SCHEDULE 189

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Lawrence Livermore Laboratory
University of California
Livermore, California

Biomedical and Envir
Science Program

1. CONTRACTOR: University of California

2a. PROJECT TITLE: Marshall Island Radioecology Studies and Dose Evaluations: 1. Enewetak 2. Bikini

2b. GROUP: Analysis and Assessment

189 No.: Abstracted Title:

3. BUDGET ACTIVITY NO.: RX-04-04

4. DATE PREPARED: Nov. 12, 1974

5. METHOD OF REPORTING: Annual

6. WORKING LOCATION: Livermore, California

7. PERSON IN CHARGE: M. L. Mendelsohn/ D.W. Wilson

8. PROJECT TYPE: New Project

9. PERSONNEL ASSIGNMENT AND LEVEL OF EFFORT (MAN-YEARS):

Man-Year Summary	FY 1975	FY 1976	FY 1977
Lead Scientist: W.L. Robison	(1 Jan. 75 to 30 June 75)		
Associates:			

Other Support			
Total Man-Years	4.0	8.0	8.0
Direct Man-Years	3.4	7.0	7.0

10. FUNDING (10^3):	FY 1975	FY 1976	FY 1977
Operating Costs			
Manpower Costs	152.0	344.0	384.0
Materials and Services	36.0	76.0	79.2
Total Operating Costs	188.0	420.0	463.2
Obligations for Capital Equipment not Related to Construction	14.0	6.0	6.0

11. REACTOR CONCEPT: Not Applicable

12. MATERIALS: Not Applicable

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13. PUBLICATIONS:

I. Contributions to Enewetak Radiological Survey, USAEC Nevada Operations Office, Las Vegas, Rept. NVO-140, Vols. I, II, and III, as listed:

1. R. Ray, J. Koranda and K. Marsh, "Enewetak," I, 3-47 (1973).

2. H.L. Beck, J.E. McLaughlin, P.H. Gudiksen and D.E. Jones, "External Dose Estimate," I, 117-131.

3. V. Nelson and V.E. Noshkin, "Marine Program," I, 131-225.

4. J.J. Koranda, J.R. Martin, S.E. Thompson, M.L. Stuart, D.R. McIntyre and G.D. Potter, "Terrestrial Biota Survey," I, 225-349.

5. B. Clegg and D.W. Wilson, "Air Sampling Program," I, 349-372.

6. W.L. Robison, "Dietary and Living Patterns," I, 492-498.

7. H.L. Beck, J.E. McLaughlin, P.H. Gudiksen and D.E. Jones, "External Dose Determination," I, 498-507.

8. D.W. Wilson, "Evaluation of the Inhalation Pathway," I, 507-515.

9. L.R. Anspaugh, "Relationship Between Resuspended Plutonium in Air and Plutonium in Soil," I, App. A, 515-525.

10. W.L. Robison, "Dose Estimates for the Marine Food Chain," I, 526-541.

11. Y.C. Ng, B.J. Berger, D.J. Pederson, Y.E. Ricker, and S.E. Thompson, Jr., "Evaluation of the Dosage from Terrestrial Foods," I, 542-611.

12. W.L. Robison, "Summary of Dose Assessment," I, 612-625.

II. W.L. Robison, W.A. Phillips, Y.C. Ng, D.E. Jones, and O.A. Lowe, "Annual Bone and Whole-Body Doses," Appendix X in Report by the AEC Task Group on Recommendations for Cleanup and Rehabilitation of Enewetak Atoll, pp. 1-12, Tables 1-10 (1974).

III. W.L. Robison, Y.C. Ng, W.A. Phillips and S.E. Thompson, "Preliminary Assessment of Bikini Atoll," Draft Report to DOS August 1974.

IV. J.J. Koranda, "Preliminary Studies of the Persistence of Tritium and Carbon^{14} in the Pacific Proving Ground," Health Physics 11, pp. 1445-1457 (1965).

