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April 7, 1969

Mr. Tommy F. McCraw
Division of Operational Safety
U. S. Atomic Energy Commission
Washington, D. C. 20545

Dear Tommy:

We have examined your draft report "Levels of Environmental Radioactivity in Bikini Atoll" and agree that the information generated during the 1967 survey would be of great general interest to the public. We sought to rectify this situation several months ago by preparing a paper suitable for general distribution which summarized our work and also included some of the population exposure estimates for completeness. This approach was modified, at the suggestion of DBM, with regard to statements on population exposures, sociological problems, and resettlement plans. We have now rewritten the paper eliminating the sensitive topics and including only our characterization of the radiation fields on the atoll and a discussion of the isotope identification work. We have submitted this paper as a technical report to Science. Hopefully we will see publication without too much further delay. A copy is enclosed for you.

We hope we have succeeded in presenting the major technical conclusions of the survey in this paper. Of course, most of the details and the descriptive treatment of the survey are in HASL-190. As yet unsaid, are many of the sociological aspects of the resettlement program. Perhaps you may want to restructure your draft report in light of our recently prepared paper. We would suggest that the emphasis in future papers be on the background and logistics of the survey and on various aspects of the resettlement of the atoll. Because of your greater responsibilities regarding this project, DBM might not object to your discussing in print many of the topics which we cannot.

Regarding the disposal of scrap metal from the atoll, we have no further comments or suggestions to add to the guidelines which you have prepared.

Regards,

Burt

Hal

Burton G. Bennett
Harold L. Beck, Physicists
Radiation Physics Division

Enclosure:
As Stated Above

EXTERNAL RADIATION ON BIKINI ATOLL

Abstract. An intensive radiological survey of the islands of Bikini Atoll was conducted in May 1967 for the purpose of determining the levels and components of the external gamma radiation fields in this former nuclear weapons testing area. Total exposure rates were found to vary considerably from site to site and island to island with levels measured over soil ranging from less than 10 μr/hr to over 500 μr/hr. Major contributors to the radiation fields included ^{137}Cs, ^{60}Co, ^{125}Sb, and ^{102m}Rh, the recently identified long-lived isomer of ^{102}Rh. A large number of other isotopes were identifiable in Ge(Li) spectra of soil samples.

An extensive radiation survey of the islands of Bikini Atoll has revealed several interesting features of the residual environmental radiation fields in a heavy local fallout area a number of years after the initial deposition. Bikini Atoll is the former weapons test area in the mid-Pacific where more than 20 nuclear tests were conducted from 1946 to 1958. The survey, conducted in May 1967, included measurements of the external radiation levels and determination of the principal isotopes contributing to the total external exposure rates on each island of the atoll. Because of the high intensity of the radiation fields generated by the tests, we were able to detect at the time of this survey many long-lived fission and activation products which were undetectable or unnoticed in previously surveyed fallout areas because of their trace presence. It was also possible to relate the residual radiation fields on the atoll to various locations of test ground zeros, to meteorological conditions affecting local fallout at the time of the tests, and to weathering and radioactive decay processes occurring subsequent to the cessation of testing activities.

Bikini Atoll consists of some 15 islands and 2 island complexes made up of a number of small interconnected islands (Fig. 1). The islands are located on a coral rim surrounding a lagoon 22 miles long and 13 miles wide. Total land area of the atoll is 2.32 square miles. Over half the area is included in the 3 largest islands, Bikini, Eneu, and Nam. The largest island, Bikini, is 2½ miles long and ½ mile wide.

