydroxide,

12. centrifuge and decant supernatant liquid,

13. wash precipitate with 10 ml distilled H_2O, centrifuge and discard wash,

14. dissolve precipitate in 1:1 HCl (1-2 ml), slurry and bring volume to 25 ml with distilled H_2O,

15. add 2-3 ml saturated oxalic acid, 0.5 - 1 ml NH_4OH, stir and digest at 85-90°C for 1 hour,

16. filter through preweighed glass fibre filter and dry at 100-110° for 10 minutes,

17. weigh sample and paper and determine gravimetric yield of ^{90}Yttrium,

18. mount and beta count,

19. count again in 24-48 hours to verify ^{90}Yttrium decay.

Counting Equipment

^{90}Strontium is counted as its daughter product ^{90}Yttrium using an anti-coincidence low background beta counter. The system has an absolute 51% counting efficiency and a background range of 1.0 - 1.5 cpm. Recovery of the gamma-emitting ^{85}Sr tracer is determined using a NaI (Tl) crystal and multichannel analyzer.

DETERMINATION OF PLUTONIUM IN URINE, WATER AND MISCELLANEOUS SAMPLES BY ALKALINE-EARTH PHOSPHATE PRECIPITATION

Reagents

Sodium Nitrate	
Octyl Alcohol	
Nitric Acid	Conc. and 7.2N
Phosphoric Acid	85%
Potassium Hydroxide	4N
Hydrochloric Acid	Conc.
Eluting Solution	30 ml HCl, 0.3 ml HF/Liter H_2O
Calcium Nitrate	Saturated Solution (Filtered)
Hydrogen Peroxide	30%
Anion Exchange Resin	AG1x4 50-100 mesh
Sodium Bisulfate	5%
Ammonium Hydroxide	58%
Sodium Sulfate	15% (Filtered)
^{242}Plutonium Tracer	4 d/m/ml

Plutonium is co-precipitated with urine salts by alkaline earth phosphates. The organic material carried by the precipitate is dry ashed in a muffle furnace. Plutonium and urine salts are dissolved in 7.2N nitric acid. The plutonium fraction is absorbed onto an anion exchange resin and eluted with 0.36N HCl - 0.008N HF. Plutonium is electrodeposited onto ½" diameter stainless steel discs and its activity determined by alpha pulse height spectrometry.

The procedure is as follows:

1. add sample to an appropriate size beaker recording aliquot volume. Rinse sample container with 7.2N HNO_3 and add to sample beaker,
2. add an additional 5 ml of conc. HNO_3, place sample on a stirring hot plate and adjust temperature to 80° ± 5°C,

3. add ^{242}Pu tracer, 1 ml of 85% H_3PO_4, 0.2 ml of saturated Ca $(NO_3)_2$. If subsequent ^{90}Strontium analysis is to be performed on sample add 1 ml strontium carrier, 1 ml yttrium carrier and 1 ml of ^{85}Strontium tracer to the sample as well,

4. when sample has reached 80°C, add 10 ml of 30% H_2O_2 and stir sample 30 minutes. If the sample is allowed to stand overnight, all reagents except H_2O_2 should be added immediately after aliquoting,

5. add 100 ml of 58% NH_4OH and allow sample to digest for one hour. If excessive foaming occurs add 1-2 drops octyl alcohol,

6. remove sample from hot plate, remove stirring bar and after 1-2 hours check for complete precipitation by adding a few drops of NH_4OH,

7. allow precipitate to settle overnight,

8. aspirate supernate taking care not to disturb precipitate,

9. wash down the sides of the beaker with 25-30 ml of conc. HNO_3 and bring to complete dryness on a hot plate at 150°C,

10. repeat step 9,

11. place sample in a 500°C preheated muffle furnace for 2 hours,

12. remove sample and cool to room temperature,

13. add enough conc. HNO_3 to cover the salts and bring to dryness at 150°C,

14. repeat step 13 five times,

15. dissolve salts in 70 ml of 7.2N HNO_3,

16. add 25 mg of $NaNO_2$, cover and heat at 80°C for 10-15 minutes,

17. allow solution to stand 24-48 hours,

18. prepare AG1x4 anion exchange resin by filling resin bottle with distilled water, shake by inverting several times and allow to settle 20-30 minutes. Carefully pour off the fines and repeat this procedure three times. Store resin in distilled water,

19. prepare exchange column by placing a glass wool plug at the bottom of a glass column (stem 100mm x 10mm O.D. and reservoir 120mm x 45mm) filling the stem of the column to the neck with washed resin,

20. condition the resin with 200 ml of 7.2N HNO_3,

21. add sample to the column with minimal disturbance to the resin bed. If any crystals remain in the sample it should be filtered through a Whatman #40 paper before introduction to the column,

22. wash down the sides of the sample beaker with 5-10 ml of 7.2N HNO_3,

23. when sample has drained add the beaker wash to the column,

24. repeat steps 22 and 23,

25. when the washes have drained, wash the column with 250 ml of 7.2N HNO_3. On samples that require subsequent ^{90}Strontium analysis the column effluents from steps 21 through 25 should be combined and evaporated to dryness. Proceed with standard chloride conversion and dissolve in 60 ml of 0.08N HCl and continue with step 1 of the HDEHP procedure,

26. add 2 ml of 5% $NaHSO_4$ to a 30 ml beaker and place the beaker under the column,

27. elute the plutonium by adding 30 ml of 0.36N HCl-0.008N HF to the column.

28. evaporate eluent to dryness at 120°C or under infrared lamps.

Electrodeposition Procedure

1. Add 4 ml of 15% Na_2SO_4 electrolyte solution to the sample and allow to stand at least 30 minutes,
2. assemble and leak test the plating cell,
3. add the sample to the electrodeposition cell,
4. rinse the beaker with distilled water and add wash to cell filling cell to within 1/4 inch of the top,
5. attach the cathode lead to the bottom of the cell. Anode to cathode distance should be 5 mm,
6. electrodeposit plutonium at 500 milliamps for 3 1/2 hours,
7. at end of the plating period, fill the cell with 4N KOH and continue plating for 30 seconds,
8. remove the cathode lead and cell from the rack and discard the solution carefully washing the cell with distilled water. This step should be carried out as quickly as possible to prevent dissolution of the plutonium from the plated disc,
9. handling the disc by the unplated edge only, wash with distilled water and dry under infrared lamps for 20-30 minutes,
10. determine the plutonium activity by alpha pulse-height spectrometry.

Counting Equipment

The alpha counting is performed using silicon surface barrier detectors coupled to a computer based pulse height analysis system. The detector has a relative counting efficiency of approximately 20% using a ^{242}Pu standard. The MDL for ^{239}Pu has a range of 7-35 femtocuries. Samples are counted for 200,000 seconds and all peaks are manually integrated.

It is noted that urine activity concentrations for ^{239}Pu corresponding to 5 Rem in 30 years to bone surfaces and liver tissue are 0.3 and 1.3 femtocuries per liter respectively. Thus for radiation protection purposes in the Marshall Islands, large volume samples are required in order for this method to have practical application. This procedure has an overall chemical recovery of 60-80%.

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^{129}I Analysis of Marshall Island Environmental Samples

Analytical and Quality Assurance Procedures

F.P. Brauer* and J.R. Naidu**

INTRODUCTION

Neutron activation analysis is used for trace level measurements of iodine in biological and environmental materials. Both mono-isotopic natural iodine (^{127}I) and the long-lived (1.6×10^7 years) fission-produced ^{129}I occur in sample materials and can be analyzed by neutron activation analysis (1,2,3). Since the environmental sources of ^{127}I and ^{129}I are different, which may result in different chemical forms and ecological pathways, measurement of the ^{129}I/^{127}I isotopic ratio is essential in studies of the radioecology of ^{129}I (2,4).

Various processes contribute to the release of ^{129}I to the environment (5,6,7,8). Naturally occurring ^{129}I results from spontaneous fission of uranium and from cosmic-ray produced spallation reactions with atmospheric xenon. Man-made releases of ^{129}I have resulted from nuclear weapon tests and from nuclear installation operations.

ANALYSIS METHOD

Determination of the ^{129}I concentration and the ^{129}I/^{127}I ratio in most environmental and biological materials requires initial separation of the contained iodine. Once separated, the iodine is irradiated with neutrons in a nuclear reactor, purified further to reduce levels of interfering radionuclides, and then determined by gamma-ray spectrometric measurements.

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The procedure used for iodine isolation prior to neutron activation is a modification of that of Studier (1,9). The soil sample to be processed may be a filter, activated charcoal, ion-exchange resin, animal parts, vegetation or soil. Freeze drying can be used as appropriate to remove moisture from the sample prior to analysis. The sample is spiked with a known amount of ^{125}I for estimation of the overall procedure yield. The iodine is separated by placing the sample in a quartz combustion apparatus and igniting the sample at high temperature (up to 1000°C) in a stream of oxygen. The off-gases are passed through a small bed of activated charcoal that retains the iodine.

The iodine is further purified by burning the original charcoal trap in oxygen and trapping the released iodine on several milligrams of activated charcoal. The iodine is then removed from the charcoal by heating the charcoal in a vacuum system, trapping the iodine in a quartz tube at liquid nitrogen temperature, and sealing the tube to make a quartz irradiation ampoule. The ^{125}I in the ampoule is determined by gamma-ray spectrometry to estimate the pre-irradiation processing yield. Typical yields range from 90% to 100%.

Quartz ampoules containing the iodine separated from the samples are irradiated with reactor neutrons for 8 to 24 hours. Comparator standards containing known ratios of ^{125}I, ^{127}I and ^{129}I are irradiated with each set of samples. The neutron capture reactions used for the iodine activation analysis are:

$$^{127}I(n,\gamma)^{128}I \xrightarrow[25\ min]{\beta^-,\gamma} {}^{128}Xe \quad (1)$$

$$^{127}I(n,2n)^{126}I \xrightarrow[13\ day]{\beta^-,\gamma} {}^{126}Xe \quad (2)$$

$$^{129}I(n,\gamma)^{130}I \xrightarrow[12.4\ hr]{\beta^-,\gamma} {}^{130}Xe \qquad (3)$$

Interfering reactions include:

$$^{125}I(n,\gamma)^{126}I \xrightarrow[13\ day]{\beta^-,\gamma} {}^{126}Xe \qquad (4)$$

$$^{127}I(n,\gamma)^{128}I(n,\gamma)^{129}I(n,\gamma)^{130}I \xrightarrow[12.4\ hr]{\beta^-,\gamma} {}^{130}Xe \qquad (5)$$

Interference from reaction (4) is minimized by use of small activity levels of ^{125}I so that ^{126}I production by reaction (2) predominates. Reaction (5) limits the improvement in sensitivity that can be obtained by increasing the exposure time and neutron flux. Neutron exposure conditions are selected on the basis of expected stable iodine content of given sample types in order to limit the correction required due to reaction (5) to less than 10%.

Following irradiation the quartz ampoules are cleaned, frozen with liquid nitrogen and crushed into a reaction vessel containing a dilute H_2SO_4 solution of iodine and bromine carriers and $Na_2S_2O_5$ (sodium pyrosulfite). Excess SO_2 is removed by sparging with nitrogen. The bromide and iodide ions are then oxidized to bromine and iodate by the addition of $KMnO_4$ and the bromine distilled from the solution. The iodate remaining in the reaction vessel is reduced to iodide with $Na_2S_2O_5$ and then oxidized to iodine with H_2O_2. The iodine is distilled from the reaction vessel into a $Na_2S_2O_5$ solution. The iodine fraction is further purified by oxidation with H_2O_2, extraction into CCl_4, and back extraction with $Na_2S_2O_5$ solution. The extractions are repeated as necessary for iodine decontamination. The iodine is finally precipitated as AgI and mounted on thin plastic scintillators for counting.

The ^{126}I, ^{128}I and ^{130}I activities produced in the sample and comparator standards during irradiation are determined by gamma-ray spectrometry from several spectra collected over a period of time. Low-level, beta-gated, multiple gamma-coincidence spectrometric techniques (10) are used when required to measure very small amounts of activity. The ^{125}I activity is also measured in the sample and comparator standard by gamma-ray spectrometry.

The components in the time-dependent gamma-ray spectra of samples and the comparator standard are calculated by a weighted least-squares method (11). The amounts of ^{127}I and ^{129}I in the comparator standard are determined from the known ^{125}I, ^{127}I, ^{129}I ratios by measurement of the ^{125}I. The $^{130}I/^{129}I$, $^{128}I/^{127}I$ and $^{126}I/^{127}I$ ratios are then calculated for the comparator standard. The ^{127}I content of the sample is determined from either the ^{126}I of ^{128}I activity produced in the sample, the induced ^{130}I activity is used to determine the ^{129}I concentration, and the ^{125}I activity is used to calculate the overall procedure yield. Corrections are made for interferences, procedure yield, laboratory blanks and sampling blanks where applicable. The results obtained are the ^{127}I and ^{129}I concentrations per unit amount of sample and the $^{129}I/^{127}I$ ratio. Iodine isotopic atom ratios for $^{129}I/^{127}I$ as low as 10^{-12} have been measured (2). The overall procedure yield for iodine recovery is about 50%.

COMPARATOR STANDARDS

We have used several different comparator standards for iodine activation analysis. Elemental iodine (I_2) standards were prepared by isotopic dilution with known amounts of natural iodine (^{127}I) of mass spectrometrically analyzed

^{129}I samples. Very large dilution factors were required in order to achieve isotopic ratios typical of most analytical samples. A value of 2.1 x 10^{-8} for the $^{129}I/^{127}I$ atom ratio was determined from the dilutions and mass spectrometric data for one of these isotopically diluted iodine mixtures; this mixture is still used in our laboratory for long-term measurement control. This isotopic mixture has also been used as a routine comparator standard. A 1-to-10 mg aliquot of the elemental iodine isotopic mixture is irradiated with samples or other standards to be analyzed. After irradiation the iodine is further purified by solvent extraction and precipitated as AgI. The iodine content is determined from the weight of the AgI. The $^{128}I/^{127}I$, $^{126}I/^{127}I$ and $^{130}I/^{129}I$ activity-to-mass ratios can then be determined from the AgI weight, the known $^{129}I/^{127}I$ ratio and the gamma-ray spectrometric data. Measurement of the amount of AgI radiometrically with ^{110m}Ag tracer has also been satisfactory. In this case, excess Ag+ containing a known $^{110m}Ag/Ag$ ratio is used to precipitate the iodine and the total iodine is determined from the ^{110m}Ag content of the AgI as measured by gamma-ray spectrometry. Both methods depend upon stoichiometric AgI precipitation. The ^{110m}Ag radiometric method, however, is not affected by moisture, as are the AgI weight measurements.

Another standard material we have used for ^{127}I activation analysis calibrations of our comparator standard is hexaiodobenzene (C_6I_6). The results of this method agreed with the AgI calibration methods. Hexaiodobenzene is available as high purity (99.9%), weighed pellets of about 1.55 g each. Low neutron exposures are required due to the large amounts of iodine in the pellets.

A mixed ^{125}I, ^{127}I, ^{129}I comparator standard has also been prepared to simplify analysis and to reduce the amount of ^{127}I in the standard. This reduces the ^{128}I activity to measurable levels within a few hours of reactor discharge and also reduces the influence on the standard of multiple neutron captures on ^{127}I to produce ^{130}I. This standard was prepared in solution form so that 1 to 10 μℓ would produce sufficient activity for iodine activation analyses. It was made from unknown amounts of NH_4 ^{127}I(10g), ^{125}I (10 mCi) and from 0.1% of the solution contained in an ampoule of (NBS) ^{129}I, Standard Reference Material (SRM) number 4949 in 100 ml of aqueous solution. The ^{125}I solution had been aged 6 months to eliminate any ^{126}I activity. The solution composition per μℓ at make-up is shown in Table I.

TABLE I

Composition of Comparator Standard for Iodine Activation Analysis

^{125}I	320 dps/μℓ
^{127}I	87.5 μg/μℓ
^{129}I	6.0×10^{11} atoms/μℓ
$^{129}I/^{127}I$	1.45×10^{-6} atom ratio

The ^{125}I, ^{127}I, ^{129}I standard solution requires the addition of ^{125}I ($T_{1/2}$ = 60 days) about once a year. The added ^{125}I is contained in less than 100 μℓ to minimize dilution of the standard. Annually after the ^{125}I addition the composition of the standard solution is compared by activation analysis to that of the older mixed elemental iodine standard, to the C_6I_6 standard, and to sealed measured aliquots of NBS-SRM-4949. Sufficient sealed quartz irradiation ampoules of the standard solution are then prepared for use over a year's time.

The mean $^{129}I/^{127}I$ atom ratio of the original elemental iodine isotopic standard (nominal 2.1×10^{-8} atom ratio) based on the standard solution isotopic composition is 2.04 x 10^{-8} from 79 activation analysis measurements over a 10 year period. The observed standard deviation is ±0.46 x 10^{-8} and the standard deviation of the mean is ±0.05 x 10^{-8}.

Interlaboratory standards containing ^{129}I and ^{127}I in a basic KI solution at three different isotopic ratios were received at the Battelle Pacific Northwest Laboratory (PNL) from Dr. O.K. Manuel of the University of Missouri (12). These standards were analyzed at PNL by the activation analysis method described in this paper and in Dr. Manuel's laboratory by an activation analysis method that uses mass spectrometric Xe isotope ratio determinations (13). Measurements at both laboratories were based on the NBS ^{129}I standard (SRM-4949). Good agreement between the laboratories was observed over a ^{129}I concentration range of 10^5, as shown in Table II.

TABLE II

Interlaboratory Comparison of Activation Analysis Results

Sample	Lab*	^{127}I (mg)	^{129}I (atoms)	$^{129}I/^{127}I$ (atom ratio)
UMR-IO-(129,53)No. 1	UMR	10.0 (gravimetric)		$5.39 \pm 0.29 \times 10^{-5}$
	PNL	11±3	$3.0 \pm 0.7 \times 10^{15}$	$5.6 \pm 0.4 \times 10^{-5}$
UMR-IO-(129,53)No. 2	UMR	1.0 (gravimetric)		5.4×10^{-7}
	PNL	1.0±0.3	$2.7 \pm 0.1 \times 10^{12}$	$5.7 \pm 0.6 \times 10^{-7}$
UMR-IO-(129,53)No. 3	UMR	1.0 (gravimetric)		5.4×10^{-9}
	PNL	0.8±0.3	$2.2 \pm 0.7 \times 10^{10}$	$5.7 \pm 1.8 \times 10^{-9}$

*UMR: University of Missouri, Rolla
PNL: Pacific Northwest Laboratory

BIOLOGICAL AND ENVIRONMENTAL STANDARDS FOR QUALITY CONTROL

Quality control of iodine activation analysis requires the use of standard materials similar to the sample materials analyzed. Such standard materials are needed to check the total procedure from iodine separation to final measurements. The materials should be homogeneous, easy to store, and available in quantity over a period of years.

Several biological and environmental standard samples were obtained from NBS and IAEA. These included orchard leaves (NBS-SRM-1571), river sediment (NFS-SRM-4350), clam (IAEA-MA-B-1), human blood serum (IAEA-H-6), and wheat flour (IAEA-V-5). Also, grass collected from the Hanford Reservation was dried and mixed for use as a standard. Replicate iodine activation analyses were made on these materials, for which preliminary results are summarized in Table III. The values are given as means of replicate measurements ±95% confidence intervals ($SD \cdot \frac{t}{\sqrt{n}}$).

The natural iodine (^{127}I) measurements on these samples were found to agree with the assigned values to within measurement uncertainties. Larger uncertainties were observed for the concentration values than for the isotopic ratio values, as expected from an evaluation of the error sources in the procedure. Additional replicate analyses are expected to reduce the uncertainties.

TABLE III

Iodine Activation Analysis Results on Standard Materials

Material	Concentration			Isotopic Ratio
	^{127}I ng/g	^{129}I Atoms/g	^{129}I pCi/g	$^{129}I/^{127}I$ Atom Ratio
Orchard Leaves, SRM-1571	188± 26	$1.6\pm0.3\times10^{8}$	$6.0\pm2.8\times10^{-6}$	$1.7\pm0.7\times10^{-7}$
NBS Value	170			
River Sediment, SRM-4350	5400±5000	$8.6\pm10.0\times10^{8}$	$3.2\pm3.7\times10^{-5}$	$3.2\pm0.9\times10^{-8}$
Clam, MA-B-1	5500±1300	$3.2\pm0.3\times10^{9}$	$1.2\pm0.2\times10^{-4}$	$1.3\pm0.1\times10^{-7}$
Human Blood Serum, H-6[a]	590± 90	$2.5\pm0.4\times10^{9}$	$9.3\pm1.4\times10^{-5}$	$8.8\pm0.2\times10^{-7}$
IAEA Value	800± 129			
Wheat Flour, V-5	<10	$4.8\pm2.9\times10^{7}$	$1.8\pm1.1\times10^{-6}$	
IAEA Value	2.88±1.23			
Grass, PNL-56593	200± 70	$4.1\pm0.8\times10^{10}$	$1.5\pm0.3\times10^{-3}$	$4.3\pm0.8\times10^{-5}$

[a]Dry weight basis
(dry/wet weight ratio = 0.0826).

Marshall Island soil samples have been analyzed at the Battelle Pacific Northwest Laboratories and Table IV presents the data. Included in this table are analyses of samples from locations other than the Marshall Islands. Comparisons, however, have to be made with reference to the effect of storage of samples prior to analyses. Data from samples analyzed at Hanford indicate that losses of ^{129}I from samples is minimal.

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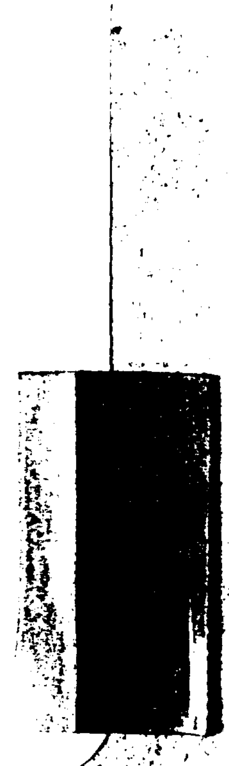
SUMMARY OF ^{129}I AND GAMMA-RAY SPECTROMETRIC ANALYSIS RESULTS

Sample Number	PNL Number	Collection Date	^{129}I Atoms/g	Gamma Radioactivity as of 7/12/78: ^{125}Sb Atoms/g	^{137}Cs Atoms/g	^{155}Eu Atoms/g	^{60}Co Atoms/g	On 7/12/78 $^{129}I/^{137}Cs$	At Collection $^{129}I/^{137}Cs$	Location
7500	87161	3/54		$1.8x10^7$	$5.1x10^{10}$	$7.1x10^7$	$9.8x10^7$			Labardz, Rongelap
7501	87162	3/54	$6.8x10^{10}$	$1.1x10^7$	$2.5x10^{10}$	$1.5x10^7$	$5.5x10^7$	2.7	1.5	Labardz, Rongelap
9772	87163	7/54	$4.8x10^{10}$	$1.0x10^7$	$1.7x10^{10}$	$5.9x10^7$	$6.4x10^7$	2.8	1.6	Kabelle, Rongelap
9773	87164	7/54		$1.1x10^7$	$4.7x10^9$	$3.2x10^7$	$7.0x10^7$			Kabelle, Rongelap
19293	87165	1/55	$1.3x10^{11}$	$6.9x10^6$	$7.7x10^9$	$1.7x10^7$	$1.7x10^7$	17.	9.9	Kabelle, Rongelap
19297	87166	1/55	$1.5x10^{11}$		$1.5x10^8$			1000.	580.	Rongelap
19500	87167	10/55	$2.2x10^{11}$		$2.4x10^8$	$6.2x10^5$	$3.2x10^6$	920.	540.	Rongelap
19505	87168	10/55	$2.5x10^{10}$		$1.2x10^9$	$1.7x10^6$	$4.8x10^6$	21.	12.	Rongelap
19497	87169	10/55	$3.0x10^{10}$		$9.6x10^8$			32.	19.	Rongelap
5539	87170	7/56	$4.7x10^{10}$	$1.4x10^6$	$1.9x10^9$		$1.1x10^7$	25.	15.	Kabelle, Rongelap
5554	87171	7/56			$1.5x10^9$	$2.5x10^6$	$4.6x10^6$			Rongelap
5558	87172	7/56	$2.0x10^{10}$	$5.4x10^9$	$1.6x10^9$	$1.3x10^6$	$2.7x10^6$	13.	7.8	Rongelap
5562	87173	7/56	$1.1x10^{10}$		$4.7x10^8$	$2.2x10^6$	$5.8x10^6$	23.	14.	Rongelap
5728	87174	7/57			$1.6x10^9$	$5.8x10^6$	$9.8x10^6$			Kabelle, Rongelap
5729	87175	7/57	$7.6x10^{10}$	$3.3x10^6$	$7.3x10^9$	$1.6x10^7$	$2.1x10^7$	10.	6.2	Kabelle, Rongelap
5753	87176	7/57	$3.9x10^{10}$		$1.0x10^9$	$1.8x10^6$	$3.6x10^6$	39.	24.	Rongelap
19289	87177	1/55	$4.1x10^9$		$7.0x10^7$			59.	34.	Uterik
19290	87178	1/55	$9.3x10^8$				$1.4x10^6$			Uterik
37256	87179	11/74	$4.2x10^9$		$8.7x10^8$	$3.0x10^6$	$3.6x10^6$	4.8	4.4	Enewetak, Rongelap
37330	87180	11/74	$6.6x10^9$		$3.7x10^8$	$6.4x10^6$	$4.9x10^6$	18.	16.	Enewetak, Rongelap
	871	5/55	$3.6x10^8$		$4.9x10^8$		$1.0x10^7$	.73	.43	Nevada Test Site
	881	5/55	$9.8x10^7$		$5.6x10^6$			18.	11.	Nevada Test Site
	1450	1/57	$2.3x10^8$		$5.0x10^8$	$3.3x10^7$		.46	.28	Nevada Test Site
	90680	1/67	$2.1x10^{10}$							Eninman, Bikini
	90681	5/67	$8.6x10^{11}$							Aomen Yurochi, Bikini
9951	87217	12/54	$1.8x10^{11}$		$1.2x10^7$	$4.5x10^5$		15000.	8700.	Ponape
5591	87218	7/56	$2.8x10^{10}$		$1.2x10^6$		$2.6x10^5$	23000.	14000.	Kusaie
	4645	8/57	$1.1x10^7$							Florida
	8360	5/66	$5.1x10^7$							Hawaii



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AN EVALUATION OF PHYSIOLOGICAL PARAMETERS AND THEIR INFLUENCE ON DOSES CALCULATED FROM TWO ALTERNATIVE DOSIMETRIC MODELS FOR THE GASTROINTESTINAL TRACT

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ABSTRACT

Two dosimetric models, the catenary compartmental model (Be70) and the slug flow model (Sk75) are examined using three sets of physiological parameters: (1) those proposed by Eve (Ev66), (2) those proposed by ICRP (IC59), and (3) those obtained from the Textbook of Physiology and Biochemistry by Bell et al. (Be72).

The impact of physiological parameters on the dosimetry of the tract is illustrated by comparing calculated maximum permissible daily activity ingestion rates for single, unabsorbed, particle emitting radionuclides with an effective energy term of unity.

The conclusions drawn from this intercomparison of six different cases are: (1) Current dosimetric models which use physiological parameters described in this article do not significantly disagree, and (2) for the determination of average dose equivalent rates to segments of the tract due to chronic, long term ingestion of any radionuclide, the catenary compartmental model is a mathematically simpler approach. The catenary model in addition has certain advantages for the calculation of the photon dose contribution to one segment from cumulated activity (disintegrations) in another segment.

INTRODUCTION

Physiological parameters may influence the absorbed dose rate delivered to the walls of the gastrointestinal tract. Historically, physiological parameters used to calculate the absorbed dose rate to the walls of the tract were chosen from data published by "ICRP Committee II on Permissible Dose for Internal Radiation" (IC59). ICRP indicates a mathematical model whereby the stomach is considered a holding vessel which releases its contents after one hour to the small intestine. They further suggest that for single, particle emitting radionuclides and for segments other than the stomach, the absorbed dose rate to the walls of each segment is to be calculated from one-half the quotient of the activity input rate into each segment and the average mass flow rate through each segment. A more recent study by I. S. Eve (Ev66) suggests different values for the same physiological parameters as well as an alternative dosimetric model.

Our method uses physiological parameters published by Eve and ICRP. Additionally, a third set of physiological parameters is selected largely from data published by Bell et al. (Be 72).

It is noted that a chosen numerical value for a physiological parameter applies only for the purpose of conservatively estimating standards. It does not truly reflect the actual situation in a single human subject, even if the subject resembles standard man. Often physiological parameters are defined in such a way as to eliminate unnecessary mathematical detail in a conservative model. Additionally, actual numerical values for parameters are dependent upon a multitude of ever changing factors. For example, human physiological data describing the transport of mass through the gastrointestinal tract is dependent upon a subject's physical state, emotional state, and diet. Diet is in turn dependent upon a subject's geographical location, season of the year, a subject's personal taste, and his income. The physical state obviously has an influence upon the value of a physiological parameter; however, the emotional state also has an impact. For example, the residence time of a meal in the stomach of subjects in a state of fear is as long as twelve hours, whereas excitement reduces the normal residence time (Be72).

The impact of alternative values for the physiological parameters is evaluated in terms of the maximum permissible daily activity ingestion rate for single, unabsorbed, particle emitting radionuclides using the catenary compartmental model (Be70) and the slug flow model (Sk74). These dosimetric models are current and both make use of previous suggestions and ideas put forth by Eve and ICRP.

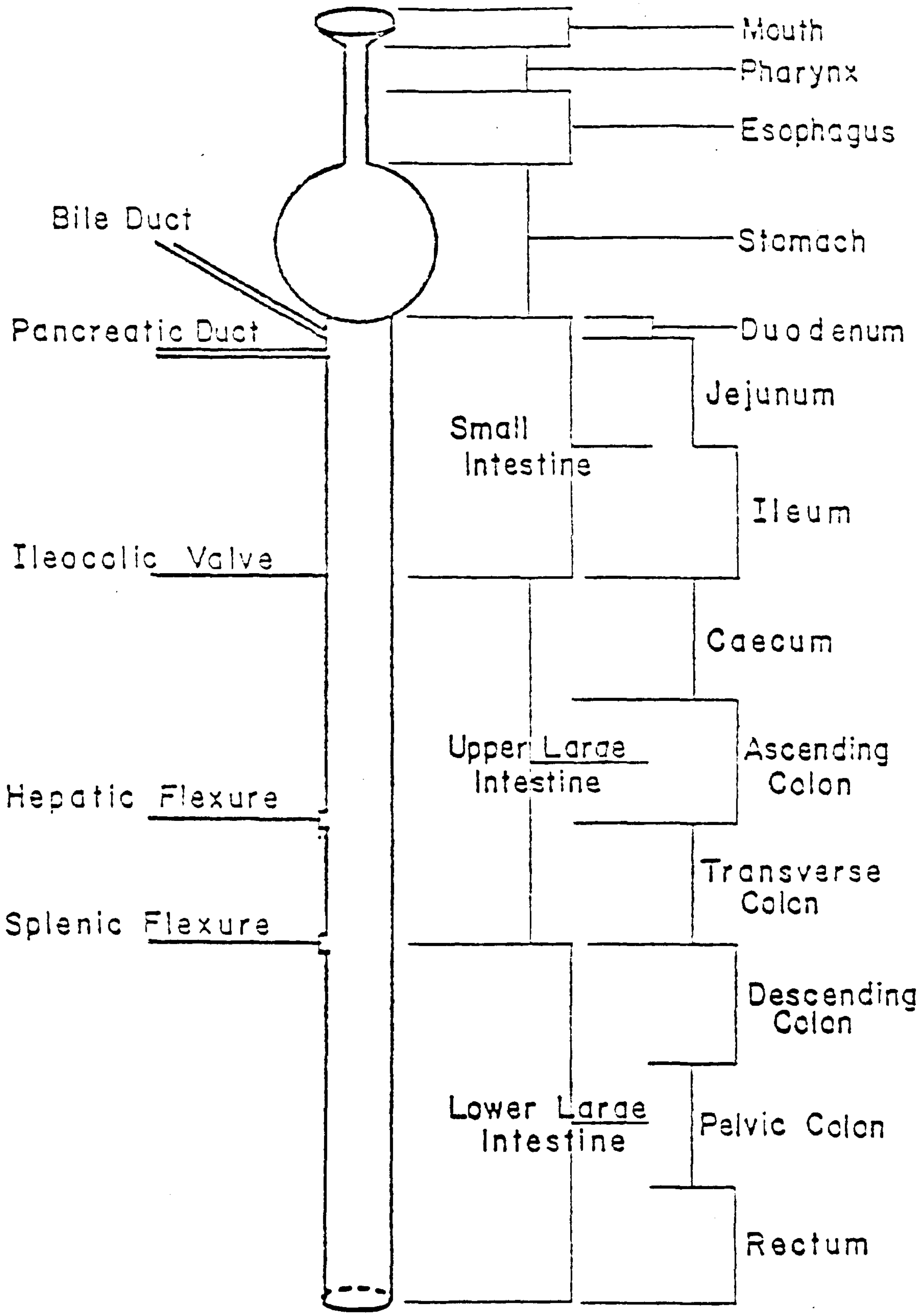
THE STOMACH

The various segments of the gastrointestinal tract are pictured in Figure 1. Since radioactive material is contained in the mass contents of the tract, it is assumed that the walls of the tract are irradiated from one side only. Dosimetric models which describe the dose or dose rate to the walls of the tract do, in fact, describe the dose or dose rate to the mass contents of each dosimetrically important segment of the tract (the stomach, S, the small intestine, SI, the upper large intestine, ULI, and the lower large intestine, LLI) and assume that one-half the spatial equilibrium dose or dose rate to the contents is delivered to the walls of each segment by particle radiation emitted from radionuclides. The dose equivalent or dose equivalent rate is calculated by applying the appropriate modifying factors to the absorbed dose or dose rate.

