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Long Term Activity Estimates For The Northern Marshall Islands

This paper provides preliminary upper-bound estimates of the residual gamma activity on the northern Marshall Islands due to U.S. atmospheric testing at Bikini. These estimates are intended to be indicative of the activity to be determined by up-coming detailed surveys. Estimates are also provided for islands in the Enewetak atoll and compared with the 1972 survey. Finally, an analysis of wind profiles and fallout patterns is presented which serves to delineate those northern Marshall islands which were uncontaminated by fallout from the Bikini tests.

I. APPROACH

After 20 years or so, the principal fission products of interest are Sr^{90} and Cs^{137}, whose characteristics are summarized below.

Isotope	Curies/kt of Fission at H+1	Fraction of Total Curies	Half Life	Decay Mode
Sr^{90}	110	2.1×10^{-7}	29y	β only
Cs^{137}	320	6.1×10^{-7}	30y	β(100%) and γ(93%)

The fractional contribution of Cs^{137} to the one-hour dose rate is not the same as the fraction of total Curies at one hour since the Cs^{137} γ energy is lower than that average energy for all fission products (.66 MeV vs. 2 MeV). This results in a roentgen response for Cs^{137} that is 0.41 times that for the inventory taken as a whole. At some time after burst, when Cs^{137} is the only remaining fission product γ-emitter, the dose rate is given by

$$\dot{D}(T) = \dot{D}(1\ hr)\ [6.1\times10^{-7} \times 0.41]\ (0.5)^{T/30}$$

where T is in years. Note that beta activity is not being considered here on the presumption that the survey techniques distinguish between 25

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beta and gamma. The above equation permits estimating the long term gamma activity, provided there are one-hour dose rate measurements at the locations of interest.

II. RESULTS

The first step in the analysis was to compare the dose-rate estimates developed as prescribed above with recent surveys performed for the Enewetak atoll. This comparison would indicate the magnitude of the difference due to neglecting the migration of the isotopes into the soil and plant uptake. Figure 1 is a map of the Enewetak atoll showing the location of 3 islands chosen for the comparison--Alice, Janet, and Yvonne. Table 1 lists the measured dose rate from the 1951-58 operations for these three islands as well as the 1972 estimates for the Cs^{137} component.

The 1972 survey (reported in NVOO-140) provides average exposure rates separately for Cs^{137} and Co^{60}. (This latter isotope is not a fission product but results from weapon debris activation). In addition, average profiles are provided of Cs^{137} concentration (pCi/g) versus soil depth for Alice and Janet. It is important to note that there evidently have been no cleanup activities (which would invalidate the comparisons discussed here) on Alice and Janet. Yvonne is a different situation because of construction and earth moving activities during the testing period. Large variations in exposure rates occur on Yvonne; thus, mean levels are misleading. For this reason, Yvonne will be dropped from the comparison.

Table 2 provides the Cs^{137} survey data for Alice and Janet. The dose rates can be compared directly with the estimates of Table 1. As expected, the estimates are high since among other reasons it was assumed that the activity was all on the surface. The soil profiles of activity concentration versus depth can be used to develop a pseudo dose rate by relocating the activity back to the surface. A comparison of this value with the estimate is useful in that the difference is