The techniques utilized on this survey were largely those developed and used by the Health and Safety Laboratory (HASL) for the past several years in conducting detailed investigations of the properties of the external radiation environment in the United States (1). The prime instrumentation used for the survey measurements included a high-pressure ionization chamber, a NaI(Tl) field spectrometer system for <u>in situ</u> γ-ray spectrometry, and a number of hand-held survey type instruments (G-M counters and scintillation detectors). A total of 16 working days were spent on the atoll, but because of the number of islands to be surveyed and the difficult logistical problems and environmental conditions (difficult access, dense vegetation, high temperatures, humidity, etc.), we restricted spectrometer and ionization chamber measurements to 16 representative locations on the main islands of Bikini, Eneu, and Nam. The hand-held survey meters were used for the remainder of the survey measurements. The survey meters were first "field calibrated" at the prime measurement locations, i.e. the survey meter readings were compared with the more accurate ionization chamber and spectrometer measurements to obtain a calibration factor for the particular gamma-ray spectrum encountered in the field. These hand-held instruments were then used to extend the survey throughout the atoll. In this way the variations in radiation levels from island to island and on individual islands could be studied in some detail.

The external gamma radiation levels were found to vary considerably from island to island around the atoll. It was possible, however, to roughly classify most islands into one of three general areas, characterized by the relative exposure rates and also the composition of the radiation fields. These areas are blast areas immediately surrounding the ground zeros of tests where the highest exposure rates were measured, heavy fallout areas down-wind from the blast areas with intermediate exposure rates and non-blast, low fallout areas where the lowest exposure rates were measured.

The location, code name and year of each announced nuclear weapons test (2) have been indicated on the map in Fig. 1. From the locations of the tests it can be seen that the blast areas include the western tip of Eneman, Lomilik near the center of the Aomen-Iroij Complex, and the northwestern reef near Nam. Since the prevailing winds in the area are generally in a westerly or southwesterly direction, the heavy fallout areas are primarily the islands of the southwestern reef. There were exceptions to the normal wind pattern, however, most notably for shot Bravo in 1954 when unexpected high altitude winds carried fallout eastward over Bikini Island and on to the Marshallese natives of Rongelap Atoll. Thus some of the non-blast areas, which include the islands of Bikini, Eneu, and the eastern half of the Aerokoj-Eneman Complex, experienced lesser but not insignificant amounts of local fallout. The island of Eneu on the southeastern rim of the atoll was the most favorably situated to avoid local fallout and exhibited some of the lowest exposure rates measured (3-7 μr/hr).

In addition to this general pattern of radiation levels around the atoll, considerable variation was found on individual islands. Typically, the exposure rates on a given island ranged from very low near the lagoon and ocean shores to much higher near the center of the island. This effect can be related to the density of vegetation and thickness of organic soil layer. Near the shores the vegetation was sparse and the soil very sandy, conducive to weathering and deeper penetration of fallout. Vegetation was much more dense over the central parts of the islands, where increased amounts of organic matter in the soil influenced the retention of fallout near the surface of the ground.

Figure 2 shows a typical radiation profile for a survey transect across the middle of Bikini Island from the lagoon shore to the ocean beach. Readings of the portable scintillation counter were made every 50 ft. along this

2850 ft. transect. Geiger counter readings were recorded every 150 ft. Ionization chamber and field spectrometer measurements were made near the beginning of the transect and at areas along the transect where the survey meters indicated significantly high or low levels. The measurement points in Fig. 2 have been enclosed in dotted lines to illustrate the general nature of the variation in radiation levels across the island. The exposure rates along the transect and for Bikini Island in general were 20-40 μr/hr near the shore, 50-80 μr/hr in the interior, and up to 120 μr/hr at scattered hot spots. The field spectrometer measurements showed the exposure rate levels on Bikini Island to be due primarily to three radionuclides, with about 75% of the exposure rate at a given site due to ^{137}Cs, 15% to ^{60}Co, and 10% to ^{125}Sb. Natural emitters (uranium, thorium, and potassium) were almost entirely undetectable in the field spectra. This is not surprising since the coral soil of the atoll is predominately $CaCO_3$.