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14. SCOPE:

A program of radionuclide measurements in soil, water, and biota, radioecological transport modeling, and dose evaluation in the Marshall Islands is propose to fulfill two immediate objectives and one long-term goal. The immediate objectives are (1) to meet present high-priority needs for effective rehabilitation of Enewetak Atoll and (2) to support the ongoing evaluation at Bikini Atoll. The long-term goal is to assure a continuing evaluation effort in support of the implementation of resettlement and rehabilitation in both regions.

The Enewetak Survey and Evaluation effort that resulted in the report NVO-140 (Enewetak Radiological Survey) provides a comprehensive description of the radiological status of that Atoll at one point in time, for the specific purpose of evaluating constraints on rehabilitation and for developing cleanup plans. The implementation of resettlement, however, requires additional studies over a longer time-range to assess the time-dependence of radionuclide removal from the Atoll as well as to support a continuing evaluation effort.

Previous evaluations of the atolls were based upon a limited amount of direct sampling of critical foods in the terrestrial food; these foods (coconut, pandanus fruit, arrowroot, and breadfruit) were very scarce on Bikini — and on Enewetak as well. Predicted doses, therefore, were based on correlation studies that attempted to relate radionuclide concentrations in soils to those in food plants and animals. The Enewetak survey was very thorough, but the dose evaluations were developed without the benefit of time-dependence information relating to the environmental residence times of the critical radionuclides. Thus, there is need both for intensified studies of radionuclide transport in terrestrial food chains and for long-term studies of the cycling and fate of the long-lived radionuclides.

This justification for operating funds therefore proposes an LLL program with the following specific objectives:

1. To make measurements at both Atolls that will delineate the natural processes and the rates of uptake, redistribution, and removal of radionuclides in the ecosystem, and to develop or refine the concentration factors for the critical radionuclides.
2. To develop further understanding of the terrestrial food chains so as to derive guidelines for agricultural practices and for agricultural development that will minimize population exposure via terrestrial foods.
3. To use these new data and constants to refine the projected doses published in NVO-140 for Enewetak and in the preliminary assessment report for Bikini.
4. To define the need for and to develop guidelines for any long-term radioecological surveillance on Enewetak.
5. To develop a comprehensive understanding of the resuspension pathway on inhabited Marshall Island environments.

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6. To produce an ecological systems model of radionuclide transport, recycling, and fate for the long-lived radionuclides on these coral island environments.
7. In the long-term, to provide a continuing evaluative capability of dose-to-man, so that DBER and DOS can call upon us to provide quantitative descriptions of radiological consequences of proposed actions.

These goals will be met by a combination of research tasks covered in this 189 and a previous submission.

Marine Sciences of Radionuclides in the Marshall Islands (already funded by DBER, RX-02-02 V. E. Noshkin).

Both field work and the assessment and evaluation for Bikini will be closely coordinated with those for Enewetak, to maintain a high degree of control and uniformity in sample collection, agricultural methods, analytical procedures, and follow-up assessments. The final assessment would be so integrated that information derived from both studies would be applied to extend our previous evaluations of both Enewetak and Bikini.

The Enewetak people, the Micronesian Legal Services, and the Trust Territory were told that within a 5-year period we could produce definitive information concerning the time-dependence of the radionuclides in the environment and a more definitive time-table for use of the northern part of the atoll. It is important that the necessary field work at Enewetak and Bikini began immediately. But some of the necessary research involves planting of food crops and evaluation of agriculture practices which in many cases involve lag times of three or four years before results will begin to be available.

We propose, therefore, that the initial critical studies outlined below be started at the earliest possible time that essential logistics and transportation support become available. The necessary logistic and transportation support is of primary importance in any studies conducted in the Pacific atolls. (More details on the requirements are described in the body of the 189's.) At this time, Dr. Victor Noshkin, Group Leader for Marine Sciences at LLL, is already funded by DBER for marine and groundwater studies at Enewetak Atoll. He is scheduled for a tour at Enewetak Atoll in January and February of 1975 along with personnel from the University of Hawaii and will have the LCU at his disposal. Part of his program includes lens-water studies on many of the northern islands at Enewetak Atoll where we must perform the necessary terrestrial ecology studies and evaluate the agricultural practices. We have discussed with Noshkin the coordination of the necessary terrestrial and agricultural work and dual use of the LCU; we find that the two programs would be very compatible. The available space and the capability of the LCU should be entirely adequate to support the implementation of both programs because they involve the same area.