Unabsorbable, radioactive, particulate matter entering the stomach is initially ingested with food or fluids or initially deposited on the surfaces of the respiratory tract and oral cavity and later expectorated or swallowed. Removal mechanisms such as secretion and subsequent flowing of saliva out of the oral cavity and the beating action of the ciliated epithelium lining the respiratory tract tend to transport unabsorbed particulate matter into the stomach. Particulate matter deposited on the surfaces of the upper respiratory tract (excluding nasal passages) and the oral cavity is transported rapidly to the stomach provided that the removal mechanisms are functional (Ha64). In this study the oral cavity, pharynx, and esophagus are not considered critical segments. This is because contaminated food and fluids, contaminated mucinous fluid cleared from the trachea, and contaminated saliva cleared from the oral cavity are transported through the oral cavity, pharynx, or esophagus to the stomach where the

Figure 1

GASTROINTESTINAL TRACT SEGMENTS


Mouth
Pharynx
Esophagus
Stomach
Bile Duct
Pancreatic Duct
Duodenum
Jejunum
Small Intestine
Ileum
Ileocolic Valve
Caecum
Upper Large Intestine
Ascending Colon
Hepatic Flexure
Transverse Colon
Splenic Flexure
Descending Colon
Lower Large Intestine
Pelvic Colon
Rectum

mean residence time is considered to be several orders of magnitude greater than the mean residence time in the mouth, pharynx, or esophagus.

Bell et al. (Be 72) indicate that the initial mass of a standard liquid meal, M_o, and the mass emptying time in the stomach, t_o, are related by the following empirical equation:

$$t_o = 4M_o^{1/2}\ (\text{grams})^{-1/2}\ \text{minutes}, \qquad (1)$$

where the cancelling unit for the algebraic quantity, $M_o^{1/2}$, is shown in parentheses, $(\text{grams})^{-1/2}$.

Unfortunately, true stomach emptying is not totally characterized by so simple an expression as Equation (1). Many variables such as the ingestion of solid food and the position of the subject are not considered. However, a change in the square root of an initial liquid meal in the stomach changes the emptying time, and both mass of the contents and emptying time influence the absorbed dose to the stomach wall. A single intake calculation for the dose to the wall of the stomach would yield greatly different results if the intake is considered to be mixed with only a few grams of saliva and gastric secretions instead of hundreds or thousands of grams of food, fluids, and secretions.

The absorbed dose rate to the wall of the stomach is dependent upon the mass of the contents and the mean emptying time or residence time of the stomach. From Equation (1) it can be shown that if a standard breakfast and lunch are taken, then some portion of the meals will be present during the morning and afternoon hours of a working day. A change in the mass content of the stomach from several thousand grams to a few grams during a stomach emptying time of several hours is normal. If continuous introduction of a radio-nuclide is due to ingestion of contaminated food or fluids, then the standard daily intake rate of food, fluids, and secretions which enter the stomach may properly reflect the normal mass content of the stomach. If, however, continuous exposure to contaminated air during the latter part of the working day results in radioactive particulate matter entering the stomach with small quantities of swallowed saliva or mucinous fluid cleared from the trachea, then a mass content which reflects the fact that this intake is mixed with only small amounts of resting gastric juices during the last few hours of a working day may be more appropriate.

In this study the standard daily ingestion and secretion mass flow rates are used to determine the mass content of various segments. These hourly expressed mass input rates are:

$\dot{M}_F$ = 50 grams/hours (Ev66),

$\dot{M}_{SL}$ = 50 grams/hour (Be72),

$\dot{M}_{FL}$ = 80 grams/hour (Ev66),

$\dot{M}_G$ = 60 grams/hour (Be72),

where $\dot{M}_F$ represents the mass flow rate of food, $\dot{M}_{SL}$ represents the mass flow rate of saliva, $\dot{M}_{FL}$ represents the mass flow rate of fluids, and $\dot{M}_G$ represents the mass flow rate of gastric secretions. Thus, the continuous total mass flow rate through the stomach, $\dot{M}_S$, is 240 grams per hour.

Eve (Ev66) determined that the mass content of the stomach, M_S, was 250 grams based on the standard daily throughput. Stomach emptying was considered to be exponential, and Eve defined the time, T_S, for the mass content to be reduced by a factor 'e' as a mean time of passage (or mean residence time). The mean time of passage for 250 grams was determined to be one hour.

This project considers mass to enter the stomach at the rate of 240 grams per hour. If it takes one hour for the main portion of the mass to pass through the stomach, then the standard mass content of the stomach, M_S, is 240 grams; that is,

$$M_S = \dot{M}_S T_S = 240 \text{ grams} . \qquad (2)$$

ICRP (IC59) also lists a mean residence time of one hour and a mass content of 250 grams for the stomach. The three sets of parameters values for the stomach along with values for other segments are given in Table 1.

In reference to the dosimetric models used here, it is noted that the time interval during which mass remains associated with a segment is defined as a mean residence time or mean time of passage only when the segment is considered a compartment where uniform, instantaneous mixing applies. The inverse of the associated mean residence time for mass in a compartment represents the instantaneous fraction of the contents or radionuclides transferred per unit time to the next segment or compartment in the tract. The catenary model assumes this situation for all segments of the tract.

The slug flow model considers the stomach as the only segment or compartment where uniform instantaneous mixing applies. The remainder of the GI Tract is considered as a perforated pipe through which food residues and secretions flow in a slug type fashion. As the slug moves through the gut (this partly leaking pipe), mass as well as radionuclides may be absorbed through the mucosa lining the tract. However, for the purposes of this study involving unabsorbed radionuclides, only mass is assumed to be lost from the slug. This is assumed to occur via a linear first order process and to occur only in the small intestine

TABLE 1

A SUMMARY OF PHYSIOLOGICAL PARAMETER

VALUES APPLICABLE TO THE

GASTROINTESTINAL TRACT

Segment	Standard Mass Content (gm)	Transit Time (h) (Mean Residence Time)
ICRP VALUES		
S	250	1.0
SI	1100	4.0
ULI	135	8.0
LLI	150	18.0
EVE'S VALUES		
S	250	1.0
SI	450 (Sk75)	4.0
ULI	220	13.0
LLI	135	24.0
PROJECT VALUES		
S	240	1.0
SI	580	4.0
CA	165	9.0
TLLI	160	28.0

and upper large intestine. Appropriate linear first order rate constants are chosen to maintain a mass and fluid balance in the tract. Thus a slug in each segment of the pipe travels through each dosimetrically important segment of the pipe for a time interval defined as the transit time. The transit and mean residence times are numerically equal for a given segment; however, a different action is mathematically modeled during these two physically meaningful time intervals.

The catenary compartmental model and the slug flow model both assume that gastric emptying is a linear first order process described by an appropriate rate constant that gives the instantaneous fraction of the stomach's mass that is removed and transferred to the small intestine per unit time. As noted above, this transfer rate constant is given by the inverse of the mean residence time for material in the stomach. If constant introduction of the radionuclide occurs for periods of time much longer than the mean residence time and if uniform, instantaneous mixing of the normal mass and the radionuclide occurs, the average dose equivalent rate, $\bar{\dot{H}}_S$, to the walls of the stomach is proportional to:

$$\bar{\dot{H}}_S = P\left[\frac{\lambda}{\lambda + \frac{1}{T_S}}\right]\frac{1}{M_S} \quad \text{, where} \qquad (3)$$

$P \equiv$ the radioactive atom introduction rate into the stomach,

$\lambda \equiv$ the decay constant for the single radionuclide,

$\frac{1}{T_S} \equiv$ mass transfer rate constant for the stomach,

$\frac{\lambda}{\lambda + \frac{1}{T_S}} \equiv$ fraction of the radioactive atoms entering the stomach that decay in the stomach. This is an absolute fraction, since a radionuclide is either transferred to the small intestine or it decays in the stomach.

The slug flow model additionally allows for the absorption of radioactive atoms through the mucosa lining the stomach, a situation not considered here. However, absorption of acidic lipid soluble substances does occur in the stomach (Be72) and special situations can be accounted for by using an appropriate rate constant to describe this absorption.

THE SMALL INTESTINE

Eve (Ev66) suggests that irradiation of certain cells of the small intestine may occur from all sides in the presence of beta emitting radiation. The tissue of concern would be the mitosing cells at the base of the crypts of Lieberkuhn. In the absence of other literature addressing this question, it is assumed that irradiation from one side only applies to each segment or compartment of the tract.

Originally the slug flow model used physiological parameters proposed by Eve. Skrable et al. [SK75], however, adjusted Eve's value for the mass content of the small intestine from 400 grams to 450 grams in order to maintain 135 grams of feces output each day. Based on values given by Bell et al. [Be72], an hourly expression of the daily mass input to the small intestine is summarized as follows:

$\dot{M}_S$ = 240 grams/hour (transferred from the stomach),

$\dot{M}_P$ = 30 grams/hour (Be72),

$\dot{M}_{IS}$ = 60 grams/hour (Be72),

$\dot{M}_B$ = 30 grams/hour (Be72),

where $\dot{M}_P$ represents the mass flow rate of pancreatic juice, $\dot{M}_{IS}$ represents the mass flow rate of intestinal secretions, and $\dot{M}_B$ represents the mass flow rate of bile. The total mass flow rate into the small intestine, $\dot{M}_{SI}$, is 360 grams/hour.

Eve's value of 400 grams for the mass content of the small intestine does not reflect the dilution volume presented by the cycling of fluids secreted into and absorbed from the small intestine each day. Bell et al. [Be72] indicate that saliva, gastric juice, bile, pancreatic juice, and intestinal secretions are absorbed through the walls of the small intestine along with nutrients contained in food and fluids. They also indicate that the absorption of foodstuffs in healthy individuals is virtually complete during passage through the small intestine (all carbohydrate, 95% of fat, 90% of protein). In addition, they list a value for the standard mass flow rate passing the ileocolic valve into the caecum, $\dot{M}_{ULI}$, as approximately 1000 grams per day. If one considers mass absorption to be a linear first order process and the transit time through the small intestine, T_{SI}, to be four hours (Sk74), then the instantaneous fraction of mass absorbed per unit time through the walls of the small intestine, λ_{SI}, is:

$$\lambda_{SI} = \frac{1}{T_{SI}} \ln \frac{\dot{M}_{SI}}{\dot{M}_{ULI}} ,$$

(4)

$$\lambda_{SI} = .55 \text{ hours}^{-1}.$$

Thus, by assuming slug flow, the standard mass content of the small intestine, M_{SI}, is:

$$M_{SI} = \frac{\dot{M}_{SI}}{\lambda_{SI}} \left(1 - e^{-\lambda_{SI} T_{SI}} \right) ,$$

(5)

$$M_{SI} = 580 \text{ grams}.$$

A summary of physiological parameters applicable to the small intestine is given in Table 1.

Development of dosimetric equations describing the average dose equivalent rate to the small intestine are found in (Be70) and (Sk75). Proportionalities are reproduced here:

Catenary Compartmental Model:

$$\bar{\dot{H}}_{SI} = \left[\frac{\frac{1}{\tau_S}}{\lambda + \frac{1}{\tau_S}}\right] P \left[\frac{\lambda}{\lambda + \frac{1}{\tau_{SI}}}\right] \frac{1}{M_{SI}} \text{ , where} \tag{6}$$

$\bar{\dot{H}}_{SI}$ ≡ average dose equivalent rate to the walls of the small intestine,

τ_{SI} ≡ mean residence time of the mass content of the small intestine.

Again the dosimetric equations presented here were developed by assuming that constant introduction of the radionuclide occurs for periods of time much longer than the mean residence time associated with a particular segment.

Slug Flow Model:

$$\bar{\dot{H}}_{SI} \propto \left[\frac{\frac{1}{\tau_S}}{\lambda + \frac{1}{\tau_S}}\right] P \left(1 - e^{-\lambda\tau_{SI}}\right). \tag{7}$$

It is to be noted that dosimetric equations (6) and (7) differ only because of the factors $\frac{\lambda}{\lambda + 1/\tau_{SI}}$ and $1 - e^{-\lambda\tau_{SI}}$ which result respectively from the assumptions of uniform instantaneous mixing and slug flow in the small intestine. The quotient of the slug flow factor by the catenary model factor has a maximum value of 1.098 for a λT_{SI} value of 1.793. For $\lambda T_{SI} << 1$ (e.g., long lived radionuclides) or $\lambda T_{SI} >> 1$ (e.g., short lived radionuclides), the factors are equal. Thus for the same input rate into the small intestine the two models yield average dose equivalent rates which differ by only a small percentage. It can be shown that the percentage difference would be even smaller for doses delivered by serially related radionucldies; however, the input rates to the segment considered must be equal (Sk74).

THE UPPER LARGE INTESTINE

From previous considerations involving the physiology of the small intestine, it is apparent that water is the major component of unabsorbed residues entering the upper large intestine. Bell et al. [Be72] indicated that the mass of this residue is much reduced during its passage through the caecum and ascending colon, the first two sub-segments of the upper large intestine. The standard mass flow rate at the hepatic flexure, $\dot{M}_T$, is approximately 135 grams per day. Dosimetrically this is important since the dose equivalent rate is proportional to the specific activity. Eve suggests the entire upper large intestine as the dosimetrically important segment; however, little absorption of water occurs in the transverse colon. Eve's values for the mean residence time, T_{ULI}, and the mass content, M_{ULI}, for the upper large intestine are 13 hours and 220 grams, respectively.

If one considers the transit time through the caecum and ascending colon T_{CA}, to be 9 hours (Be72), then the instantaneous fraction of mass absorbed per unit time, λ_{CA}, through the walls of the caecum and ascending colon is:

$$\lambda_{CA} = \frac{1}{T_{CA}} \ln\left(\frac{\dot{M}_{ULI}}{\dot{M}_T}\right), \qquad (8)$$

$$\lambda_{CA} = .22 \text{ hours}^{-1}.$$

Thus assuming slug flow the standard mass content of the caecum and ascending colon, M_{CA}, is:

$$M_{CA} = \frac{\dot{M}_{ULI}}{\lambda_{CA}}\left(1 - e^{-\lambda_{CA} T_{CA}}\right), \qquad (9)$$

$$M_{CA} = 165 \text{ grams}.$$

A summary of physiological parameters applicable to the upper large intestine or the caecum and ascending colon is given in Table 1.

Proportionalities describing the average dose equivalent rate to the upper large intestine, $\bar{\dot{H}}_{ULI}$, under the conditions of constant, continuous intake of a single, unabsorbed, particle emitting radionuclide are:

Catenary Compartmental Model:

$$\bar{\dot{H}}_{ULI} = \left[\frac{\frac{1}{T_S}}{\lambda + \frac{1}{T_S}}\right]\left[\frac{\frac{1}{T_{SI}}}{\lambda + \frac{1}{T_{SI}}}\right] \propto \left[\frac{\lambda}{\lambda + \frac{1}{T_{ULI}}}\right] \frac{1}{M_{ULI}} \quad \text{, and} \tag{10}$$

$$\bar{\dot{H}}_{CA} = \left[\frac{\frac{1}{T_S}}{\lambda + \frac{1}{T_S}}\right]\left[\frac{\frac{1}{T_{SI}}}{\lambda + \frac{1}{T_{SI}}}\right] \propto \left[\frac{\lambda}{\lambda + \frac{1}{T_{CA}}}\right] \frac{1}{M_{CA}} \quad . \tag{11}$$

Slug Flow Model:

$$\bar{\dot{H}}_{ULI} = \left[\frac{\frac{1}{T_S}}{\lambda + \frac{1}{T_S}}\right]\left(e^{-\lambda T_{SI}}\right) \propto \left(1 - e^{-\lambda T_{ULI}}\right) \frac{1}{M_{ULI}} \quad \text{, and} \tag{12}$$

$$\bar{\dot{H}}_{CA} = \left[\frac{\frac{1}{T_S}}{\lambda + \frac{1}{T_S}}\right]\left(e^{-\lambda T_{SI}}\right) \propto \left(1 - e^{-\lambda T_{CA}}\right) \frac{1}{M_{CA}} \quad . \tag{13}$$

It is to be noted that the effective atom input rates to the upper large intestine predicted by Equations (10) and (12) (or by analogy, Equations (11) and (13)) differ. The quotient of the slug flow effective atom input rate to the upper large intestine, P^S_{ULI}, by the catenary model effective atom input rate, P^C_{ULI}, is given by:

$$\frac{P^{S}_{ULI}}{P^{C}_{ULI}} = \frac{e^{-\lambda T_{SI}}}{\frac{1/T_{SI}}{\lambda + \frac{1}{T_{SI}}}} = \left(1 + \lambda T_{SI}\right) e^{-\lambda T_{SI}} . \qquad (14)$$

For short lived radionuclides (e.g., $\lambda T_{SI} >> 1$), the effective atom input rates differ by a large factor. The atom input rate predicted by the slug flow model in such cases is substantially less than the value predicted by the catenary model. In effect the catenary model tends to predict larger activities and doses in the lower segments as compared to those predicted by the slug flow model. Thus the critical segment predicted by either model may differ for the shorter lived radionuclides.

For long lived radionuclides (e.g., $\lambda T_{SI} << 1$), both models predict the same effective input rates; therefore, the doses to the upper large intestine (or by analogy the doses to the caecum and ascending colon) would not differ significantly, as already shown for the small intestine where the input rates are identical.

THE LOWER LARGE INTESTINE

Defecation is a complex act and involves contraction of the rectum and the pelvic colon. The pelvic floor is pulled up over the fecal mass and a large portion of the mass content of the lower large intestine is eliminated. A routine elimination of 80 grams every 13 hours or 200 grams every 33 hours is an individual characteristic. Ball et al. [Ba72] indicate an average of 135 grams eliminated in circadian fashion.

In this study the remainder of the tract is considered a long pipe from which no mass is absorbed, and the rectum an exit through which mass is passed quickly. Thus this TLLI segment includes the mass content of the transverse colon and lower large intestine. The transit time of mass through the TLLI segment, T_{TLLI}, is the sum of the transit times for the lower large intestine and transverse colon, approximately 28 hours. The standard mass content of this segment, M_{TLLI}, is thus

$$M_{TLLI} = \dot{M}_I \, T_{TLLI} \quad , \tag{15}$$

$$M_{TLLI} = 160 \text{ grams} \quad .$$

Eve indicates that the mass content for the lower large intestine, M_{LLI}, is 135 grams and the mean residence time, T_{LLI}, is 24 hours. These values reflect a single elimination of the entire mass content of the descending and pelvic colons on a daily basis. This project also considers a mass output of 135 grams each day from the end portion of the colon; however, immediately after defecation the TLLI segment still contains 25 grams of mass, primarily in the transverse colon. This mass moves down the tract to fill the pelvic colon, and during the next 24 hours an additional 135 grams of mass enters into the TLLI segment. Again a 135 gram slug of mass is cut off and forced out, and the cycle is repeated.

A summary of physiological parameters applicable to the LLI or TLLI segment is given in Table I.

Proportionalities describing the average dose equivalent rate to the lower large intestine following continuous ingestion of a single, unabsorbed, particle emitting radionuclide are:

Catenary Compartmental Model:

$$\bar{\dot{H}}_{LLI} = \left[\frac{\frac{1}{T_S}}{\lambda + \frac{1}{T_S}}\right]\left[\frac{\frac{1}{T_{SI}}}{\lambda + \frac{1}{T_{SI}}}\right]\left[\frac{\frac{1}{T_{ULI}}}{\lambda + \frac{1}{T_{ULI}}}\right] P \left[\frac{\lambda}{\lambda + \frac{1}{T_{LLI}}}\right] \frac{1}{M_{LLI}} , \qquad (16)$$

Slug Flow Model:

$$\bar{\dot{H}}_{LLI} = \left[\frac{\frac{1}{T_S}}{\lambda + \frac{1}{T_S}}\right]\left(e^{-\lambda T_{SI}}\right)\left(e^{-\lambda T_{ULI}}\right) P \left(1 - e^{-\lambda T_{LLI}}\right) \frac{1}{M_{LLI}} . \qquad (17)$$

Analogous equations may be written for the TLLI segment by replacing M_{LLI} with M_{TLLI} and T_{LLI} with T_{TLLI}. This replacement mathematically extends the segment of concern up to the hepatic flexure. All proportionalities presented here represent the average dose equivalent rate to any segment of concern and are used to determine the maximum permissible daily activity ingestion rates for standard man.

Figure 2 illustrates a mass input/output balance for the physiological parameters used here. These parameters, Eve's parameters, and those given by ICRP are used to calculate the maximum permissible daily activity injestion rates for single unabsorbed radionuclides with an effective energy term of unity (Table 2). Table 3 lists the critical decay constants for the six different cases studied, and Figure 3 illustrates the maximum and minimum calculated values for the maximum permissible daily activity ingestion rate.

TABLE 2

MAXIMUM PERMISSIBLE DAILY ACTIVITY

INGESTION RATES FOR SINGLE, UNABSORBED

PARTICLE EMITTING RADIONUCLIDES

WITH AN EFFECTIVE ENERGY TERM OF

UNITY

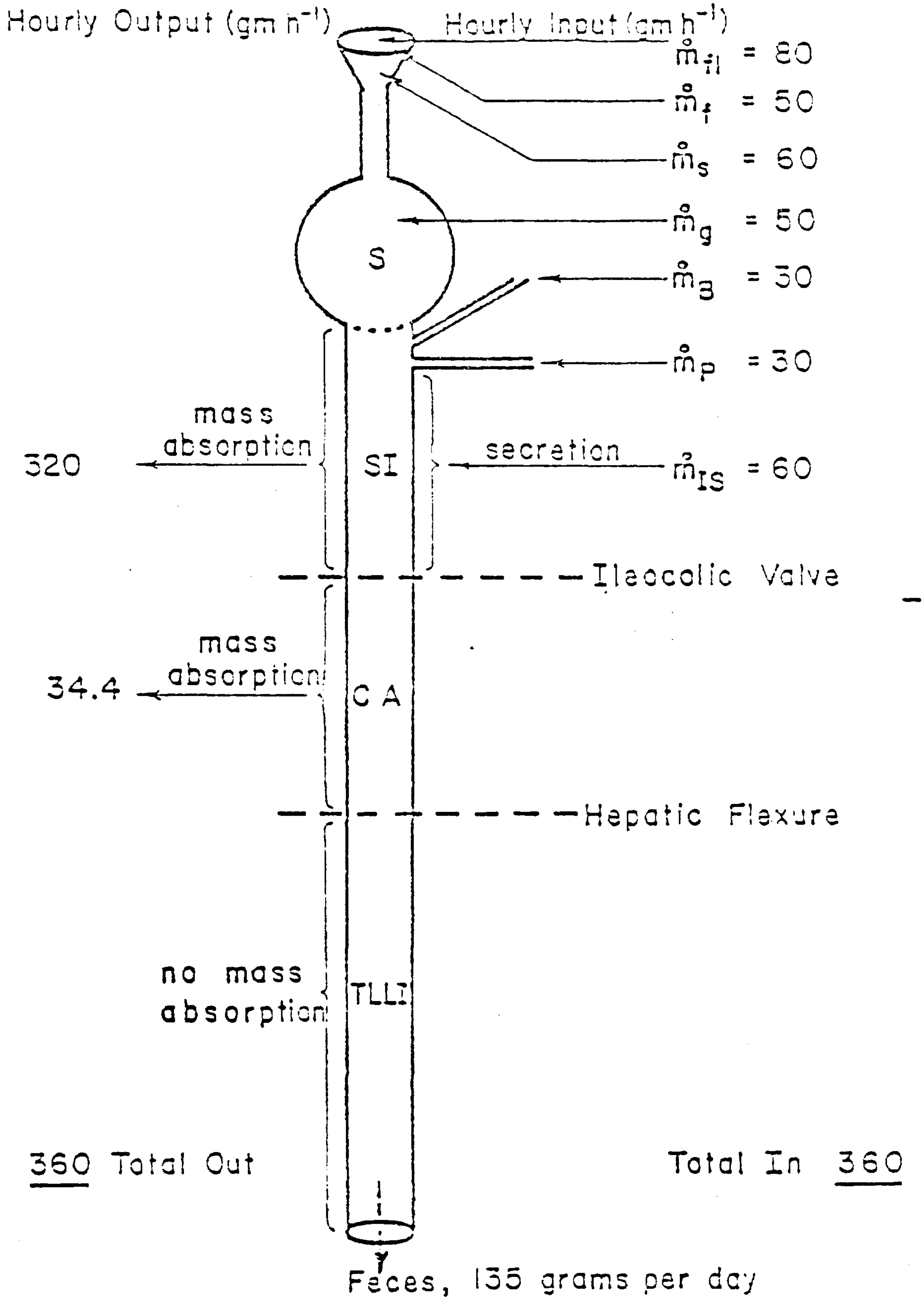
Decay Constant	CATENARY COMPARTMENT MODEL						SLUG FLOW MODEL					
	Eve's Parameters		ICRP Parameters		Project Parameters		Eve's Parameters		ICRP Parameters		Project Parameters	
λ (h^{-1})	µCi/d	CS*	µCi/d	CS*	µCi/d	CS*	µCi/d	CS*	µCi/d	CS*	µCi/d	CS*
.01	.333	LLI	.449	LLI	.337	TLLI	.305	LLI	.417	LLI	.303	TLLI
.02	.465		.583		.466		.403		.518		.397	
.03	.624		.738		.619		.544		.640		.517	
.04	.813		.913		.799		.722		.790		.663	
.05	1.03		1.12		1.01		.955		.973		.859	
.06	1.29		1.32	ULI	1.25		1.26		1.15	ULI	1.10	
.07	1.59		1.45		1.52		1.47	ULI	1.26		1.39	
.08	1.92		1.59		1.80	CA	1.63		1.37		1.54	CA
.09	2.19	ULI	1.73		1.97		1.80		1.49		1.68	
0.1	2.41		1.88		2.16		2.00		1.62		1.83	
0.2	5.29		3.81		4.46		5.11		3.63		4.25	
0.3	9.54		6.60		7.80		10.1	SI	7.73		9.21	
0.4	14.1	S	10.4		12.3		12.7		14.1	S	13.5	S
0.5	15.1		15.1	S	14.5	S	15.1	S	15.1		14.5	
0.6	16.1		16.1		15.5		16.1		16.1		15.5	
0.7	17.1		17.1		16.4		17.1		17.1		16.4	
0.8	18.1		18.1		17.4		18.1		18.1		17.4	
0.9	19.1		19.1		18.3		19.1		19.1		18.3	
1.0	20.1		20.1		19.3		20.1		20.1		19.3	
2.0	30.2		30.2		29.0		30.2		30.2		29.0	
3.0	40.2		40.2		38.6		40.2		40.2		38.6	
4.0	50.3		50.3		48.3		50.3		50.3		48.3	
5.0	60.3		60.3		57.9		60.3		60.3		57.9	
6.0	70.4		70.4		67.6		70.4		70.4		67.6	
7.0	80.5		80.5		77.2		80.5		80.5		77.2	
8.0	90.5		90.5		86.9		90.5		90.5		86.9	
9.0	101		101		96.5		101		101		96.5	
10.0	111		111		106		111		111		106	

*Critical Segment

(

Figure 2

MASS FLOW INPUT/OUTPUT BALANCE



Hourly Output (gm h⁻¹)
Hourly Input (gm h⁻¹)
$\mathring{m}_{fl}$ = 80
$\mathring{m}_f$ = 50
$\mathring{m}_s$ = 60
$\mathring{m}_g$ = 50
$\mathring{m}_B$ = 30
$\mathring{m}_P$ = 30
S
mass absorption
320
SI
secretion
$\mathring{m}_{IS}$ = 60
Ileocolic Valve
mass absorption
34.4
CA
Hepatic Flexure
no mass absorption
TLLI
360 Total Out
Total In 360
Feces, 135 grams per day

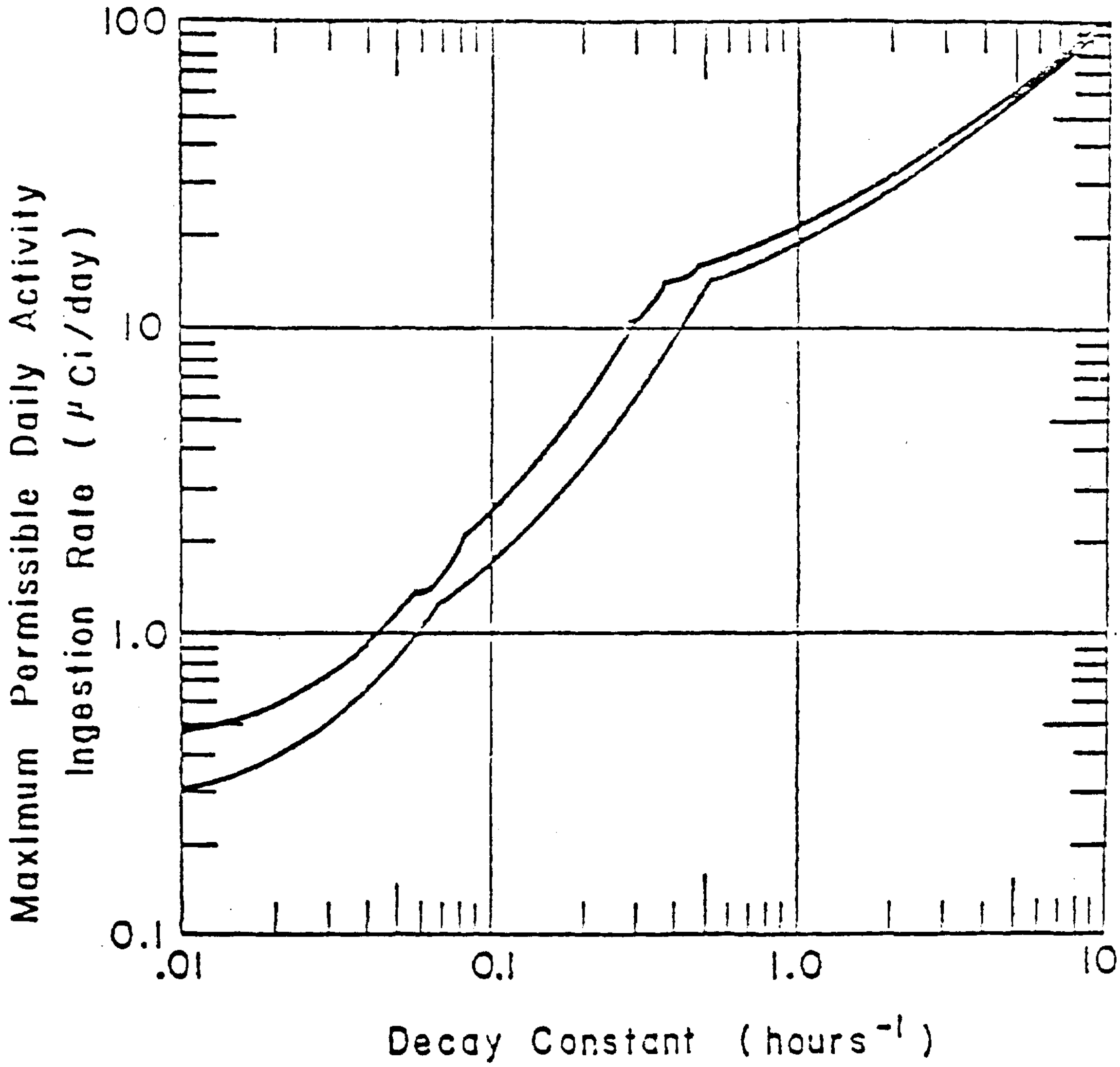
Table 3

CRITICAL DECAY CONSTANTS

PARAMETER VALUES, MATHEMATICAL MODEL	CRITICAL DECAY CONSTANTS (h^{-1})	CRITICAL SEGMENT
Eve, Catenary Model	$\lambda \leq .0837$ $.0837 \leq \lambda \leq .377$ $\lambda \geq .377$	LLI ULI S
ICRP, Catenary Model	$\lambda \leq .0569$ $.0569 \leq \lambda \leq .496$ $\lambda \geq .496$	LLI ULI S
Project, Catenary Model	$\lambda \leq .0739$ $.0739 \leq \lambda \leq .426$ $\lambda \geq .425$	TLLI CA S
Eve, Slug Flow	$\lambda \leq .0631$ $.0631 \leq \lambda \leq .274$ $.274 \leq \lambda \leq .442$ $\lambda \geq .442$	LLI ULI SI S
ICRP, Slug Flow	$\lambda \leq .0569$ $.0569 \leq \lambda \leq .332$ $\lambda \geq .382$	LLI ULI S
Project, Slug Flow	$\lambda \leq .0706$ $.0706 \leq \lambda \leq .347$ $\lambda \geq .347$	TLLI CA S

Figure 3

MAXIMUM AND MINIMUM VALUES
FOR THE MAXIMUM PERMISSIBLE DAILY
ACTIVITY INGESTION RATE



100
10
1.0
0.1
.01
0.1
1.0
10
Maximum Permissible Daily Activity
Ingestion Rate (μCi/day)
Decay Constant (hours⁻¹)

CONCLUSION

Figure 2 illustrates the physiological occurrences obtained for the gastrointestinal tract. Food and fluid input and feces output are in agreement with that proposed by Eve. Disagreement about the standard mass content of the small intestine and the choice of critical segments for the remainder of the tract is apparent. However, changes in the physiological parameters over the ranges studied do not significantly alter the maximum permissible daily activity ingestion rates for single, unabsorbed, particle emitting radionuclides (Table 2).