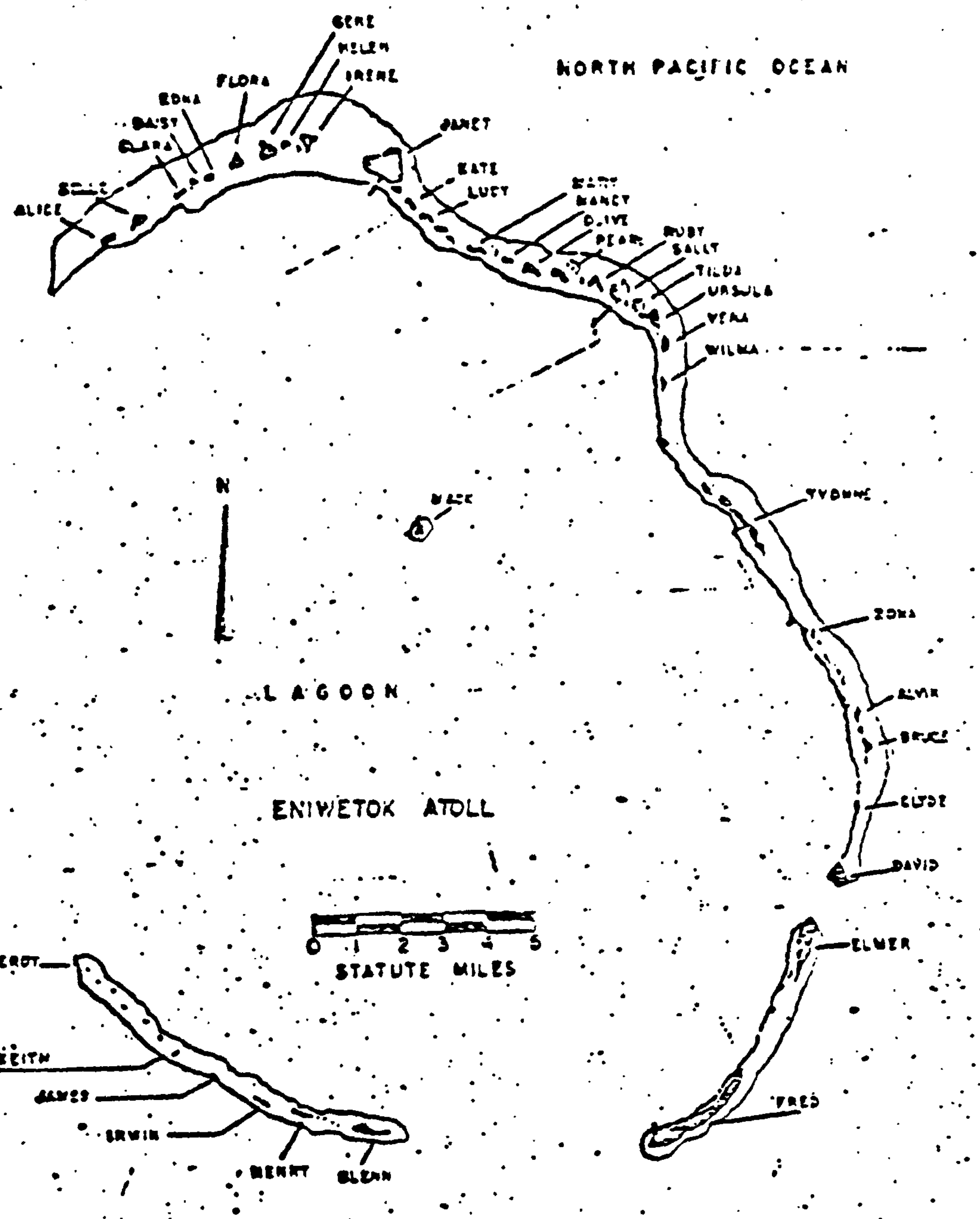


Figure 1. Islands in the Enewetak Atoll

Table 1. Dose Rate Estimates for Enewetak

OPERATION	YEAR	ONE-HOUR DOSE RATES * (R/HR)		
		ALICE	JANET	YVONNE
GREENHOUSE	51	550	800	0-1000
IVY	52	2000	2000	55
CASTLE	54	50	15	0
REDWING	56	430	480	550-8060
HARDTACK	58	850	90	305-2500

* DASA-1251

ISLAND	1972 DOSE-RATE* ESTIMATE (MR/HR)
ALICE	0.7
JANET	0.7
YVONNE	0.2-2.0

*Cs^{137} only.

Table 2. Selected Cs^{137} Data from 1972 Enewetak Survey

Island	Surface Dose Rate (mr/hr)	Activity Density (pCi/g) as a Function of Soil Depth (z in cm)
Alice	.042	$67 \exp(-.011 z), 0 < z < 70$
Janet	.025	$\begin{cases} 47 \exp(-0.67 z), & 0 < z < 8.2 \\ 22 \exp(-.025 z), & 8.2 < z < 75 \\ 0.55 \exp(-.0031 z), & 75 < z < 180 \end{cases}$

then attributable not to soil migration but rather to plant uptake and other losses. To develop this pseudo dose rate, the following equation was used:

$$A(Ci/m^2) = \rho \times 10^{-8} \int_0^{z_{max}} \alpha(z)dz$$

where α is the activity density in pCi/g, z is the depth in cm, ρ is the soil density (1.8g/cm^3) and the factor of 10^{-8} provides the conversion from pCi to Ci and from cm^{-2} to m^{-2}. The dose rate for Cs^{137} is given by

