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REPORT BY

THE AEC TASK GROUP ON RECOMMENDATIONS FOR

CLEANUP AND REHABILITATION OF ENEWETAK ATOLL

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INTRODUCTION

On September 7, 1972, the Atomic Energy Commission (AEC) agreed to provide radiological criteria for cleanup and rehabilitation of Enewetak Atoll to the Department of Defense (DOD) and to the Department of Interior (DOI). AEC also agreed to conduct a comprehensive radiological survey. The purpose of the survey was to gain a sufficient understanding of the total radiological environment of Enewetak Atoll to support judgment as to whether all or any part of the Atoll can safety be reinhabited and, if so, to describe cleanup actions to be taken and any constraints.

Radiological survey field operations were conducted between mid-October 1972 and mid-February 1973. Samples taken in the field have been analyzed and complete results of the survey have been published as a Nevada Operations Office document (NVO-140), Enewetak Radiological Survey, Vols. I, II, III. An abstract of NVO-140 is presented in Appendix I of this report, and the "Summary of Findings" chapter is reproduced here in Appendix II.

In July 1973, a Task Group was established to review the Survey findings and to prepare cleanup and rehabilitation recommendations for consideration by the Commission. Members of this Task Group are: Mr. T. McCraw (AEC/OS), Dr. W. Nervik (LLL), Dr. D. Wilson (LLL), and Mr. W. Schroebel (AEC/DBER). Advisors and consultants to the Task Group have included Dr. E. Held (AEC/REG), Dr. R. Conard (BNL), Dr. H. Soule (AEC/WMT), Dr. N. Barr (AEC/DBER), Dr. R. Maxwell (AEC/DBER), Mr. L. J. Deal (AEC/OS), and Mr. R. Ray (AEC/NVO). Staff liaison representatives from DNA, EPA, and DOI participated in Task Group meetings.

The job of the Task Group is to recommend radiological criteria for cleanup and rehabilitation of Enewetak Atoll and to recommend those remedial measures and actions needed to reduce exposures of the Enewetak people to levels within these criteria, and to keep exposures as low as practicable. The Task Group, advisors, and consultants have carefully reviewed the AEC Radiological Survey results; current information on the life style, diet, and rehabilitation preferences of the Enewetak people; applicable radiation protection guidance established by various national and international Radiation Standards bodies; and current laws and regulations pertaining to disposal of radioactive waste materials.

The recommendations that were developed are those that, in the judgment of the Task Group, advisors, and consultants, are most appropriate for the U.S. Government to take to provide a radiologically acceptable environment for the Enewetak people considering they will be long-term residents on the Atoll.

TASK GROUP STATEMENT CONCERNING THE RADIOLOGICAL SURVEY RESULTS

After thorough review of the Radiological Survey Report, the Task Group makes the following observations:

- The survey provides an exceptionally complete data base for estimating radiation doses. It includes the results of an aerial gamma radiation survey of land area plus radiochemical data from the analysis of over 4500 samples of air, soil, sediment, water, and marine and land animals.

- The Survey report, plus the Master Plan for Rehabilitation and resettlement of Enewetak Atoll*, provide an accurate, comprehensive, and up-to-date assessment of the likely living patterns and diet of the Enewetak people.
- Several important components of the Enewetakese diet are either not now available on the atoll, or are available in quantities which are small compared to the needs of the people. Pigs and chickens are not available at all, but will be reintroduced. No breadfruit is growing now; pandanus and tacca are growing only in scattered locations; and coconut is growing in quantity only on the southern islands. Breadfruit, pandanus, tacca, and coconut must be planted and will begin to produce crops after about eight years.

  Radiation dose estimates for these foods have had to be based on correlations with plants and animals now present on the atoll and on inferences drawn from earlier surveys on Bikini and Rongelap. There are many data points, and these correlations provide the best method currently available for estimating internal exposures. Nevertheless, the method is not as reliable as direct measurement of the foods produced in the areas of concern.
- Air sampling at Enewetak, accomplished largely during a three week period in December 1972 on uninhabited northern islands, showed extremely low levels of airborne radioactivity. Com-

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*"Enewetak Atoll Master Plan for Island Rehabilitation and Resettlement," (3 Vols.), Holmes and Narver, Inc., Nov. 1973.

prehensive air sampling during 12 consecutive months under conditions closely approximating human habitation and soil disturbance would provide more accurate data on which to base inhalation exposure estimates.

- The Enewetak People advise that catchment rainwater is the customary principal source of water for human consumption. Except in emergencies, water from underground lenses is not consumed. Samples of underground water were not obtained during the survey, and radiochemical analytical data on lens water is limited to that obtained from a few samples taken on JANET in 1971. A thorough lens water sampling, analysis, and assessment program requires sampling through a full rain-dry season cycle, 12 consecutive months at a minimum. Arrangements for sampling fresh water lenses are being made.
- It is the opinion of the Task Group that the results of additional air sampling or lens water sampling probably would not significantly change the dose estimates in NVO-140 nor change the recommendations of this Task Group.

RADIATION CRITERIA RECOMMENDED BY THE TASK GROUP

A review of the radiation protection standards and guides considered by the Task Group to be applicable to Enewetak is presented in Appendix III. This review indicates that the numerical standards and radiation protection philosophy of both national and international standards bodies are similar.

Summarizing that appendix, the specific guidance and criteria used by the Task Group in its assessment of the data and recommended for cleanup and rehabilitation of the atoll, are as follows:

- The population dose to the Enewetak people should be kept to the minimum practicable level.
- A value of 50 percent of the Federal Radiation Council (FRC) Radiation Protection Guides (RPG's) for individuals is recommended for the criteria to be used in evaluating the various exposure reduction options considering that such exposures cannot now be precisely determined.

  The following values apply:

Whole body and bone marrow -	0.25 Rem/yr
Thyroid -	0.75 Rem/yr
Bone -	0.75 Rem/yr

- The guide for gonadal exposure of the population should be - 4 rems in 30 years.
- The guidance for ^{239}Pu in soil should be the following*:
  a. < 40 pCi/gm of soil - corrective action not required
  b. 40 to 400 pCi/gm of soil - corrective action determined on a case-by-case basis** considering all radiological conditions.
  c. > 400 pCi/gm of soil - corrective action required.

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*These values are recommended for use in cleanup of Enewetak Atoll only.

**See Appendix III for additional guidance.

ASSESSMENT OF DOSES AND THE RESULTS OF ALTERNATIVE CORRECTIVE ACTIONS

The Task Group approach for development of judgments and recommendatior for the radiological cleanup and rehabilitation of Enewetak was to consider a number of alternatives for exposure reduction that may be feasible. Basi(the procedure involved four steps:

- Assessment of doses for a population living on the atoll in its current radiological condition.
- Assessment of dose reductions that might be expected due to modific tion of the diet.
- Assessment of dose reductions that might be expected due to removal of contaminated soil.
- Comparison of these dose assessment matrices with the population d guidelines used by the Task Group.

The Enewetak Radiological Survey Report (NVO-140) contains estimates population doses on the atoll in its current radiological condition for si living patterns chosen to be most representative of the Enewetak people's desired life style after they return. In addition, dose estimates are ma for each of these living patterns for each of the following corrective act

- Gravel the village area and plow the village island.
- Import pandanus and breadfruit from the southern islands (ALVIN-KEITH) for inhabitants of the northern islands.
- Import pandanus, breadfruit, coconut and tacca from the southern islands.
- Import pandanus, breadfruit, coconut, tacca, and domestic meat fı the southern islands.

The estimates for 30 year whole body doses in the Survey Report are summarized in Table 1, and 30 year bone dose estimates are summarized in Table 2. Note that the option for "Gravel Village Area - Plow Village Island," achives a minimal reduction in radiation exposure of whole body and bone for all living patterns, and those living on JANET would have to import most foods to avoid exceeding a whole body exposure of 4 rems in 30 years. Population dose guidelines used by the Task Group include annual dose rates as well as 30 year intergrals for genetic doses. Tables 3 and 4 show estimates of the maximum annual whole body and bone dose.*

In considering the reduction in exposure that may be achievable through removal of contaminated soil, the Task Group has taken the position that these predicted exposures are approximations only. The effectiveness of such actions to reduce internal exposures must be confirmed through analysis of test plantings.**

In its assessment of dose reductions that might be possible due to removal of contaminated soil, the Task Group posed the following questions: "Given the dose estimates of Tables 1-4, and the dose reductions that can be expected due to modifications of the diet, can equivalent dose reductions be achieved by removal of soil and, if so, what volume of soil would have to be removed from contaminated islands"? In order to address this question

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*A detailed description of the calculations leading to the estimates in Tables 3 and 4 is given in Appendix IV.

**The Task Group does not favor soil removal as a dependable or feasible exposure reduction action. However, such action is reviewed in the Task Group Report in order to present a complete picture of the various possibilities considered.

one must know or have estimates of the areas to be used for housing and villages, for growing pandanus and breadfruit, for growing coconut, and for raising domestic animals.