Additionally, the mathematical models used here do not yield significantly different values for the cases studied. It is noted that uniform instantaneous mixing and slug flow represent two extremes of mass transfer and movement, whereas the true nature of the passage of mass through the tract is probably between these two extremes. That is, motion of the tract would tend to mix the contents in a segment and between segments; however, mass is released to the small intestine at a rate which the small intestine can handle, and it leaves the lower large intestine in a slug type fashion.

It is recommended that the choice of a mathematical model be predicated upon simplicity. The catenary compartmental model is not mathematically cumbersome even for serially related radionuclides which were not specifically addressed here. The slug flow model can be directly related to physiological data such as mass flow rates at various points along the tract, thus allowing for estimation of instantaneous dose rates at these points. However, dosimetry involving photon emitting radionuclides in the tract should be done using the catenary model since calculations would be simpler than ones involving a slug flow description in which the distribution of radioactive material is non-uniform.

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MARSHALL ISLANDS RADIOLOGICAL FOLLOWUP*

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Abstract

In August, 1968, President Johnson announced that the people of Bikini Atoll would be able to return to their homeland. Thereafter, similar approval was given for the return of the peoples of Enewetak. These two regions, which comprised the Pacific Nuclear Testing Areas from 1946 to 1958, will probably be repopulated by the original inhabitants and their families within the next year. As part of its continuing responsibility to insure the public health and safety in connection with the nuclear programs under its sponsorship, ERDA (formerly AEC) has contracted Brookhaven National Laboratory to establish radiological safety and environmental monitoring programs for the returning Bikini and Enewetak peoples. These programs are described in the following paper. They are designed to define the external radiation environment, assess radiation doses from internal emitters in the human food chain, make long range predictions of total doses and dose commitments to individuals and to each population group, and to suggest actions which will minimize doses via the more significant pathways.

Introduction

The U.S. nuclear testing programs of the 1940s and 1950s had significant local environmental impacts on the coral atolls of Bikini and Enewetak in the Marshall Islands. The high level close-in fallout made these atolls uninhabitable for many years. Fallout from the BRAVO event, which took place at Bikini in 1954, was inadvertently deposited on the nearby atolls of Rongelap, Rongerik and Utirik. In all, some thirteen atolls in the northern Marshalls were probably affected to a greater or lesser extent by fallout from these nuclear tests. Of these, however, the most significant long term radiological impact was on the test atolls, Bikini and Enewetak, and on Rongelap Atoll.

In 1957, Rongelap was reoccupied by its original inhabitants who had been evacuated two days after BRAVO. During the past several years, definitive plans have been made to repatriate the original inhabitants of Bikini and Enewetak Atolls, and their families. It is hoped that their return can take place soon.

In order to identify radiological problems from residual radioactivity in the environment, and to provide a data base for dose predictions applicable to the returning populace, ERDA (and its predecessor, the AEC), has sponsored many radiological surveys in the Marshall Islands. These surveys began during test operations and have been conducted periodically up to the present time. Results of the surveys have been published in numerous reports and scientific journals. References 1 through 12 are published reports of AEC/ERDA supported surveys of these atolls. References 13 through 29 are a portion of the published reports on work with collected environmental samples supported by AEC/ERDA.

Evaluation of survey results for Bikini Atoll, the consideration of predicted exposures compared with applicable radiation standards, and the acknowledgement of the many benefits to the people if they could return, led to the decision to clean up and rehabilitate that atoll. The Department of Defense, Department of the Interior (DOI), and AEC (now ERDA) participated in a joint effort of clean up and rehabilitation of Bikini Atoll starting in February, 1969. Clean up was completed in the fall of that year. Agricultural rehabilitation and housing construction is being conducted by DOI.

The decision to return the Enewetakese to their atoll led to a comprehensive survey conducted at Enewetak in 1972-1973.[10] A regional survey planned for 1976 will provide baseline radiological data for future dose assessments throughout nearly all of the northern Marshall Islands which may have been affected by the testing program. Environmental evaluations at Rongelap and Utirik Atolls have been undertaken periodically in association with ERDA's medical evaluations program there over the past 20 years.[30-42]

From all of these earlier surveys, it became apparent that periodic environmental monitoring and dose assessments must be made for Bikini, Enewetak, Rongelap and perhaps other atolls in the northern Marshalls to maintain a current radiological data base and to provide current information on individual and population doses. This followup monitoring is being performed by Brookhaven National Laboratory at the request of the Division of Operational Safety, U.S. Energy Research and Development Administration.

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*Research carried out at Brookhaven National Laboratory under the auspices of the U. S. Energy Research and Development Administration.

DRAFT

AN INTERCOMPARISON OF NATURAL AND TECHNOLOGICALLY ENHANCED BACKGROUND RADIATION LEVELS IN MICRONESIA

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ABSTRACT

The United States Pacific Nuclear Testing Program resulted in local and regional fallout contamination of islands in the central Pacific basin, in an area which is generically known as Micronesia. Most of this contamination affected the Northern Marshall Islands of eastern Micronesia, which either served as the actual test sites or which were in relatively close proximity to them. Since all of the Marshall Islands are low coral islands or atolls, the natural radioactivity content of their soil is among the lowest on earth; and their natural radiation environment is dominated by the contribution of cosmic rays. In contrast, the high islands of the Caroline groups, to the west of the Marshalls, are characterized by volcanic soils having a significant complement of radionuclides in the uranium and thorium chains. Several field trips by S&EP Division personnel to Micronesia between 1975 and 1980 have afforded opportunities to study the natural radiation environments of the coral atolls of the Marshalls and several high islands in the Carolines; and to evaluate the contributions of fallout fission and activation products to the inventories of soil radioactivity in these locations. The analytical methods employed included in situ gamma spectrometry and exposure rate measurements with pressurized ion chamber survey instruments. These measurments were supplemented by laboratory analyses of soil samples. The results of these studies have indicated that significant contributions from radioactive fallout can be evaluated in situ with relative ease on coral islands. In contrast, the higher natural radioactivity content of high island soils,

as well as the greater distance of these islands from the test areas, combine to make evaluations of local fallout contributions from U. S. Pacific tests indistinguishable from the contributions of the world-wide fallout.

INTRODUCTION

Many small-scale radiological surveys were conducted during the 1950's and 1960's at or near the Pacific testing areas in the northern Marshall Islands; however, definitive evaluations of the impacts of residual fallout radioactivity were not made until the 1970's (1-5). These evaluations were conducted on those islands known or suspected to be contaminated by tropospheric fallout from the tests at Bikini and Enewetak Atolls. Environmental studies of peripheral areas in the central Pacific were conducted on a small scale during the testing years (1946-1958) by the University of Washington, and thereafter in 1975, 1979, and 1980 by Brookhaven National Laboratory as well. Those studies yielded significant data on background radiation levels in these areas, and form the basis for this report.

The Marshall Islands are all comprised of coral atolls or partially drowned atolls formed by coral limestone accretions on subsiding volcanic bases. Drilling studies at Enewetak established that the limestone cap may exceed 1280 meters in thickness (6). As a result, the contributions of the uranium and thorium series to the radiation environment in the Marshalls are virtually nil. External background radiation levels on those islands which are remote from the test sites are dominated by cosmic radiation supplemented by small contributions from ^{40}K, cosmogenic radionuclides and world-wide fallout. These coral islands exemplify some of the lowest terrestrial radiation environments on earth.

In contrast, the Caroline Islands, immediately west of the Marshalls (Fig. 1) are comprised of high volcanic islands with fringing coral reefs, as well as coral atolls and islands. The high island soils contain ^{232}Th and ^{238}U and their daughters. The additional contributions of gamma emitters among these radionuclides result in background exposure rates (at 1 meter above the ground) which are nearly a factor of two higher than those similarly measured on the coral atolls (Table 1). Contributions of stratospheric and tropospheric fallout are, of course, superimposed on these natural background radiation sources.

METHODS

Data for this study were obtained during three field trip years (1975, 1979 and 1980). The first of the field trips was conducted jointly with the University of Washington, Laboratory of Radiation Ecology (LRE), which was responsible for determining background concentrations of fallout radionuclides in soil and in terrestrial and marine biota (7). Brookhaven National Laboratory (BNL) was tasked with the measurement of external background radiation. Subsequent field trip activities focused on external radiation measurements only.

The measurement sites were generally restricted to the District Centers of the Trust Territory of the Pacific Islands because of their accessibility via commercial airline. The Trust Territory was the United Nations-established region which encompassed most of Micronesia. It is presently being phased out with the formation of several sovereign states within this region. Data are also included for some of the central and southern Marshall Islands which were reached by U. S. Department of Energy field trips ships.

Field measurements of external radiation were conducted with a pressurized ion chamber environmental radiation monitor, and by in situ gamma spectrometry with (5 cm X 5 cm) sodium iodide scintillation detectors. Soil samples were also collected at most of the measurement sites. These were later analyzed in the laboratory for gamma emitters by high resolution gamma spectrometry; and for $^{90}Sr/^{90}Y$, and in some cases ^{239}, ^{240}Pu by radiochemical separation and counting. Data on strontium and transuranics are not included in this report.

The primary purpose of the in situ gamma spectral measurements was to provide a data base for energy dependence corrections for the stainless steel-walled ion chamber detector. As a result the measurements were made at low resolution (100 KeV per channel) from 0 to 2.5 MeV. A programmable calculator was used to fold the gamma spectra into the ion chamber response characteristic to correct for energy dependence in the environmental radiation monitor. Correction factors were typically about +5%.

The ion chamber instrument presented the instantaneous exposure rate digitally in μR/hr based on samplings of the ambient exposure rate a few times per second. The average exposure rate data presented in this report represent the energy-corrected means (±1σ) for ten or more instantaneous readings taken over several minutes.

RESULTS AND ANALYSIS

Table 1 presents the means (±1σ) of exposure rate measurements at various locations in Micronesia. Soil samples (Table 2) from these areas were analyzed for gamma-emitting radionuclides by the University of Washington, Laboratory for Radiation Ecology (3, 7) and by Brookhaven National Laboratory. The vertical distribution of fallout nuclides in the soil was determined by vertical sampling profiles to a depth of 50 cm. Activity concentrations of ^{137}Cs tended to decrease exponentially with depth, with a "relaxation length" of about 5 cm^2g^{-1}. Areal depositions of ^{137}Cs were calculated by integration of the depth distribution determined from the vertical sampling profiles. Exposure rates were then calculated by applying the coefficient for ^{137}Cs at 4.8 cm^2g^{-1} from EML-378 (8). These samples were also analyzed for ^{40}K and for the uranium and thorium chains for which the vertical profile data were averaged at each sample location. The respective exposure rate contributions were calculated from coefficients in HASL-195 (9). The cosmic ray contribution was assumed to be 3.2 μR/hr. (10).

Attempts were made to reconstruct ambient background exposure rates from soil analyses and the cosmic ray contribution at Majuro, Ponape and Truk. These data are presented in Tables 3, 4 and 5. These locations are sufficiently distant (> 500 km) from the test sites (Bikini and Enewetak Atolls in the northern Marshalls) that no evidence could be found to suggest that they received tropospheric fallout from the atmospheric nuclear tests at these sites. Comparisons of measured exposure rates at Majuro with those at Kwajalein, Wotje and Ailuk Atolls in the central and eastern Marshalls (Table 1) tend to support this contention; however, firm conclusions must await the publica-tion of the results of the Northern Marshall Islands Radiological Survey, a large-scale environmental assessment of the regional impact of the testing program performed in 1978.

It should be noted that exposure rates measured at Rongelap and Utirik Atolls, in the northern and northeastern Marshalls respectively, are significantly higher than those in the central and southern islands. Rongelap and Utirik are known to have been contaminated by the Bravo Test on March 1, 1954, and virtually all of the contemporary incremental exposure rates above background at these sites is attributable to residual ^{137}Cs contamination in the soil and vegetation.

The reconstructed exposure rate at Majuro (Table 3) is reasonably close to the measured value. The difference is attributed to the exposure rate contribution from ^{40}K in biota (for which no assessment was included in the calculated value), and to uncertain-ties in the soil analyses. Tables 4 and 5 present similar analyses for Ponape and Truk, both high volcanic islands in the Caroline group to the west of the Marshalls. These islands differed from Majuro by virtue of the contributions of the uranium and thorium chains in their volcanic soils, and their higher annual rainfall. Comparisons of measured and calculated exposure rates at Truk were excellent. The significant difference between the two values at Ponape is attributed primarily to uncertainties in the soil analyses.

CONCLUSIONS

Background exposure rates may be accurately reconstructed from careful analyses of soil gamma emitters and the contribution of cosmic rays. In situ measurements of exposure rates will reflect significant contributions above background of fallout gamma emitters, especially in locations where contributions of the uranium and thorium chains can be ignored. It is intuitively obvious that a continuum exists geographically between areas which received worldwide and tropospheric fallout and those which received only stratospheric (or worldwide) fallout. The islands of Micronesia exhibit this continuum such that beyond about five hundred kilometers from the test sites it may be impossible to distinguish between the contributions to contemporary environmental exposures from U. S. Pacific nuclear tests and those attributable to multinational worldwide fallout.

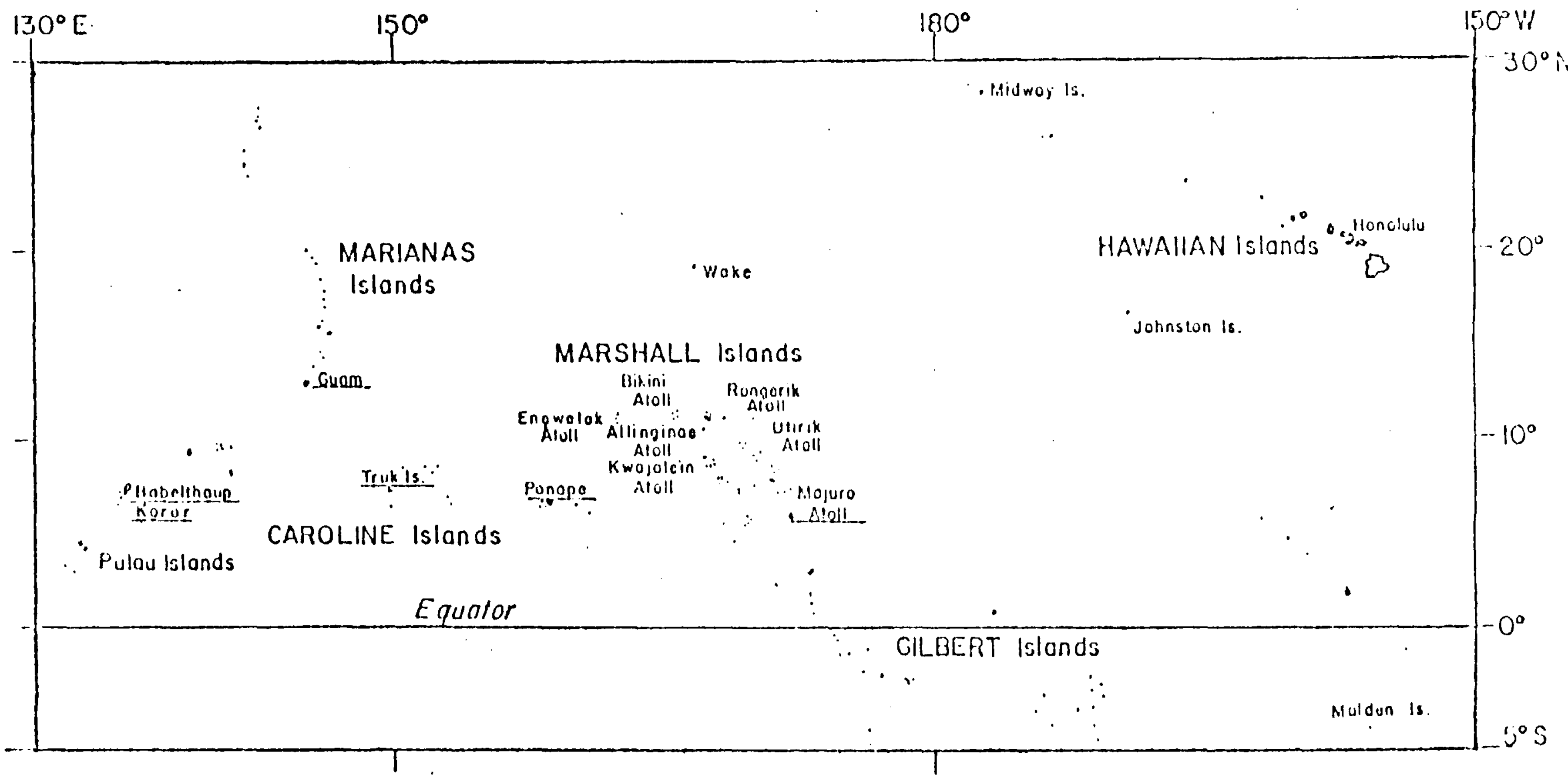
130° E
150°
180°
150° W
30° N
20°
10°
0°
5° S
Midway Is.
MARIANAS Islands
Wake
HAWAIIAN Islands
Honolulu
Johnston Is.
MARSHALL Islands
Guam
Bikini Atoll
Rongerik Atoll
Enewetak Atoll
Allinginae Atoll
Utirik Atoll
Kwajalein Atoll
Truk Is.
Ponape
Majuro Atoll
Babelthaup
Koror
CAROLINE Islands
Palau Islands
Equator
GILBERT Islands
Muldun Is.

FIGURE 1

TABLE 1

EXPOSURE RATE DATA FOR
VARIOUS LOCATIONS IN MICRONESIA

LOCATION	ISLAND TYPE (date)	LOCATION	AVG. EXPOSURE RATE (μR/hr.)	NUMBER OF MEASUREMENTS
Majuro, Majuro	Coral Atoll (11/75)	Southern Marshall Is	3.7 ± 0.3	65
Roi-namur Kwajalein	Coral Atoll (9/76)	Central Marshall Is	3.4 ± 0.2	180
Ormej, Wotje	Coral Atoll (9/76)	East Central Marshall Is	3.7 ± 0.3	180
Wotje, Wotje	Coral Atoll (9/76)	East Central Marshall Is	3.8 ± 0.3	119
Ailuk, Ailuk	Coral Atoll (9/76)	East Central Marshall Is	3.8 ± 0.4	155
Utirik,[a] Utirik	Coral Atoll (9/76, 10/77)	Norhteastern Marshall Is	4.1 ± 0.5	270
Aon,[a] Utirik	Coral Atoll (9/76)	Northeastern Marshall Is	4.1 ± 0.3	90
Rongelap,[b] Rongelap	Coral Atoll (9/76, 10/77)	Northern Marshall Is	7.1 ± 1.1	380
Bikini,[c] Bikini	Coral Atoll (9/75)	Northern Marshall Is	~40 (range ~ 10-100)	> 1000
Kolonia, Ponape	High Volcanic (11/75)	Eastern Caroline Is	6.5 ± 0.5	90
Moen, Truk	High Volcanic (11/75)	Central Caroline Is	6.5 ± 0.6	30

(a) Contaminated by Bravo Test, 1954.
(b) Heavily contaminated by Bravo Test, 1954
(c) Pacific Nuclear Test Site. Data from BNL 51003 (5) and UCRL-51879, rev.1. (2).

TABLE 2

AVERAGE GAMMA-EMITTING RADIONUCLIDE CONTENT OF SOME MICRONESIAN SOILS

LOCATION	NUCLIDE	ACTIVITY CONCENTRATION[(a)] OR INTEGRATED AREAL DEPOSITION
Majuro, Marshall Islands	^{137}Cs	0.43 pCi/cm^2
Majuro, Marshall Islands	^{40}K	0.70 pCi/g
Ponape, Eastern Caroline Islands	^{137}Cs	2.51 pCi/cm^2
Ponape, Eastern Caroline Islands	^{40}K	< 0.22 pCi/g
Ponape, Eastern Caroline Islands	U	1.81 ppm
Ponape, Eastern Caroline Islands	Th	9.17 ppm
Truk, Central Caroline Islands	^{137}Cs	4.71 pCi/cm^2
Truk, Central Caroline Islands	^{40}K	< 0.22 pCi/g
Truk, Central Caroline Islands	U	2.18 ppm
Truk, Central Caroline Islands	Th	5.62 ppm

(a) Data derived from soil sample analyses by University of Washington LRE, NVO-269-35(7), and Brookhaven National Laboratory (unpublished data).

TABLE 3

CALCULATED EXPOSURE RATE FOR MAJURO, M. I. BASED ON SOIL

SOURCE	BASIS	CALCULATED[b] EXP. RATE (μR/hr.)
^{137}Cs	Avg. Deposition 0-10° N. Lat. (a) 2.1 pCi/cm²	8.9×10^{-2}
^{137}Cs	Soil Sample Analyses: 0.43 pCi/cm²	1.9×10^{-2}
^{40}K	Soil Sample Analyses: 0.7 pCi/g	3.0×10^{-2}
Cosmic	(a)	3.2
	Total Calculated	3.3 μR/hr.
	Total Measured	3.7 ± 0.3 μR/hr.

(a) UNSCEAR (11)

(b) EML-378 (8), HASL-195 (9)

TABLE 4

CALCULATED EXPOSURE RATE
FOR KOLONIA, PONAPE BASED
ON SOIL RADIOANALYSES

SOURCE	BASIS (a)	CALCULATED (b) EXP. RATE (μR/hr.)
U chain	Soil Analyses ^{238}U, ^{226}Ra, ^{214}B	1.2
Th chain	Soil Analyses ^{232}Th, ^{228}Th, ^{212}Pb	2.8
^{40}K	(c)	< 0.1
^{137}Cs	Soil Analyses 2.7 pCi/cm^2	0.1
Cosmic		3.2
	Total Calculated	7.4 μR/hr
	Total Measured	6.5 ± 0.5 μR/hr.

(a) Soil data from University of Washington, Rpt. NVO-269-35 ([illegible]) and Brookhaven National Laboratory (unpublished)

(b) EML-378 ([illegible]) and HASL-195 (9)

(c) UNSCEAR (11)

TABLE 5

CALCULATED EXPOSURE RATE FOR TRUK[(a)] BASED ON SOIL RADIOANALYSES

SOURCE	BASIS[(b)]	CALCULATED[(c)] EXP. RATE (μR/hr.)
U chain	Soil Analyses ^{238}U, ^{226}Ra	1.4
Th Chain	Soil Analyses ^{232}Th, ^{228}Th	1.8
^{40}K	(d)	< 0.1
^{137}Cs	Soil Analyses 4.7 pCi/cm^2	0.2
Cosmic	(d)	3.2
	Total Calculated	6.7 μR/hr
	Total Measured	6.5 ± 0.6 μR/hr.

(a) Data averaged for Fefan, Moen and Dublon Islands.
(b) Soil data from University of Washington, LRE. NVO-269-33 (7).
(c) EML-378 (8), HASL-195 (9).
(d) UNSCEAR (11).

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[illegible] Safety Program Review

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Guide for Visiting Staff

Brookhaven National Laboratory

Guide for Visiting Staff

Brookhaven National Laboratory

Office of Scientific Personnel

June 1976

Contents

Introduction

Large numbers of scientists and students from all parts of the United States and many other countries are appointed as visitors to Brookhaven National Laboratory each year. These visitors come from their own institutions for periods of a few weeks, for the summer, for a year or two, or on an intermittent schedule. Every attempt is made to see that the transition from campus and research institute to Brookhaven is easy, convenient and productive. Thus, this booklet describes some features of Brookhaven and the environs that have been found to be of particular interest to those unacquainted with the Laboratory. Scientific policies, personnel procedures and insurances are dealt with in other publications. Questions not answered by, and comments about, this Guide, may be addressed to the Office of Scientific Personnel.

Before Arrival

Location

Brookhaven National Laboratory is in the approximate geographic center of Long Island, about 100 kilometers (65 miles) east of New York City. (See map at back.) The Laboratory is in an isolated area and does not offer the normal services of city, town or village. The nearest villages are more than 8 kilometers (5 miles) away.

Climate

Brookhaven's climate is typical of mid-latitude locations on eastern continental shores. The nearby ocean modifies the general climate, reducing to a marked degree the temperature extremes found inland and assuring a relatively even distribution of precipitation throughout the year. Unlike western Europe, however, the prevailing westerly winds occasionally bring periods of harsh continental weather with departures from normal temperatures and prolonged periods of strong winds.

Fall is usually considered Long Island's finest season and October the most pleasant month. There are many clear, mild days with temperatures ranging from 7° to 21°C (45° to 70°F) and with low humidity. The bodies of water surrounding Long Island usually remain suitable for recreation until early in November.

Winter and spring are often an almost continuous season at Brookhaven. Frequent coastal storms provide about 100 mm (4 inches) of precipitation per month, which may be either snow or rain depending on the course and nature of the individual storms. In 1952-1953, for example, only 300 mm (12 inches) of snow fell during the entire season whereas the 1966-1967 winter produced 1900 mm (75 inches). Four to five-day periods of extremely cold, windy weather are often experienced, and below zero temperatures (−17 C) occur almost every winter. Because of the low ocean temperature, the month of April is frequently more like winter than spring.

Brookhaven's summers are normally fairly cool because of vigorous sea breezes, although maximum temperatures above 32°C (90°F) do occur with persistent winds from the interior of the continent. The relative humidity tends to be quite high and oppressive days are often encountered from late June through August.

Hurricanes occasionally pass close to Long Island, generally in August or September. They are now carefully followed by radar and aircraft, so that adequate warning is assured.

Travel In some cases, partial or all travel expenses will be reimbursed by the Laboratory and will be so noted on the Appointment Allowances form. Requests for financial assistance in the purchase of travel tickets should be directed to the Office of Scientific Personnel. When the cost of tickets is reimbursed by the Laboratory, government regulations require that an American carrier be used.

Household Goods Information as to the shipment of personal belongings and household goods will be sent at the time of appointment. If household goods are involved the Laboratory will arrange for a moving company to contact the visitor at his home.

Personal Belongings Personal belongings are assumed to fit in an automobile, if the visitor drives to the Laboratory. If it is necessary to ship them, any allowance toward this cost will be stated in the Appointment Allowances form. Visitors from abroad should not ship their personal effects too far in advance of their arrival as they will not be sent to the Laboratory, but will be held by Customs in New York and will be subject to storage charges.

Cost of Living Visitors supported by other institutions must be sure the financial support they are receiving will be adequate under living conditions in this area. The relative isolation of the Laboratory reduces the range of housing available and makes transportation expensive and troublesome. The typical cost of various accommodations is $100 per month for a single room, $250 to $400 per month for furnished apartments. For a family of four, food costs would be at least $60 per week. A used car costs between $800 and $2,000; gasoline about 13¢ per litre (60¢ per gallon). Compulsory liability insurance to operate a car is $160 or more per year. Rental cars are available from local agencies on a daily, weekly and monthly basis

No stores, shops or public restaurants may be found on or near the site. The Laboratory maintains a cafeteria on site. Information on restaurants may be obtained from the Public Relations Office. No regularly scheduled public transportation is available. For extended stays an automobile is a necessity.

Automobile Licenses No private vehicle may be driven unless the operator possesses a valid state operator's or chauffeur's license. Long term visitors should apply for a New York State license upon arrival. A New York State operator's license is not required if legal residence is in another state. International licenses, accompanied by a national driver's license, are valid from one year of date of issue. However, many countries have a reciprocal agreement with New York State and, in such cases, national licenses are honored for one year, provided they are stamped by the American Automobile Association.

Housing On-Site A number of furnished apartments for married scientists and dormitory rooms for single persons are available on the Laboratory site. The period these accommodations are made available will be determined at the time of the appointment. Rent charges for periods of less than one month may be prorated

The apartments are supplied with furniture, towels and bed linen, kitchen facilities and utensils. Irons, toasters and other electrical appliances are not supplied. The electricity available is 100 volt AC. No provision can be made for larger appliances that require either 220 volt supply or plumbing alterations, or both. Coin-operated washing and drying machines are located in the Apartment Area. Television connections are available in apartments, but not in detached units or dormitory rooms.

Pets Prior approval to harbor pets in apartments must be obtained from the Housing Office. Pets are prohibited in dormitories.

Schools Children living on the Laboratory site may attend a public elementary school (Grades Kindergarten through 6), or a Junior-Senior High School (Grades 7 through 12) at no cost. Students at both schools are transported to and from the Laboratory by school bus. Generally, the school term begins a day or two after Labor Day (first Monday in September) and ends late in June.

Nursery School For pre-schoolers, a cooperative school (with parent participation), known as the Upton Nursery School, has been organized on the Laboratory site for children ages 3 and 4. School begins about the second week in September and ends the second week in June. Classes are small and children attend one-half day for usually 2 or 3 days per week. At present, the fee is $32 per month for 3 days, $22 for 2 days. Enrollment is limited and it is advisable to pre-register well before arrival.

Personal Mail Personal mail should be sent in the visitor's name c/o the Department, Brookhaven National Laboratory, Upton, Long Island, New York 11973. Letters will be delivered to the department address; there is no mail delivery to the Apartment Area. Packages can be picked up at the Laboratory mail room. Packages sent prior to arrival should be marked "Hold for Arrival". Post Office boxes may be rented at the on-site U.S. Post Office.

The First Visit

Transportation to the Laboratory Most overseas visitors arrive via J.F. Kennedy International Airport, or by ship docking at a New York City pier. If the Office of Scientific Personnel has received prior notice, a car and driver will be sent to bring the visitor and family and hand luggage to the Laboratory. This service is available during regular working hours (8:30 a.m. to 5 p.m., Monday through Friday) and is for those making an initial trip to Brookhaven who are unfamiliar with the area. The driver will be glad to answer questions and will stop en route to enable the visitor to buy food supplies. The driver is not permitted to transport large pieces of luggage or trunks. Arrangements can be made to have these shipped to the Laboratory by commercial carrier.

Long Island Limousine Service is available from metropolitan airports to the Laboratory.

For those driving their own automobiles, the map in this booklet indicates the best route to the Laboratory.

Some visitors to Brookhaven will find it convenient to take a train from New York City. A Long Island Railroad train presently leaves Pennsylvania Station every **weekday** morning at 8:30 a.m. and arrives at Patchogue at 10:06 a.m. This train is met by a Laboratory bus and passengers en route to BNL are brought to the site. The train also stops at Jamaica (the station closest to J.F. Kennedy Airport) at 8:51 a.m. The Long Island Railroad schedule changes seasonally.

Visitors will not be reimbursed for the rental of automobiles without prior approval.

Housing If a housing reservation has been made on the Laboratory site, the first thing to do on arrival is to pick up a key at the Housing Office, 2 Center Street. For arrivals after 5 p.m. or on a weekend, keys are held at the Police and Security Office, 24 Upton Road.