$$\dot{D}(R/HR) = 6.21\ A(Ci/m^2)$$

Table 3 summarizes the comparison between the estimated and measured Cs^{137} dose rate and the pseudo dose rate as well. As can be seen, the estimate is a factor of about 20 higher than the measured value and that roughly half of this difference can be accounted for by mechanisms other than soil migration. This comparison indicates that simple estimates can be used to provide bounding upper limits and that it might be possible to refine these estimates to within an order of magnitude by correcting for soil migration. The conditions for this refinement would be:

a.) that for the location of interest, there had been no cleanup or major earth moving prior to the survey and

b.) that the soil profiles would be similar to that found on undisturbed Enewetak islands receiving fallout (such as Fig. 1409 of "Summary of Findings" chapter of NVOO-140).

Having compared dose rate estimates with survey results for Enewetak, we can now turn to those islands in the northern Marshalls that were contaminated by fallout from shots at Bikini.

Because the estimating scheme being used requires the one-hour dose rate as input, it is important to first establish that off-site measurements were made in all cases where there was fallout on the islands of interest. If these data are incomplete, estimations cannot

Table 3. Comparison of Estimated and Measured Cs^{137} Activity

ISLAND	DOSE RATE (MR/HR)		
	ESTIMATE	DIRECT MEASUREMENT	INFERRED FROM SOIL PROFILE*
Alice	0.7	.042	0.50
Janet	0.7	.025	0.10

*Calculated by relocating activity to surface.

ISLAND	RATIO (ESTIMATE/MEASURED)	
	DIRECT MEASUREMENT	INFERRED MEASUREMENT*
Alice	17	1.4
Janet	28	7.0

be made. Table 4 summarizes the fallout pattern characteristics from the Bikini tests. The last column in most cases indicates that the wind directions precluded fallout on the islands. The definite exceptions are Bravo and Yankee. For Bravo and Yankee, off-site measurements were in fact made. None of the Enewetak shots resulted in fallout on Bikini or other islands to the east, so the test operations in Table 1 can be ignored.

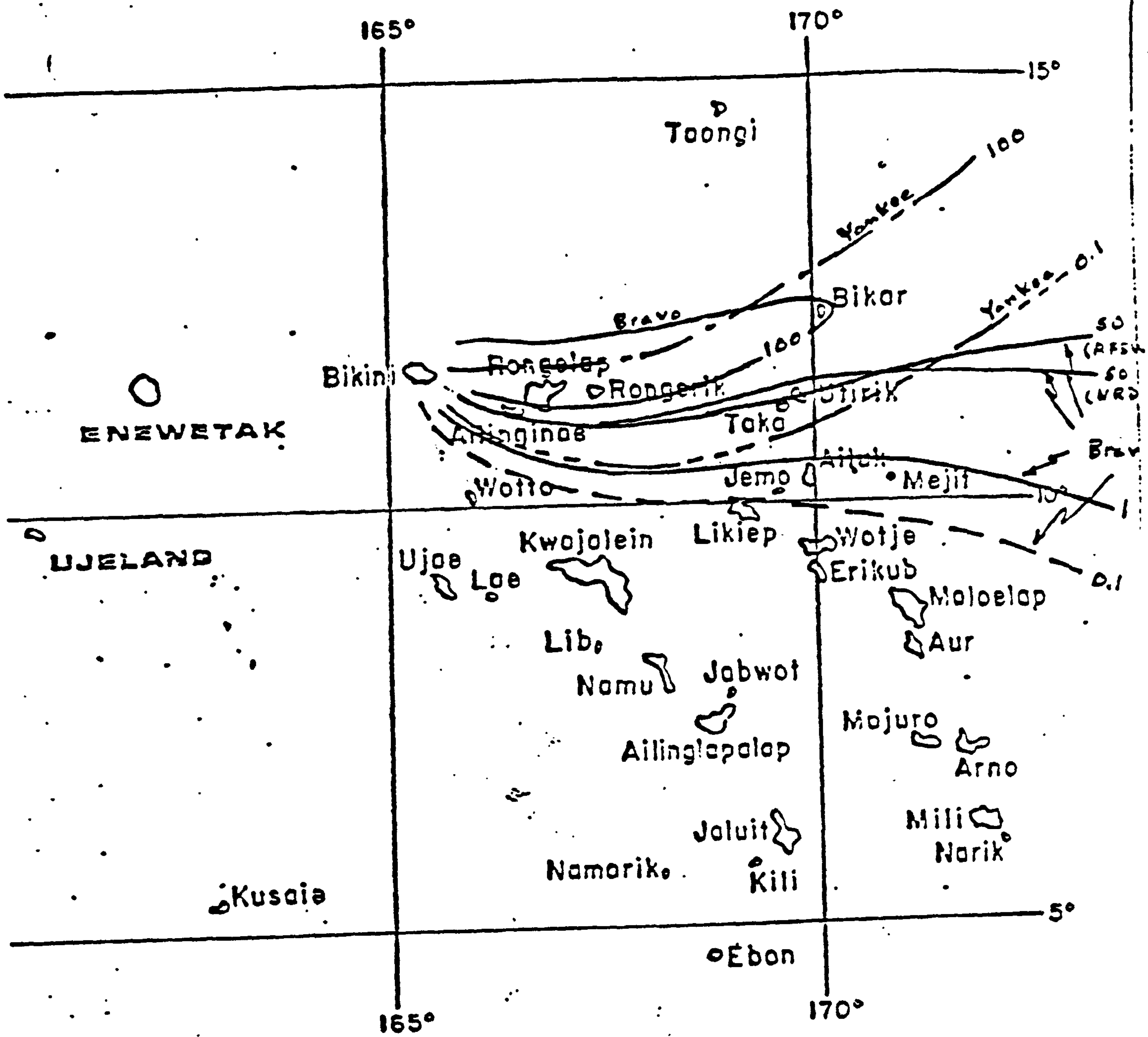
Figure 2 shows the Marshall Islands relative to the test locations. The Bravo fallout pattern has been reconstructed independently by AFSWP, NRDL and RAND using some modelling, while the Yankee pattern is based on extensive surveys. The one-hour dose rates for affected islands are given in Table 5. All of the listed islands are outside the lowest dose-rate (100R/HR) contour for Yankee (Rongelap is just barely); the levels are stated only to the nearest decade since extrapolation had to be used. The range of values for Rongelap and Rongerik is due to the variation of the Bravo pattern across the respective island. By and large, Bravo is the predominant contributor.