Figure 1 shows the Enewetak Atoll Land Use Plan as presented in the Enewetak Atoll Master Plan. Of the northern islands only Enjebi (JANET) is expected to be a residence and agricultural island. Aej (OLIVE), Lujor (PEARL), Amon (SALLY), Bijile (TILDA), Lojwa (URSULA), and Alamebel (VERA) are intended to be used as agricultural islands, and the remainder (ALICE, BELLE, CLARA, DAISY, IRENE, KATE, LUCY, MARY, NANCY, and WILMA) as food gathering and picnic islands.

Figure 2 shows the land use plan for Enjebi Island (JANET), including 14 housing areas (560,000 ft^2, assuming an average housing area to be 200' x 200' in size), a community center (200,000 ft^2), subsistence agricultural areas (1,100,000 ft^2), and commercial agricultural areas (7,300,000 ft^2).

In order to get an approximation of the amount of soil that would have to be removed to bring about a given dose reduction, one needs to determine the three dimensional distribution of the radioactive contamination. Figure 3 shows the average ^{90}Sr activities (pCi/gm) in soil samples collected to a depth of 15 cm on JANET. Similar figures for ^{137}Cs, ^{60}Co, and ^{239}Pu may be foun[d in] Appendix II of NVO-140. In addition to the 15 cm deep samples, radioactivity distribution as a function of depth ("profile samples") was measured in fourteen locations on JANET. Data from these profiles are presented in Figs. B.8.2.a-n of Appendix II of NVO-140. Inspection of these profiles indicates that, on the average, about 40 cm of soil would have to be removed to reduce the activity in the top 2 cm layer by a factor of 10. In addition, as the depth increases the slope of the activity-vs-depth curve tends to decrease,i.e., the activity levels do not go to zero, even at depths greater than 100 cm. Table 5 shows pertinent data for ^{90}Sr.

In an attempt to quantify this distribution and obtain an approximation of the "average profile" for calculational purposes, ^{90}Sr and ^{137}Cs data for each of fourteen profile samples have been reproduced in Tables 6 and 7. The average values for ^{90}Sr for each sampling depth are plotted in Fig. 4. It is apparent that from the surface to about 30 cm the ^{90}Sr specific activity is decreasing with a "soil half thickness" of 8.4 cm, while in the 30 to 85 cm depth range the half thickness increases to 22 cm. The levels to not get as low as those found on the southern islands (~0.5 pCi/gm) at any depth down to 180 cm. Those profile samples which lie in or closest to the subsistence agriculture areas of Figure 2 have been averaged and plotted in Fig. 5. In this set, the half thickness is only 4 cm from the surface to 10 cm, but increases to 25.5 cm in the 10 to 85 cm depth range. Similar treatment of the ^{137}Cs data is plotted in Figs. 6 and 7. In Fig. 6, where all samples are averaged, the half thickness is 4.5 cm down to about 10 cm, and 12 cm from 10 to 85 cm. Levels equal to those found on the southern islands (~0.2 pCi/gm) are found at depths below about 100 cm. In Fig. 7, the subsistence agriculture case gives a half thickness of 2.7 cm down to 10 cm, and 17.8 cm from 10 to 85 cm.

For both ^{90}Sr and ^{137}Cs it is apparent that the profile averaged over all samples is more conservative than is the profile for subsistence agricultural areas for estimating the affects of soil removal: therefore the Task Group has used Figs. 4 and 6 for estimating dose reductions that might occur due to removal of soil.

In making these dose reduction approximations, one must keep two things in mind; first, that the NVO-140 does estimates for terrestrial foods grown an island such as JANET are based on correlations between certain indicator plants and average soil concentrations in the 0-15 cm samples (Fig. 3) since foods such as pandanus and breadfruit were not found on JANET and, second, that these concentrations are averaged over the 0-15 cm depth of Figs. 4 and Estimates of dose reductions to be expected due to removal of soil to a give depth, therefore, require an estimate of the ratio of the average concentrat of the nuclides of concern in the 0-15 cm depth of the newly exposed surface to that for the surface which is present now. This approach does not consi the radioactivity in the soils deeper than 15 cm which may be important, particularly for plants with roots that penetrate deeply into the soil. Ta presents these average concentrations and ratios for ^{90}Sr and ^{137}Cs for eac increment from the present surface down to 105 cm as derived from Figs. 4 a These estimates indicate, for example, that removal of 15 cm of soil may re the terrestrial food dose due to ^{90}Sr by a factor of 3.3 and that due to ^{137}Cs by 3.2. However, such reduction may or may not be actually achieved There is no experience to support these reduction levels.

Using the data of Table 8, one may assess the dose reductions that mi occur due to specific cleanup actions on JANET. Table 9 shows the doses that might occur due to seven different conditions. Case D represents the contributors to the 80 Rem bone dose of Table 2 using values for ^{90}Sr ^{137}Cs averaged over all of JANET. Case D1 indicates that if subsistence agriculture is limited to the area shown in Fig. 2 (i.e., along the lagoon shore) the ^{90}Sr and ^{137}Cs levels may be reduced to such an extent that the resulting 30 yr bone dose becomes 57 Rem. Removal of a half-thickness of

^{137}Cs (4.5 cm) in the residential areas has little effect since that action influences only the external gamma dose. Removal of successive 15 cm layers of soil in the subsistence agricultural areas, however, may reduce the bone dose by significant amounts. Removal of the top 15 cm layer, for example, may reduce the 30 year bone dose from 57 Rem to 19 Rem, while removal of an additional 15 cm may bring the dose down to 10.7 Rem.

Since soil removal-vs-bone dose reduction would possibly be most effective for pandanus and breadfruit, a variation on the estimates of Table 9 may be obtained by preferentially stripping soil in areas where these trees are to be grown. For case D-1, for example, if pandanus and breadfruit are grown in the subsistence agricultural areas only in sections from which 15 cm of soil have been removed, the resulting bone dose may drop from 57 Rem to 29.7 Rem (i.e., 57 39.1 + 11.8). If an additional 15 cm layer is removed, the dose may drop to 23.7 Rem.

The maximum dose reduction that can be achieved is through importation of clean soil from the southern islands or from outside the atoll. ^{90}Sr concentrations in the average profile (Table 6) do not get as low as those on the southern islands even at a depth of 180 cm. To achieve this maximum effect, however, sufficient clean soil has to be imported to encompass the entire root system of the mature trees and the water supply for these crops must not have ^{90}Sr levels higher than those found in the southern islands. Any replacement soil should be coarse and granular. Such soil is less likely to blow away or wash away. Given these conditions, the 57 Rem bone dose of case D1 may be reduced to 18.9 Rem (57-39.1 + 2.1 (0.45) (the 2.1 Rem from Table 241 and 0.45 from Table 243 of NVO-140).

As to the question of whether equivalent dose reductions (equivalent to reductions obtained through modification of the diet) could be obtained through removal of contaminated soil, the Task Group holds the opinion that some reduction is possible. However, the magnitude of this reduction is uncertain and can only be determined reliably through measurement of the radionuclide content of the important food items such as pandanus and breadfruit grown in the modified condition. This would require a research effort to grow test plantings of the various food crops in the soil removal and replacement areas using various fertilizers and trace minerals, and analysis of radionuclide content of the fruit produced. There is the possibility that radioactivity in the fruit could be reliably predicted from analysis of stems and leaves of young and as yet unproductive plants. This would require additional study. Considering the time required for such studies and that the levels of radioactivity in soil are being reduced by radioactive decay and weathering, it may take about as long to return people to JANET using soil removal and confirmatory studies as would be needed without such actions.

In the commercial agriculture areas of JANET and the other northern islands the item of concern is the radioactivity level of coconuts (i.e., "Can the Enewetakese sell their copra?"). Data in NVO-140 (pg 560-562) indicate that ^{137}Cs is the principal man-made radionuclide found in coconut meat, with the relationship ^{137}Cs (copra) = 1.3 ^{137}Cs (soil) at ^{137}Cs soil concentrations greater than 4.7 pCi/gm. NVO-140 also indicates that ^{40}K is found in copra at an average concentration of 6.8 pCi/gm. Since ^{40}K is a naturally occurring radionuclide and is always present in copra, it seems able to judge the marketability of copra grown in Enewetak Islands on the of its ^{137}Cs content relative to the naturally occurring ^{40}K. If the ^{137}Cs in soil is less than 5.2 pCi/gm, for example, the ^{137}Cs content of the copr produced may be less than its ^{40}K content, and one might argue that its mar ability should be unaffected. Table 10 shows the mean ^{137}Cs soil concentra and soil removal actions that may reduce the ^{137}Cs concentration in copra t values equal to and twice that of the natural ^{40}K for all northern islands (average profile data for PEARL, ALICE, BELLE, and CLARA, plotted in Figs. 8-11 and included in Table 8, were used in the calculations for each of the islands).