Check In Procedure On the **initial** visit, every visitor holding an appointment of any kind must check in at the Personnel Office, 58 Brookhaven Avenue. This is necessary to activate the appointment and to ensure that certain required procedures are followed. An identification card and automobile sticker are also provided. Regular working hours are from 8:30 a.m. to 5 p.m., Monday through Friday.

Insurance While at Personnel, those visitors on long-term salaried appointments will be briefed as to the Laboratory's medical, life and retirement programs. For those not eligible for these programs, or who are not otherwise protected while here, private medical insurance coverage should be arranged.

Travel Expenses The department secretary will assist in the preparation of a voucher for reimbursement of allowable travel expenses. All receipts and ticket stubs should be attached to the voucher.

Salary Checks Salary checks are distributed monthly on the last day of the month and reflect the pay period which ends on the 25th of each month. Arrangements can be made through the Payroll Office to have salary checks sent directly to a bank for deposit to an account.

Loans Personal loans, repayable by Payroll deduction, may be arranged through the on-site branch of a local, privately-run, full service bank.

While You Are Here

Services and Facilities Please refer to the site map at back for the location of scientific departments and administrative offices. In addition, Laboratory services include a cafeteria (schedule below), the Brookhaven Center, a Post Office, and a service station for automobiles.

Cafeteria Schedule

Monday - Friday

7:30 a.m. -	10:30 a.m.	Breakfast
10:30 a.m. -	11:15 a.m.	Coffee, Snacks
11:15 a.m. -	1:30 p.m.	Lunch
1:30 p.m. -	5:00 p.m.	Coffee, Snacks
5:00 p.m. -	6:30 p.m.	Dinner

Saturday, Sunday & Holidays

9:00 a.m. -	2:00 p.m.	Brunch

Brookhaven Center The Brookhaven Center is open from 5:00 p.m. until 11:30 p.m. every evening Sunday through Friday. Light dinner, bar service and other amenities are available.

Recreation The recreational facilities at the Laboratory are as varied as the activities it supports. They include the swimming pool and gymnasium, the Recreation Building, tennis courts and softball fields. Specific announcements concerning activities and special events are carried in the weekly paper the Brookhaven Bulletin and various office bulletin boards. In addition, good swimming, boating and fishing are within 16 kilometers (10 miles) of the Laboratory.

Off Site Housing According to the nature and length of an appointment, it may be necessary for the visitor to find housing in the surrounding communities. Off-site listings may be consulted in the Housing Office and notices are carried in the Brookhaven Bulletin A list of suggested real estate agents is available from the Office of Scientific Personnel.

Medical Care The Industrial Medicine Clinic of the Medical Department is responsible for required medical examinations of personnel and for first aid. For the usual personal and family medical problems, employees are expected to use physicians and facilities in their communities. Physicians at the Clinic may be consulted for information on physicians practicing in the various residential areas.

Radiation Safety Expert assistance and a variety of services are provided by the Safety and Environmental Protection Division on all matters of radiation safety. Rules on radiation safety, including the use of personnel monitoring equipment and the wearing and handling of protective clothing and equipment should be followed. In addition to normal fire and safety requirements, the Laboratory has established standards appropriate to its operations. These are made known to newcomers shortly after arrival through a safety orientation interview. Investigators planning to bring equipment or apparatus with them should determine in advance whether any of the fire or safety standards apply. This may be done through direct contact with Plant Protection and Safety Audit, 20 N. Technology Street.

Shopping Trips For those without their own transportation, a car leaves the children's shelter in the Apartment Area every Tuesday and Friday at 9 a.m. upon request. It arrives in Patchogue at 9:30 a.m. and leaves at noon, returning to the Apartment Area by 12 30 p.m. Please call the number listed in the Directory at back under Shopping Trips the day before you wish to use this service. In addition, there is a limited bus service available to certain local areas from the BNL Main Gate. Bus schedules may be obtained at the Travel Office, 2 Center Street.

Hospitality Committee The Hospitality Committee, composed of the wives of staff members, offers help in the orientation of newcomers. A staff member in the Personnel Office acts as liaison for this group.

On Departure

Termination Procedure On termination of a Laboratory appointment, a check-out sheet is prepared by the department secretary and involves stops at the Library, Personnel Office and the Cashier for the return of books, identification cards, payment of bills, receipt of final checks, etc. Alien visitors returning to their home countries should have the proper documents for their departure from the United States. (See section Of Special Interest to Aliens.)

Transportation As was the case for arrival, the Laboratory will, on advance notice, arrange for the transportation of the visitor and family and hand luggage to the airport or pier during regular working hours.

Shipping of Goods The Laboratory cannot be expected to ship goods, books or belongings accumulated during the stay. Visitors should make arrangements for shipping large pieces of luggage and trunks by private carrier. The crating and shipping of goods are considered private matters and should not involve Laboratory equipment, material or labor.

Of Special Interest To Aliens

Visas The visa stamped in a passport at a U.S. Embassy or Consulate grants permission to enter the United States during the period of its validity. The number of times the visa may be used is indicated before the words "application(s) for admission into the United States". Usually a non-immigrant visa is valid for either **one** or **unlimited (multiple)** applications.

Form I-94 The period of authorized stay in the United States is entered on Form I-94 (also known as Arrival Departure Record) which is stapled in the passport. It is important that the proper mailing address (Brookhaven National Laboratory, Upton, L.I., New York 11973) be entered legibly on this form. Any extensions of stay are recorded on the reverse side of this form by an immigration inspector.

Exchange Visitors (J-1) The Laboratory sponsors an Exchange Visitor Program for temporary appointments, not to exceed three years. Information concerning limitations and other conditions of this visa may be obtained at any U.S. Consulate. In order to obtain a J-1 visa the Office of Scientific Personnel will mail Form DSP-66 with the letter of appointment; to apply, the form must be presented to a U.S. Embassy or Consulate in the home country. If this type of visa is obtained, the stay in the United States must be extended annually. Thirty days to two weeks before the expiration of an authorized stay, the Office of Scientific Personnel should be contacted for a new DSP-66 form which must be completed and sent, together with Form I-94, to the Immigration Office in New York City.

Each time the visitor leaves the United States on a business or vacation trip, copy 3 of Form DSP-66 should be taken. Also, passports should be checked to ensure that the visa is still valid and that it may be used for more than one entry.

Students (F-1) Permission to continue practical training must be renewed every six months. Before the first six months expire, the visitor should (1) get a letter in duplicate from the Office of Scientific Personnel stating the terms of the appointment; (2) complete Form I-538 and send it, together with the above letter, to the Foreign Student Advisor at the visitor's school for signature; (3) take or mail to the Immigration Office in New York City the following: Form I-94, signed Form I-538 (application to accept employment, and letter from the Laboratory.

Visitors (B-1) A type B-1 visa (temporary visitor for business) is available for those coming from abroad who will not be receiving a salary from a U.S. institution. Permission to stay can be granted for periods of up to two years.

For the purpose of opening a U.S. bank account, such visitors should obtain a special social security number by contacting the local Social Security Administration Office in Patchogue.

Sailing Permits When an individual holding any type of visa (including immigrant) leaves the United States, or departs for reasons of vacation or business, a sailing permit should be obtained several days, but not more than three weeks, in advance of departure. (See also section on Exchange Visitors.) However, a sailing permit is not required for an individual with a B-1 visa who has been in the United States for less than 90 days. If the appointment at the Laboratory has been salaried, a statement of earnings should be requested from the Fiscal Division, 37 Brookhaven Avenue, and taken with passport, copy of last U.S. income tax return (if any) and return ticket (if any) to a local office of the U.S. Internal Revenue Service, whose location can be recommended by the Internal Audit Group, 37 Brookhaven Avenue. In the case of unsalaried appointments, a letter stating the conditions of appointment should be requested from the Office of Scientific Personnel.

Alien Registration Number When corresponding with the Immigration and Naturalization Service, the Alien Registration Number (if any) should be stated to expedite the handling of the request. This number, sometimes designated as a File Number, is not issued upon arrival in the United States unless a "file" exists at that time. It is usually an eight-digit number prefixed by the letter "A". A permanent file is made upon application for extension of stay or any change of visa status. File numbers issued in previous years should also be stated.

Alien Address Registration During January of each year, all aliens in the United States must report their addresses to the Commissioner of Immigration and Naturalization Service. Alien address report cards are available at the U.S. Post Office, 2 Center Street.

INS New York Office The address and telephone number of the Immigration and Naturalization Service office having jurisdiction over Brookhaven National Laboratory is as follows:

U.S. Department of Justice
Immigration and Naturalization Service
20 West Broadway
New York, N.Y. 10007
Telephone: Area Code 212, 349-8735

Taxes Aliens are required to pay U.S. income tax, New York State income tax and U.S. Social Security tax on income derived from sources within the United States. However, those individuals with F-1 or J-1 visas are exempt from U.S. Social Security taxes. Otherwise, tax rates, exemptions and exceptions vary with type of visa, duration of appointment, residency, and tax treaties. Aliens should inquire at the Alien Tax Bureau of the Internal Revenue Service for information concerning their particular tax situation. Other information may be obtained from publications #518 (Foreign Scholars and Educational and Cultural Exchange Visitors) and #519 (United States Tax Guide for Aliens), available from the U.S. Government Printing Office, Washington, D.C., for 75¢ per copy.

Individuals filing tax returns for previous years, after having left the United States, may obtain the appropriate forms from a U.S. Embassy or Consulate.

BNL Telephone No.
Area Code: 516, 345-2123

Directory

For Information On	Who	Where	Tel. Ext.
Automobiles: government vehicles, Stony Brook Univ. parking permits	J. Cross	2 Center	2535
Brookhaven Bulletin	B. Petersen	40 Brookhaven	2345
Guest & Research Collaborator appts.	G.A. Price	40 Brookhaven	3336
Hospitality Committee	J. Garron	58 Brookhaven	2113
Housing Office	D. Metz	2 Center	2541
Identification cards & auto stickers	Personnel	58 Brookhaven	2882
Insurance - medical	Personnel	58 Brookhaven	2877
Mail	Mail Room	2 Center	2534
Medical check-up	Ind. Med. Clinic	30 Bell	3670
Medical emergencies	Ind. Med. Clinic	30 Bell	2222
Notary Public	S.W. Eriksen	40 Brookhaven	3332
	R. Flack	40 Brookhaven	3316
	G. Callister	30 Bell	3694
Nursery School	B. Laskee	58 Brookhaven	2873
Personnel Records	M. Austin	58 Brookhaven	2875
Plant Safety	R.W. Young	20 N. Technology	4271
Recreation Office	B. Laskee	58 Brookhaven	2873
Salary Checks	O. Vario	37 Brookhaven	2487
Sailing Permits	F. Federmann	37 Brookhaven	2482
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Travel policy	Office of Scientific Personnel	40 Brookhaven	3336
Travel Reservations	Travel Office	2 Center	2531
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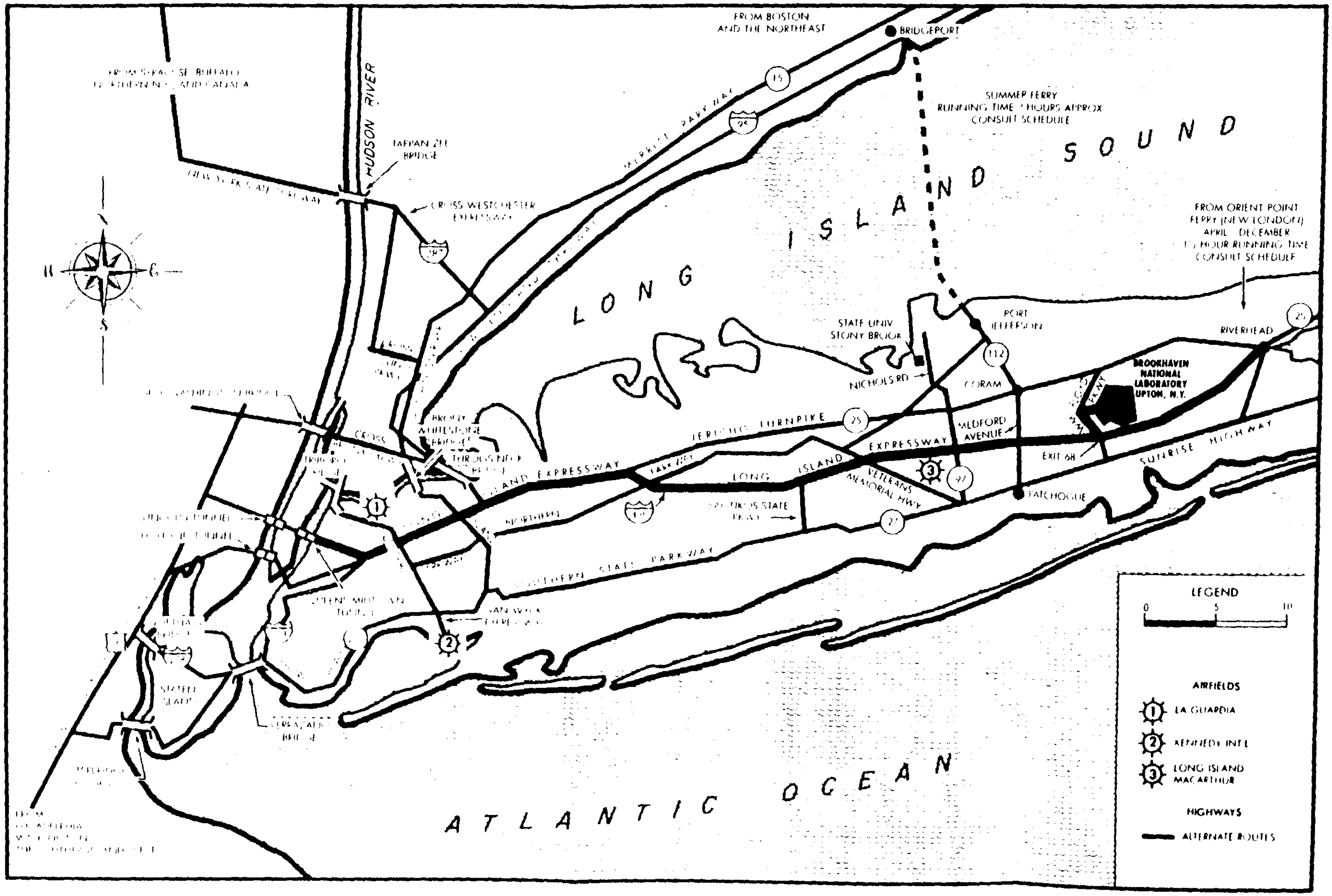
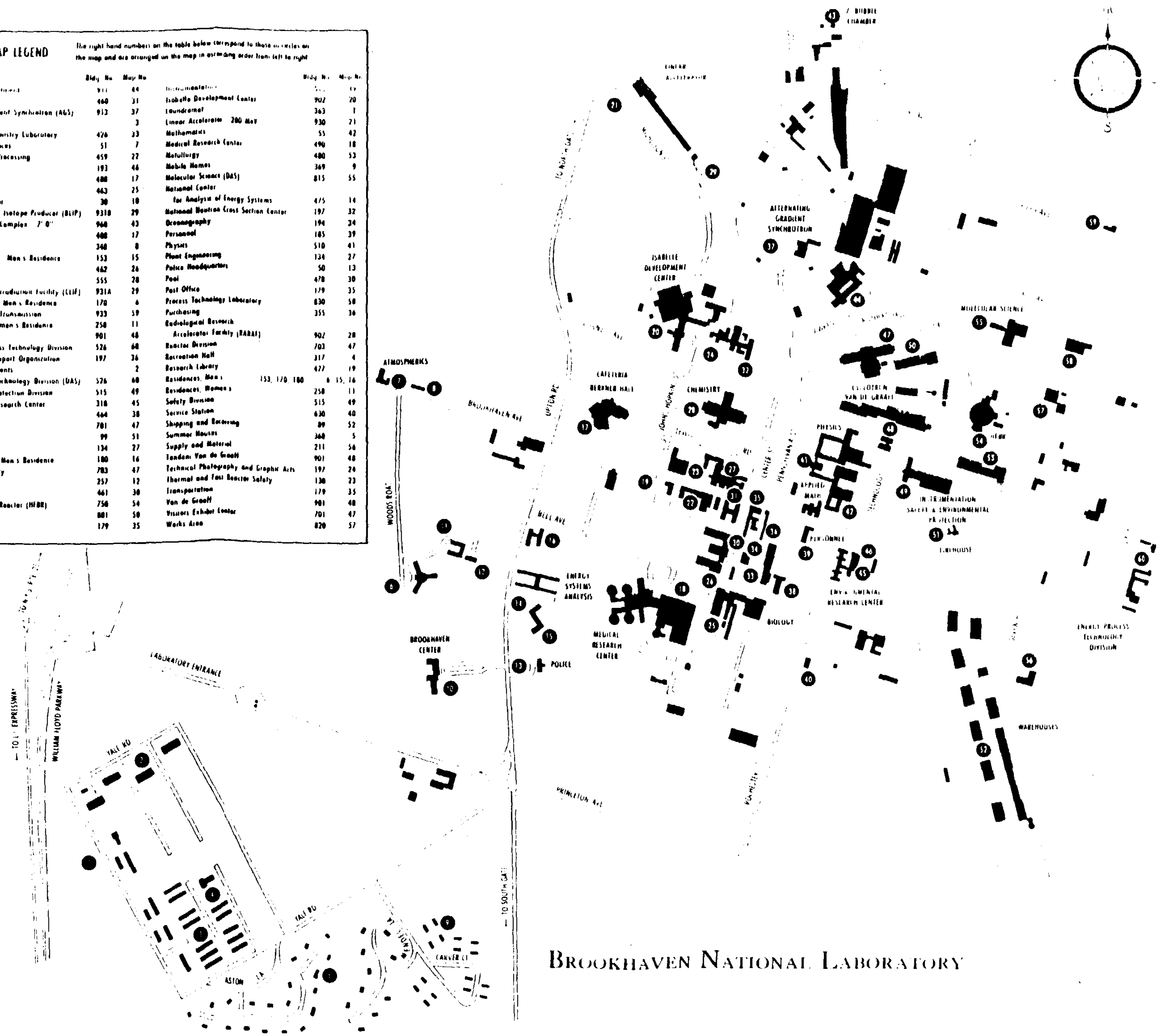


APPROACHES TO BROOKHAVEN NATIONAL LABORATORY

BEST ROUTE FROM NEW YORK CITY

BROOKHAVEN NATIONAL LABORATORY



MAP LEGEND

The right hand numbers on the table below correspond to those in circles on the map and are arranged on the map in ascending order from left to right

	Bldg No	Map No		Bldg No	Map No
[illegible] Department	911	44	Instrumentation	[illegible]	[illegible]
Administration	460	31	Isabelle Development Center	902	20
Alternating Gradient Synchrotron (AGS)	913	37	Laundromat	363	1
Apartments		3	Linear Accelerator 200 MeV	930	21
Atmospheric Chemistry Laboratory	426	33	Mathematics	55	42
Atmospheric Sciences	51	7	Medical Research Center	490	18
Automatic Data Processing	459	22	Metallurgy	480	53
Bank	193	46	Mobile Homes	369	9
Berkner Hall	488	17	Molecular Science (DAS)	815	55
Biology	463	25	National Center		
Brookhaven Center	30	10	for Analysis of Energy Systems	475	14
Brookhaven Linac Isotope Producer (BLIP)	931B	29	National Neutron Cross Section Center	197	32
Bubble Chamber Complex 7' 0"	968	43	Oceanography	194	34
Cafeteria	488	17	Personnel	185	39
Calibration	348	8	Physics	510	41
Cavendish House Men's Residence	153	15	Plant Engineering	134	27
Central Shops	462	26	Police Headquarters	50	13
Chemistry	555	28	Pool	478	30
Chemistry Linac Irradiation Facility (CLIF)	931A	29	Post Office	179	35
Compton House Men's Residence	170	6	Process Technology Laboratory	830	58
Cryogenic Power Transmission	933	59	Purchasing	355	36
Curie House Women's Residence	258	11	Radiological Research		
Cyclotron	901	48	Accelerator Facility (RARAF)	902	20
DAS Energy Process Technology Division	526	60	Reactor Division	703	47
DAS Technical Support Organization	197	36	Recreation Hall	317	4
Efficiency Apartments		2	Research Library	477	19
Energy Process Technology Division (DAS)	526	60	Residences, Men's 153, 170, 180		6, 15, 16
Environmental Protection Division	515	49	Residences, Women's	258	11
Environmental Research Center	318	45	Safety Division	515	49
ERDA BHO	464	38	Service Station	630	40
Exhibition Hall	701	47	Shipping and Receiving	89	52
Fire Department	99	51	Summer Houses	368	5
Fiscal	134	27	Supply and Material	211	56
Fleming House Men's Residence	180	16	Tandem Van de Graaff	901	48
Gas Reactor Safety	703	47	Technical Photography and Graphic Arts	197	24
Guest House	257	12	Thermal and Fast Reactor Safety	130	23
Gymnasium	461	30	Transportation	179	35
High Flux Beam Reactor (HFBR)	750	54	Van de Graaff	901	48
Hot Laboratory	801	50	Visitors Exhibit Center	701	47
Housing	179	35	Works Area	820	57

BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.

Upton, New York 11973

Safety & Environmental Protection Division

(516) ~~345~~ 282- 4207

May 5, 1981

Dr. Bruce Wachholz
Office of Health &
Environmental Research
U.S. Department of Energy
Washington, D.C. 20545

Dear Dr. Wachholz:

The enclosed material is submitted to help you in the May 21 and 22 review of Brookhaven's Marshall Islands Radiological Safety Program. Included are

1) Guide for Visiting Staff,
2) Schedule, and
3) Publications and Drafts Package.

The maps in the Guide for Visiting Staff will assist you in travelling to the Laboratory and during your stay. A room has been reserved for you at the Laboratory site. Louisa Morrison, FTS 666-4208, will assist you in making any arrangements.

If you have questions, please do not hesitate to call either myself or Louisa.

Sincerely,

Edward T Lessard

Edward T. Lessard
Program Director
Marshall Islands Radiological Safety Program

ETL/slg

Enclosure

Marshall Islands Radiological Safety Program Review Schedule

May 21 and 22, 1981

Day	Time*	Discussion Leader	Location	Discussion Topics
Thursday May 21	0830-1000	*Bruce Wachholz*	Bldg. 535 Conference Room	Preliminary Review Committee meeting to be followed by a welcome by *Charles Meinhold*
	1000-1100	*Andrew Hull*	Bldg. 535 Conference Room	Marshall Islands radiological safety 1954 to 1981. An overview of the Medical Department and Safety & Environmental Protection Division programs.
	1100-1200	*Edward Lessard*	Bldg. 535 Conference Room	Marshall Islands Radiological Safety Program Highlights 1974 to Present. Shortly before lunch a tour of the whole-body counting and bioassay facilities will be given for interested Review Committee members.
	1200-1300		Cafeteria	LUNCH
	1300-1500	*Robert Miltenberger*	Bldg. 535 Conference Room	Whole-body counting and bioassay instrumentation, quality assurance and results. Will include a summary of the relevant portions of the previous BNL medical program and cover our measurements of Sr-90, Fe-55, Cs-137, Pu-239, Zn-65 and Co-60. The air sampling program will also be discussed.
	1500-1700	*Jan Naidu*	Bldg. 535 Conference Room	Exposure rate, vegetation, animal, and soil measurements, instrumentation, and quality assurance. Nuclides included are I-129, Cs-137, Sr-90, and Co-60. Diet and living pattern studies including Marshallese foods, food gathering, food supply shipments, copra production, fishing and other activities.
	1715		Bldg. 535 Lobby	COCKTAILS
	1900		Room A Berkner Hall	GUEST DINNER
Friday May 22	0900-1200	*Edward Lessard*	Bldg. 535 Conference Room	Dosimetry models and methods. Results of dose assessment for Rongelap, Utirik, Enewetak, and Bikini populations. Nuclides include Cs-137, Sr-90, Co-60, Fe-55, Pu-239, iodine isotopes and Zn-65. Data storage, records, publications and transmission of information.

* The time allotted is approximate and will deviate according to the desire of the Review Committee.

DRAFT

UASG 81-20

Castle-Bravo Air Concentration and Deposition Patterns from a 3-D Particle-in-Cell Coce*

by

Kendall R. Peterson

May 18, 1931

ABSTRACT

The MATHEW-ADPIC code suite has been extensively modified to give the total external dose from the detonation of the Castle-Bravo nuclear test at Bikini Atoll until evacuation of the inhabitants of nearby atolls. The advantages of this code suite is that it uses all the observed winds (in a mass-conservation sense) at and after the detonation to provide dose rates and doses due to passage of the debris cloud and to the time-integrated deposition up to evacuation time. Previous assessments have given the fallout pattern (deposition only) at time H+1 hours.

The present code formulation gives excellent agreement with the estimated total external dose (based on measurements) to people on Rongelap and Ailinginae atolls.

*Work performed under the auspices of the U. S. Department of Energy under Contract No. W-7405-ENG-48.

Acknowledgments

The author is indebted to Rolf Lange, Leonard Lawson, and Hoyt Walker of Lawrence Livermore National Laboratory for their assistance in developing the suite of computer programs used in the calculations.

Grateful thanks are also due to Nathaniel Greenhouse* and Edward Lessard of Brookhaven National Laboratory for supplying me with meteorological and dose rate data for the Castle-Bravo test.

*Present affiliation: Lawrence Berkeley National Laboratory, Berkeley, California 94720.

INTRODUCTION

Operation Castle was an atmospheric nuclear test series conducted in the Marshall Islands from March to May of 1954. The most notorious test of the series was Bravo, a 15 megaton[1] thermonuclear explosive. The top of the resultant debris cloud reached to nearly 35 km at stabilization time.[1]

Because of an unexpected shift in mid-tropospheric wind directions following detonation of Bravo, the fallout pattern, instead of heading in the predicted northeast direction, had an easterly alignment. As a result, persons on the atolls of Rongelap and Rongerik were exposed to relatively high levels of fallout from the nuclear explosion. Prompt action was taken by U. S. Task Force personnel to evacuate the natives of these islands. Some of the natives on Rongelap, the closest to the detonation point, suffered temporary nausea and minor skin burns. None exhibited any medium or long term effects from their exposure.

However, after about 10 years, those Rongelap natives, who were young children in 1954 developed non-maligment nodules on their thyroid glands. Since then the occurrence of similar nodules among the Utirik natives has been reported. The rate of occurrence has been higher than would be expected statistically. The purpose of this report is to calculate deposition and surface air concentration plots, using a three-dimensional particle-in-cell suite of codes to estimate the doses at the islands from which the natives were evacuated. We will also consider the dose from rainout as part of the debris cloud crossed the atolls. Finally, the calculated time history of air concentrations on the downwind islands will be presented for several nuclides.

Several fallout patterns for Castle Bravo were prepared in the late 1950's. Some of the better known patterns appear in Ref. 1 and were prepared by (a) the Air Force Special Weapons Project, (b) the Naval Radiological Defense Laboratory, and (c) the Rand Corporation. A comparison of these three patterns shows significant differences in the maximum dose rates, as well as the shapes of the contours. This is due in large part to the subjectivity involved in the calculations. Portions of the AFSWP and NRDL contours were based on dose rate measurements at Rongelap, Rongerik, and Utirik, as well as a crude estimate of the dose rate received by the Japanese fishing ship, the Lucky Dragon. The remainder of these patterns were obtained using the observed winds in a subjective manner to bend the pattern and achieve an approximate mass balance.

The Rand contours used estimated winds between Bikini and Rongelap. These winds were obtained from interpolation of streamline analyses at several levels at different times.

By contrast, the altered versions of the MATHEW-ADPIC codes used in this report allow us to use the observed winds at different locations and different times after detonation. No artificial bending of the pattern is required. The only subjectivity lies in the selection of code input parameters. At all times, the codes automatically assure conservation of mass.

COMPUTER CODES

The suite of codes developed for the Atmospheric Release Advisory Capability (ARAC) were extensively modified in order to incorporate a larger number of upper air wind levels. All prior uses of the codes have been to handle calculations for releases that did not rise higher than a few kilometers. Also, the standard ARAC codes do not involve sophisticated gravitational fall velocity calculations, nor do they include time-integrated deposition.

One of the major codes that was modified is MATHEW[2]; its purpose is to adjust observed winds, using variational analysis methods, so as to conserve mass from cell to cell. After modification, all observed upper air wind data from 10 m to 35 km were entered as input. This was done for four time periods, using winds for one to three observing stations for each time. The obvious advantages of this code (over most other fallout codes) is that mass is not permitted to accumulate in any of the cells and winds are available for each 3-D cell intersection for four times.

The MATHEW winds are used then by the modified ADPIC[3] particle-in-cell code to calculate the transport, diffusion, and deposition of an instantaneous source. Modifications required of ADPIC, to handle the Bravo test, consisted of allowing more upper air input than is used in typical ARAC assessments. Furthermore, since particles falling from the stratosphere undergo a large increase in air density, it was necessary to add a turbulent wake correction to the larger particles; this correction follows the method set forth by McDonald.[4] Other modifications were to incorporate a tropical atmosphere into the fall velocity calcuations and to make the particle activity increase as the cube of particle radius. Finally, time-integrated deposition was added; this allows calculation of the total dose from detonation time to evacuation.

INPUT DATA

Surface meteorological observations were available from some atolls and from the U.S.S. Curtiss which cruised south of Bikini; however, since the larger particles fall rapidly from the debris cloud to the surface and spend little time near the surface, not many surface reports were used. Of far greater importance are the upper air wind observations taken at four sites near Bikini atoll. Other significant input data consisted of a flat topography, cell sizes of 34 km (east-west) by 17 km (north-south), and 1 km in the vertical, stem and cap debris cloud geometries at stabilization time, source rates for both gross fission products and selected individual nuclides, and particle size spectrum parameters.

CALCULATIONS

Gross Fission Products

The time-integrated external dose pattern (in rads) due to gross fission products from detonation time to evacuation time of Rogelap atoll (51 hours) are shown in Fig. 1. The numbers next to Ailinginae, Rongerik, and Utirik atolls are integrated values up to the time people were evacuated from those atolls.

For comparison, the value of total dose, estimated by Dunning[5] and Strauss[6] are given in Table 1. Note that the agreement is very good for Rongelap and Ailinginae atolls. However, calculations for Rongerik and Utirik are at odds with earlier estimates. The code calculations for Rongerik are higher, while those for Utirik are lower. This variation appears to be in part a problem of "tuning"; also a possible variation in wind directions and speeds at late times when the only wind observations were from the U.S.S. Curtis, south of Bikini (some distance from the atolls of concern) may be an explanation.

Table I. Comparison of gross fission product total external doses for computer calculations vs. estimates by Dunning[5] and Strauss[6]

Atoll	Evacuation Time (hours)	Present Calculations (rads)	Previous Estimates (roentgens)	Ref.
Rongelap (northern part)	51	1300	2000	[6]
Rongelap (southeastern part)	51	110	175	[5]
Ailinginae (Sifo Island)	58	24	<100	[5]
Rongerik (southeastern part)	30	340	78	[5]
Utirik	78	0.33	∿10	[5]

With the modified MATHEW-ADPIC code suite, it is possible to calculate the instantaneous immersion dose rate from gross fission products as a function of time. This can be done for any time inteval. Figures 2a to 2f show surface immersion dose rate contours for every three hours from one hour after Bravo cloud stabilization time to H+16 hours. Note that after an easterly traverse, most of the debris reaches the trade wind level; the contour pattern moves south and finally toward the southwest.

Individual Nuclides

Calculations were made of instantaneous and time-integrated concentrations at 2 m above the surface for the several atolls affected by Castle-Bravo. The nuclides considered were Te-129, I-131, I-133, Cs-137, and Eu-155. These calculations agree well with observations at Rongelap and Ailinginae atolls, but are too high at Rongerik and too low at Utirik atoll. The surface concentrations for Rongelap, both the northern and southeastern parts of the atoll, and for Ailiginae Atoll are presented in Figures 3a to 5e. The time of arrival of the first Bravo debris is in agreement with reports made by the inhabitants.

REPORTS OF RAIN DURING BRAVO FALLOUT

Transcripts of post-detonation briefings suggest that self-induced rainout occurred for a short time after Bravo was detonated. The crew of the Japanese fishing ship, No. 5 Fukura Maru (Lucky Dragon), while fishing downwind just outside the exclusion zone, noted that the initial fallout on their ship was accompanied by "a light rain or drizzle."[7] It is unlikely that this was a continuation of the self-induced rainout, some two or more hours after Bravo's detonation; it was probably a natural rain system superimposed on the debris cloud.