Table 6 provides 1977 estimates of the Cs^{137} dose rate for these islands. On the basis of the limited comparison performed for the Enewetak case, these values could be reduced by a factor of about 6 to account for soil migration, provided the geology is similar to that for Enewetak.

The final part of this paper is devoted to identifying with high confidence which islands did not receive fallout from the Bikini tests. Table 4, as discussed above, indicates that only Bravo and Yankee definitely resulted in fallout on the islands; this is based on the use of off-site measurements to reconstruct their respective fallout patterns. The other shots in the Castle operation, for which there were no off-site measurements, apparently were not a problem. However, a detailed investigation is warranted and is reported on in the appendix. Also contained there is an extrapolation of the Bravo and Yankee patterns to a level consistent with background.

Table 4. Fallout From Bikini Shots

Shot	Yield	Type	Wind Dir (to)	Off-Site Meas.	Concl.
CROSSROADS					
Able (6-30-46)	23KT	Air	W	No	Direction
Baker (7-24-46)	23KT	UW	N	No	Direction
CASTLE					
Bravo (2-28-54)	15MT	Surface	E	Yes	Problem
Romeo (3-28-54)	+	Barge	W	No	Direction
Koon (4-6-54)	110KT	Surface	NE	No	Direction
Union (4-25-54)	+	Barge	NE	No	Direction
Yankee (5-4-54)	+	Barge	NE	Yes	Problem
REDWING					
Cherokee (5-20-56)	>1MT	Air	NW	No	Direction
Zuni (5-27-56)	3.5MT	Surface	NW	Yes	Direction
Flathead (6-11-56)	+	Barge	N	Yes	Direction
Dakota (6-25-56)	+	Barge	N	No	Direction
Navajo (7-10-56)	+	Barge	NW	Yes	Direction
Tewa (7-21-56)	5MT	Barge	NW	Yes	Direction
HARDTACK					
Fir (5-11-58)	+	Barge	W	No	Direction
Nutmeg (5-21-58)	N	Barge	W	No	Direction
Sycamore (5-31-58)	-	Barge	W-NE	No	Direction
Maple (6-10-58)	-	Barge	W-N	No	Direction
Aspen (6-14-58)	-	Barge	N	No	Direction
Redwood (6-27-58)	-	Barge	NW	No	Direction
Hickory (6-29-58)	N	Barge	W	No	Direction
Cedar (7-2-58)	-	Barge	NE	No	Direction
Poplar (7-12-58)	+	Barge	N-W	No	Direction
Juniper (7-22-58)	-	Barge	NW	No	Direction