On JANET, for example, the commercial agriculture area in its current condition should yield copra with an average $^{137}Cs/^{40}K$ concentration ratio about three. Removal of a 6 cm thick layer of soil may reduce this value to two, and removal of 14 cm may result in copra with equal concentrations of ^{137}Cs and ^{40}K. Note that for islands planned to be used for commercial agriculture, it is possible that only JANET and PEARL have ^{137}Cs soil valu high enough to yield copra with a $^{137}Cs/^{40}K$ ratio greater than 2. Test plantings of coconut would be needed in areas where removal of soil has been conducted and the level of ^{137}Cs in coconut meat analyzed before any committment is made for planting of coconut trees in commercial quantities With additional study it may be possible to predict with confidence the level of ^{137}Cs in coconut meat through analysis of stems and leaves of immature trees. This would save time.

DISPOSAL OF CONTAMINATED MATERIAL

For disposal of contaminated material, there appears to be several categories, each requiring separate consideration:

1. Contaminated scrap, non-plutonium.
2. Contaminated soil, non-plutonium.
3. Contaminated scrap, plutonium.
4. Contaminated soil, plutonium.
5. Pieces of plutonium metal.

Some of the above are below the ground surface such as in burial sites. Some is near the surface such as the pieces of plutonium metal on YVONNE. With regard to disposal, the Task Group considers it appropriate to cite the objectives for disposal, to list possible approaches for disposal, and to suggest possible interim measures where appropriate.

Table 12 and the discussion in NV-140, Vol. I, contains information on known or suspected burial sites for radioactive debris. The Holmes and Narver "Engineering Study For A Cleanup Plan, Enewetak Atoll-Marshall Islands," HN-1348.1, contains information on the location and quantity of other above ground contaminated scrap.

Considering the relative short radiological halftimes for the fission products and induced radioactivity found on such scrap and debris, the Task Group suggests that the objective for disposal is to make this debris, particularly scrap metal, unavailable to the people when they return. Possible approaches for disposal are:

1. Disposal in water filled and underwater craters.
2. Shallow land burial wherein the radiation level of the scrap is not significantly greater than the radiation level on land.

3. Disposal in deeper portions of the lagoon. It is expected that this would be a modest addition to similar material already there from past test operations.

For contaminated soil, other than plutonium, the Task Group has not recommended removal of such soil and therefore there would be no requirement to select a method of disposal. If such disposal were required, the objective would be to assure that there would be no pathway for any exposure of the Enewetak people to this radioactivity and a minimal followup requirement to insure that this situation continues after disposal.

The Task Group view is that because of its extreme long half life, disposal of plutonium in the form of contaiminated soil and scrap is a problem of greater magnitude than for fission products and induced activity. In its deliberations, the Task Group has assumed that the disposition of such material will be such that there is no potential for exposure of the residents of the atoll once cleanup has been completed. This is then the objective for cleanup.

Recommmendations which follow will treat the questions of how to approach recovery of the higher levels of plutonium contaminated soil and the pieces of plutonium metal, and Appendix III of this report contains guidance on decisions to be made on whether removal of plutonium contaminated soil is justified on various islands. It is the view of the Task Group that as a minimum, cleanup must accomplish the recovery of the plutonium contaminated materials, soil and scrap, from the various islands including buried scrap, with placement in stockpiles as few in number as possible. The object is to get better control of the materials and to minimize spread of contamination.

YVONNE may be a suitable site for such stockpiling with the quarantine continued until proper disposal is accomplished. It is the hope of the Task Group that deliberation and decisions on disposal of plutonium contaminate soil and scrap will not delay other cleanup and rehabilitation actions.

As for considering disposal, there appears to be three possibilities:

1. Disposal wherein there is an irrevocable committment of the contaiminant to the environment.
2. Disposal wherein, with some difficulty, a later decision could change the method of disposal.
3. An effort made to find a way to reduce the volume and amount of materi requiring disposal in either way (1 or 2) above.

The following ideas have been put forth for disposal of plutonium contami soil and scrap:

1. Disposal of plutonium contaminated scrap in the deep lagoon or deep ocean.
2. Make the contaminated soil into concrete blocks with disposal in deep ocean or through burial on land.
3. Disposal of contaminated soil in the form of cement poured into deep drill holes on land with the scrap added.
4. Disposal of soil and scrap in the water filled craters on YVONNE wit a thick concrete cover.
5. Return of these materials for burial in the U.S. in packaged form or as concrete blocks.

Any ocean disposal plans must be coordinated with the Environmental Protection Agency. The Enewetak people should be informed of any plans for land burial within the atoll.

It may be possible to reduce the amount of material requiring disposal by removal of the plutonium from the most highly contaminated soil. The Task Group does not have adequate information to determine whether this may be feasible. Research to determine whether this can be accomplished could be conducted with YVONNE used as the study site.

TASK GROUP OBSERVATIONS AND CONCLUSIONS

In the radiologically complex Enewetak Atoll environment there are a large number of options that may be considered for cleanup and rehabilitation of various islands. The Task Group has considered as many of these as possible in the time available. To the extent possible the Task Group has attempted to arrive at a consensus of opinion among the drafting group and its technical advisors. Comments on draft material have been solicited from staff of several Federal agencies. Their suggestions have influenced the approach to development of recommendations and have led to numerous changes of a technical nature. Regarding each option, the following have been considered.

1. Determination of the radiological exposure to be expected and comparison of predicted exposures with accepted radiation exposure criteria.
2. The feasibility of actions or restrictions inherent in the option.
3. The effectiveness of the option in bringing exposures within the criteria and any uncertainties regarding the effectiveness.

4. The possible impact on the Enewetak people and on the environment.

Choice of the best overall method for reduction of exposures to the lowest practicable level is a matter of judgment and opinion. The Task Group has deliberated whether actions of an engineering nature such as soil removal are preferable to actions that would restrict use of certain islands for permanent habitation and food production. The adverse impact of engineering actions on the atoll environment and the uncertainties regarding effectiveness have been viewed on the one hand, and the question of the extent to which the Enewetak people would comply with restrictions on the other.

NVO-140 and this Task Group report present the radiation doses that may be associated with a broad range of options and provide data for calculating doses for other options for anyone who wishes to do so. The dose reduction expected for one option can be compared with that of another. Dollar costs for cleanup actions are being prepared by DNA; and the impact and acceptability of restrictions can be evaluated through discussions with the Enewetak Council.

In NVO-140, and in the previous section of this report, dose estimates - and therefore options - were considered in matrix form (e.g., living pattern vs. diet, or diet source vs. amount of soil removed). While these matrices serve to indicate in detail the range of conditions to be found on the atoll, the Task Group feels that its' recommendations are presented more effectively in narrative form.

There are three basic questions to be addressed: e.g., "Is the radiation environment acceptable or can it be made acceptable for the Enewetak people to return to their atoll," "Is the radiation environment on Enjebi acceptable or can it be made acceptable for the people to return," and "Are there islands which are not acceptable for people to conduct their normal agricultural and social activities, and, if so, are there any actions that could be taken or restrictions imposed that would keep exposures within acceptable criteria?"

Within this framework of data and basic questions, the Task Group has focused attention on the following options (see Fig. 146, Appendix II):

Option I

a. No return of the Enewetak people.

b. No radiological cleanup.

This clearly represents a no-cost, no-radiation-dose option. Just as clearly, it runs contrary to the expressed wishes of the Enewetak people. In addition, choice of this option cannot be defended using current radiation protection philosophy and standards since the predicted exposures for persons living on the southern islands are well within acceptable standards.

Option II

a. Return to the southern islands (ALVIN-KEITH).

b. Agriculture limited to the southern islands.

c. Travel restricted to the southern islands.

d. No restrictions on fishing.

e. No radiological cleanup.

This is an option with zero cost for radiological cleanup that results in population doses well below the guides (Row A of Tables 1-4). It differs from later options in that it leaves the problems of contaminated scrap in many areas of the atoll, and the Pu in soil on YVONNE, IRENE, and in the burial sites on SALLY, plus generally contaminated areas on ALICE, BELLE, CLARA, and PEARL, unresolved. Such a choice would establish the need for off-limits areas in perpetuity, at least for YVONNE, since the metallic Pu is expected to be present on the surface of the island indefinitely unless cleanup is performed. Under current conditions there is a potential for exposures exceeding Federal standards through the inhalation pathway and the possibility of spread of the contamination if access to the island is not controlled. This accounts for the current quarantine of the island. Limiting all agriculture to the southern islands is difficult to justify because some of the northern islands are lightly contaminated. From Tables 1-4, for example, it can be seen that limiting only the growth of pandanus and breadfruit to the southern islands would permit all other substance agricultural practices on JANET-WILMA without the radiation exposure criteria being exceeded. Similarly, it is difficult to justify limiting travel to the southern islands since the ambient gamma levels on the northern islands do not represent a significant external exposure potential for occasional visitation.

Option III

a. Return to the southern islands (ALVIN-KEITH).

b. Substance Agriculture limited to the southern islands plus JANET-WILMA except that pandanus and breadfruit are limited to the southern islands

c. No restrictions on travel.

d. No restrictions on fishing.

e. Remove Pu contamination on YVONNE,. IRENE and the SALLY burial sites.

f. Remove radioactive scrap.

This is one of the less expensive options in that it requires removal of only the most seriously contaminated materials. In practical terms, it maximizes unrestricted use of areas of the atoll having low radioactivity levels, leaves no hazardous legacies for the indefinite future, and permits living patterns which, with high confidence, are expected to result in population doses well below the recommended radiation criteria.