Another report of rain during Bravo fallout was made by a group of Rongelap natives after evacuation.[8] They lived in Rongelap Village, on the southern part of Rongelap Atoll, and stated that it "rained a little" during the afternoon of March 1st.

Another interview with an American Air Force radio operator[8] who had been on Rongerik Atoll prior to evacuation disclosed that "rain commenced about 2100 [LST] and continued for 30 minutes."

Finally, the S. S. Roque, owned by Micronesian Lines, left Kwajalein at 0845 LST and arrived at Utirik at about noon on March 2, 1954. The ship left Utirik (apparently a few days later) and arrive at Majuro Atoll on March 7. A radiological survey at Majuro disclosed radiation readings of 10 to 30 mr/h on March 7. The ship's captain mentioned that he had encountered rain squalls during his voyage, but was not specific about where or when. It appears certain that the S. S. Roque encountered Bravo fallout, possibly accompanied by rain showers, either while approaching or while in harbor at Utirik. If 10 mr/h are "grown back" to five or six days earlier (when the Bravo debris cloud passed near Utirik), the dose rate is estimated at about 100 mr/h.

SUMMARY AND CONCLUSIONS

Extensive modification of the MATHEW-ADPIC code suite has produced contours of Castle Bravo accumulated and time-integrated deposition for gross fission products. Through the use of dose conversion factors, these contours have been converted to dose rates and total doses up to the time of evacuation from the atolls affected by the debris cloud. In addition, both instantaneous and time-integrated surface concentrations have been calculated. For the nearest atolls, the calculations agree well with the measurements and total dose estimates based on these measurements. At the more distant atolls the agreement is not as good, indicating the need for more "tuning" of the code input parameters.

The internal dose to the inhabitants of the affected atolls have not been made in this report. Interviews with natives of Rongelap Village and Ailinginae[8] indicate that many people ate fresh seafood and drank water from cisterns following contamination of their islands. Although there is no direct evidence that those at Utirik ate and drank contaminated food and water, it seems likely that they did since the dry deposition from Bravo was considerably less than at atolls to the west. However, the previous section indicated that rain probably occurred during the time of fallout. This would result in wet deposition, producing local doses 10 to 50 times greater than in those areas where rain did not occur. This effect could have resulted in development of thyroid nodules in those Utirik residents who consumed contaminated food and water.

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2. Sherman, Christine A., "A Mass-Consistent Model for Wind Fields over Complex Terrain," J. Appl. Meteor., Vol. 17, No. 3, pp. 312-319.

3. Lange, Rolf, "ADPIC - A Three-Dimensional Particle-In-Cell Model for the Dispersal of Atmospheric Pollutants and its Comparison to Regional Tracer Studies," J. Appl. Meteor., Vol. 17, No. 3, pp. 320-329.

4. McDonald, James E., "An Aid to Computation of Terminal Fall Velocities of Spheres," J. of Meteor., Vol. 17, No. 3, pp. 463-465.

5. Dunning, Gordon M., "Protective and Remedial Measures Taken Following Three Incidents of Fallout," in Proceedings of A Symposium on Radiological Protection of the Public in A Nuclear Mass Disaster, Interlaken, Switzerland, 26 May - 1 June 1968.

6. Strauss, Lewis, Statement made at hearings of the Joint Committee on Atomic Energy, June 4-7, 1957.

7. Lapp, Ralph E., The Voyage of the Lucky Dragon, Harper and Brothers, New York, NY, 1958.

8. Sharp, Robert, "Exposure of Marshall Islanders and American Military Personnel to Fallout," WT-938, Operation Castle - Project 4.1 Addendum, April 1957.

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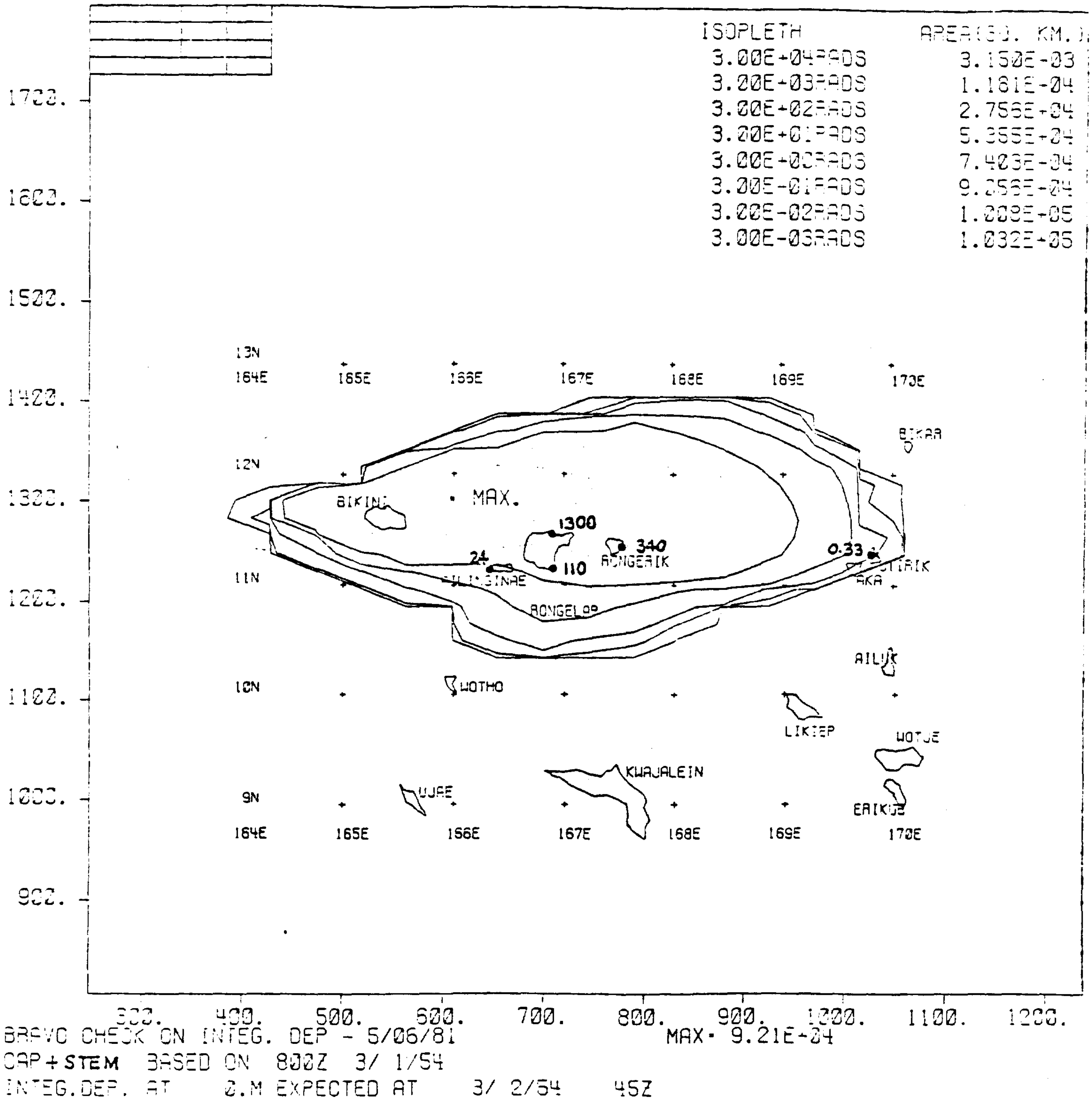


Figure 1. Castle Bravo time-integrated external gamma dose from gross fission products. Contours are for an H+51 hour evacuation time from Rongelap. Numbers added for other atolls are integrated to the appropriate evacuation time for those atolls.

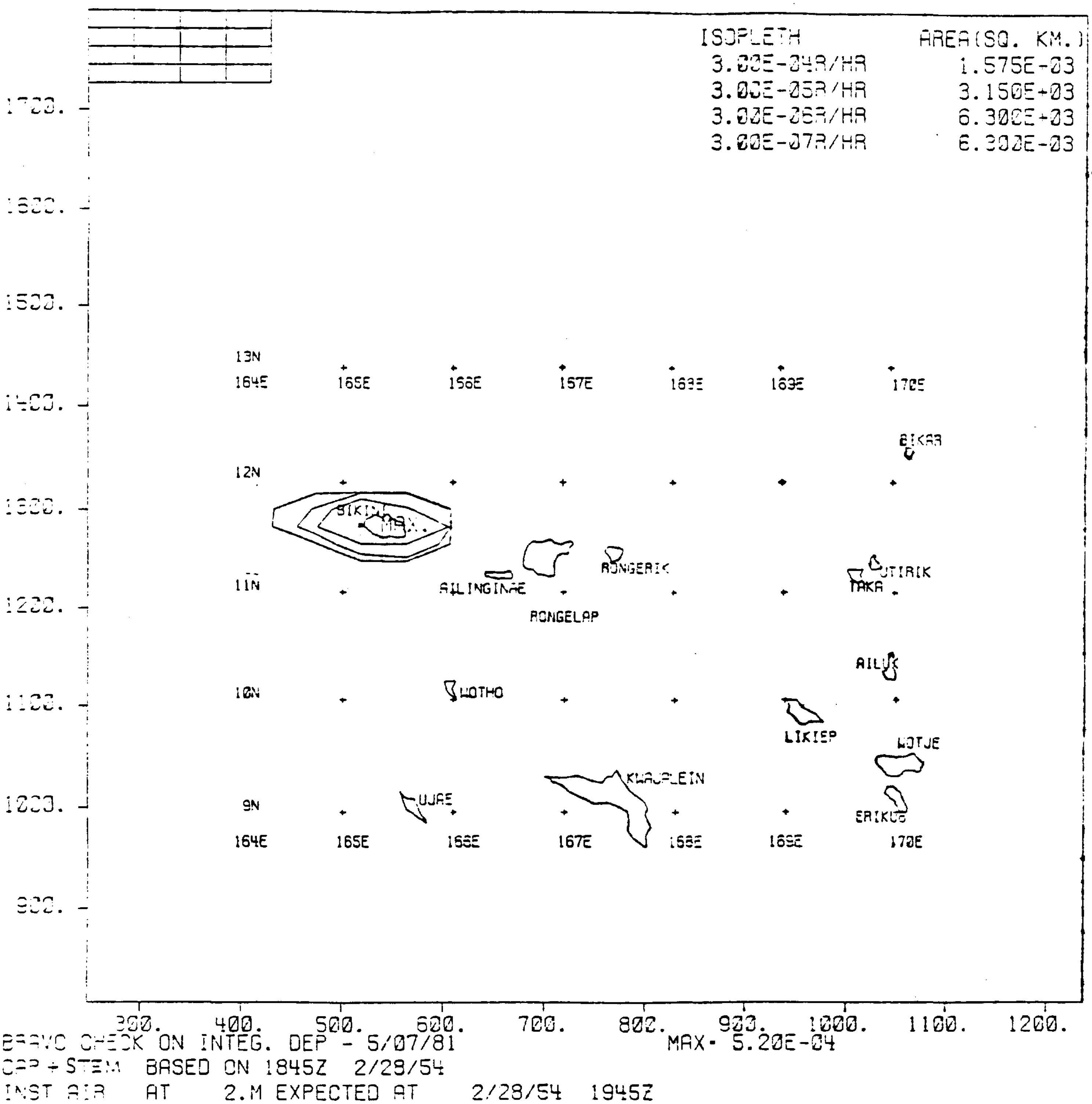


Figure 2a. Castle Bravo instantaneous external gamma dose rate contours from gross fission products. Time is H+1 hour.

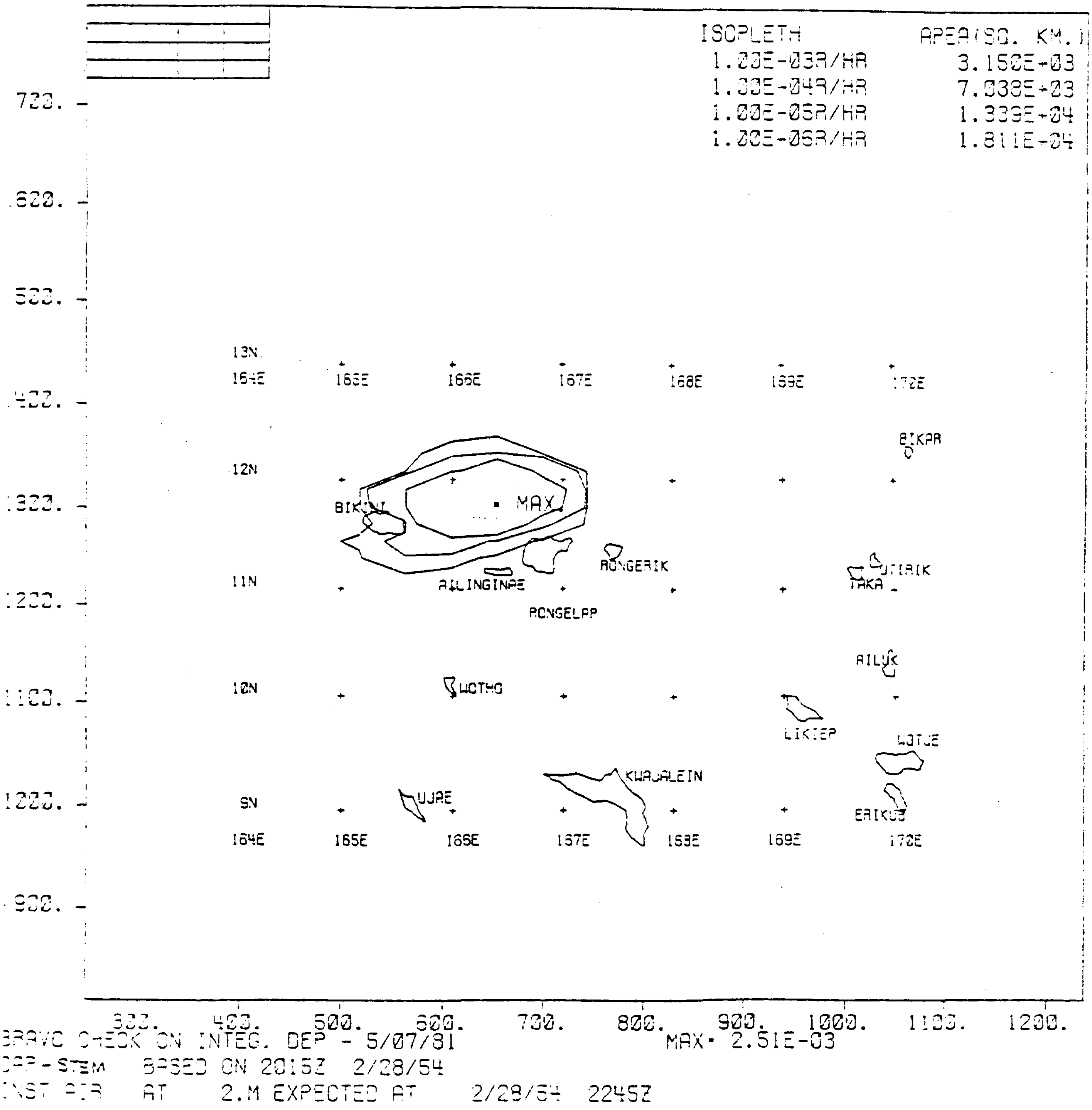


Figure 2b. Same as Fig. 2a, except time is H+4 hours.

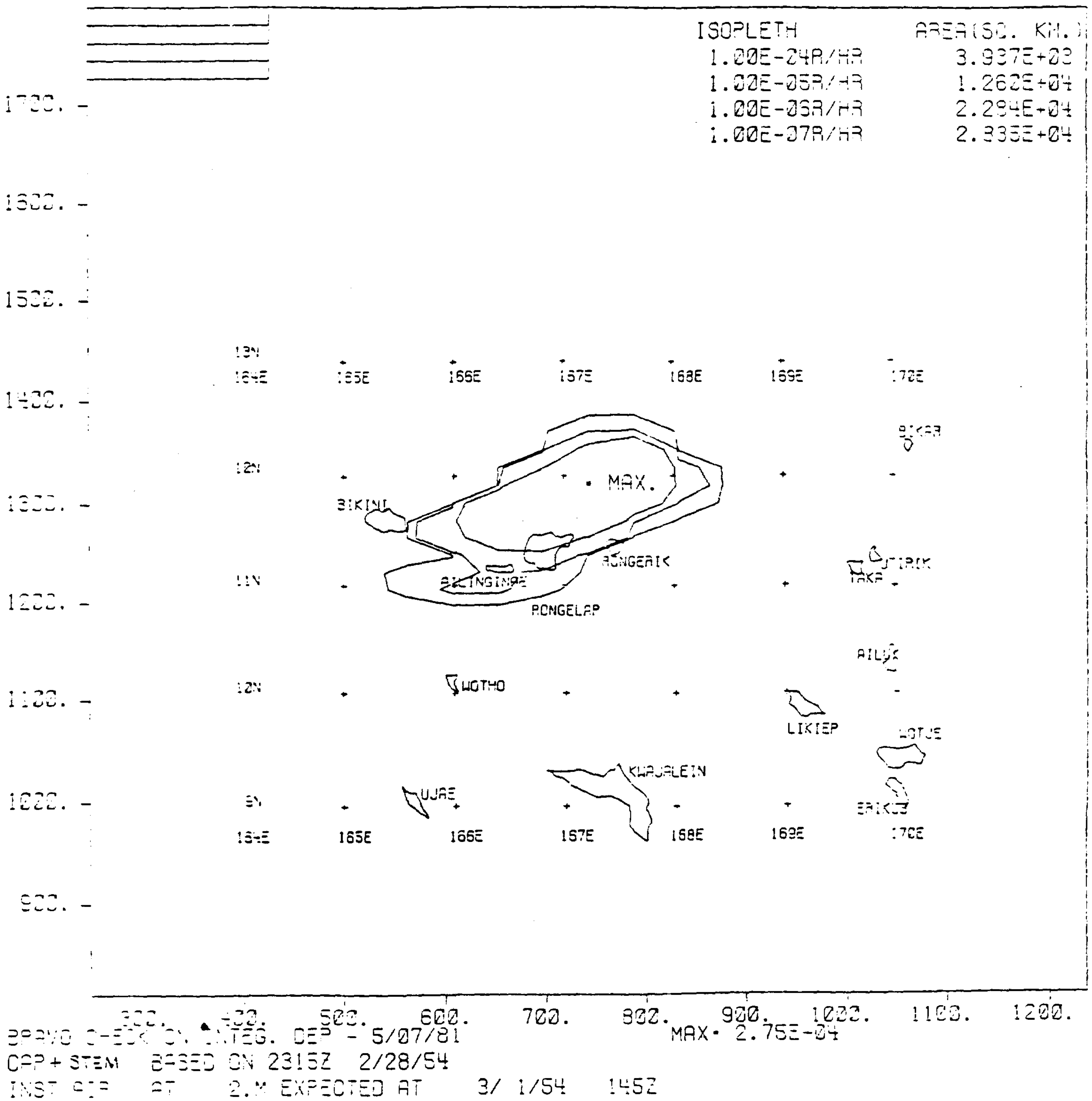


Figure 2c. Same as Fig. 2a, except time is H+7 hours.

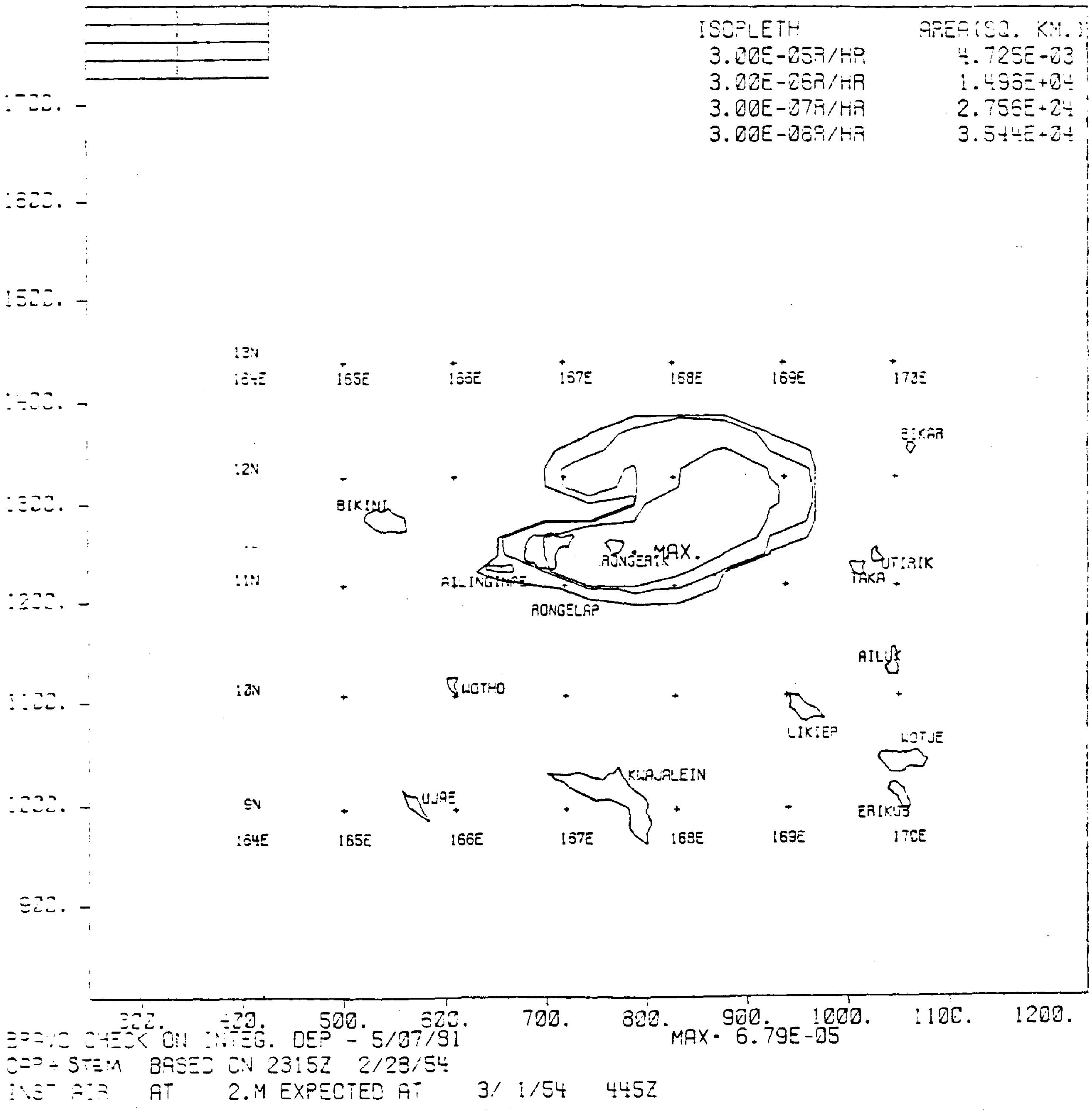


Figure 2d. Same as Fig. 2a, except time is H+10 hours.

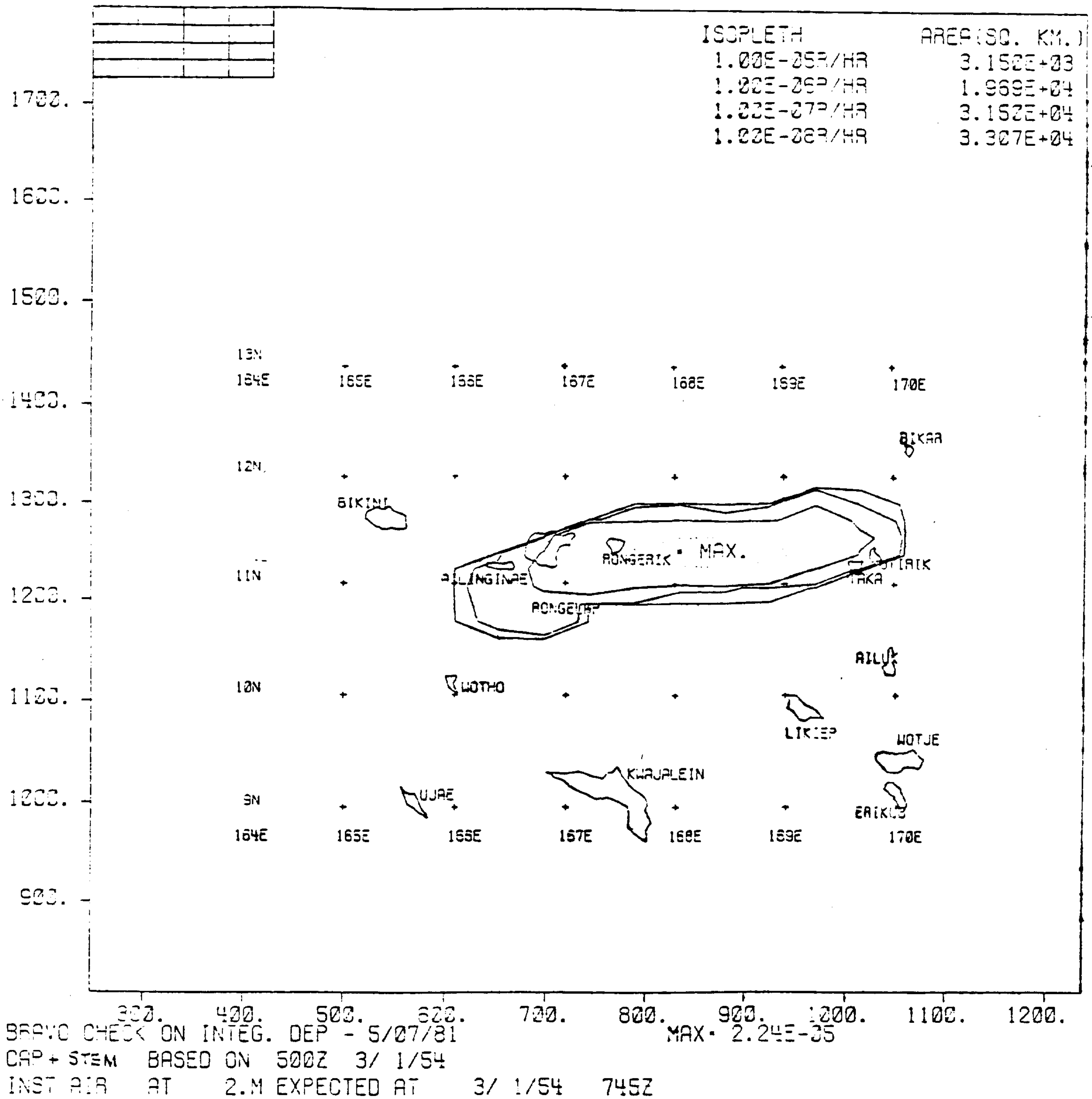
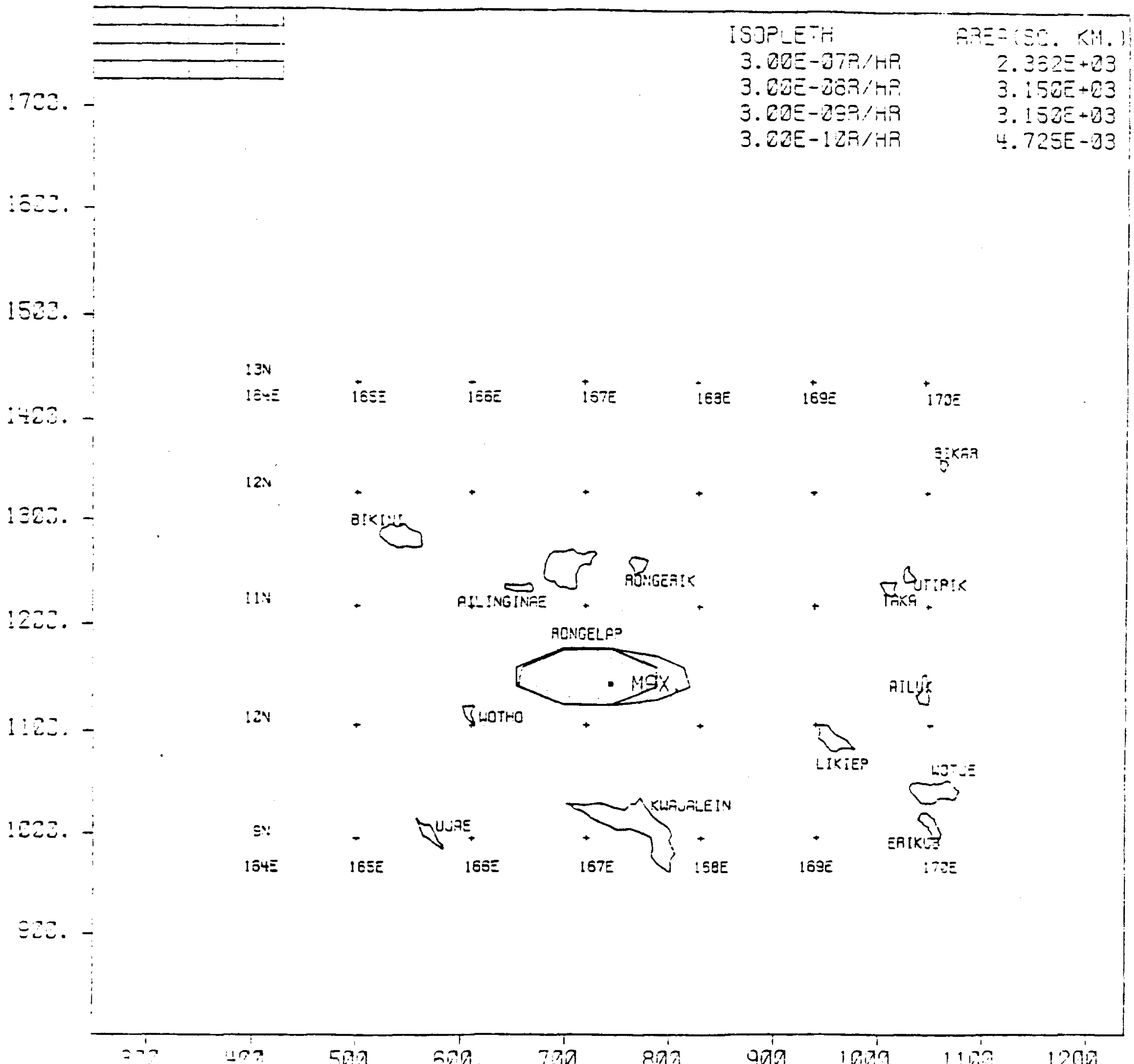


Figure 2e. Same as Fig. 2a, except time is H+13 hours.



BRAVO CHECK ON INTEG. DEP - 5/07/81 MAX- 8.59E-07
CAP + STEM BASED ON 500Z 3/ 1/54
INST AIR AT 2.M EXPECTED AT 3/ 1/54 1045Z

Figure 2f. Same as Fig. 2a, except time is H+16 hours.