Representative exposure rates in air 1 meter above the ground from γ-ray emitters in the soil obtained from the analysis of the field spectra and ionization chamber measurements on Bikini, Eneu and Nam are given in Table 1. The measurements on Bikini are for locations on the central transect for which the radiation profile is given in Fig. 2. Exposure rates from cosmic radiation (3.4 μR/hr) are not included. More detailed data on the measurement of the radiation fields on these islands as well as for the rest of the atoll are given in reference 3. As indicated in the Table, the composition of the radiation field on Eneu was quite similar to that of Bikini, i.e. predominantly ^{137}Cs with some ^{60}Co and ^{125}Sb, even though the exposure rate levels were much lower. The island of Nam, however, due to its proximity to several test sites, had several properties of blast areas, including higher exposure rates and increased amounts of ^{60}Co and ^{125}Sb in the soil relative to ^{137}Cs.

To complement our field spectrometry on the larger islands and to characterize the composition of the radiation field on islands where we were unable to obtain field spectra, a large number of soil samples were collected from throughout the atoll. These samples, which were obtained in several depth increments, were analyzed quantitatively in the laboratory by NaI(Tl) gamma spectrometry and also qualitatively by Ge(Li) spectrometry. We were thus able to obtain not only the activities of the major isotopes present but also their depth distribution. We found that in high activity areas most of the activity ([illegible] or more) was usually in the top 2 to 3 inches of soil. Because of the large local variations in soil activity on all the islands it was not possible to calculate accurate exposure rates in air from the one or two soil samples obtained per site. Inasmuch as the field spectrometer and ionization chamber "see" large areas (~30 feet in diameter), they average out the local variations giving very reliable absolute exposure rates. The soil samples proved very useful, however, for identifying and determining relative activities of the isotopes present which were then used to estimate the relative contributions of these isotopes to the exposure rates at the various sites (3). The relative exposure rate values obtained for the same sites with the spectrometer-ionization chamber system and from soil sample analysis agreed quite well.

The composition of the radiation field determined from the soil samples and field spectrometry for low and intermediate fallout areas differed considerably from that for blast areas. The high contribution to the exposure rate from ^{137}Cs for Bikini Island was found typical of other non-blast areas of the atoll. In blast areas, however, ^{60}Co was the dominant contributor to the exposure rate levels with ^{125}Sb also quite prominent. The relatively minor contribution of ^{137}Cs compared to ^{60}Co and ^{125}Sb in blast areas is quite significant and may be related to the types of weapons tests conducted nearby. Many of these tests were conducted on barges and the resulting activation of ^{59}Co and ^{60}Ni in the steel of the barges account for the large amount of ^{60}Co activity.

The maximum exposure rates measured on Bikini Atoll in 1967, somewhat over 300 μr/hr, were in blast areas very near the ground zeros of tests. At one isolated area on West Eneman near the ground zero for two surface tests we measured an exposure rate just over 500 μr/hr. Since vegetation in that area was generally sparse and the organic content of the soils was quite low, weathering may be of some significance in reducing the radiation levels in these areas more rapidly than in the more densely vegetated areas. Also the greater proportional contribution of the shorterlived ^{60}Co and ^{125}Sb relative to ^{137}Cs to the exposure rates in these areas will also cause the radiation levels to decrease more rapidly with time.

High resolution Ge(Li) spectrometry of soil samples allowed us to make detailed identification of the radionuclides present at various sites around the atoll. The spectra of Bikini Island soils exhibit very prominent ^{137}Cs and ^{60}Co peaks, while peaks due to ^{125}Sb and rhodium isotopes are barely discernable above the background. Trace amounts of other isotopes such as ^{155}Eu, ^{152}Eu and ^{241}Am are also evident.