This option does not specify action against radioactivity in soil of the islands such as ALICE, BELLE, and CLARA, nor does it recommend that residences be built on JANET. By implication, therefore, resettlement of JANET would have to wait for radioactive decay and weathering processes to reduce contamination levels to acceptable values on these islands. Since the predominant isotopes, ^{137}Cs and ^{90}Sr, each have half-lives of thirty years, the waiting period could be slightly more than one generation for each factor of two reduction in dose. On the other hand the reduction could proceed at a somewhat faster rate. On JANET, reducing the maximum annual child's bone marrow dose from 0.72 rem/yr (Table 4, Case D-I) to the guide level of 0.25 rem/yr through natural decay of the ^{90}Sr would theoretically require a wait of about 50 years considering only radiological decay. It is not expected that such a reduction will actually take that long.

Option IV

a. All of Option III a, c, d, e, and f, plus:

b. Return to JANET and build residences and community center in locations shown on the Master Plan.

c. Remove a minimum of 30 cm of soil in all areas where pandanus and breadfruit are to be grown on JANET; import clean soil in which to establish these plants; or import pandanus and breadfruit from the southern islands.

If these actions proved to be as effective as the theoretical predictions, this would permit return of the Enjebi people to their island. It should be emphasized, however, that even with the above actions, predicted doses are near or slightly above the criteria for annual exposures and also above the 30 year criteria. The levels are expected to be well above those of Option III

Option IV c describes three ways in which essentially the same end can theoretically be achieved. Importation of food is the most dependable action but this imposes a long-term burden on the Enjebi people which they may find objectionable. Removal of soil alone is another alternative, but the effectiveness of the action is uncertain for reducing population dose since ^{90}Sr and ^{137}Cs are found so far below the surface on JANET. Importing soil for a of subsistence crops such as pandanus and breadfruit would possibly reduce the dose from these foods to levels comparable to those found on the southern islands provided that sufficient soil is imported to encompass the entire root system of the mature trees. The water supply for these crops must not have radioactivity levels higher than those in the southern islands. How this can be insu is not obvious at this time.

The Task Group considers Option IV a-c, by itself, to be unacceptable at this time. Even with the actions and restrictions indicated, exposures would be too high to provide an acceptable margin within the criteria. This is especially true for children born at about the time of rehabitation. Importation of food from the southern part of the atoll or other sources is believed to represent an impractical solution to the problem of excessive internal exposure. Use of a layer of clean soil in areas for food production is not known to be effective, would be hard to regulate, and would constitute an experiment involving the Enjebi people. In addition, use of clean soil for subsistence crops may have little affect on levels of radioactivity in domestic animals and coconut crabs, which range over the entire island.

Since Option IV a-c is expected to result in population doses near or slightly above the radiation criteria, further dose reduction may possibly be achieved by:

d. Removal of 15 cm of soil in the subsistence agricultural area of JANET.

e. Removal of 15 cm of soil in the commercial agricultural area of JANET.

These actions result in a theoretical reduction factor of 3 to 4 for ^{137}Cs and ^{90}Sr in the remaining top cm layer of soil - or have roughly the same theoretical effect as waiting sixty years for radioactive decay to take place. Whether food crops would show a similar reduction is uncertain. This action would possibly result in an ultimate finding that doses would be below the criteria but above that expected for people living on the southern islands.

Most significantly, however, implementation of Option IV a-e would remove a minimum of 15 cm of soil from essentially the entire island of JANET. Since the top soil on that island is charitably described as meager, such action would leave JANET a sand island. Heroic actions would be required to either reconstitute the remaining soil through use of fertilizers and other additives, or import top soil sufficient to support subsistence and commercial agriculture. With any of these actions a period of time would be required, possibly as long as 8-10 years, or until test plantings of coconut, pandanus, and breadfruit are grown and analyzed for their radioactivity content, before a decision could be made to settle people on JANET. An additional period of 8-10 years would be required after a decision to plant subsistence and commercial crops in quantity before the island could support its inhabitants.

Option V

a. All of Options IV a-e, plus:

b. Removal of a minimum of 10 cm of soil from PEARL.

c. Removal of a minimum of 47 cm of soil from ALICE, 14 cm from BELLE, and 10 cm from CLARA.

d. If pandanus and breadfruit are to be grown on northern islands other than JANET, the criteria of Option IV c should apply, i.e., plant in soil having a ^{90}Sr content of 4.6 pCi/gm or less, or bring clean soil to the island with a depth sufficient to contain the roots of these trees.

If these actions achieved a level of exposure reduction as large as the calculational result, this would permit use of the entire atoll according to the Master Plan. This option is clearly much more expensive than other options since it requires removal of additional soil and requires reconstitution of soil in the cleared areas. Consideration of these actions as a viable option is clouded by uncertainties regarding the exposure reduction that can be achieved through partial soil removal and by selective soil replacement.

For comparative purposes, population dose estimates for Options I-V are presented in Table 11.

RECOMMENDATIONS

After careful review of all available radiological data the Task Group members' specific recommendations are as follows:

1. The people of Enewetak Atoll may be safety returned to their homeland provided certain actions are taken and precautions observed.
2. In the interest of achieving a minimum practicable dose for the Enewetak people the Task Group recommends that:
   a. The first villages and residences be constructed on ELMER, FRED, DAVID, or on any of the southern islands (ALVIN-KEITH) that the Enewetak people choose.

b. Growth of all subsistence crops such as pandanus, breadfruit, tacca, pigs, chickens, and all other terrestrial food stuffs except coconut be limited to islands ALVIN-KEITH.

c. Subsistence and commercial coconut may be grown on any island in in the atoll without any remedial measures except ALICE, BELLE, CLARA, DAISY, IRENE, JANET, and YVONNE.

d. Fishing be permitted anywhere.

e. Travel be unrestricted to all islands except YVONNE. When the Pu contamination on YVONNE is removed, the restriction of travel to that island can be lifted.

f. Wild birds and bird's eggs be collected anywhere.

g. Coconut crabs be collected only on the southern islands.

h. Wells which are intended to provide lens water for human consumption or for agricultural use be drilled only on the southern islands. When drilled, water from each well should be checked for bacteria, salinity, and radioactivity content before the well is approved for use.

3. It is recognized that the people of Enjebi have a strong desire to return to live on that island. The island contains three ground zero locations from nuclear tests and was within about three miles of the Mike event that had a total yield of about 10 Megatons. Enjebi was the most heavily contaminated of the larger islands in the atoll. The Task Group has been unable to determine any way in which radiation exposures can be brought within the acceptable criteria, that is both reliable and feasible, in order to resettle Enjebi at the same time as islands in the south of the atoll. It is reasonable to expect that

one day the island can be resettled. There appear to be two possible approaches:

a. Soil removal followed by studies with test plantings to determine whether exposure for Enjebi residents would be within acceptable criteria.

b. Conduct of studies using test plantings to determine when exposures would be within acceptable criteria but no soil removed.

In either case, housing construction and planting of subsistence and commercial crops would be deferred until research with test plantings showed acceptably low levels of radioactivity. The Task Group recommends the second approach as one having minimal adverse impact on the island environment.

4. The research program in 3 above should also include a determination of radioactivity levels in copra and other food crops produced on PEARL, CLARA, ALICE, and BELLE. YVONNE should also be included after removal of plutonium contaminated soil.

5. All radioactive scrap metal and contaminated debris identified during the Holmes and Narver Engineering Survey should be removed. If additional contaminated debris is discovered in the course of cleanup and rehabilitation operations, it too should be removed. Specifically included in this recommendation are the three locations on SALLY and one on ELMER where contaminated debris is known to be buried. This debris should be exhumed and removed.

6. The quarantine of YVONNE should be continued in effect until the plutonium contamination on that island is reduced to acceptable levels Should any Enewetak people return to the atoll before cleanup is

begun or before completion, an authority responsible for enforcement of the quarantine should be identified and should be in residence in the atoll when people return.

7. The distribution of plutonium contamination on YVONNE is sufficiently complex that specific recommendations for cleanup cannot be presented. It is expected that the true picture of this contamination will unfold as the decontamination effort proceeds. Presented are some of the requirements and objectives that will establish a background from which plans can be made for recovery of plutonium on YVONNE.

   a. Decontamination of YVONNE is seen as an iterative process, namely, removal of soil, monitoring of radioactivity levels, and removal of more soil. This amounts to a search for the higher plutonium levels and reduction of these to the lowest practicable value.

   b. A team of experts should be assembled who can make and interpret field radiation and radioactivity measurements, advise on cleanup actions, and provide necessary health physics support including protection of workers, decontaimination of workers and equipment, and packaging and handling of collected plutonium.

   c. The objectives of the cleanup are two:

      (1) Recovery of the pieces of plutonium that have been observed on or near the island surface. Some contain milligram quantities of plutonium metal and are easily detected with field survey instruments such as the FIDLER.

      (2) Recovery of plutonium contaminated soil. To a first approximation, the location of the zones of higher Pu concentrations are shown in the survey profil samples.