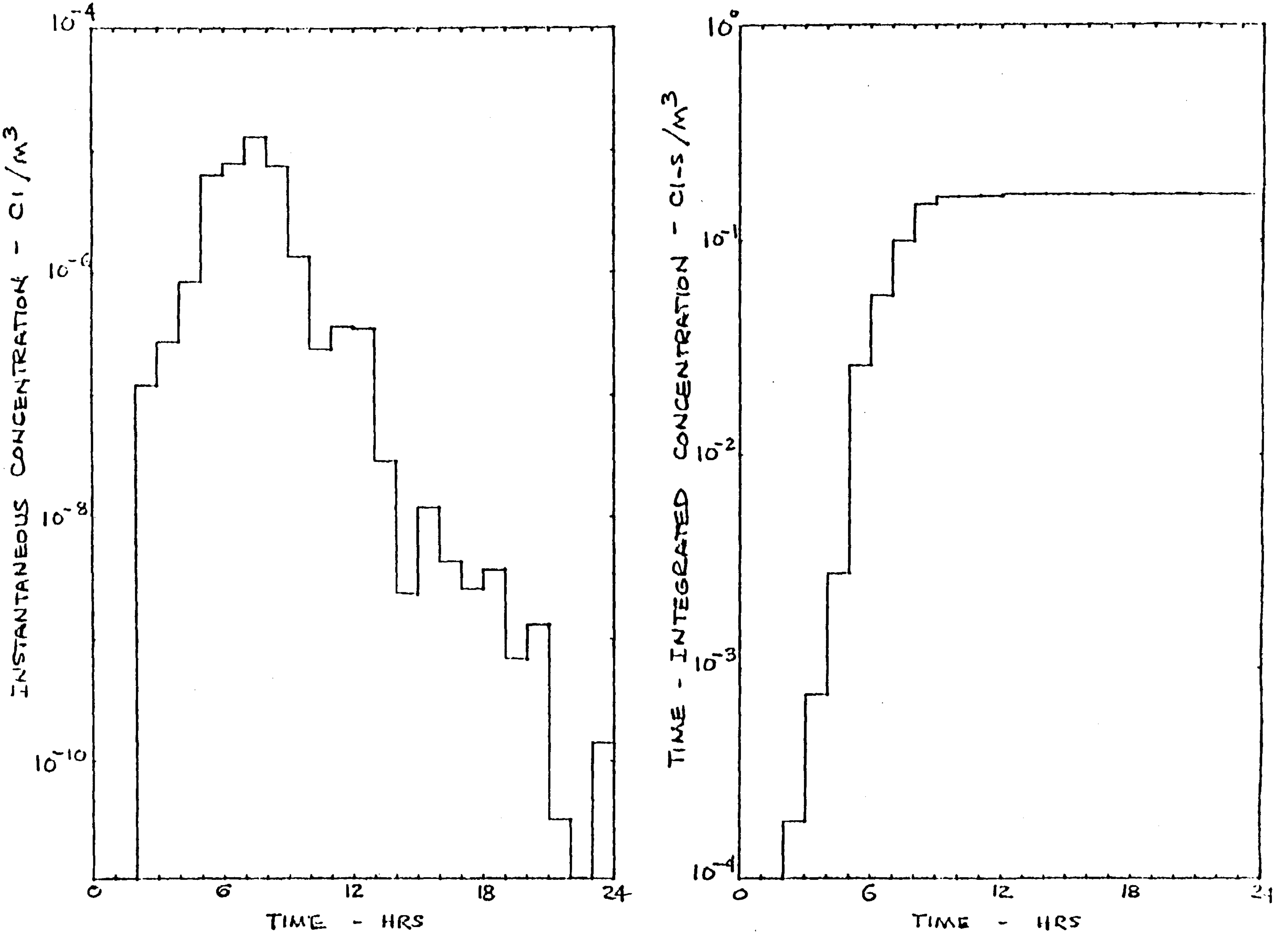


Figure 3a. Castle Bravo instantaneous and time-integrated surface air concentrations for northern part of Ronelap. The nuclide is tellurium-129.

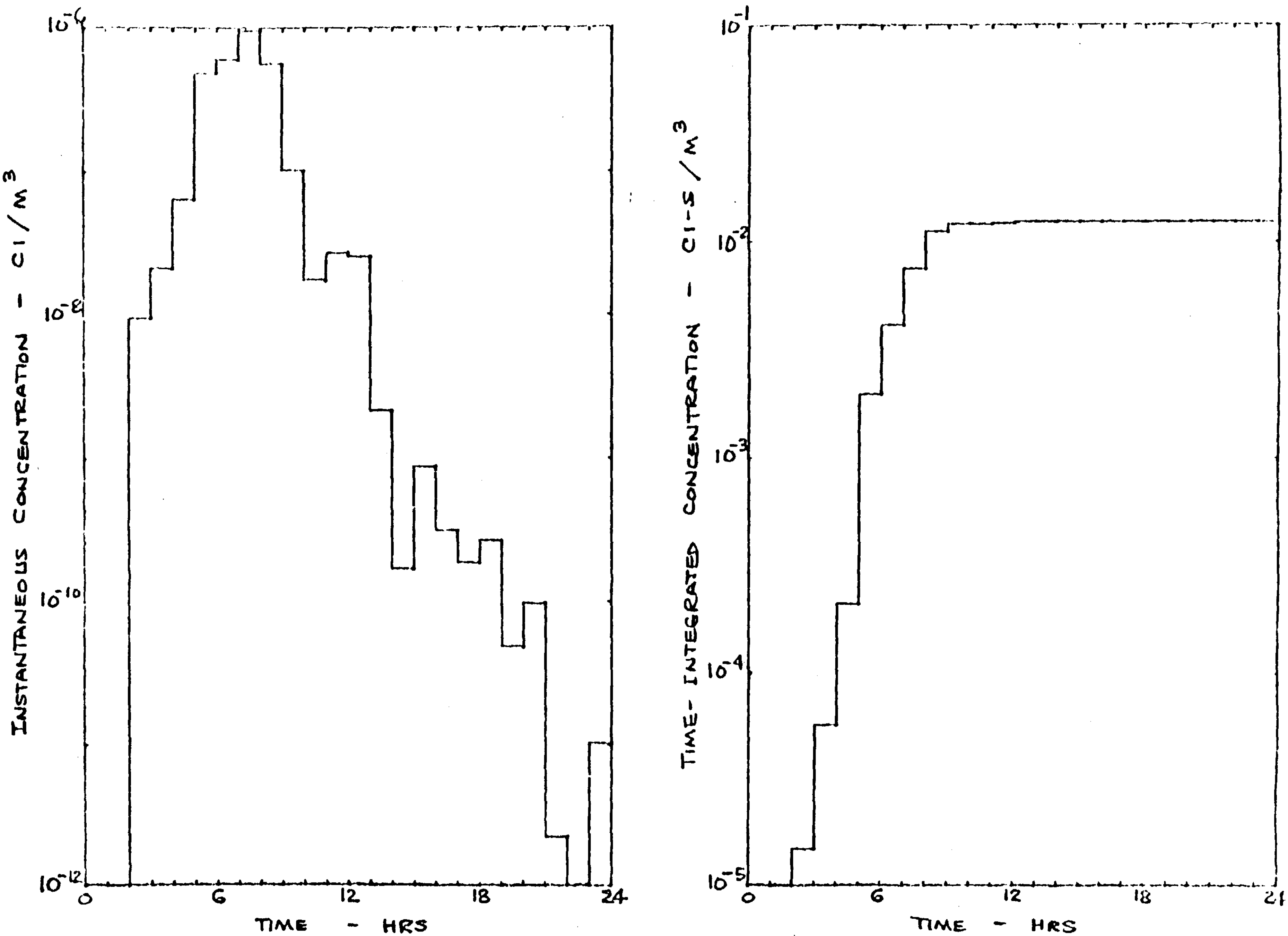


Figure 3b. Same as Fig. 3a, except nuclide is iodine-131.

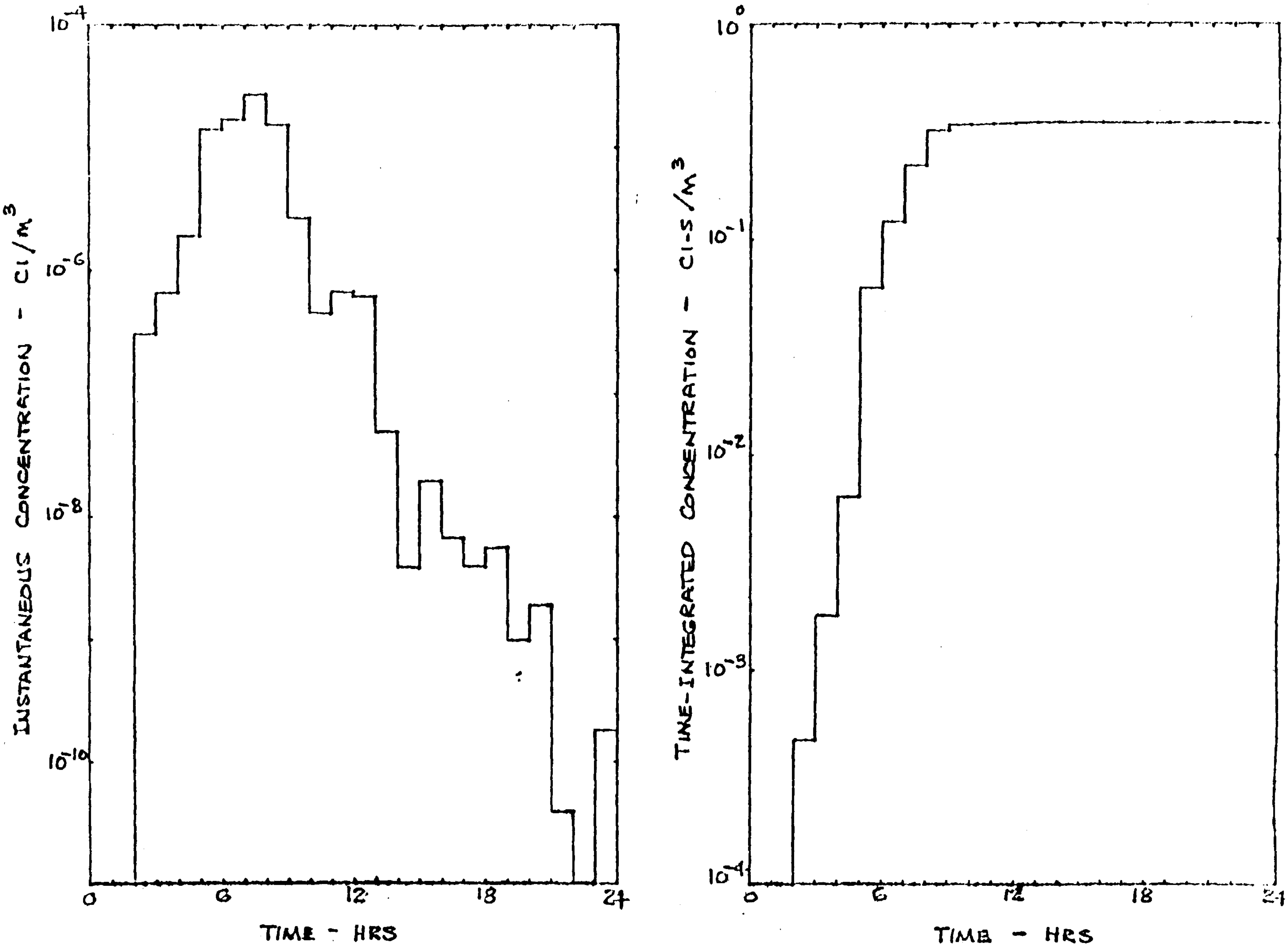
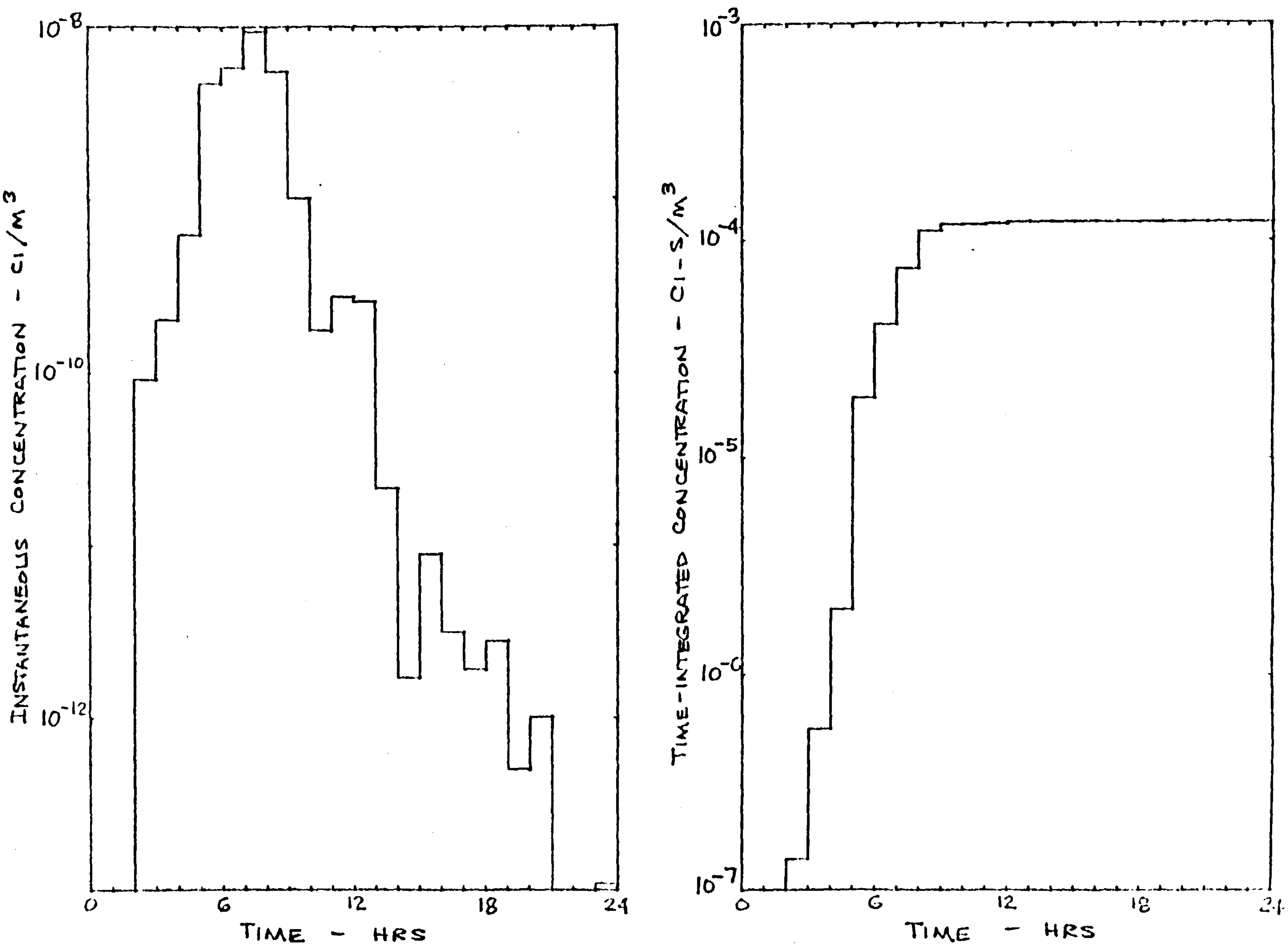


Figure 3c. Same as Fig. 3a, except nuclide is iodine-133.



Figures 3d. Same as Fig. 3a, except nuclide cesium-137.

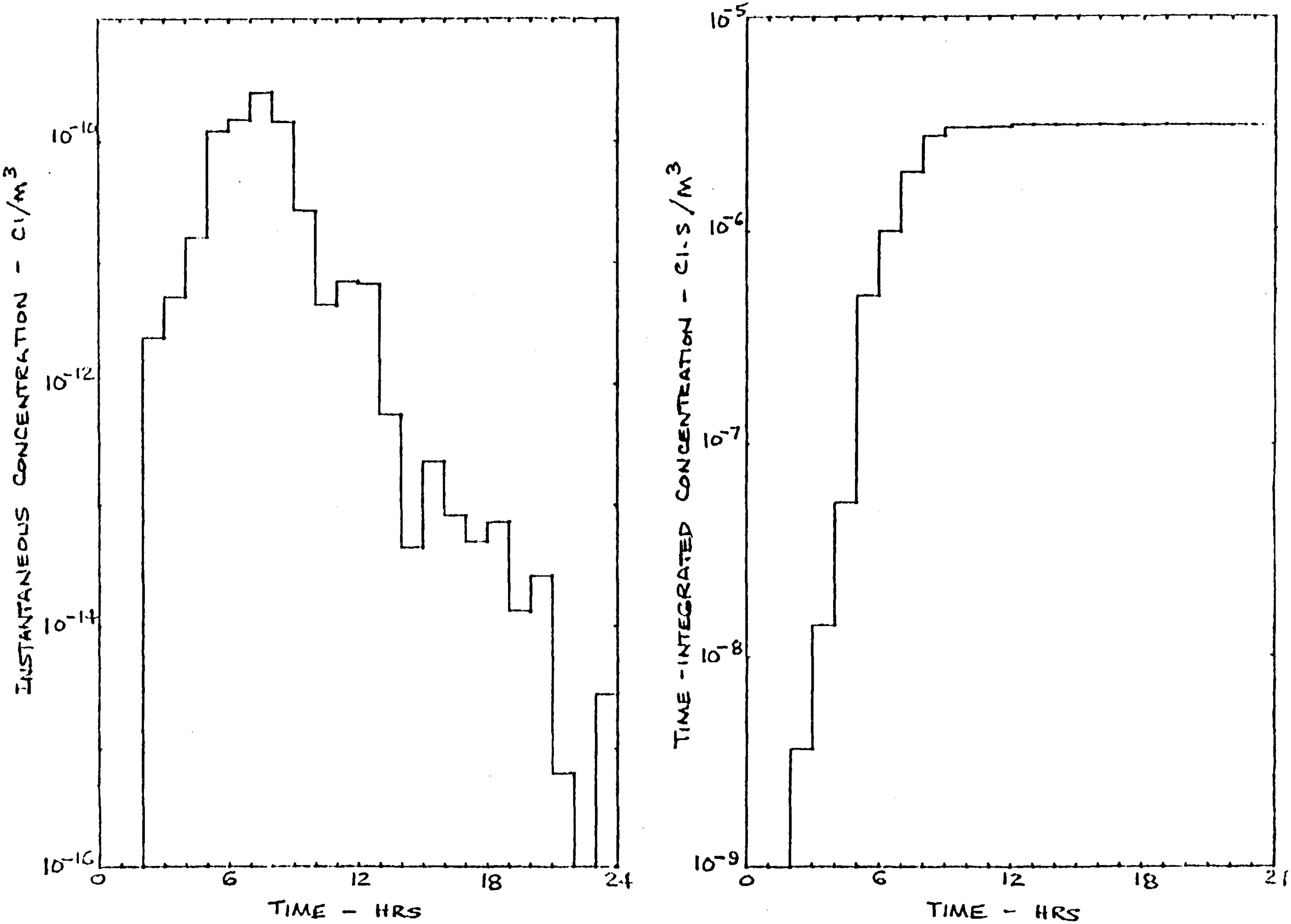
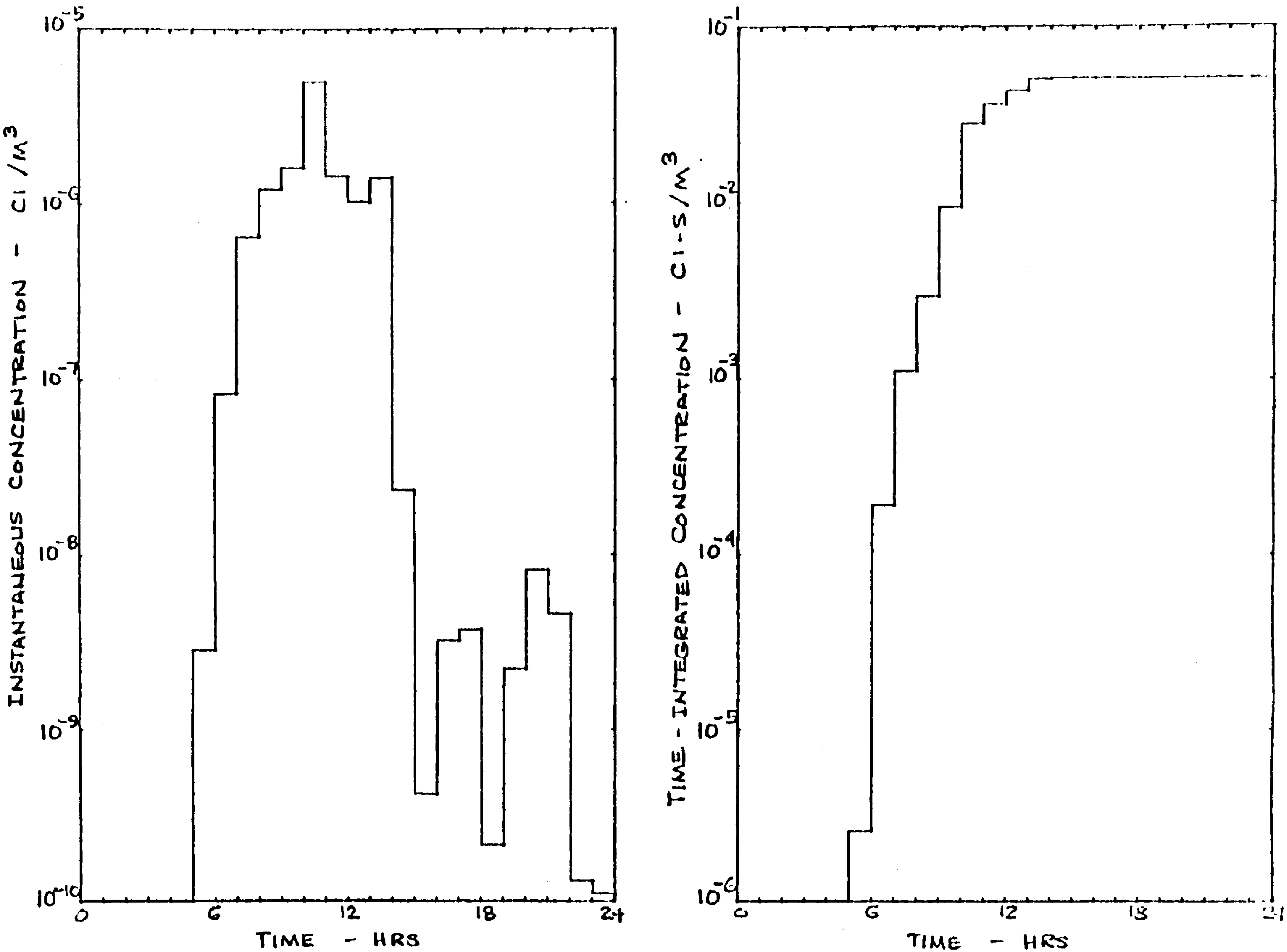


Figure 3e. Same as Fig. 3a, except nuclide europium-155.



Figures 4a. Castle Bravo instantaneous and time-integrated surface air concentrations for southeastern part of Rongelap. The nuclide is tellurium-129.

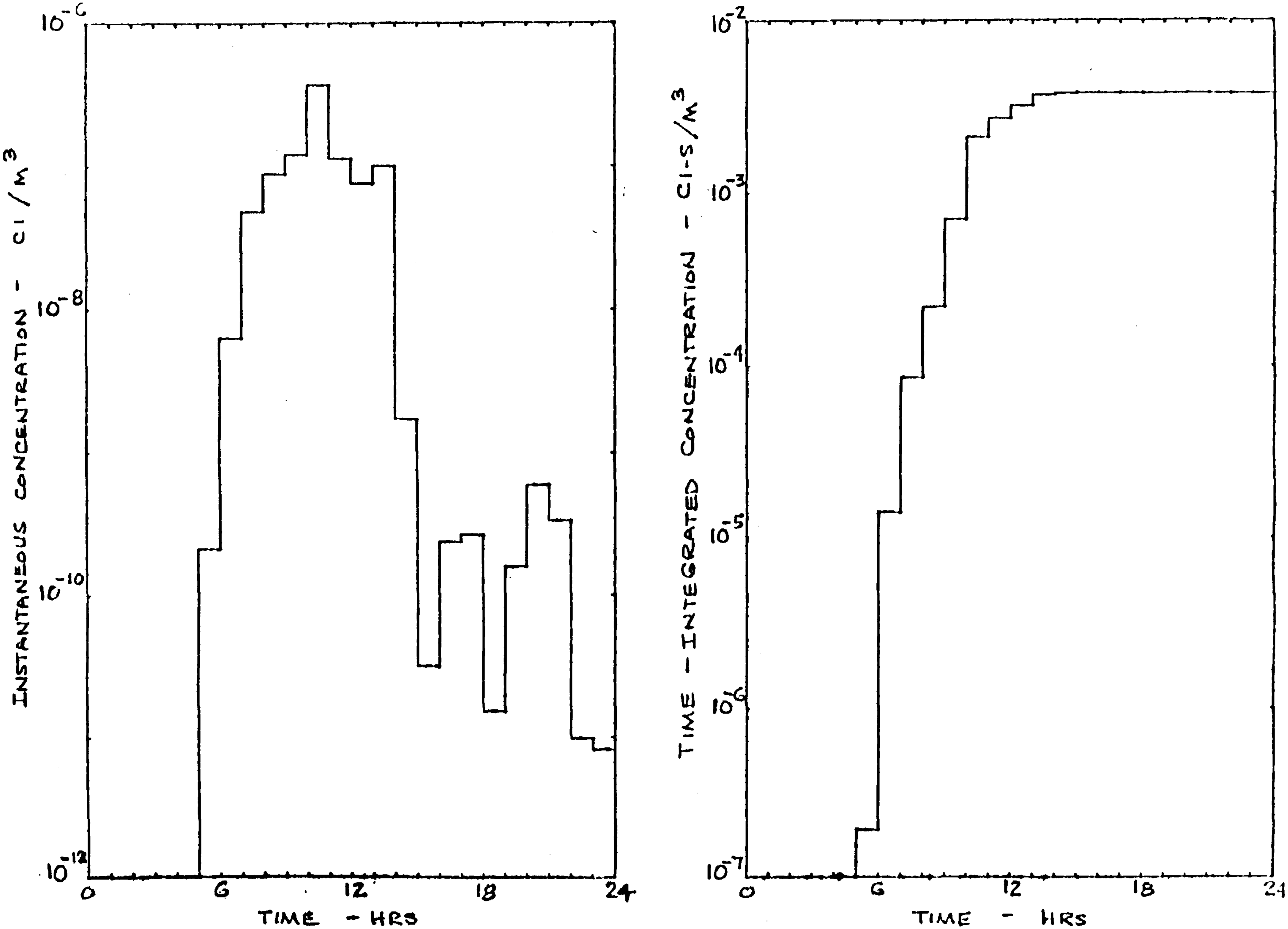


Figure 4b. Same as Fig. 4a, except nuclide is iodine-131.

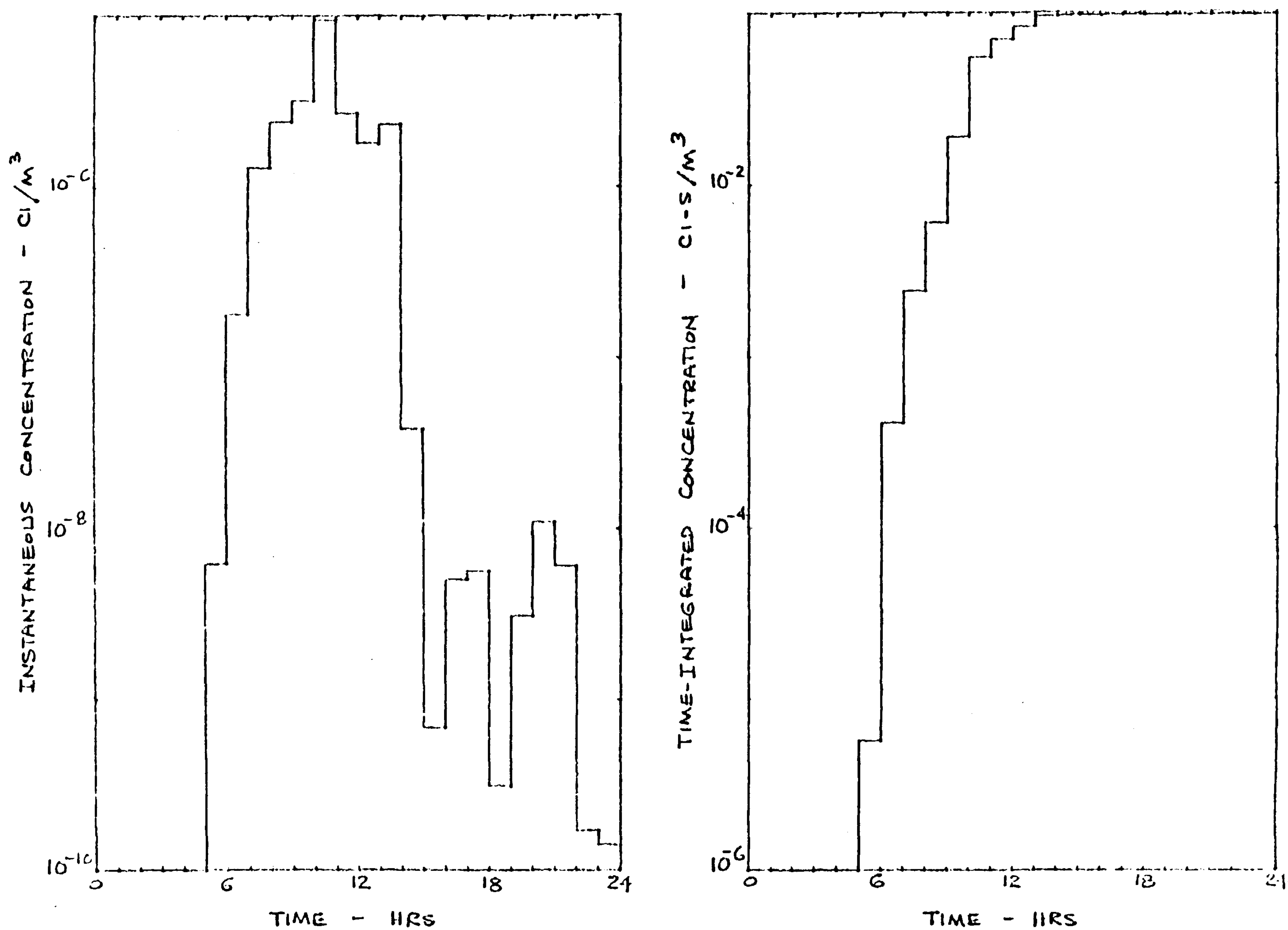


Figure 4c. Same as Fig. 4a, except nuclide is iodine-133.

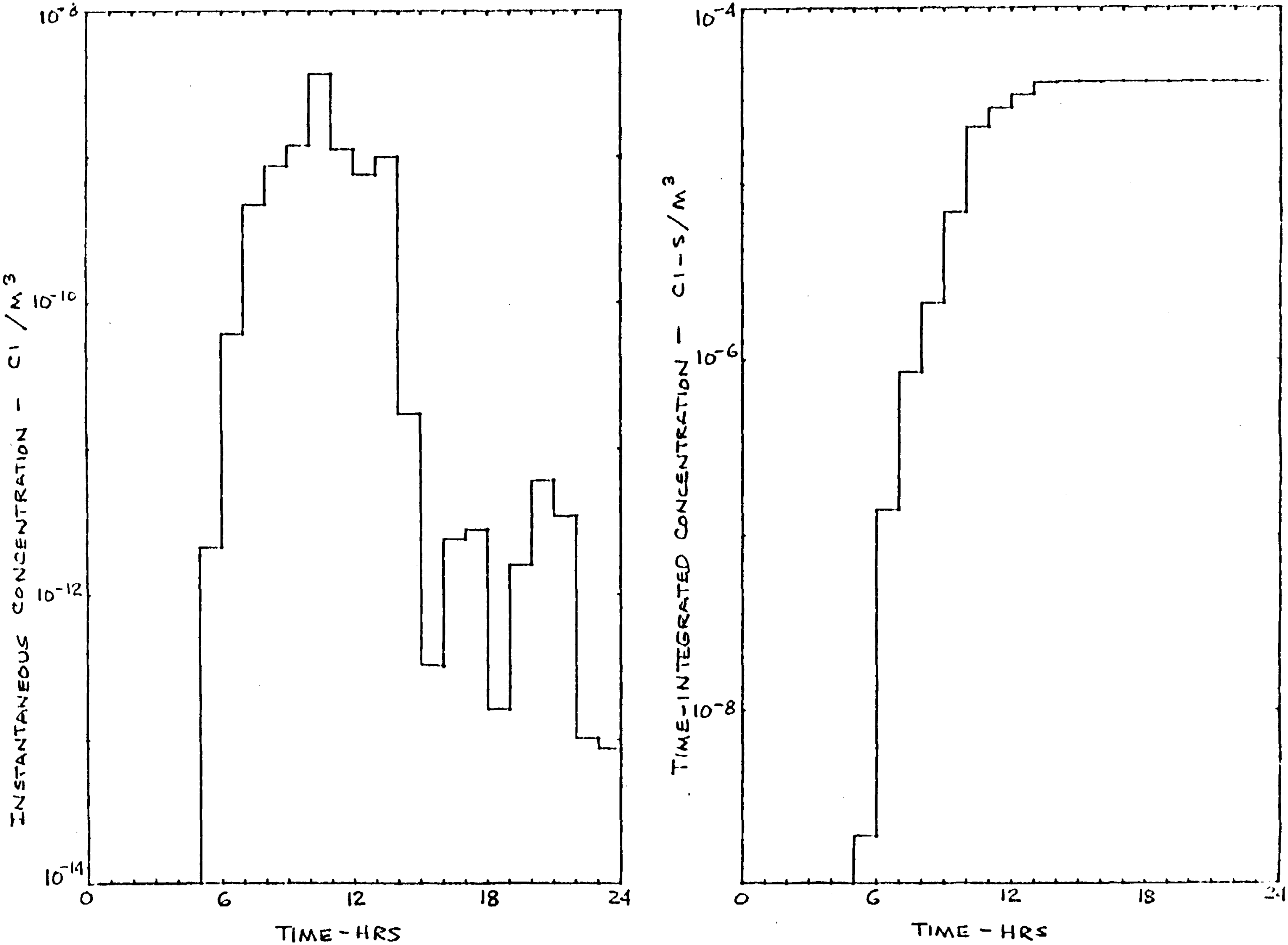


Figure 4d. Same as Fig. 4a, except nuclide is cesium-137.