The Ge(Li) spectrum for a soil sample from Lomilik Island, a near ground zero blast area approximately in the center of the Aomen-Iroij Complex, is shown in Fig. 3. The exposure rate at this site was several hundred μr/hr, due primarily to ^{60}Co (75%), with ^{125}Sb, ^{102m}Rh, and ^{137}Cs accounting roughly equally for the remainder. The prominent ^{60}Co peaks are evident in Fig. 3, as are all the gamma-ray lines of ^{125}Sb and the recently identified (4) long lived isomer (2.9 y) of rhodium which we have designated ^{102m}Rh. Peaks from ^{155}Eu, ^{152}Eu, ^{241}Am, ^{144}Ce, ^{101}Rh and ^{54}Mn are also clearly identifiable. Several peaks in this spectrum have not yet been definitely identified.

The composition of the radiation field on Lukoj, a heavy fallout area, is indicated by the Ge(Li) spectrum shown in Figure 4. This densely vegetated island exhibited exposure rates of from 60 to 200 μr/hr. Approximately 60% of the exposure rate at the soil sampling site in the high exposure rate interior of the island was from ^{60}Co, 30% from ^{125}Sb and ^{102m}Rh and the remainder principally from ^{137}Cs. Again the relatively large ^{60}Co and ^{125}Sb activities relative to ^{137}Cs contrast with the Bikini Island situation. The peaks characteristic of ^{102m}Rh are quite prominent in Fig. 4 along with the ^{60}Co, ^{125}Sb and ^{137}Cs peaks. Also easily identifiable are peaks from ^{241}Am, ^{155}Eu, ^{101}Rh, ^{106}Rh, ^{144}Ce, and ^{65}Zn.

In addition to the isotopes identified in Figs. 3 and 4 we detected ^{207}Bi in a soil sample from the Bravo crater on the northwestern reef. We also have tentatively identified ^{133}Ba in a soil sample from Nam Island. Although most of the isotopes identified are familiar longer-lived fission products, such as ^{137}Cs (30 years), ^{125}Sb (2.7 years), ^{106}Ru-Rh (367 days), and ^{144}Ce (284 days) or frequently observed activation products such as ^{54}Mn (303 days) and ^{65}Zn (245 days), other isotopes such as ^{60}Co, ^{102m}Rh, ^{207}Bi, ^{152}Eu, and ^{155}Eu are only rarely identified in environmental samples, particularly with such prominence as that displayed, for instance, by the 7 intense lines of ^{102m}Rh identifiable in Figure 4. The appearance of 12 distinct lines of ^{125}Sb in the soil sample spectrum in Fig. 3 is also quite unusual. ^{152}Eu (12.7 years), an apparent activation product, has been found previously (5) in Trinitite, an artifical mineral produced in the first nuclear explosion in New Mexico in 1945. ^{101}Rh (3 years) and ^{102}Rh (206 days) are also activation products. ^{102}Rh is known to have been used as a tracer material in several weapons tests. All but the least intense gamma-ray lines from ^{102m}Rh can be identified in Fig. 4, the first time as far as we know that this recently discovered isomer has been identified in an environmental sample (6).

The radiation situation on Bikini Atoll provided a unique opportunity for investigating an aged, relatively intense fallout field. We were able to relate most of the features which we observed on the atoll to the test locations and environmental conditions at and subsequent to the times of the tests. A large number of radionuclides, including several unusual for environmental samples, were found contributing to the wide range of external gamma radiation levels. Utilization of the combination of ionization chamber and field spectrometric measurements with laboratory Ge(Li) spectrometry of soil samples proved to be a very effective method of analyzing this complex radiation environment.

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REFERENCES AND NOTES

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2. S. Glasstone, The Effects of Nuclear Weapons, USAEC (1962).

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6. The Ge(Li) analyses were carried out on an 8 cm³ planar detector. The Lomilik soil sample (Fig. 3) weighed 106 gm and was counted for 923 minutes. The Lukoj sample (Fig. 4) was 61 gm and was counted for 2950 minutes.