TABLE 1. 30 Year Integral Whole Body Dose (Rem)

Living Pattern*	I Current Condition (no corrective action)	II Gravel Village Area - Plow Village Island	III Import Pandanus and Breadfruit	IV Import Pandanus, Breadfruit, Coconut, and Tacca	V Import Pandanus Breadfruit, Coconut, Tacca, and Meat
A	1.0	1.0	1.0	1.0	1.0
B	4.4	4.4	2.2	1.9	1.3
C	5.7	4.4	2.7	2.4	1.8
D	11	8.9	4.4	3.7	1.9
E	14	13	6.6	5.7	3.3
F	31	24	11.3	9.1	3.5

*Living Pattern	Village Island	Agriculture	Visitation
A	FRED/ELMER/DAVID	ALVIN through KEITH	Southern Islands
B	FRED/ELMER/DAVID	KATE through WILMA	Northern Islands
C	JANET	KATE through WILMA	Northern Islands
D	JANET	JANET	Northern Islands
E	JANET	ALICE through IRENE	Northern Islands
F	BELLE	BELLE	Northern Islands

TABLE 2. 30 Year Integral Bone Dose (Rem)

Living Pattern	I Current Condition (no corrective action)	II Gravel Village Area - Plow Village Island	III Import Pandanus and Breadfruit	IV Import Pandanus, Breadfruit, Coconut and Tacca	V Import Pandanus, Breadfruit, Coconut, Tacca and Meat
A	3.8	3.8	3.8	3.8	3.8
B	35	35	11.5	9.1	4.1
C	37	35	12	9.6	4.6
D	80	78	23	18	4.7
E	135	134	38	27	6.1
F	220	213	61	43	6.3

TABLE 3. Maximum Annual Whole Body Dose (Rem)

Living Pattern	I Current Condition (no corrective action)	II Gravel Village Area - Plow Village Island	III Import Pandanus and Breadfruit	IV Import Pandanus, Breadfruit, Coconut, Tacca	V Import Pandanus, Breadfruit, Coconut, Tacca, and Meat
A	0.039/0.039*	-	0.039/0.039	0.039/0.039	0.039/0.039
B	0.234/0.236	-	0.125/0.128	0.091/0.122	0.090/0.083
C	0.237/0.241	-	0.128/0.133	0.093/0.127	0.089/0.094
D	0.540/0.542	-	0.245/0.252	0.146/0.187	0.087/0.097
E	0.749/0.761	-	0.350/0.367	0.246/0.328	0.182/0.211
F	1.56/1.55	-	0.662/0.663	0.357/0.475	0.192/0.191

*Child/Adult - both starting Jan. 1974.

TABLE 4. Maximum Annual Bone Marrow Dose (Rem)

Living Pattern	I Current Condition (no corrective action)	II Gravel Village Area - Plow Village Island	III Import Pandanus and Breadfruit	IV Import Pandanus, Breadfruit, Coconut, Tacca	V Import Pandanus Breadfruit, Coconut, Tacca, and Meat
A	0.047/0.045*	-	0.047/0.045	0.047/0.045	0.047/0.045
B	0.314/0.294	-	0.148/0.149	0.122/0.130	0.097/0.091
C	0.317/0.300	-	0.151/0.178	0.121/0.135	0.096/0.096
D	0.718/0.677	-	0.293/0.294	0.168/0.204	0.094/0.094
E	1.06/0.989	-	0.428/0.437	0.253/0.354	0.184/0.213
F	2.08/1.92	-	0.786/0.774	0.415/0.516	0.199/0.193

*Child/Adult - both starting Jan. 1974.

TABLE 5. ^{90}Sr Profile Sample Data on JANET

Profile Sample Number	Depth to Reduce Act. by Factor of 10	^{90}Sr Act. in Top 2 cm	^{90}Sr Act. in Top 15 cm	^{90}Sr Act. Below 100 cm Max. (pCi/gm)	"Av."
	(cm)	(pCi/gm)	(pCi/gm)		
100	7	360	150	11 (50 cm)	
135	56	18	10	1.3 (100 cm)	1
136	> 100	14	17	3.6 (100 cm)	3.6
137	15	34	16	2.1 (130 cm)	0.4
138	9	100	28	1.3 (150 cm)	0.4
139	12	410	220	5.4 (150 cm)	0.9
140	66	54	95	4.8 (115 cm)	2.
141	12	100	39	4.8 (135 cm)	2.5
142	60	90	95	46 (120 cm)	10.5
143	> 100	21	31	13 (100 cm)	13
144	76	50	46	2.4 (100 cm)	1
145	18	27	26	0.7 (100 cm)	0.3
147	25	87	200	0.6 (160 cm)	0.3
901	25	110	185	8.5 (40 cm)	--
Av.	42 cm	105.4	82.7	7.1*	3.0

*(No. 100 and No. 901 excluded)

Mean ^{90}Sr concentration in top 15 cm samples:

JANET: 44 pCi/gm

Southern islands:

DAVID, ELMER, FRED: 0.41 pCi/gm

All others except

LEROY: 0.52 pCi/gm

Table 6. ^{90}Sr Concentrations (pCi/gr) in Profile Samples Taken on JANET

Profile No.	Sample Depth (cm) 0-2	2-5	5-10	10-15	15-25	25-35	35-45	45-55	55-65	65-75	75-85	85-95	95-105	105-115	115-125	125-135	135-145	145-155	155-165	165-175	175-185
100 *	360	220	75	21	12	12	11	11	8.2												
135 *	18	16	7	8	5.5	5	5.2	3	1.3	1.3	1.5	1.3	1.3	1.0	0.85						
136 *	17	10	17	20	50			6.4	5.3	5	3.8	5.3	3.7								
137	34	17	8.5	4.6	2.7	1.6	1.6	0.85	0.78	0.68	0.28	7.8	0.43	0.5	0.4	0.4	2.1	0.43	0.35	0.41	0.25
138	100	26	14	8	4.8	2.4	2.2	2.6	3.2	2.1	1.4	0.9	0.47	0.42	0.3	-	0.32	1.3	0.31	0.45	0.45
139	410	460	160	50	28	34	26	9.3	0.9	1.0	0.8	0.23	0.85	0.8	0.47	0.3	0.31	5.4	1.2	1.5	
140 *	54	6	18	17	14	15	10	15	10	3.5	2.8	1.7	1.1	0.93	0.8	3.8					
141 *	100	78	18	8	5.4	5.2	5.2	4.6	3.2	2.8	2.8	3.0	2.6	2.4	2.3	1.8	4.9	1.5			
142	90	95	120	110	78			14	12	8.2	7.2	5.6	4.8	4.1	46	22	4.3	3.5	3.3	2.9	2.7
143 *	21	26	42	26	500	68	26	25	21	3.7	11	11	12.5								
144	27	43	51	49	21	13	9	6.8	6.8	5.8	5.4	4.0	2.9	2.0	1.6	1.5	1.2	0.86	0.62	0.54	0.67
145	27	22	27	27	3.4	0.3	0.45	0.3	0.3	0.31	0.3	0.43	0.74	0.27	0.26	0.33	0.29	0.31	0.26	0.31	0.31
147	87	35	24	50	19	5.8	1.5	0.35	0.55	0.4	0.4	0.26	0.20	0.27	0.29	0.3	0.18	0.22	0.63	0.46	0.42
901	110	200	230	160	40	2.4	8.6														
Av.Composite	103.9	90	58	40	23.8	13.7	8.9	7.6	5.6	2.9	3.1	3.5	2.7	1.3	5.3	3.8	1.7	1.7	0.95	0.94	0.8
Av/Subsistence Agriculture Area (*Profiles)	86	59.3	29.5	16.7	22.8	21.	11.5	10.8	8.2	3.3	4.4	4.5	4.4	1.4	1.3	3.5	4.9	1.5			

Table 7. ^{137}Cs Concentrations (pCi/gm) in Profile Samples Taken on JANET.