Fallout Intensities in R/hr @ H+1

Figure 2. Marshall Islands Affected by Bravo and Yankee Fallout

Table 5. One Hour Dose Rates for Bravo and Yankee

Island	Dose Rate (R/Hr)	
	Bravo	Yankee
Rongelap	200-2400	100
Ailinginae	100-200	0.1
Rongerik	200-800	10
Taka	20	0.1
Bikar	100	10
Utirik	25	0.1
Ailuk	1	0

Table 6. Cs^{137} Dose Rate Estimates for 1977

Island	Dose Rate (mR/HR)
Rongelap	.044 - 3.7
Ailinginae	.015 - .030
Rongerik	.030 - .12
Taka	.003
Bikar	.015
Utirik	.004
Ailuk	.00015

On the basis of this investigation, the following islands are extremely unlikely to have received fallout from the Bikini or Enewetak tests at levels higher than the background exposure of 200 mrem/year:

Wotto
Ujae
Lae
Lib
Majuro
Namorik
Kusaie

~~Likiep~~
Wotje
Erikub
Maloelap
Arno
Kili
Kwajalein

Aur
Namu
Jabwot
Ailinglapalap
Mili
Narik
Jaluit
Ebon

and any other islands circumscribed by the above.

The following islands may have received some fallout from nuclear tests. It is unlikely that the intensities would have resulted in an exposure of more than 2 rem the first year; subsequent annual exposures would have been less than background:

Jemo
Ailuk
Mejit

The following islands did receive fallout with intensities ranging from 1 to 2000 R/hr at 1 hr. They are listed in estimated order of decreasing residual activity:

Rongelap
Taongi (based on cloud drift only - no survey data available)
Rongerik
Ailinginae
Bikar
Utirik
Taka

III. CONCLUSIONS

The above estimates, even when corrected for soil migration, can only be considered preliminary; they are very likely to be upper bounds. Note that only Cs^{137} has been considered. The addition of Sr^{90} (a beta-emitter) and Co^{60} (which results from weapon debris activation) are necessary in completing the estimates of the total activity present.

The distribution of the activity in the soil, plants and organisms will not be determined by a simple survey of surface contamination. The estimates in this paper, along with such a survey, would be useful in determining such a distribution from the following kinds of additional data:

a.) water table height and variation

b.) physical characteristics of the soil strata

c.) plant categories and root depth.

APPENDIX

ASSESSMENT OF WIND PROFILES AND FALLOUT PATTERNS FOR BIKINI TESTS

The Bravo and Yankee shots, as previously discussed, both deposited fallout on the islands east of Bikini. In both cases, the lowest reported contour level was not low enough to circumscribe the total fallout deposition. Extrapolation was used to define the 0.1 R/HR (H+1) contour; this level was chosen because it results in an exposure the first year of about 200 mrem, which is about the annual background dose. Shown in Figure 2 is the southern periphery of the Bravo and Yankee patterns relative to the location of the islands.

The other Castle shots are Romeo, Koon and Union; off-site fallout measurements are not available so that their respective wind profiles have to be examined.

The Romeo winds at H+3 and H+9 (DASA 1251) were not measured above 67,000 ft. Below this altitude the dominant direction of the profile is to the north; while not measured for the test, the higher altitude winds are uniformly to the west. Thus it is safe to state that the Romeo fallout did not reach any of the off-site Marshall Islands.

Shot Koon winds were documented for all levels of interest. Except for near-surface, no winds had a northerly component that would have carried any fallout to the south and east. It can be stated with high confidence that Koon fallout carried to the north and east, and did not reach any of the Marshall Islands.