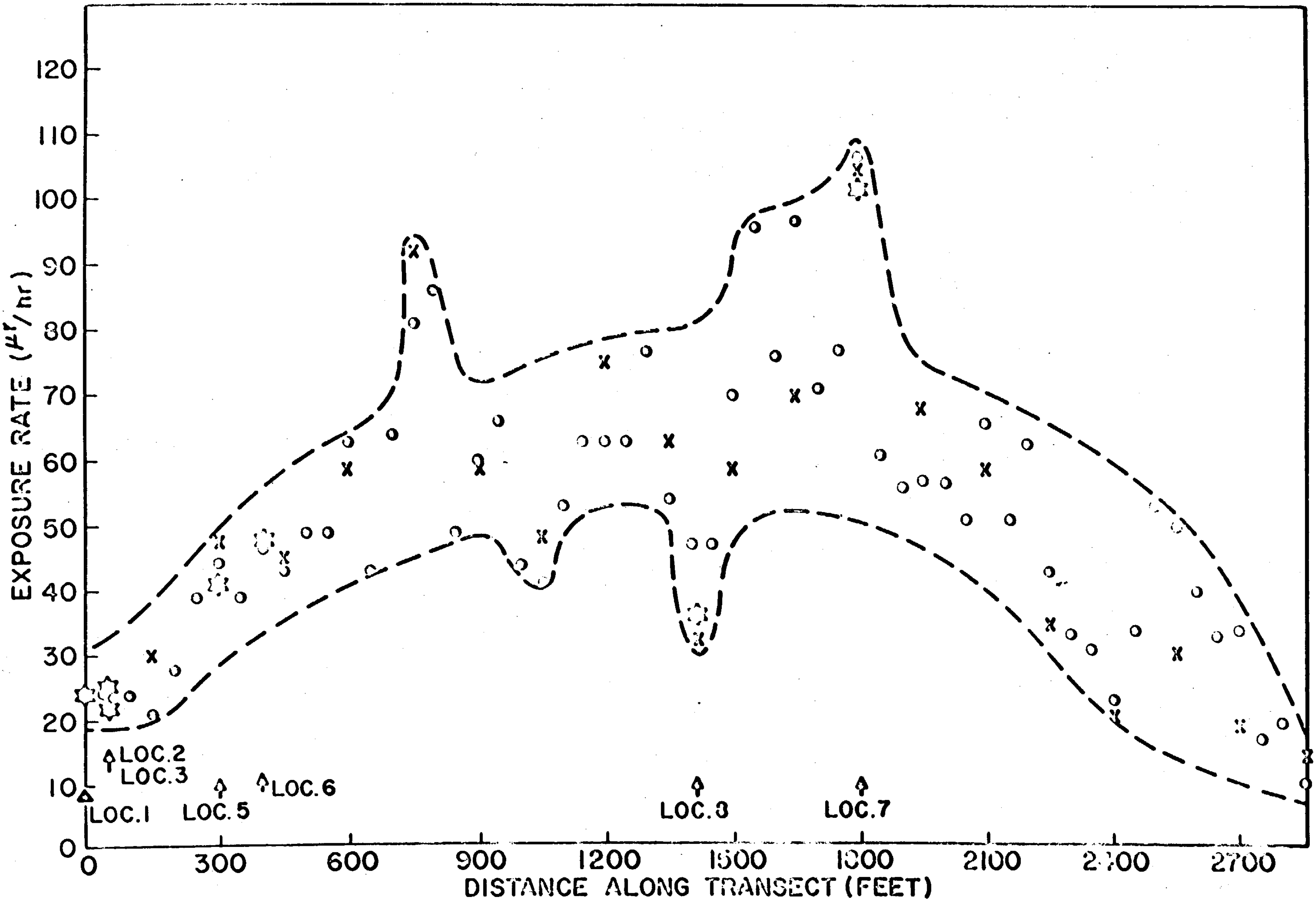
7. The 1967 Bikini environmental survey was sponsored by the Division of Biology and Medicine of the U. S. Atomic Energy Commission. The survey was conducted very much as a team effort by all members of the survey team. We, therefore, acknowledge the essential contributions of Edward Held, University of Washington Marine Radiobiologist, the survey leader; his assistant, Robert Erickson, Tommy McCraw, USAEC Division of Operational Safety; Arnold Joseph, USAEC Division of Biology and Medicine; Jack Tobin, Former Trust Territory District Anthropologist; James Hiyane, Trust Territory District Agriculturist; and Francis Tommovek and Edward Jones, U. S. Naval Radiological Defense Laboratory.