Simultaneous fielding of our program with Noshkin's alleviates one of the major concerns and problems associated with research in the Pacific atolls. Therefore, if funding were supplied for the manpower for the terrestrial part of the program and for the necessary travel and agriculture supplies, the program could be initiated immediately (January, February 1975).

The specific projects for Enewetak and Bikini are now discussed in detail.

A. Enewetak

The specific tasks to be carried out at Enewetak are as follows.

1. Test Plantings and Radionuclide Recycling

Test plots of coconut, pandanus, and breadfruit will be planted immediately. Depending on the size of the starter plants a lag time of three to five years can be expected before fruit will be available. Therefore, additional test plantings of arrowroot, squash, papaya, bananas and sweet potatoes will also be initiated immediately. These crops will produce very quickly. In conjunction with data on radionuclide concentrations in soil, they will lead to concentration factors for food products and also to direct measuremnts of radionuclide concentration in food products. Tritiated water will be injected into the groundwater at the root zone to determine the magnitude and rate of uptake of soil groundwater by the different plant species.

Various forms of fertilizers will also be evaluated for any reduction of radionuclide uptake (Cs and Sr) by these food chain plants. For example, high-potassium fertilizers may significantly reduce the uptake of Cs, and effects of phosphorus, calcium, nitrogen and other trace metals may result in greatly altered uptake of both Cs and Sr. Mulching could be used to increase the K content. Further, the vegetation cut for clearing on "cold" southern islands should be tested as a mulch in the "hot" northern islands.

Clean transported soil beds will also be established on the northern islands with clean soil from southern islands such as Japtan and Parry. The clean beds will enable us to directly evaluate the role of vegetation as a major feedback mechanism in the cycling of radionuclides in the atoll ecosystem. The use of clean beds, the removal of litter dropped from the vegetation, and mulching with clean vegetation from the south could serve to interrupt the cycling of radionuclides.

As indicated, the decay of litter to form humus material may well be the primary source of available radionuclides to plants. It is essential to evaluate the above-ground kinetics that produce the input to the groundwater system. Therefore, biomass measurements will be made on Engebi to determine the standing-crop inventories of radionuclides. Litter-fall collectors and litter-bags will be employed to determine rates of litter fall and litter decay. These measurements combined with data on groundwater cycling will be important for a comprehensive understanding of radionuclide cycling and retention in the Atoll ecosystem.

2. Distribution of Radionuclides in Soil, Soil Water, and Humus

The importance of the recycling and turnover times of radionuclides was recognized by our marine group and emphasized in their research programs. The recent research on marine and lens water at Enewetak Atoll revealed several important aspects of the terrestrial ecology that were not evident during the 1972 survey but which have considerable significance in the ultimate dose to man as he reinhabits the atoll. Preliminary data from the lens water program at Enewetak Atoll indicate that recycling and turnover of radionuclides in the atoll ecosystem can be controlled by the groundwater and the humus produced from the decay of litter dropped from the growing vegetation. It appears that effective concentration factors should be based upon the soil water concentrations of radionuclides rather than on the total soil concentrations.

Further research is required (1) to clarify the role of groundwater in controlling the disappearance of radionuclides in the Atoll, (2) to determine the actual cycling process involved in order to evaluate potential methods of blocking nuclide uptake in plant species in the food chain, (3) to determine the actual concentration of radionuclides available to the plants (probably groundwater concentration), in order to develop more accurate and reliable concentration factors for predictive purposes, and (4) to correlate radionuclide concentrations in soil water in the root zone with the concentrations in lens water, to help describe the time-dependence of radionuclides in the soil/plant/groundwater/lens-water system. Therefore, soil cores will be obtained from northern islands (e.g. Janet, Belle) in and around the planting sites. These cores will be analyzed by leaching the soil with reagents approximating soil-water solutions to determine the fraction of soil radionuclides that is available to the plants. Also, the humic fraction of the soil will be separated from the carbonate matrix to determine which portion contains the Cs and Sr.