Shot Union presented a rather unique wind problem. Although the lower altitude winds were from the east, strong northerly and westerly components existed from 12,000 to 50,000 feet. The influence of the winds is not readily apparent without further examination. Therefore a crude reconstruction of the fallout pattern was performed by determining the displacement of 50, 100 and 200μ particles which are initially assumed to be at cloud top and at cloud bottom. This permits the construction of an envelope of all such particles in the cloud. The H+6 wind profile was used and constant fall rates of .15, .57 and 2.1 m/sec, respectively, were used for the three particle sizes. (Including the altitude dependence of fall rate is probably an over-specification, considering the uncertainty in the spatial variation of the wind). Shown in Figure 3 is this envelope. Taongi is definitely affected by the Union fallout, but the other islands are outside the fallout envelope.

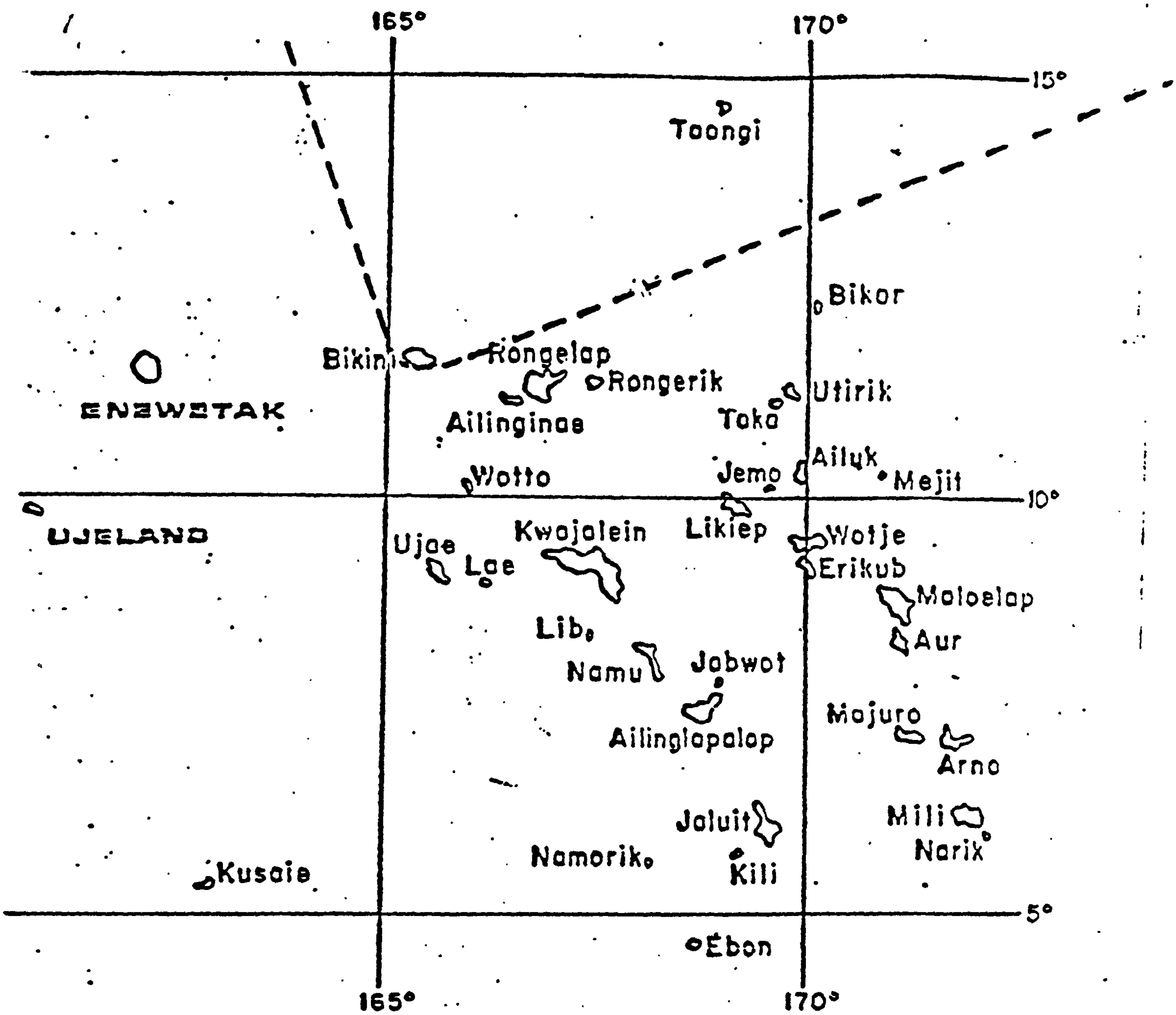


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Figure 3. Fallout Envelope for Shot Union.