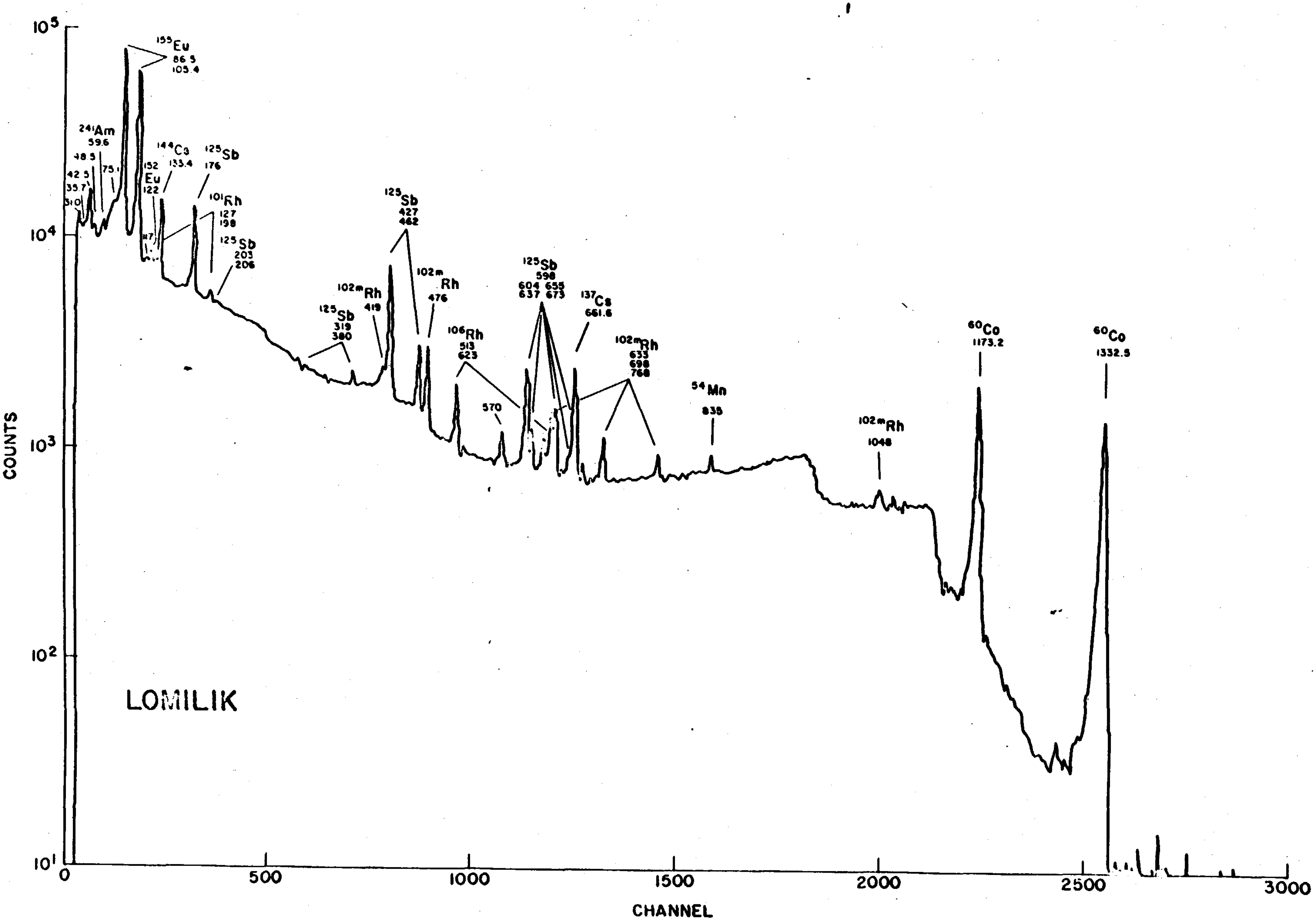
Table 1. [illegible] gamma exposure rates and major contributors to the radiation fields at representative locations on Bikini, Eneu, and Nam. The sums of the component exposure rates, obtained with the field spectrometer, are compared with the total exposure rates obtained with the ionization chamber.