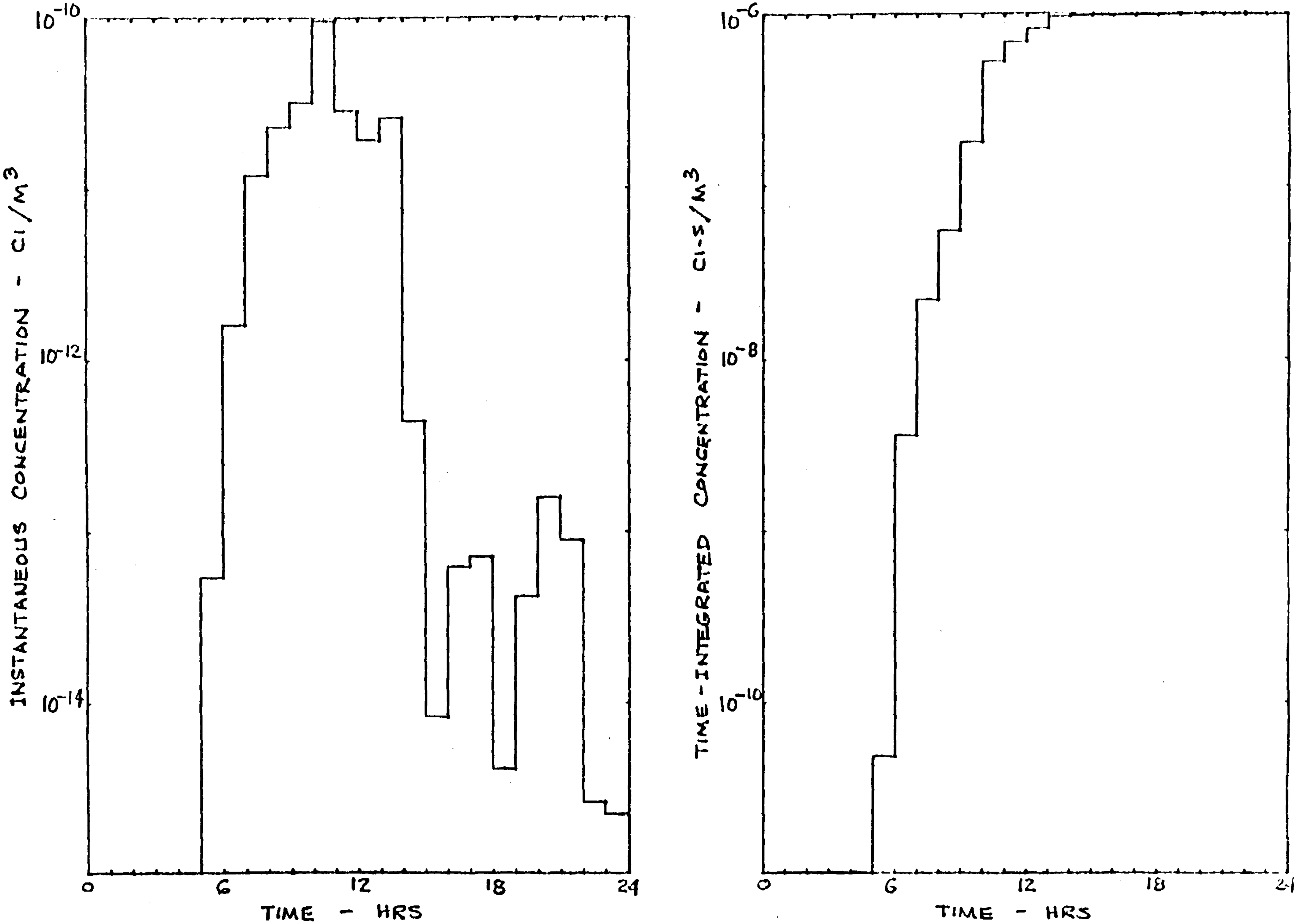


Figure 4e. Same as Fig. 4a, except nuclide is europium-155.

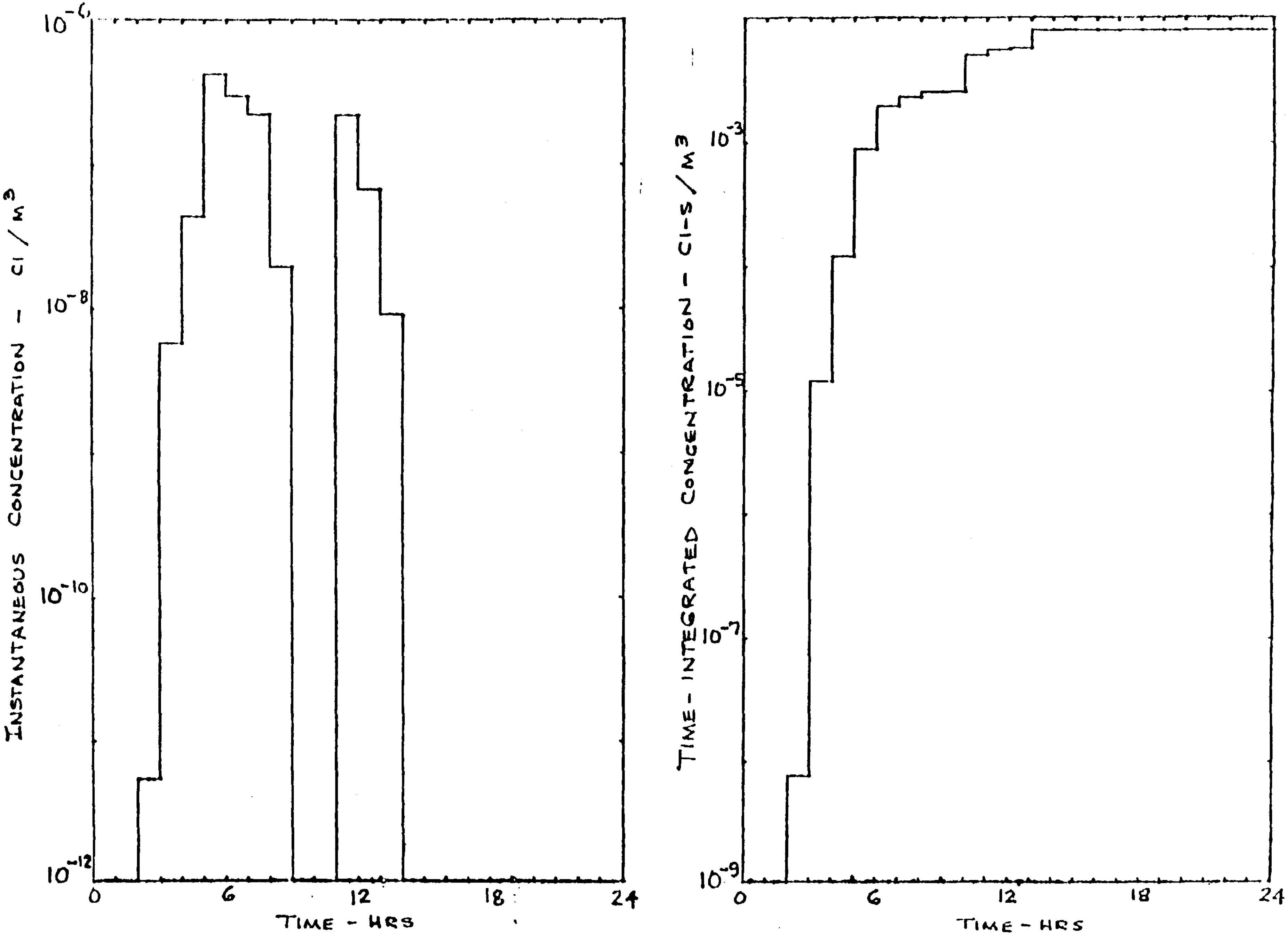


Figure 5a. Castle Bravo instantaneous and time-integrated surface air concentrations for Sifo Island, Ailinginae Atoll. The nuclide is tellurium-129.

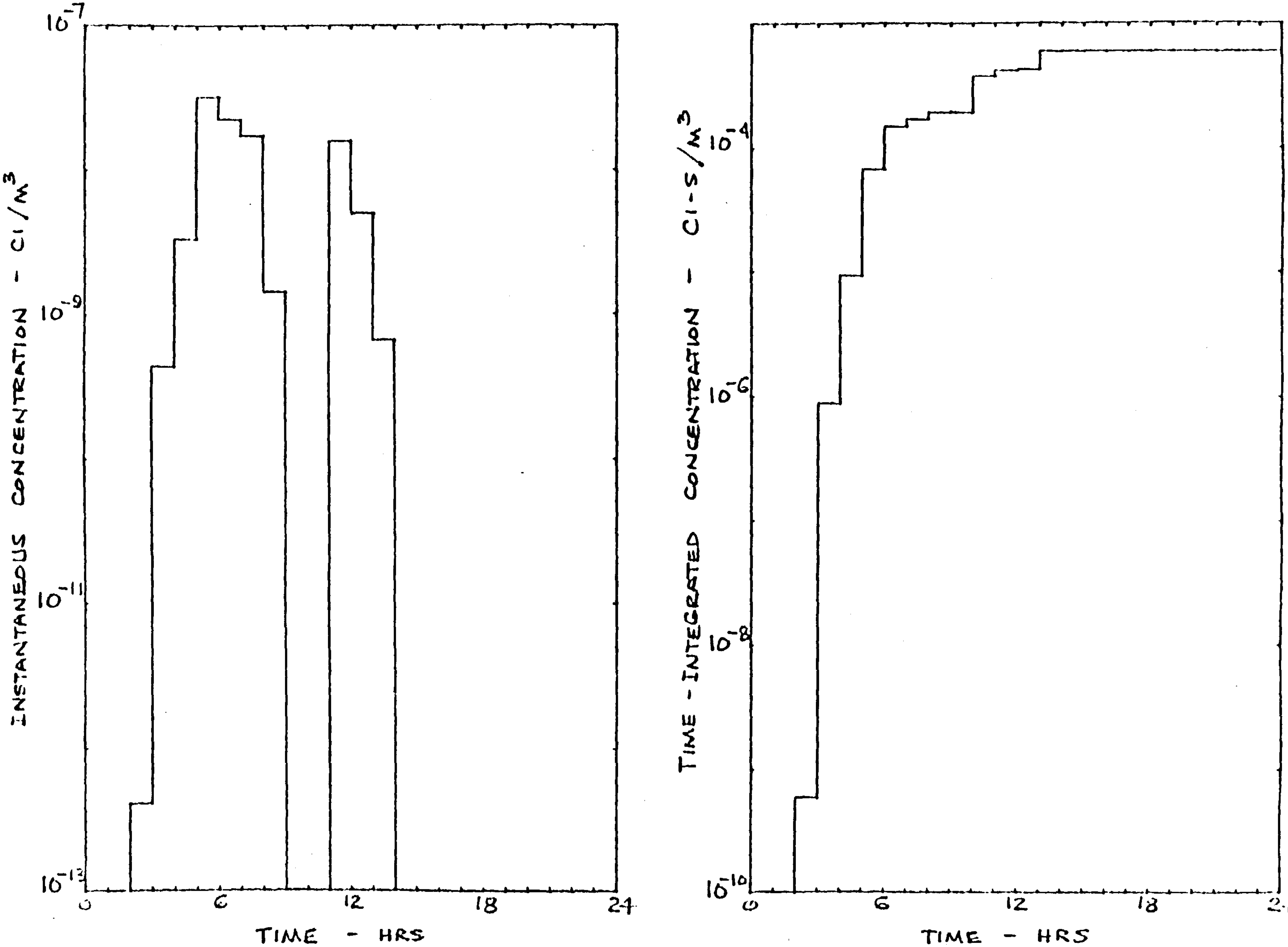


Figure 5b. Same as Fig. 5a, except nuclide is iodine-131.

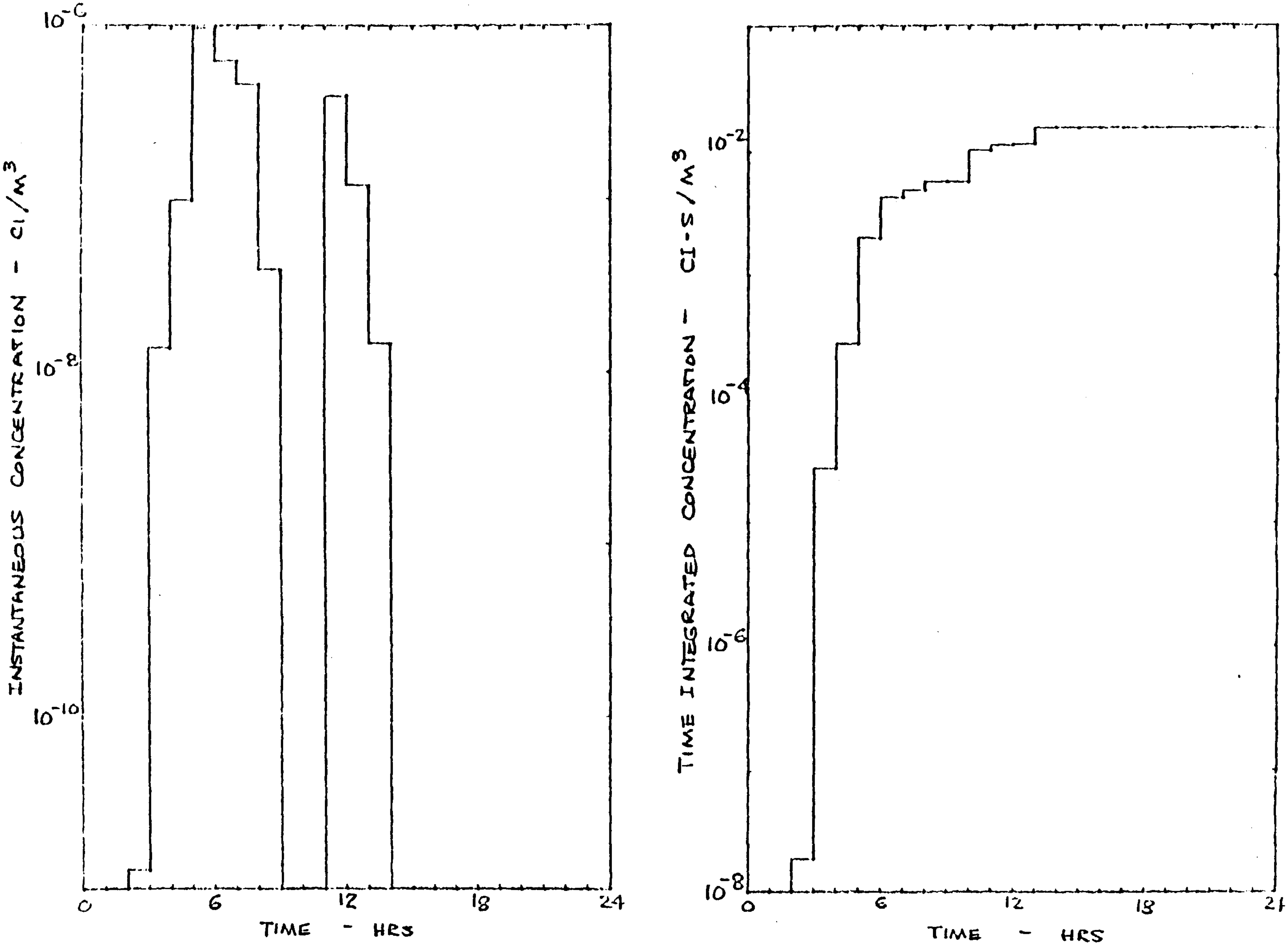


Figure 5c. Same as Fig. 5a, except nuclide is iodine-133.

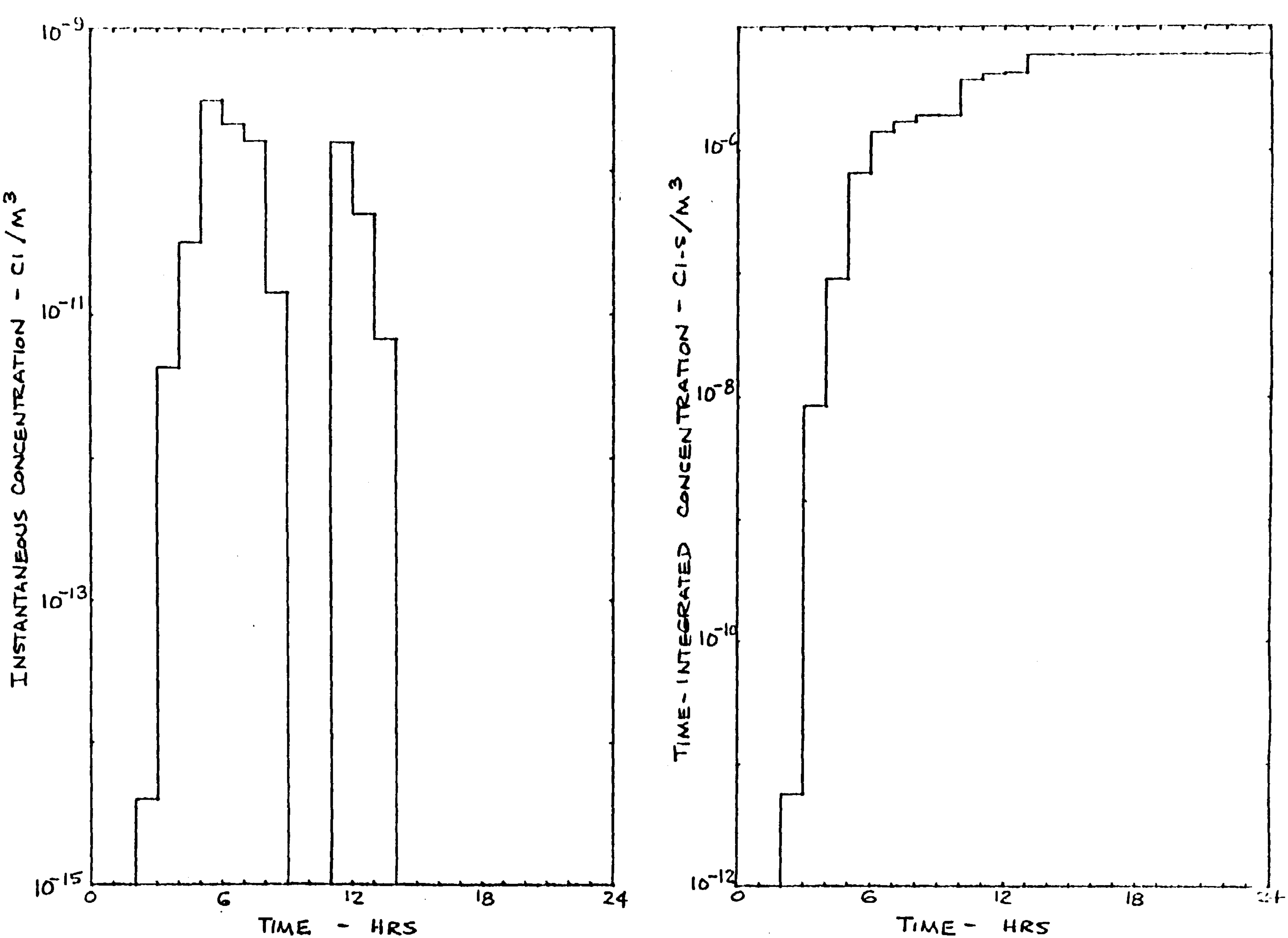


Figure 5d. Same as Fig. 5a, except nuclide is cesium-137.

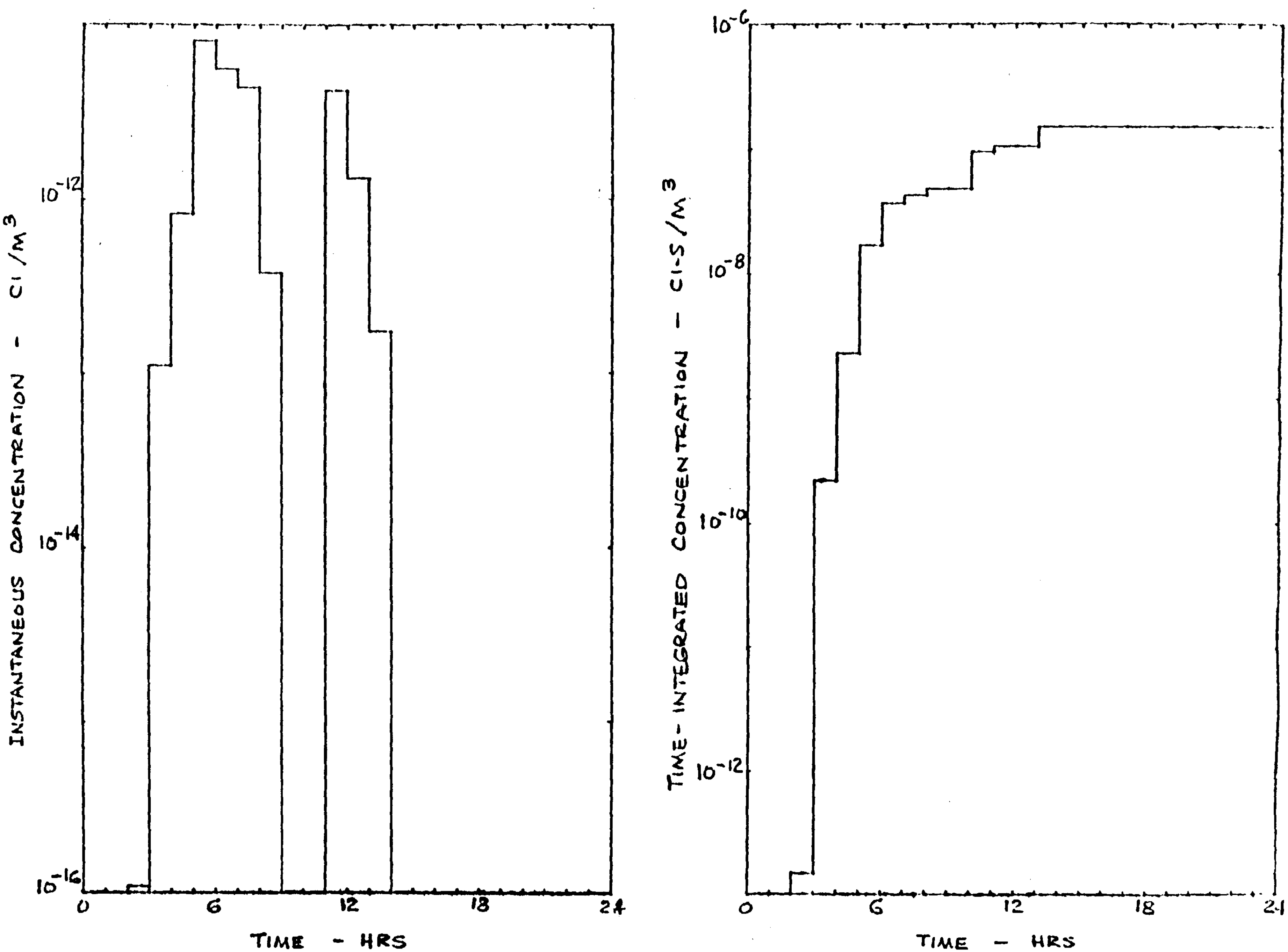


Figure 5e. Same as Fig. 5a, except nuclide is europium-155.

REEVALUATION OF ASSESSMENT OF RADIATION HEALTH EFFECTS OF THE RESETTLEMENT OF ENEWETAK ATOLL

STATEMENT ON BEHALF OF

THE PEOPLE OF ENEWETAK

to

SUBCOMMITTEE ON INTERIOR AND RELATED AGENCIES

by

Michael A. Bender, PhD

and

A. Bertrand Brill, PhD, MD

May 13, 1981

Our earlier Assessment (National Cytogenetics, October 12, 1979) was based upon the "Preliminary Reassessment of the Potential Radiological Doses for Residents Resettling Enewetak Atoll (Robison, et al., UCID-19219, July 23, 1979, draft) also used by the Department of Energy for its own health effects assessment (Ailin in Enewetak Rainin, Washington, D.C., September, 1979). For our Assessment we also adopted the genetic effects and cancer risk estimates given in the May 1979 draft of the National Academy of Sciences-National Research Council Report of the Committee on the Biological Effects of Ionizing Radiation (the BEIR III Report). Since that time final versions of both drafts have become available, and each contains revised values for estimates we used in 1979. We have examined these changes and revised our numerical health effects estimates for the resettlement of Enewetak Atoll accordingly. In summary, though there are increases in both the dose estimates and the cancer risk coefficients, they are relatively small. The resulting changes in our numerical health effects estimates in no way affect our earlier conclusions regarding the safety of the Enewetak People upon return.

Radiation Doses. The refined dose estimates given in "Reassessment of Potential Radiological Doses for Residents

Resettling Enewetak Atoll" (Robison, et al. (1980), UCRL-53066) corresponding to those we used from their earlier draft appear in Tables 30, 42 and 44.

The changes are summarized in Tab 1. It may be seen that the pertinent final estimates are somewhat higher than the earlier ones; in the important cases by roughly 20%, thus our calculated 30 year whole body dose for Enjebi people is increased from 5.6 rem to 6.8 rem, or from 186 to 226 mrem per year (page 4). Similarly, our calculated 30 year whole body dose for people returning to Enewetak and the southern islands is increased from 0.23 rem to 0.38 rem, or from the old estimates of 8 mrem per year to 13 mrem per year (page 5). The resulting revisions of the average doses to the whole Enewetak people increase the whole body dose from 2.36 rem to 2.9 rem, or from 79 mrem per year to a revised estimate of 98 mrem per year (page 5). For the case of a child born eight years after the return to Enjebi, the situation expected to cause the largest risk of genetic effects, the former calculated 4.9 rem 30 year whole body dose is revised to 6.1 rem, or from about 163 to about 204 mrem per year.

<u>Cancer Risk Coefficients.</u> The 1980 BEIR III Report contains substantially revised cancer risk estimates. We have incorporated these in our reevaluation. Thus the coefficients

given in Table 1 of our 1979 Assessment (page 30) for the linear-quadratic dose-response model become 2.81 and 7.70 for the absolute and relative risk projection models and those for the linear dose response model become 6.58 and 18.19 under the absolute and the relative projections respectively. These are not large changes (indeed one constitutes a small decrease), but the largest is roughly two fold.

Genetic Risk Estimates. The dose estimate revisions make very little difference in the numerical genetic effects estimates given in our 1979 Assessment (page 25). For example, the first generation increased risk estimate upper bound estimate is changed from 177 to 218 cases per million live births or, more meanfully perhaps, from about 0.08 to about 0.1 cases among the roughly 49 cases expected from other causes in the next Enewetak generation if the population just replaces itself. Similarly, the absolute upper limit of credible risk of genetic ill health (page 26) for a child born on Enjebi eight years from now who has a child at age 30 is increased only from roughly 3 to 4.5 chances in 10,000, which must still be compared with the roughly one chance in ten normal risk, a very small increment indeed.

Cancer Risk Estimates. The effect of the newer dose and cancer risk coefficients is also small. A comparison of the new with the old estimates is shown as Table I. It may be seen that the earlier upper bound estimate for the people returning to the souther islands of 0.05 added cancers above the 41 cases expected from other causes (page 30) is increased only to 0.09 added cases. Similarly, the upper bound estimate for the people returning to Enjebi of 0.66 case added to the normally expected 27 cases is changed to 0.99 case. We emphasize, however, that these are upper bound estimates, that the actual risk is probably smaller, and may actually be zero.

Conclusion. We have reexamined our earlier Enewetak health effects estimates in the light of more recent dose and cancer risk coefficient estimates, find the risks still small. We note that our revised estimates remain in remarkably good agreement with those provided by the DOE. We still conclude that it is entirely possible that the radiation exposures of the Enewetak people resulting from return of the dri-Enewetak to the southern islands and the dri-Enjebi to their home "will never result in even a single case of disease among either the returning population of their descendents."

Table 1. Comparison of Pertinent 1979 and 1981 Whole Body Dose Estimates

		Dose (rem)		Average Dose (mrem/yr)	
		30 yr.	50 yr.	30 yr.	50 yr.
Southern Islands	New	0.38	0.55	13	11
	Old	0.23	0.33	8	7
Enjebi-Northern Islands	New	6.8	10.1	226	201
	Old	5.6	8.0	186	159
Average (total population)	New	2.9	4.3	98	87
	Old	2.4	3.4	79	68

Table 2. Comparison of No. of added Cancer Deaths Due to Lifetime Exposure (50 years) - Enewetak Atoll Linear-Quadratic (best) and Linear (Highest) Models

Group		Absolute Risk		Relative Risk	
		LQ	Lin	LQ	Lin
Southern Island	New	.02	.03	.04	.09
	Old	.01	.02	.01	.04
Enjebi-Northern Islands	New	.15	.36	.42	.99
	Old	.09	.30	.17	.62
Total Group	New	.17	.39	.46	1.08
	Old	.10	.32	.18	.66

BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.

Upton, New York 11973

Safety & Environmental Protection Division

(516) 345-4207

April 9, 1981

Mr. T. F. McCraw
Division of Health and
Environmental Research
U.S. Department of Energy (DOE)
Washington, D. C. 20545

Dear Tommy:

The following schedule is submitted for the upcoming site review of Brookhaven's Marshall Islands Radiological Safety Program. It is tentative and can be adjusted to meet the needs of the Review Committee.

Date	Time	Discussion Leader	Location	Comment
5/21/81	0900-1000	Bruce Wachholz	Bldg 535A Conf. Rm	Preliminary Committee Meeting
5/21/81	1000-1100	Andrew Hull	Bldg 535A Conf. Rm	MIRSP Program Synopsis 1974 1981.
5/21/81	1100-1200	Edward Lessard	Bldg 535A Conf. Rm	Program highlights and tour of the whole-body counting and bioassay facilities.
5/21/81	1200-1300		Cafeteria	LUNCH
5/21/81	1300-1500	Robert Miltenberger	Bldg 535A Conf. Rm	Whole-Body counting and bioassay instrumentation, quality assurance and results. Will include a summary of the relevant portions of the previous BNL medical program and cover our measurements of Sr-90, Fe-55, Cs-137, Pu-239, Zn-65 and Co-60. The air sampling program will also be included.
5/21/81	1500-1700	Jan Naidu	Bldg 535A Conf. Rm	Exposure rate, vegetation, animal, and soil measurements, instrumentation, and quality assurance. Nuclides included are I-129, Cs-137, Sr-90, and Co-60. Diet and living pattern studies including Marshallese foods, food gathering, food supply shipments, copra production, fishing and other activities.

Date	Time	Discussion Leader	Location	Comment
5/21/81	2000	Charles Meinhold	Stony Brook	Dinner at Three Village Inn for committee members, BNL members and their spouses.
5/22/81	0900-1200	Edward Lessard	Bldg 535A Conf. Rm	Dosimetry models and methods. Results of dose assessment for Rongelap, Utirik, Enewetak, and Bikini populations. Nuclides include Cs-137, Sr-90, Co-60, Fe-55, Pu-239, iodine isotopes and Zn-65. Data storage, records, publications and transmission of information.

Under the proposed format, the various discussion leaders will be prepared to present slides and overheads on topics related to their discussion area. An open round table consideration of the topics presented by each discussion leader will follow. On May 4, 1981, I will forward 14 copies of our publications and drafts package to you. The package will also include copies of our schedule 189's, work package authorizations, and a synopsis of the program history. I will also forward a package to Bill Robison for his information.

I look forward to the review and would appreciate your suggestions concerning any aspects of the schedule or format.

Best regards,

Edward T. Lessard

Edward T. Lessard

ETL/slg

cc: V. P. Bond, M.D., Ph.D.
C. B. Meinhold
Dr. B. Wachholz

BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.

Upton New York 11973

Safety & Environmental Protection Division

(516) 345-4250

April 23, 1981

Mr. T. F. McCraw
Division of Health and
Environmental Research
U.S. Department of Energy (DOE)
Washington, DC 20545

Dear Tommy:

Enclosed are the figures you requested for the Bikinians and other populations. Drafted figures are included for Sr-90 and Cs-137 for Rongelap, Bikini and Utirik residents. Bikini mean adult body burdens which equal the minimum detection limit for the procedure are estimated for Pu-239. Figures illustrating Co-60, Fe-55 and Zn-65 are being drafted presently. Hand drawn copies are included with this letter.