Profile No.	0-2	2-5	5-10	10-15	15-25	25-35	35-45	45-55	55-65	65-75	75-85	85-95	95-105	105-115	115-125	125-135	135-145	145-155	155-165	165-175	175-185
	Sample Depth (cm)																				
100 *	210	64	23	3.1	0.7	0.44	0.44	0.27	0.22												
135 *	5.7	7.7	2.8	3.2	1.6	0.9	0.66	0.14	0.29	0.027	0.037	0.082	0.072	0.039	0.026						
136 *	6	4.8	6	4.5	6.5	6.5	2.7	1.3	0.85	0.78	1.5	0.47	0.19								
137	11	16	11	3.2	0.86	0.9	0.25	0.21	0.23	0.19	0.19	0.015	0.008	0.03	0.01	0.1	0.058	0.037	0.01	0.01	0.03
138	22	19	21	15	5.1	1.1	0.63	0.23	0.37	0.16	0.19	0.19	0.15	0.063	0.03	-	0.035	0.1	0.09	0.04	0.08
139	110	80	50	20	13	7	1.9	0.5	0.63	0.45	0.5	0.3	0.27	0.36	0.23	0.18	0.35	1.7	0.55	0.42	
140 *	43	15	4	13	2.3	1	1.1	1.5	1.5	0.42	0.36	0.38	0.35	0.21	0.19	0.73					
141 *	50	23	2.1	0.35	0.23	0.15	0.12	0.085	0.082	0.066	0.072	0.071	0.029	0.06	0.15	0.08	0.24	0.25			
142	100	63	42	49	53	26	1.5	0.72	0.45	0.23	0.24	0.27	0.35	0.29	0.18	0.17	0.15	0.34	0.39	0.53	0.52
143 *	6.1	5	5.2	7	6.1	6	5	4.7	2.9	0.1	0.21	0.37	0.93								
144	14	18	14	8	12	15	3.1	3.1	1.6	1.3	1.0	1.0	0.77	0.64	0.5	0.57	0.78	0.4	0.38	0.6	0.6
145	19	8	9.7	6.5	0.8	0.7	0.6	0.24	0.17	0.083	0.024	0.026	0.026	0.023	0.021	0.017	0.023	0.02	0.04	0.009	0.01
147	3.5	19	18	16	2.9	2.6	0.85	0.4	0.6	0.32	0.28	0.12	0.11	0.017	0.022	0.018	0.04	0.017	0.009	0.007	0.008
901	5.1	7	8.5	6.1	1.6	0.32	0.45														
Av. Composite	43.2	25.0	15.5	11.1	7.62	4.9	1.38	1.03	0.76	0.34	0.37	0.27	0.27	0.17	0.14	0.23	0.021	0.36	0.21	0.23	0.21
Av. Subsistence Agriculture	53.5	19.9	7.2	5.2	2.9	2.5	1.67	1.33	0.97	0.28	0.39	0.27	0.31	0.16							

Table 8. Concentrations of ^{90}Sr and ^{137}Cs in each 15 cm increment below the surface for the "Average Profile Samples"

Depth cm	Av. ^{90}Sr conc. (pCi/gm)	Ratio to top 15 cm	$\frac{1}{\text{Ratio}}$	Av. ^{137}Cs conc. (pCi/gm)	Ratio to top 15 cm	$\frac{1}{\text{Ratio}}$
JANET						
	^{90}Sr			^{137}Cs		
0-15	67.7	1.0	1.0	19.6	1.0	1.0
15-30	20.2	0.30	3.3	6.26	0.311	3.22
30-45	10.2	0.15	6.7	3.63	0.164	6.09
45-60	6.36	0.094	10.6	1.11	0.055	18.1
60-75	3.96	0.059	17.1	0.464	0.023	43.3
75-90	2.82	0.042	24.0	0.277	0.014	72.6
90-105	2.34	0.035	28.9	0.249	0.0124	80.6
PEARL						
0-15				12.4	1.0	1.0
15-30				3.4	0.276	3.6
30-45				1.1	0.088	11.4
ALICE						
0-15				36	1.0	1.0
15-30				24.5	0.68	1.47
30-45				16.6	0.46	2.16
45-60				11.2	0.31	3.19
BELLE						
0-15				48	1.0	1.0
15-30				9.7	0.202	4.9[illegible]
30-45				2.0	0.041	24.5
45-60				0.4	0.008	122
CLARA						
0-15				26	1.0	1.0
15-30				6.5	0.25	4.0
30-45				1.6	0.063	16
45-60				0.42	0.016	64

Tabel 9. Affect of soil removal on 30 year integral bone dose on JANET.

Soil Removal Action	^{90}Sr Conc (pCi/gm) (15 cm aver.)	Soil Volume	Bone Dose (Rem) Due To: Pandanus Breadfruit	Coconut Tacca	Meat	Total Bone Dose	Av. Est. γ Exposure Rates	External	Marine	TOTAL
D. Av. for JANET Current condition	44	0	55.5	6.8	13.2	75	40 μR/hr	4.0	0.84	80
D1. Subsistance Agric. area	31	0	39.1	4.8	9.3	53.2	28	3.3	0.84	57
D2. Remove 4.5 cm in Residential area	31	$3.2 \times 10^3 m^3$	39.1	4.8		52.8		2.8	0.84	56.4
D3a. Remove 15 cm in Subsistence Agric. Area	9.4	$1.5 \times 10^4 m^3$	11.8	1.5	2.7	16		2.2	0.84	19.0
D3b. Remove 30 cm	4.6	3.0×10^4	5.8	0.7	1.3	7.8		2.1	0.84	10.7
D3c. Remove 45 cm	2.9	4.5×10^4	3.7	0.4	0.8	4.9		2.0	0.84	7.7
D3d. Remove 60 cm	1.8	6.0×10^4	2.3	0.3	0.5	3.1		2.0	0.84	5.9

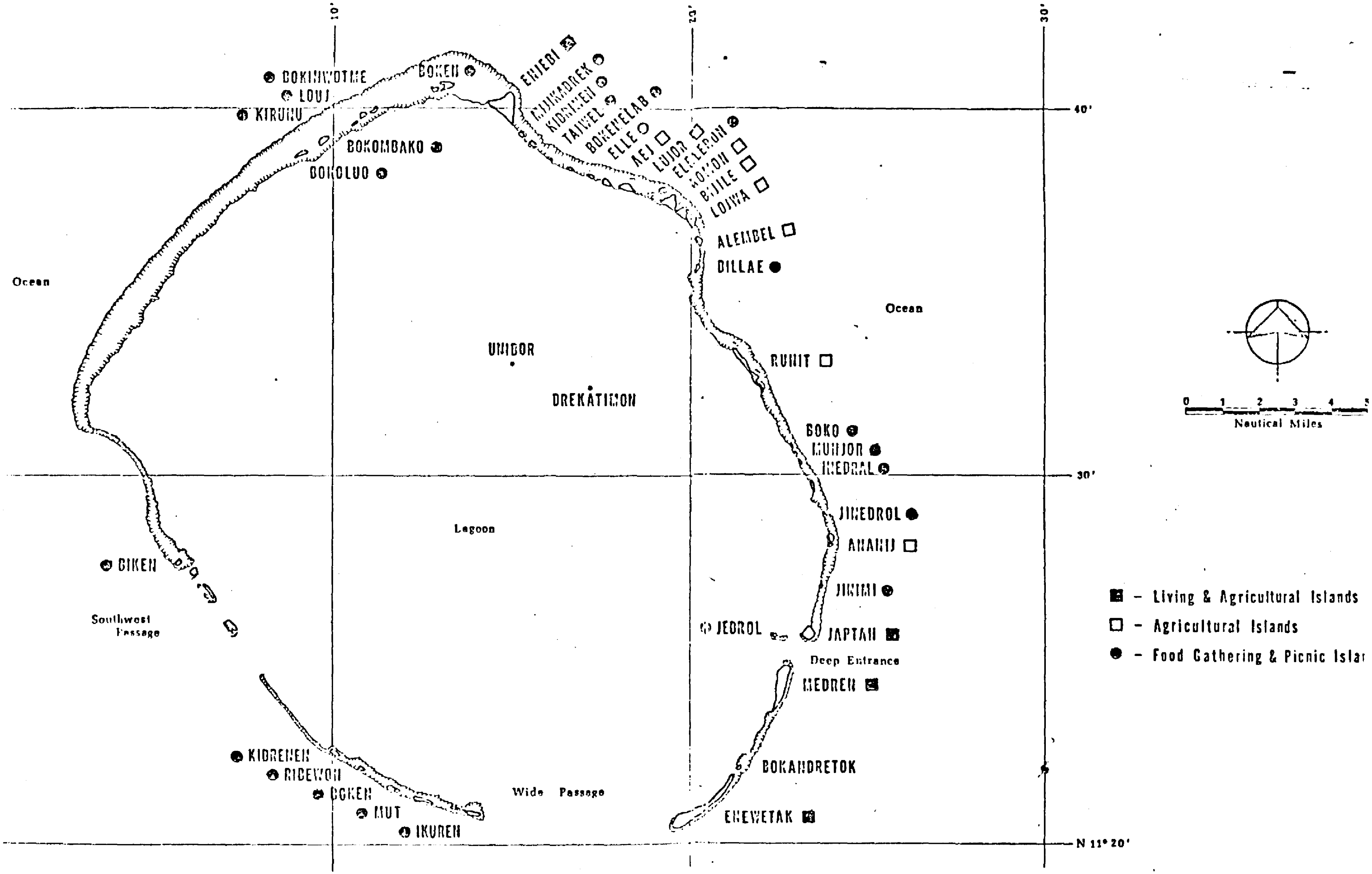
Table 10. Soil removal actions to reduce ^{137}Cs concentrations in copra

Island Comm. Agr.	Mean current ^{137}Cs conc. in soil (pCi/gm in 15 cm samples)	Area	Soil to be removed to achieve: 10.4 pCi/gm Thickness	Volume	5.2 pCi/gm Thickness	Volume
JANET	16	$6.9x10^{5}$ m^2	6 cm	$4.1x10^{4}$ m^3	14 cm	$9.7x10^{4}$ m^3
OLIVE	7.65	$1.1x10^{5}$	0		5 cm	$0.55x10^{4}$ m^3
PEARL	12.4	$1.5x10^{5}$	2 cm	$0.30x10^{4}$	10 cm	$1.5x10^{4}$
SALLY	3.0	-	0		0	
TILDA	4.2	-	0		0	
URSULA	1.7	-	0		0	
VERA	2.0	-	0		0	
Food Gathering and Picnicing						
ALICE	36	$9.3x10^{4}$ m^2	47 cm	$4.4x10^{4}$ m^3	74 cm	$6.9x10^{4}$ m^3
BELLE	48	18.6	14	$2.6x10^{4}$ m^3	21 cm	$3.9x10^{4}$
CLARA	26	1.9	10	$0.19x10^{4}$	17 cm	$0.32x10^{4}$
DAISY	11	5.6	0	-	9 cm	$0.5x10^{4}$
IRENE	3.2	-	0	-	0	-
KATE	13.1	7.4	3 cm	$0.22x10^{4}$	12 cm	$0.89x10^{4}$
LUCY	11	9.8	0	-	9 cm	$0.89x10^{4}$
MARY	9.9	5.6	0	-	8 cm	$0.45x10^{4}$
NANCY	12	8.4	2 cm	$0.17x10^{4}$	11 cm	$0.92x10^{4}$
WILMA	1.3	-	0	-	0	-

Table 11. Population Dose Estimates for Various Cleanup and Rehabilitation Options on Enewetak Atoll.