	Exposure Rates (μr/hr)				
	Components			Total	
	^{137}Cs	^{60}Co	^{125}Sb	Field Spectrometer	Ionization Chamber
Bikini					
#1 [illegible] shore	19.0 (77%)	3.0 (12%)	2.8 (11%)	24.8	24.0
#2 50' [illegible] transect	17.8 (78%)	2.4 (10%)	2.7 (12%)	22.9	22.8
#[illegible] 50' [illegible] transect (in [illegible])	18.9 (78%)	2.1 (9%)	3.3 (14%)	24.3	25.0
#5 300'	22.8 (61%)	11.3 (30%)	3.5 (9%)	37.6	41.2
#6 400'	27.2 (62%)	12.5 (29%)	4.0 (9%)	43.7	47.5
#7 1800'	83.6 (74%)	19.5 (17%)	10.3 (9%)	113.4	103.2
#8 1410'	23.1 (76%)	4.9 (13%)	3.8 (10%)	36.8	36.1

Table 1 (Cont'd)

Fneu					
#1 300' [illegible] - [illegible]	3.1 (76%)	.5 (12%)	.4 (10%)	4.0	4.1
#2 1200' [illegible] of #1	3.0 (63%)	1.5 (31%)	.3 (6%)	4.8	5.1
Nna					
#1 Near [illegible] shore	18.1 (50%)	17.2 (48%)	.6 (2%)	35.9	34.1
#2 [illegible]	25.8 (39%)	39.4 (59%)	1.1 (2%)	66.3	75.5
#3 [illegible] corner	60.6 (33%)	119.5 (66%)	2.0 (1%)	182.1	204.0


EXPOSURE RATE (μr/hr)
120
110
100
90
80
70
60
50
40
30
20
10
0
0
300
600
900
1200
1500
1800
2100
2400
2700
DISTANCE ALONG TRANSECT (FEET)
LOC.1
LOC.2
LOC.3
LOC.5
LOC.6
LOC.8
LOC.7