If the humic fraction and soil water contain the radioactivity and thus constitute the source of available radionuclides for the plants, then concentration factors can be determined for the various food and indicator plants for Cs, Sr, and Pu. Concentration factors determined previously from soil have varied over a wide range perhaps because the total soil concentration is not the critical factor. Therefore, predictive evaluations could be made more reliable by developing concentration factors based upon soil water rather than upon soil.

There is some question whether the plants of the Atoll are really shallow, surface-rooted or whether they may actually use lens water for growth where the lens is of very low saline content. Lysimeters will be installed in soil pits to collect soil-water through-flow to determine the radionuclide concentration profile as water moves downward toward the lens. The concentrations of radionuclides will be compared with those in soil water extracted from the surface horizons of the soil. When these data are available, concentration factors can be calculated for ^{90}Sr, ^{137}Cs and Pu, to provide additional estimates of the rate of input of radionuclides into the len water from the soil column.

This information, combined with the lens-volume measurements and the data on efflux via exchange with seawater (tidal effects) being obtained in Noshkin's current lens-water program will lead to a model for the kinetics of the soil/plant/lens-water system.

3. Turnover of the Lens-Water System

In the lens-water studies of the marine group, important results are being obtained on dynamics, composition, and geographic distribution of lens-water systems on many of the islands. An independent measurement of lens-water volume and dynamics can be made by using an effective water tracer such as tritium. The samples that are being obtained in the Noshkin-Budemeier study are used effectively to measure the volume, turnover, inter-lens communication, and input dilution effects from rainfall and seawater. These results can be verified by injecting the appropriate amount of tritium into several wells on the contaminated islands. The present program, if augmented by water-tracer studies, perhaps both by labelling of the internal lens-water and by surficial labelling of the soil above a lens, will yield independent, collateral measurements of lens-water characteristics. This is important because of the possibility that the turnover rate of the lens system could be the final controlling factor, other than radioactive decay, for removal of radionuclides from the atoll environment.

4. Evaluation of External Beta Dose

In NVO-140 the beta dose was given only minor attention in the external dose measurements and calculations. In reviewing the data, Beck and McLaughlin estimated that the $^{90}Sr/^{90}Y$ beta free air dose at one meter could be four times the ^{137}Cs gamma dose. The TLD's as used on Enewetak had some sensitivity to betas, the aerial system none, and the portable scintillators practically none. Limited results from TLD measurements during the survey indicate considerable lower beta exposures than the estimates, but neither can be considered reliable due to the limited data base.

To complete the external dose estimates, the range of beta to gamma dose rates should be determined. The range of ratios must be emphasized as the ratio should vary widely due to ground cover, depth of burial, etc.

A network for measuring beta doses will be established on two or three islands using a grid similar to that of the 1972 TLD survey. Belle and Daisy or Belle and Janet are good candidates due to location, exposure rates and range of ground cover offered. Adequate data can be obtained with minimal instrumentation such as TLD's with special holders for beta response and thin window GM survey instruments with pancake GM probes and removalble shields.

Data from these experiments will permit a more comprehensive assessment of external dose to the skin of persons inhabiting the atolls.

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5. Continuing Assessment of Radiological Situation at Enewetak Atoll

The dose assessments reported in NVO-140 are based upon data obtained during the 1972 survey. Long-term dose predictions are based upon these data without benefit of time-dependence information. Also, both the initial and long-term dose estimates are based upon concentration factors derived from a limited data base and from correlation analysis methods. With data obtained in this follow-up research, we can eliminate much of the uncertainty in the initial dose estimates.