The figure with Pu-239 results illustrates our upper limit estimate of the body burden. These estimates are different for the ingestion or inhalation pathways. The two curves illustrate the results obtained when one assumes that the urine activity corresponds to (a) an inhaled uptake or (b) an ingested uptake. The minimum detectable inhalation burden corresponds to an average derived air concentration of 300 fCi m^{-3}, much greater than that observed by Robison (UCRL-52176). The minimum detectable ingestion burden corresponds to 4 μCi yr^{-1}. This is much greater than that predicted by Robison. Our opinion is that our minimum detectable results can be many times larger than the actual body burden of Pu-239 in this population.

If you need further illustration of our data or require additional information, please do not hesitate to ask.

Best regards,

Edward T Lessard

Edward T. Lessard

ETL/slg
Enclosure

cc: B. Wachholz

ATOLL	URINE COLLECTION DATE	WHOLE BODY COUNT DATE
RONGELAP	MARCH 1954	APRIL 1958
	MARCH 1956	APRIL 1959
	JUNE 1957	APRIL 1961
	APRIL 1958	APRIL 1965
	APRIL 1959	APRIL 1974
	APRIL 1961	APRIL 1977
	APRIL 1963	AUGUST 1979
	APRIL 1964	
	APRIL 1967	
	APRIL 1968	
	APRIL 1969	
	APRIL 1970	
	APRIL 1971	
	APRIL 1972	
	APRIL 1973	
	APRIL 1974	
	APRIL 1978	
	AUGUST 1979	
UTIRIK	APRIL 1959	APRIL 1959
	APRIL 1974	APRIL 1974
	APRIL 1978	APRIL 1977
	AUGUST 1979	AUGUST 1979
BIKINI	APRIL 1974	APRIL 1974
	APRIL 1977	APRIL 1977
	APRIL 1978	APRIL 1978
	JANUARY 1979	JANUARY 1979
	MAY 1979	MAY 1979
	AUGUST 1980	AUGUST 1980
ENEWETAK	FEBRUARY 1980	FEBRUARY 1980
	JANUARY 1981	JANUARY 1981

CONFERENCE ROOM RESERVED FOR:

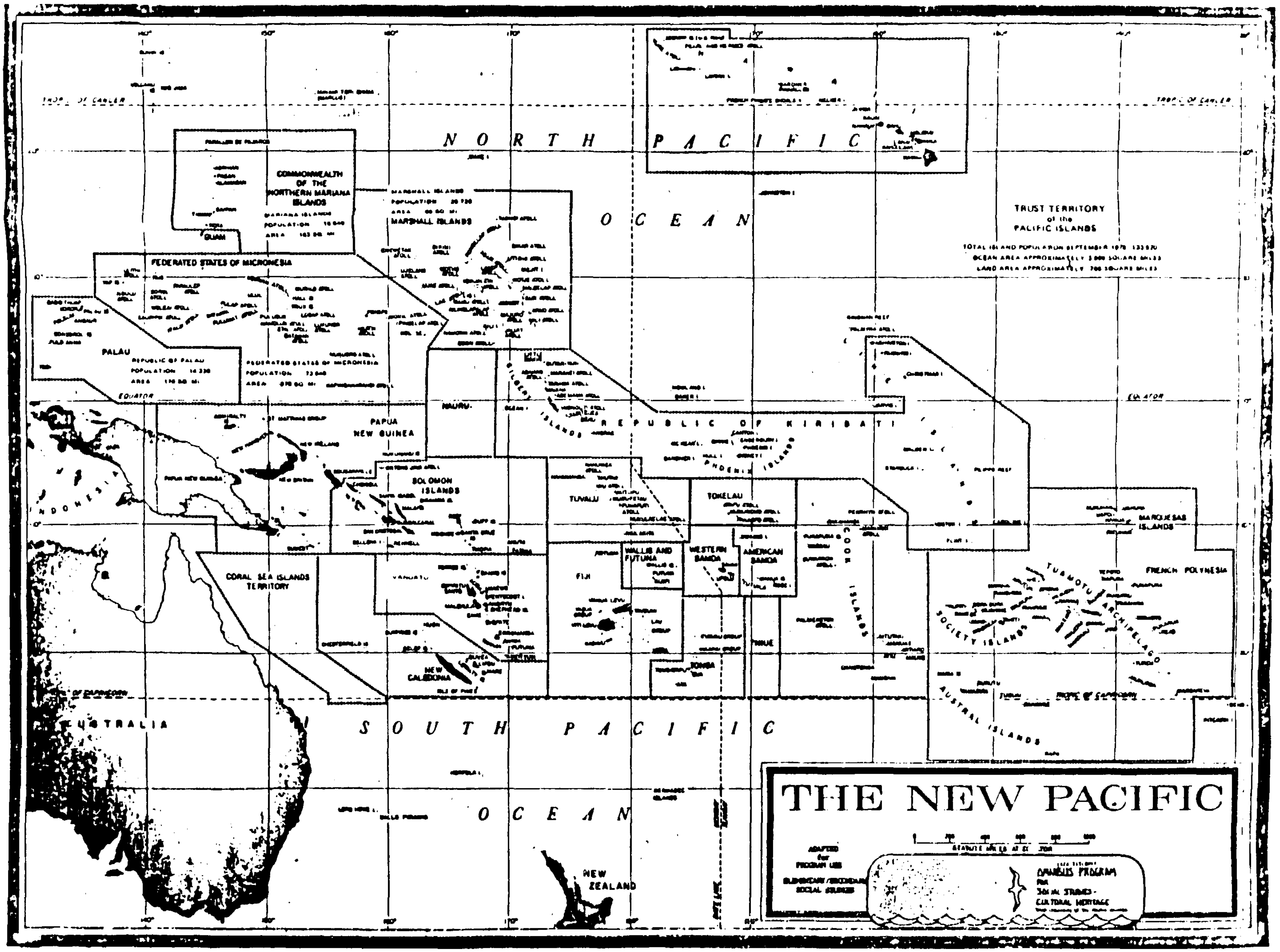
MARSHALL ISLANDS RADIOLOGICAL SAFETY PROGRAM REVIEW MEETING

Thursday, May 21 and Friday, May 22, 1981

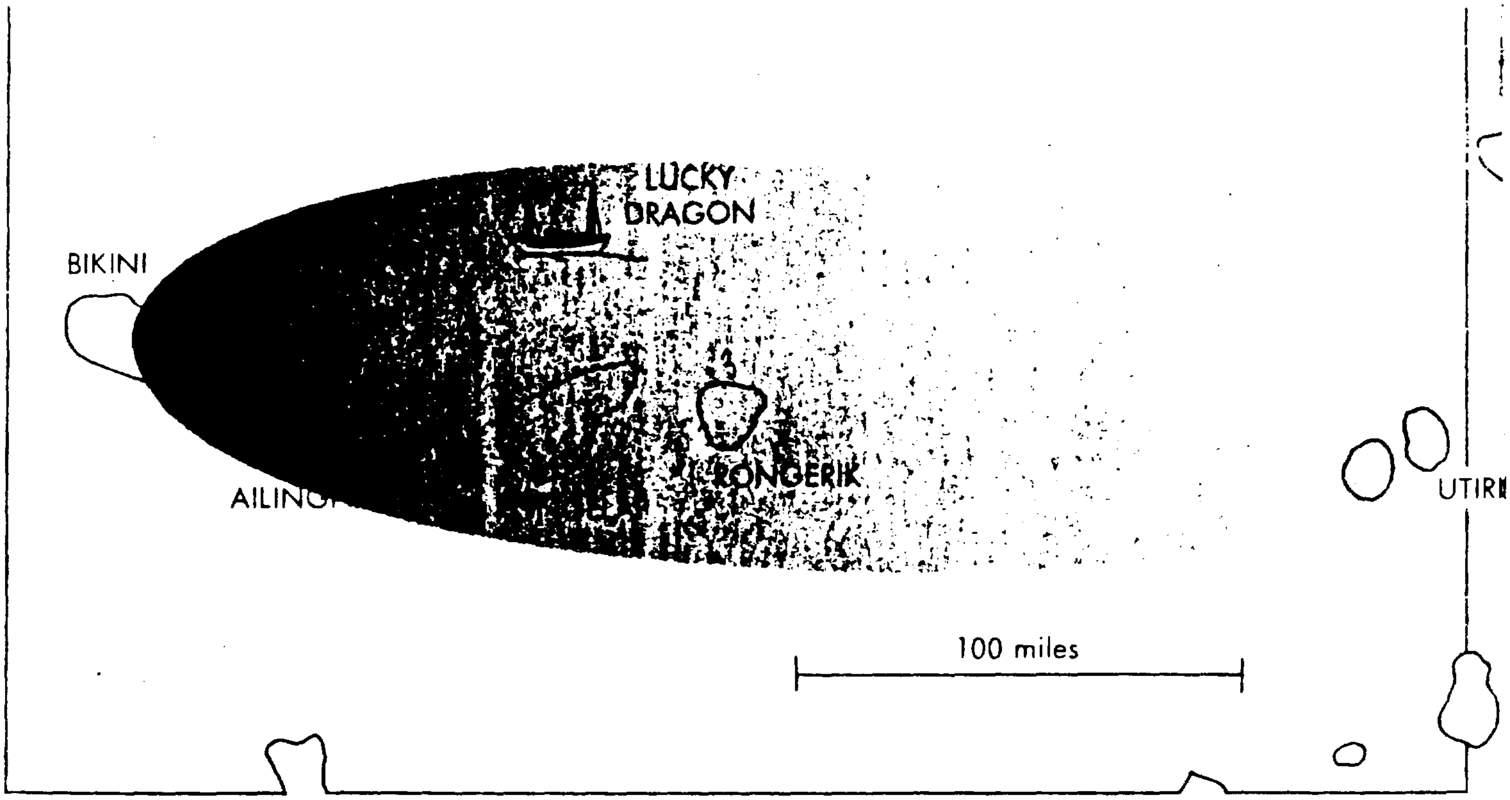
Participants

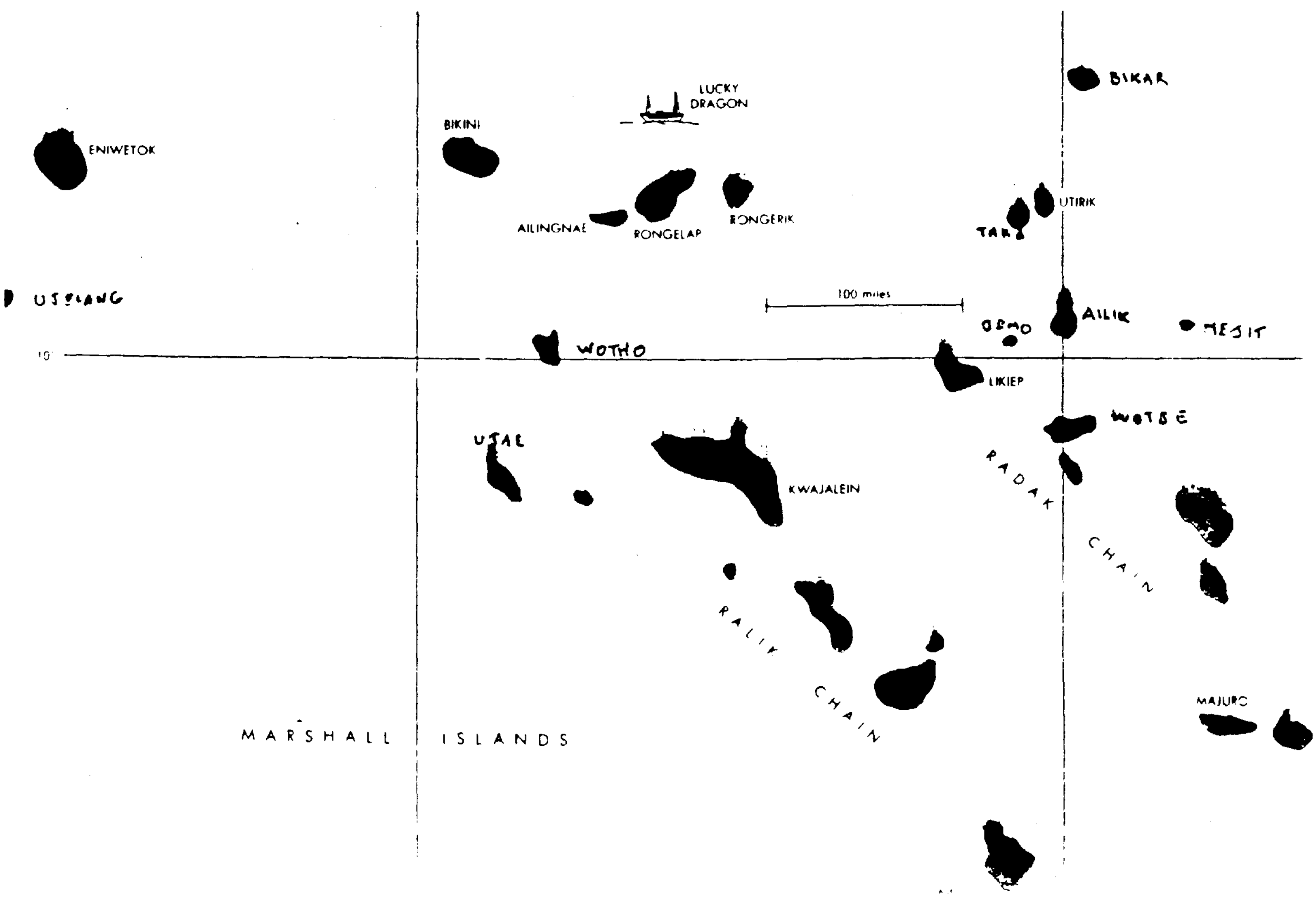
William Bair
Norman Cohen
Chet Francis
Richard Gilbert
Jack Healy
Roger McClellan?
Tommy McCraw
Jacob Thiessen
Roy Thompson
Bruce Wachholz

Robert Conard?
Stan Cohn
~~Eugene Cronkite~~
Andrew Hull
Edward Lessard
Charles Meinhold
Robert Miltenberger
Jan Naidu
Anant Morthy - RADIOCHEMISTRY α-SPECT.
Linda Olmer - RADIOCHEMISTRY - URINALYSIS (TEETH/MILK)
Joseph Steimers - CHEMISTRY
Joeseph Balsamo - INST.



THE NEW PACIFIC
NORTH PACIFIC OCEAN
SOUTH PACIFIC OCEAN
TRUST TERRITORY
of the
PACIFIC ISLANDS
COMMONWEALTH
OF THE
NORTHERN MARIANA
ISLANDS
GUAM
MARSHALL ISLANDS
FEDERATED STATES OF MICRONESIA
PALAU
REPUBLIC OF PALAU
EQUATOR
PAPUA
NEW GUINEA
NAURU
SOLOMON
ISLANDS
REPUBLIC OF KIRIBATI
TUVALU
TOKELAU
WALLIS AND
FUTUNA
WESTERN
SAMOA
AMERICAN
SAMOA
FIJI
VANUATU
NEW
CALEDONIA
CORAL SEA ISLANDS
TERRITORY
TONGA
NIUE
COOK ISLANDS
MARQUESAS
ISLANDS
FRENCH POLYNESIA
TUAMOTU ARCHIPELAGO
SOCIETY ISLANDS
AUSTRAL ISLANDS
INDONESIA
AUSTRALIA
NEW
ZEALAND
TROPIC OF CANCER
TROPIC OF CAPRICORN


LUCKY
DRAGON
BIKINI
RONGERIK
100 miles


LUCKY
DRAGON
BIKINI
ENIWETOK
AILINGNAE
RONGELAP
RONGERIK
UTIRIK
BIKAR
100 miles
AILIK
WOTHO
LIKIEP
KWAJALEIN
RADAK CHAIN
RALIK CHAIN
MAJURO
MARSHALL ISLANDS

From A Twenty-Six Year Review of Medical Findings in a Marshallese Population Exposed to Fallout in 1954. R. A. Conard et al. (In Draft)

Appendix VI

DOSE ASSESSMENT

A Early Radiation*

Table 1. Estimated gamma exposure (measurements in air).

Atoll	No. people	Approx. time fallout began	Time of evacuation	Instrument readings (mR/hr)	Est. γ exposure (R)
Rongelap	64	H+4 to 6 hr	H+50 hr (16 people) H+51 hr (48 people)	375, H+7 days	175
Ailingnae	18	H+4 to 6 hr	H+58 hr	100, H+9 days	69
Rongerik	28	H+6.8 hr	H+28.5 hr (8 men) H+34 hr (20 men)	280, H+9 days	78
Utirik	157	H+22 hr	Started at H+55 hr	40, H+8 days	14

Table 2. Estimated body burden (μCi) of Rongelap people.

	Activity* at day 1	Activity** at day 82	Max. perm. total body burden
^{89}Sr	1.6 - 2.2	0.19	40
^{140}Ba	0.34- 2.7	0.021	9
Rare earth group	0 - 1.2	0.03	
^{131}I (in thyroid gland)	6.4 -11.2		0.7
^{103}Ru	0 - 0.013	-	50
^{45}Ca	0 - 0.019	0.0	200
Fissile material	0 - 0.016 (μg)	0.0	0.4

*From U.S. Naval Radiological Defense Laboratory.
**From Los Alamos Scientific Laboratory.

Table 3. Estimated whole-body (gamma) and thyroid doses (rad)

Population	No.	Whole-body dose	Thyroid dose (incl. gamma), at exposure age: <10	10-18	>18
Rongelap	65	175	810-1800	335-810	335
Ailingnae	18	69	275-450	190	135
Utirik	158	14	60-95	30-60	30

*A reevaluation of the early whole-body and internal organ doses is in progress at Brookhaven National Laboratory. Incomplete results give some indication that the previously estimated thyroid doses may be too low. Since the results are preliminary, they are not included in this report.

Marshall Islands
Whole Body Counting

1958-1977 BNL Medical Department 1978-1981 BNL S&EP

	Bikini	Enewetak	Rongelap	Utirik	Control	Remarks
1957			4^A	2^A		At ANL
8			100			Steel Room-Chair
9			227	30		" " "
1960						
1			110			Steel Room-Chair
2						
3						
4			158			Shadow Shield-Bed
5			169			Shadow Shield-Bed
6						
7						
8						
9						
1970						
1						
2						
3						
4	31		46	22		Shadow Shield-Bed
5						Shadow Shield-Bed
6						
7	48	35 (H&N)	66	66		Shadow Shield-Bed
8	99				12(M)	Shadow Shield-Bed
9	101(M)		75	75		Shadow Shield-Bed
	129(K)					Shadow Shield-Bed
1980	200(M&K)	402			73 (M&K)	Shadow Shield-Chair
						Shadow Shield-Chair
1		378				

Explanation

K - Kili
M - Majuro
H&N - Holmes & Narver employees
LV - Large Volume Samples
R - Rongelap

Marshall Islands

1958-1977 BNL Medical Department 1978-1981 BNL S&EP

	Bikini	Enewetak	Rongelap	Utirik	Comparison	Other Atolls	Analysis By
1954 (March)			Pooled (15)				NRDL & LASL
1954 (April)			51				NRDL
1954 (June)			Pooled				NRDL & LASL
6			Pooled	10	5-Pooled (NY-HASL)	9-Likiep, 5-Majuro	NRSL & HASL
7			Pooled				?
8			15				?
9			174	18			UW
1960							
1			19				BNL-Med
3			38				BNL-Med
4			27				HASL
5			28+2 Pooled				HASL
7			24				HASL
8			22				HASL
9			23			14-Kili	HASL
1970	Pooled + 2		20				HASL
1	Pooled + 7		15				HASL
2	Pooled + 4		18				HASL
3	14		11				HASL
4	21		14	11			HASL
5	2 Pooled						HASL
6	8 + Pooled				Pooled	Ebeye, Wotje	HASL
7	5 Pooled	35 (H&N)	5 (LV)	5 (LV)			BNWL, LASL
8	49 + 5 (LV)		5 (LV)	5 (LV)		12-Majuro	BNL S&EP
9			73	73		49-Majuro	BNL S&EP
						129-Kili	BNL S&EP
1980		400				100-Majuro, Kili	BNL S&EP
1		335					BNL S&EP

Explanation of Symbols

UW - University of Washington
HASL - Health & Safety Laboratory (Now EML)
LASL - Los Alamos Scientific Lab
NRDL - National Radiological Defense Lab
H&N - Holmes & Narver
LV - Large Volume Samples

MARSHALL ISLANDS RADIOLOGICAL SAFETY PROGRAM
FIELD TRIPS 1974-1981

I. Dose Assessment-Environmental Food Chain Surveillance

4/74 - Greenhouse, Ash, Nelson - Utirik, Rongelap, Bikini

Orientation Field Trip (with Medical)

-External radiation measurements

-Sampling groundwater, soil, plants, fish, coconut crabs

12/74- Greenhouse, Nelson - Rongelap, Rongerik, Bikini

-External radiation measurements
-Sampling Fish

4/75 - Greenhouse, Williams, Reilly, Davis, Nelson - Bikini (Enue)

-External radiation levels

-Soil and vegetation (also Wotho, Kwajalein)

Guidance on Siting of Second Increment of Housing

6-7/75-Greenhouse, LLL, UWLRE, EPA - Multiagency - Bikini (Enue)

-Soil, groundwater and vegetation (to UW)

Guidance on Siting of Second Increment of Housing

11/12/75-Greenhouse, Nelson - Majuro, Ponape, Truk, Guam, Polau

Regional Radiological Background Study

3-4/76-Greenhouse, Naidu, Kuehner, Haughey, Terpilak - Bikini (Enue)

Followup of Previous Study

-β-γ dose rates

-Soil and vegetation

9/76 - Greenhouse, Nelson with Medical - Wotje, Ailuk, Utirik, Rongelap, Bikini

-Environmental surveys

II. Augmented Program: Pu Air Sampling, Residency, Dose Assessment, Diet and Life Style Study

1-2/77-Naidu - Rongelap

-Residency, effects of radiation on men

4-5/77-Greenhouse, Levine, Miltenberger - Utirik, Rongelap, Bikini, Kwajalein

-Site planning, wind-powered generators and air samplers, also conventional, Kwajalein-Pu excretion sampling

10/77 - Greenhouse, Levine, Dillingham, DeAngelis, Cua - Utirik, Rongelap, Bikini, Kwajalein

-Installation of windmills

-Large volume urine sampling collection

10/77 - Miltenberger, Cohn, Rothman, Clareus, WBC - Japtan

-WBC-Japtan Marshallese (unseccessful)

-WBC-Enewetak (Holmes and Narver employees)

1/78 - Balsamo, Sherwin - Bikini, Rongelap, Utirik

-Complete installation of wind generators and repairs

3-4/78 - Miltenberger, Lessard, Naidu - Rongelap, Utirik, Bikini

-Collect urine, soil, vegetation and fish

-5 Day Hi-Vol Air Sampling

-Residency-Utirik (Naidu)

-WBC, urine, vegetation, local foods

9/78 - Greenhouse - Nor Marshall Islands Radiological Survey

1/79 - Miltenberger, Greenhouse, Craighead - Majuro (former Bikinian)

-WBC (of 64 former Bikinians), 49 urine samples; 37 Majuro residents

-Complete Pacific Basin Study (UWLRS)

5/79 - Miltenberger, Lessard - Majuro, Kili (former Bikinian)

-WBC (of 79 former Bikinians, 50 Kili)

8-9/79-Miltenberger, Lessard, Balsamo, Hunt, Dillingham, Sherwin, Rademacher - Kwajalein, Rongelap, Utirik

-Reestablish air samplers, Kwajalein, Rongela, Utirik

-WBC 150 persons (Rongelap, Utirik)

-Environmental Monitoring (EM), Rongelap, and Utirik

-146 urines

-local foods

2/80 - Miltenberger, Levine, Greenhouse, Manalastas - Japtan, Enewetak Ujelang - Baseline data, prior to repatrition

-WBC 400

-Urine samples (400)

7-8/80-Greenhouse, Moorthy, Wells Rivera - Majuro, Kili

-WBC (200 persons)

-urine (100 persons)

1-2/81-Miltenberger, Roesler, Bennett - Enewetak

-WBC

-x-ray machine survey

WBC - whole body counting

MARSHALL ISLAND RADIOLOGICAL SAFETY PROGRAM

Environmental Sampling

	Water	Vegetation	Soil	Animal	
1955				7	Crabs - R
1956				7	" "
1957				2	Coconut Crabs - R
1958				2	" " "
1961				?	" " "
1962				3	" " "
1964				3	" " "
1965				1	" " "
1969				2	" " "
1972				2	" " "
1973				3	" " "
4/74	-	50	-	3	" " "
12/74	-	-	-	25	
6/75	-	120	130	2	
4/76	30	100	130	-	
4/78	2	50	-	-	
8/79	2	50	-	10	
8/81		*	*		

R - Rongelap

U - Utirik

* Planned R & U

Marshall Islands Radiological Safety Program

Scientific & Professional Staff

Program Directors

MIRSP

1974 - Sept 1980	Nathaniel Greenhouse
Sept 1980 - Present	Edward T. Lessard

(Dose Reassessment)

1978 - Sept 1980	Janakiram R. Naidu & Nathaniel Greenhouse
Sept 1980 - Present	Janakiram R. Naidu & Edward T. Lessard

Principal Support Staff

1974 - 1975	Frances J. Haughey
1976 - Present	Janakiram R. Naidu
1977 - Present	Robert P. Miltenberger (WBC, Data basis)
1979 - Present	Edward T. Lessard

Part-Time Staff

1978 - 1980	Florence Cua
1978 - 1980	Jerry Knight

Adjunct Staff

1974 - Present	Andrew P. Hull

Rongelap & Utirik
Dose Reassessment (DBER)
(Part-Time)

1978 - Sept 1980	Nathaniel Greenhouse
1978 - Present	Janakiram R. Naidu
1979 - Present	Edward T. Lessard

Consultants

8/78	Charles Sondhaus (UCCM)

Diet and Living Pattern Study
(LLL, DOE)

9/78	Janakiram R. Naidu Evelyn Craighead Nathaniel Greenhouse

Marshall Islands Radiological Safety Program

FY	Person-Years Sci - Prof	Other	Budget Scientific Prog ($1,000)	Budget Capital ($1,000)
1975	1.5	1.0	$125	20
1976 (inc Trans 8)	2.0	1.0	172	20
1977	2.0	1.25	207	80
1978	2.5	2.5	207 + +50 (RUDR)	10
1979	3.4	1.6	281 +50 (RUDR)	25
1980	3.8	2.2	351 +50 (RUDR)	50
1981	3.4	3.1	415 -30 385 +50 (RUDR)	5

Marshall Islands Radiological Safety Program

Major Capital Equipment Acquisitions

FY	1975	Computer Based Multi-channel (and Ge-Li)
	1976	Portable γ Spectrometer, two Reuter-Stokes RS-111
	1977	Wind powered generators (air sampling), three multi-channel analyzers, (two NaI detectors)
	1978	Peripherals alpha spectrometry (Pu)
	1979	Davidson mutli-channel, tower extension for windmills
	1980	Computer based, multi-channel P.H.S.

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     74*  [illegible] (INTEGER NUMBER 999 IN 70)
     7[illegible]  C [illegible] (DECIMAL NUMBER 999.9999 IN 70)
     76*  C [illegible] ME X(10) IN 70)
     77*  C [illegible] X(10) IN 70)
     78*  C [illegible] (NAME X(30) IN 70)
     79*  C [illegible] UTE ERROR (DECIMAL NUMBER 999.99[illegible] IN 70)
     80*  C [illegible] ERROR EXPONENT (INTEGER NUMBER 99[illegible] IN 70)
```

DATE OF REPORT 78/06/14

TO :

FROM :

SUBJECT : H-5 BIO-ANALYTICAL CHEMISTRY SECTION REPORT

ANALYTE : AM-241 URINE PAGE 1 OF 1

THE FOLLOWING DATA ARE RECORDED IN LA NOTEBOOK NO. 32718

PAGE NO. 4 ANALYST IKK VERIFIED BY IKK

LAB NO.	ID	S NO.	EMP GROUP	DATE	REF	RESULT UNITS	Rec %
78- 7274	JABAN (UTIRIK)	0	OP BNL	10/15/77		< 0.03 PC	87
78- 7279	KIOTO (UTIRIK)	0	OP BNL	4/19/77		< 0.03 PC	90
78- 7284	KIOTO (UTIRIK)	0	OP BNL	10/15/77		< 0.03 PC	89
78- 7289	AMOS (UTIRIK)	0	OP BNL	10/21/77		< 0.03 PC	96
78- 7294	NICK (RONGELAP)	0	OP BNL	4/19/77		< 0.03 PC	87
78- 7299	NICK (RONGELAP)	0	OP BNL	10/21/77		< 0.03 PC	59
78- 7304	EDMIL (RONGELAP)	0	OP BNL	10/21/77		< 0.03 PC	96
78- 7309	TARINES (RONGELAP)	0	OP BNL	10/21/77		< 0.03 PC	83
78- 7314	JERRY (RONGELAP)	0	OP BNL	10/21/77		< 0.03 PC	85
78- 7319	JAN (RONGELAP)	0	OP BNL	2/ 5/77		< 0.03 PC	80
		%REC.					
78- 7402	QC SAMPLE 0.18 PC	100		4/18/78		0.18 PC	89
78- 7403	QC SAMPLE 0 PC	--		4/18/78		< 0.03 PC	89
78- 7404	QC SAMPLE 0.45 PC	100		4/18/78		0.45 PC	95
78- 7405	QC SAMPLE 0 PC	--		4/18/78		< 0.03 PC	95
78- 7406	QC SAMPLE .90 PC	100		4/18/78		0.90 PC	97
78- 7407	QC SAMPLE 0 PC	--		4/18/78		< 0.03 PC	97
78- 7324	EVIE (RONGELAP)	0	OP BNL	7/20/77		< 0.03 PC	92
78- 7329	BOAS (BIKINI)	0	OP BNL	4/19/77		< 0.03 PC	95
78- 7334	JERRY (BIKINI)	0	OP BNL	4/19/77		< 0.03 PC	94
78- 7339	HAROLD (BIKINI)	0	OP BNL	4/19/77		< 0.03 PC	98

BNL Radiological Safety Program Budget ($)

	Operating	Capital Equipment
FY 1975	125,000	20,000
FY 1976	172,000	20,000
FY 1977	207,000	80,000
FY 1978	207,000	10,000
FY 1979	281,000	25,000
FY 1980	351,000	50,000
FY 1981	415,000 *	5,000

* Reduced to 385,000 in November 1981.

Rongelap and Utirik Dose Reassessment
Budget ($)

FY 1978	50,000
FY 1979	50,000
FY 1980	50,000
FY 1981	53,000

MALE ADULTS 16 YEARS AND OLDER

PRIVACY ACT MATERIAL REMOVED

ID	NAME	AGE	ISLAND	DATE	CO 60 UCI	EXP	CS 137 UCI	EXP	K 39-41 GRAM	EXP
			ENEWETAK	01/23/81			13.60	-3	127.20	0
2054		55.0								
			ENEWETAK	01/26/81			8.07	-3	175.20	0
			ENEWETAK	02/08/80			160.00	-4	166.00	0
2042		33.0								
			ENEWETAK	02/07/80			23.00	-4	202.00	0
1040		27.0								
			ENEWETAK	02/07/80			130.00	-4	188.00	0
1014		29.0								
			ENEWETAK	01/26/81			3.81	-3	166.00	0
			JAPTAN	02/06/80			150.00	-4	201.00	0
1156		36.0								
			JAPTAN	01/21/81	0.74	-3	9.44	-3	160.10	0
			UJELANG	02/11/80			120.00	-4	183.30	0
2164		16.0								
			UJELANG	02/11/80			72.00	-4	89.20	0
2003		49.0								
			ENEWETAK	01/25/81			6.57	-3	158.00	0
			JAPTAN	02/06/80			120.00	-4	193.00	0
2093		36.0								
			ENEWETAK	01/23/81			8.76	-3	149.00	0
			UJELANG	02/10/80			260.00	-4	146.70	0
2209		16.0								
			ENEWETAK	01/23/81			2.48	-3	95.00	0
			UJELANG	02/12/80			78.00	-4	79.00	0
1048		50.0								
			ENEWETAK	01/22/81			6.72	-3	151.20	0
			ENEWETAK	02/07/80			150.00	-4	156.00	0
1063		36.0								
			ENEWETAK	01/27/81			7.83	-3	142.00	0
			ENEWETAK	02/08/80			170.00	-4	169.40	0
205[illegible]		51.0								
			ENEWETAK	01/22/81			16.30	-3	185.10	0
			ENEWETAK	02/08/80			250.00	-4	162.70	0
125[illegible]	'GE	28.0								
			ENEWETAK	01/22/81			2.05	-2	136.00	0
100		40.0								