OPTION	30 yr whole body dose (Rem)	30 yr integral bone dose (Rem)	Max annual whole body dose (Rem)	Max annual dose to red bone marrow (Rem
I a, b	≤ 1.0	≤ 3.8	≤ (0.039/0.039)*	≤ (0.047/0.045)*
II a, b, c, d, e	1.0	3.8	0.039/0.039	0.047/0.045
III a, b, c, d, e, f	2.2	11.5	0.125/0.128	0.148/0.149
IV a, b, c	5.6	23	0.245/0.252	0.293/0.294
d	3.6	13	0.16/ 0.16	0.17/ 0.17
e	1.6	11	0.07/ 0.07	0.14/ 0.14
V a, b, c, d	(same as IV e)			

*(Child/Adult)



LAND USE PLAN — ENE

TRUST TERRITORY OF THE PA

ENEWETAK ATOLL MA

HOLMES & NARVER

Fig. 1

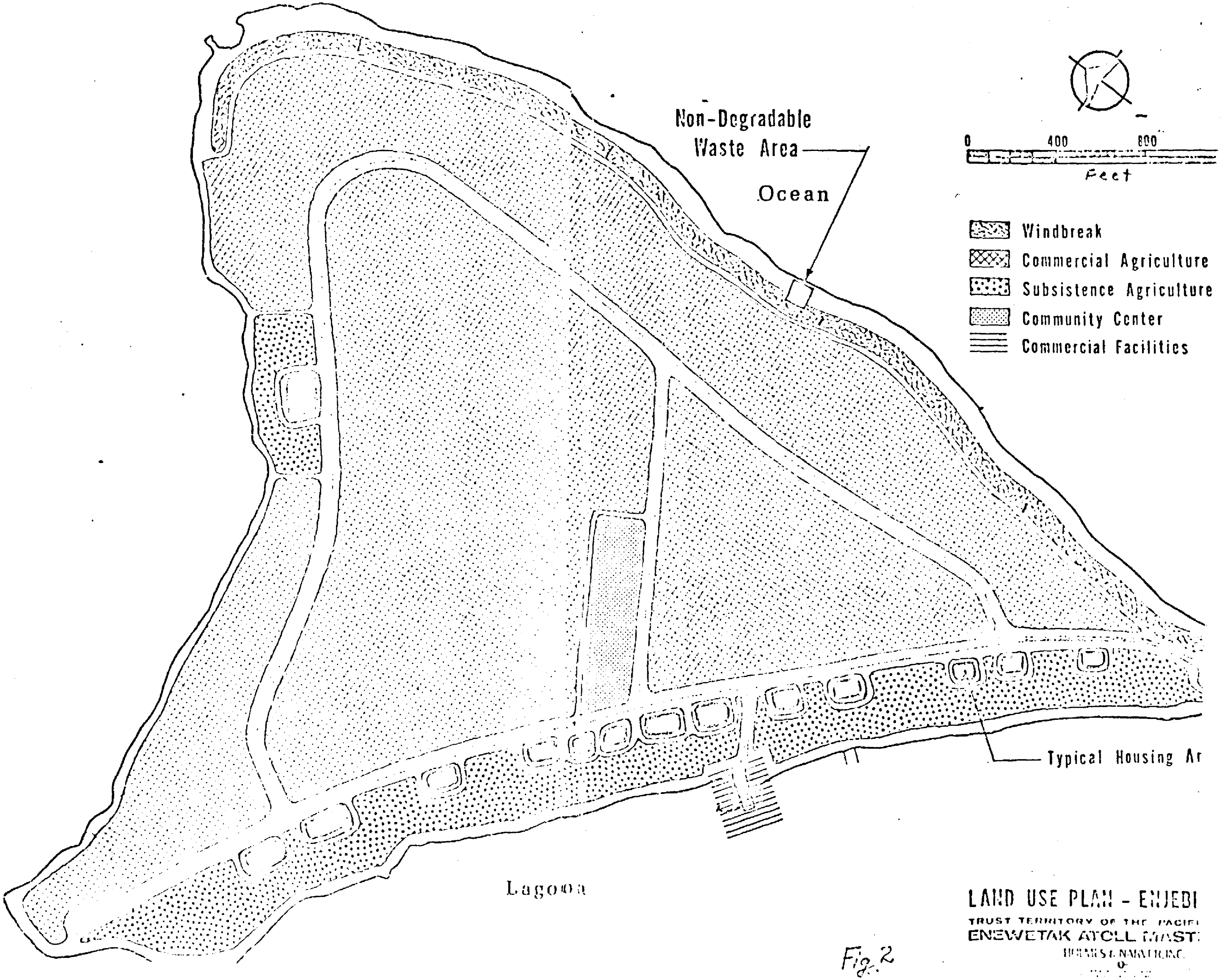

Non-Degradable
Waste Area
Ocean
0
400
800
Feet
Windbreak
Commercial Agriculture
Subsistence Agriculture
Community Center
Commercial Facilities
Typical Housing Ar
Lagoon
LAND USE PLAN - ENJEBI
TRUST TERRITORY OF THE PACIFI
ENEWETAK ATOLL MAST

Fig. 2

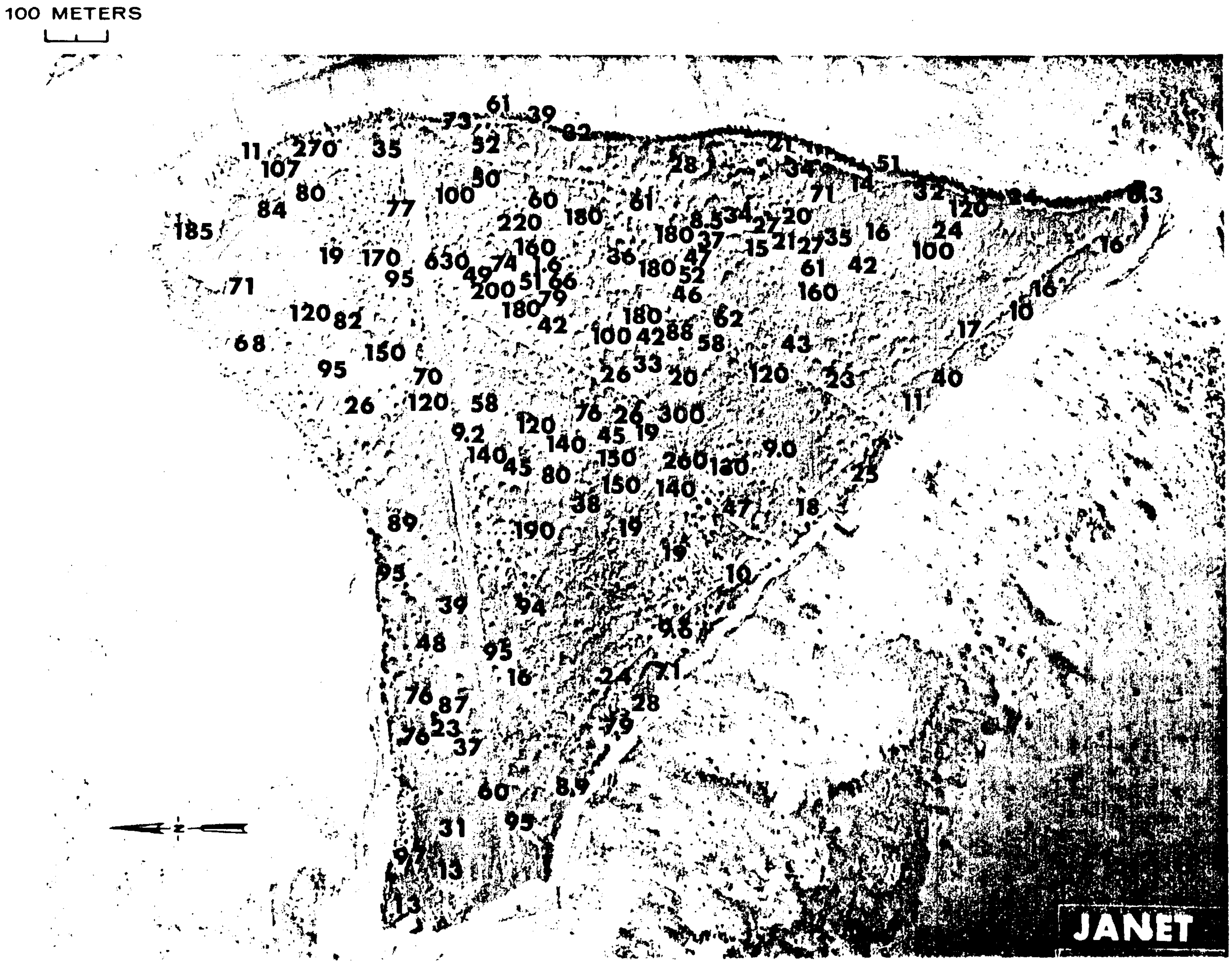


Fig. B.8.1.j. The average ^{90}Sr activities (pCi/gm) in soil samples collected to a depth of 15 cm.