We will therefore continue to update both short-term and long-term dose assessments in the light of the critical and very relevant information obtained in the follow-up work described above. The updated assessments will be quite useful in developing plans for rehabitations of northern islands, as well as for land-use planning and for specific agricultural planning. Most importantly, it will fulfill the AEC committment to the Enewetak people, the Micronesian Legal Services, and the Trust Territory.

6. Ecological Systems Model

The data base of the 1971 Enewetak Survey is perhaps the most comprehensive radioecological data base in existence. It provides an opportunity to formulate a comprehensive ecosystem model of elemental flow, and would have special payoff value for comparative evaluations of ^{60}Co, ^{90}Sr, ^{137}Cs, and ^{239}Pu. The present data base adequately describes the state of the system; ongoing and proposed DEER research will provide the kinetic information needed to describe transfer between compartments. Much of the research needed to develop such a model is already in progress or is proposed in this 189. The Analysis and Assessment Group, the Marine Group, and the Terrestrial Ecology Group will continue to integrate the new data, as it becomes available, into a systems model. In the process they will define areas where further research is needed.

B. Bikini Atoll

The tasks to be carried out at Bikini are as follows.

1. Sampling of Available Food Chain Products and Corresponding Soils

The major food crops planted five years ago on Bikini atoll provide a five-year head start for initial assessments as outlined under the objectives of the program. Banana and papaya will be collected immediately for direct measurement of radionuclide uptake. Corresponding soil samples will be collected from the area surrounding the root zone. These soil samples will be separated into fractions so that we can determine which soil component contains the activity. The fraction of the total radionuclide inventory in the soil available to the plants will be determined by leaching studies, and appropriate concentration factors will be determined. As the coconut, pandanus fruit, and

breadfruit become available over the next two years, similar sample collections and analyses will be conducted. As data become available from direct analysis of these food products, the results will be compared with the predictions derived from the soil-concentration correlation techniques to evaluate the accuracy of previous predictions for both Bikini and Enewetak.

2. Biomass Measurements of Agricultural System

Biomass measurements for typical atoll agricultural areas will be conducted at Bikini and Enewetak islands. Samples will be collected in litter-fall collectors and litter-bags to determine the rates of litter-fall and litter-decay in an agricultural area. Preliminary data for the marine lens-water program indicate that these processes may be the primary factor in controlling radionuclide cycling. More definitive data must be obtained to develop an understanding of the above-ground cycling mechanisms. These data will be of primary importance in developing the overall ecosystem model for an atoll environment. Further, they will form the basis for the implementation effort designed to minimize radionuclide uptake in terrestrial food chains and thereby to minimize dose to man.

3. Assessment of Agricultural Practices

Certain areas of Bikini Atoll that have been replanted will also be used as test plots to determine the effect of agricultural practices on radionuclide uptake. As at Enewetak, fertilizers will be evaluated for their effects in reducing the uptake of radionuclide by the various plants. The effects of litter clean-up, fertilization, and mulching will be evaluated for effectiveness in interrupting and reducing the recycling of presently available radionuclides.

4. Continued Assessments

This effort will be a closely integrated one based upon data from both Enewetak and Bikini, and as data become available, they will be used to modify previous dose predictions and to develop new assessments of the short-term and long-term use of both Bikini and Enewetak.

15. RELATIONSHIP TO OTHER PROGRAMS:

This project is integral to our DBER program in LLL, and utilizes capabilities across the program. Central to this project, the Analysis and Assessment Group of the LLL Environmental Research Section will coordinate, overview, and describe the results of the study as it did for the Enewetak Survey and Evaluation.

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16. TECHNICAL PROGRESS IN FY 1975:

This is a new effort. However, a preliminary report, similar to the Enewetak evaluation, was developed for Bikini and presented to DOS. In addition, we have been working continuously with DBER and DOS on followup assessments relative to interpretation of NVO-140 data and other matters involving Enewetak and Bikini.