LOMILIK
COUNTS
CHANNEL
10^5
10^4
10^3
10^2
10^1
0
500
1000
1500
2000
2500
3000
^{155}Eu 86.5 105.4
^{241}Am 59.6
48.5
42.5
35.7
31.0
75.1
152 Eu 122
117
^{144}Ce 133.4
^{125}Sb 176
^{101}Rh 127 198
^{125}Sb 203 206
^{125}Sb 319 380
^{102m}Rh 419
^{125}Sb 427 462
^{102m}Rh 476
^{106}Rh 513 623
570
^{125}Sb 598 604 655 637 673
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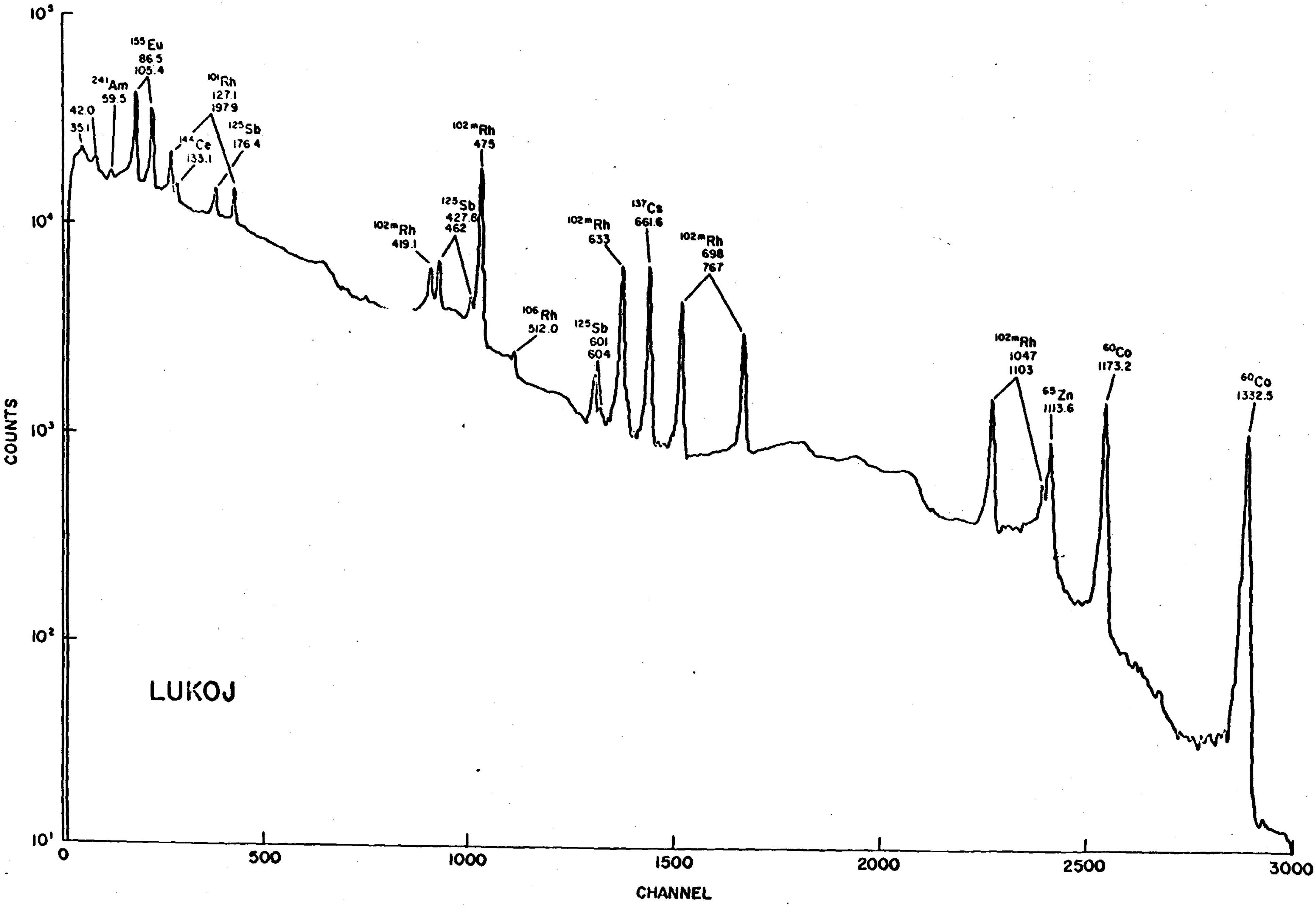
^{60}Co 1173.2
^{60}Co 1332.5


LUKOJ
155Eu 86.5 105.4
241Am 59.5
42.0 35.1
101Rh 127.1 197.9
144Ce 133.1
125Sb 176.4
102mRh 475
125Sb 427.8 462
102mRh 419.1
106Rh 512.0
125Sb 601 604
102mRh 633
137Cs 661.6
102mRh 698 767
102mRh 1047 1103
65Zn 1113.6
60Co 1173.2
60Co 1332.5
COUNTS
10^5
10^4
10^3
10^2
10^1
CHANNEL
0
500
1000
1500
2000
2500
3000