17. EXPECTED RESULTS IN FY 1975:

A. Enewetak Atoll

Results for FY 1975 would include the establishment of test plots, both regular and clean-bed, on the northern islands. Also, soil cores would be collected, leached, separated and fractionated, to assess the availability of radionuclides to plants and to assess the soil moeity with which the radionuclides are associated. Both organic and inorganic soil components will be analyzed and the radionuclide concentration in soil water profiles from surface to lens will be evaluated. Also, in combination with Dr. Victor Noshkin's program, an assessment will be made of the turnover time of the lens systems on different norhtern and southern islands.

These data will lead to more general understanding of the cycling phenomena in the atoll ecosystem as well as to better assessment of concentration factors for indicator plant species now available on the islands. Biomass measurements will be made for Engebi and perhaps one of the adjacent islands. The rate of litter fall and of litter decay will be assessed for a nonagricultural situation on Engebi. The results will be used to establish a model for the above-ground kinetics leading to radionuclide input into the root-zone groundwater system.

B. Bikini Atoll

The initial trip to the Atoll would establish the necessary experimental plots and the necessary supporting equipment for sampling collection and sample processing. It is expected that three trips per year will be required for the next few years to complete the experiment and to obtain the necessary samples.

Initial samples of banana and papaya will be collected, along with corresponding soil samples, and returned to LLL for analysis. New concentration factors will be developed from these data and the soil fractions containing the activity will be defined. Also, the measured concentrations in the fruits will be compared to predictions based upon the approach used in NVO-140 and the preliminary Bikini assessment to test the accuracy of the predicted concentrations in fruits and the doses based upon these predictions. Experiments to measure litter-fall and litter-decay rates in an agricultural system will be initiated during FY 1975.

Fertilizers would also be applied to test plots of papaya, banana, coconut, pandanus fruit, and breadfruit to begin an assessment of the effect of fertilizers upon radionuclide uptake. Initial clean-up of litter on other plots would be started to assess the possible interruption of the recycling of radionuclides. Soil samples will also be collected from these plots; if the recycling of radionuclide is blocked, it will be possible to determine the effective removal time of the radionuclides from the terrestrial environment.

18. EXPECTED RESULTS FY 1976:

A. Enewetak Atoll

Results for FY 1976 would include the harvesting of crops such as squash, arrowroot, papaya, banana, and sweet potato and the direct measurement of radionuclides in food products. From these data and from the continuing analysis of soil/soil-water data, we will be able to establish concentration factors for these food products. Effects of fertilizer on the uptake of radionuclides will also be assessed during this fiscal year. In addition the effect of clean-bed procedures, cleanup of litter, and mulching with essentially clean vegetation from southern islands will be evaluated for these faster-growing crop species. The clean-bed procedures and the use of fertilizers will be continued for coconut, pandanus, and breadfruit with expectation of results from these efforts in FY 1978. Directly measured radionuclide concentrations in food products will be compared with those used in the assessments in NVO-140, which were based upon concentrations predicted from correlation studies.

B. Bikini

Experiments on test plots with fertilizers and clean-up procedures for litter will be continued to evaluate the effect of agricultural practices on the uptake or the recycling of radionuclides by plants. Samples of papaya and banana will continue to be collected to determine by direct measurement the half-time of ^{137}Cs and ^{90}Sr in the unaltered environment. Measurements of litter-fall and litter-decay rates will be completed furing this fiscal year.

Coconut should become available during this year; the assessments would expand to include this significant food product. Pandanus fruit and breadfruit would of course be included if available. All data would be factored into continued assessments of the radiological implication of developing various food chains and agricultural practices and in the evaluation of these scenarios for immediate and long-term use of both Bikini and Enewetak.

19. MAJOR MATERIALS, EQUIPMENT AND SUBCONTRACT ITEMS:

	FY 1975	FY 1976	FY 1977
4 Drying Ovens a $1500 each	$ 6,000		
2 Generators (5 kwe) a 1500 each	3,000		
TLD's and GM Probe	1,000		
Miscellaneous	4,000	$6,000	$6,000
TOTAL	$14,000	$6,000	$6,000

20. PROPOSED OBLIGATIONS FOR RELATED CONSTRUCTION ITEMS:

None.