Fig. 3

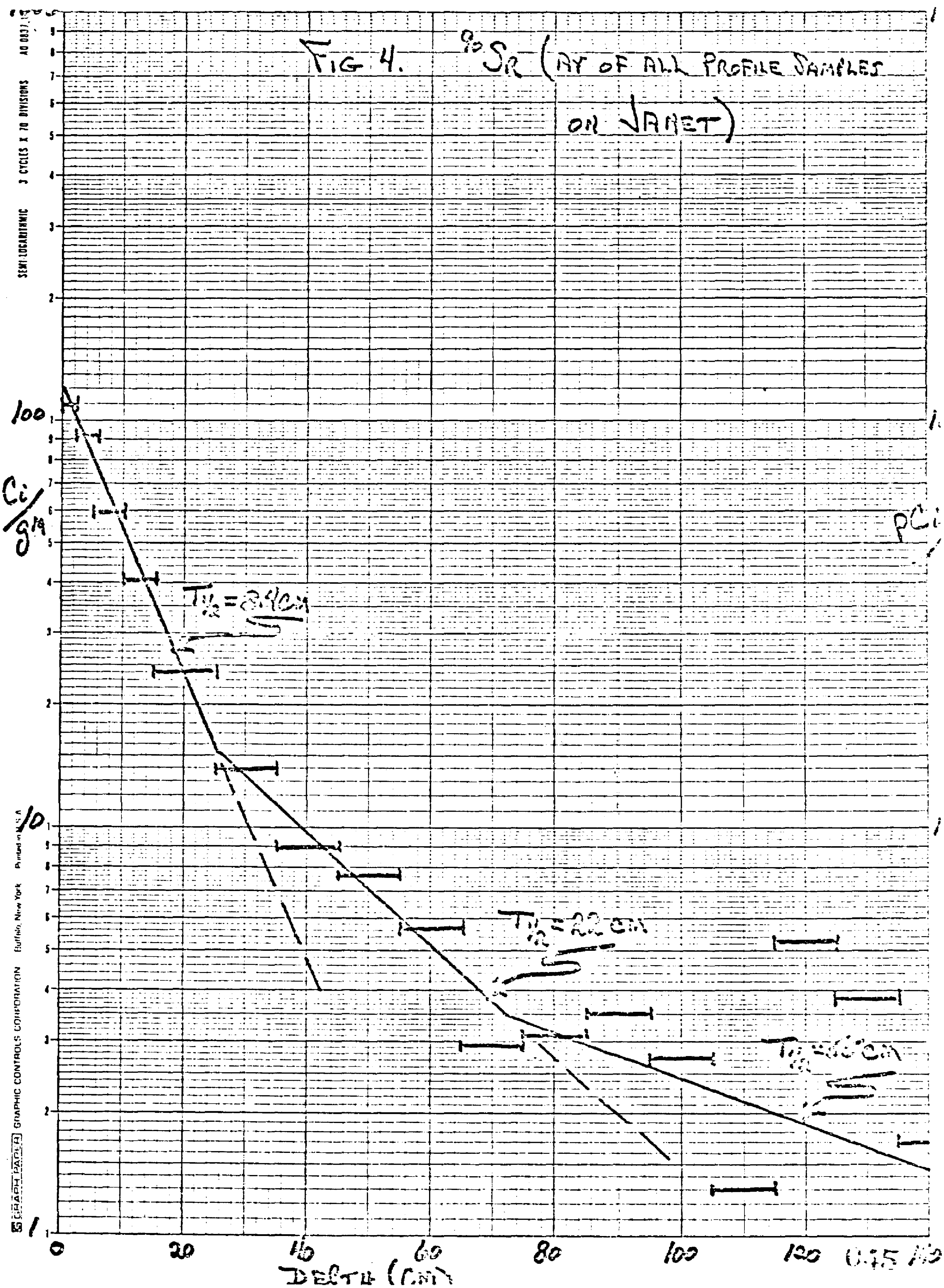


Fig 4. ^{90}Sr (Av of all profile samples on Jaret)

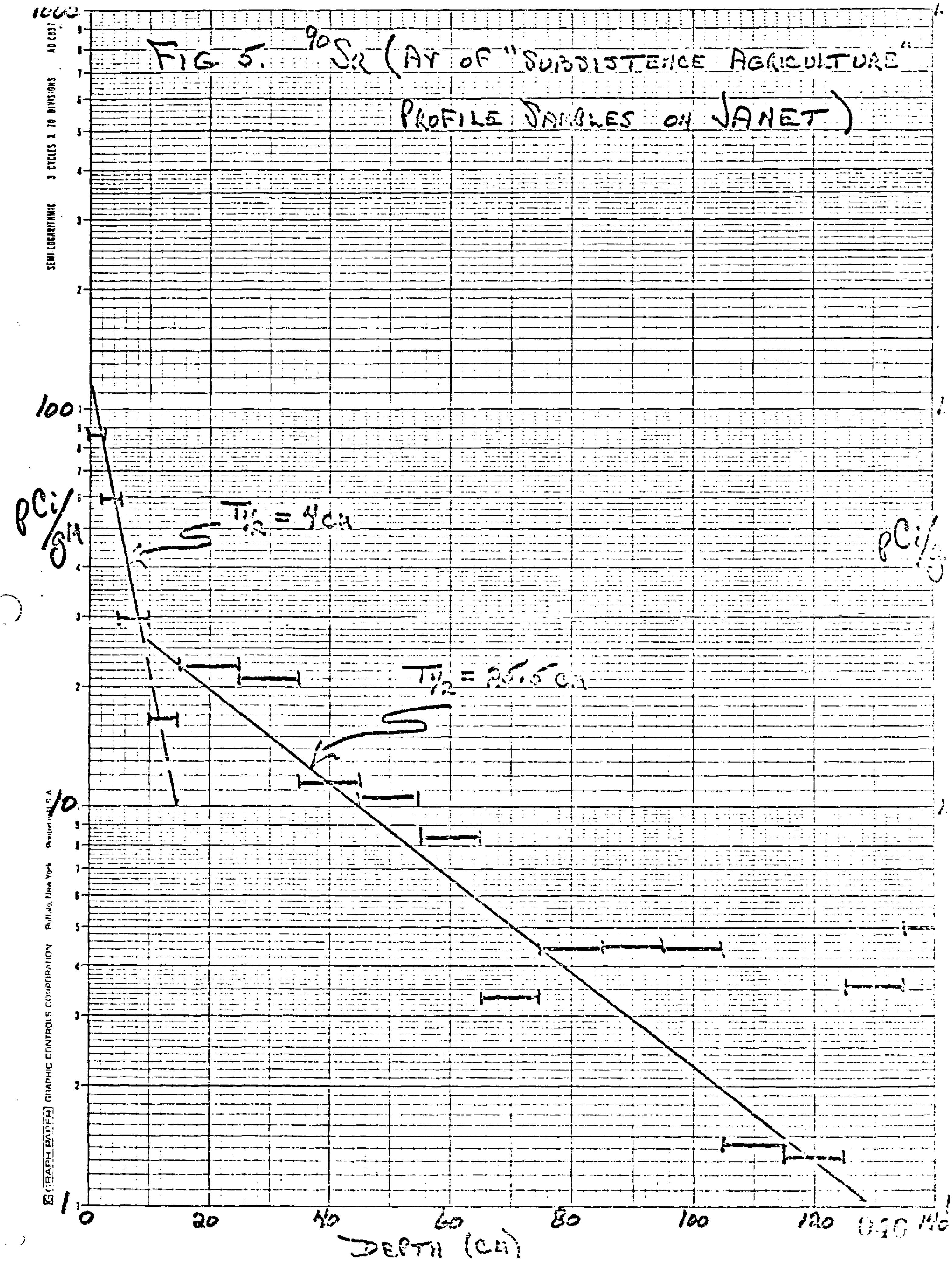
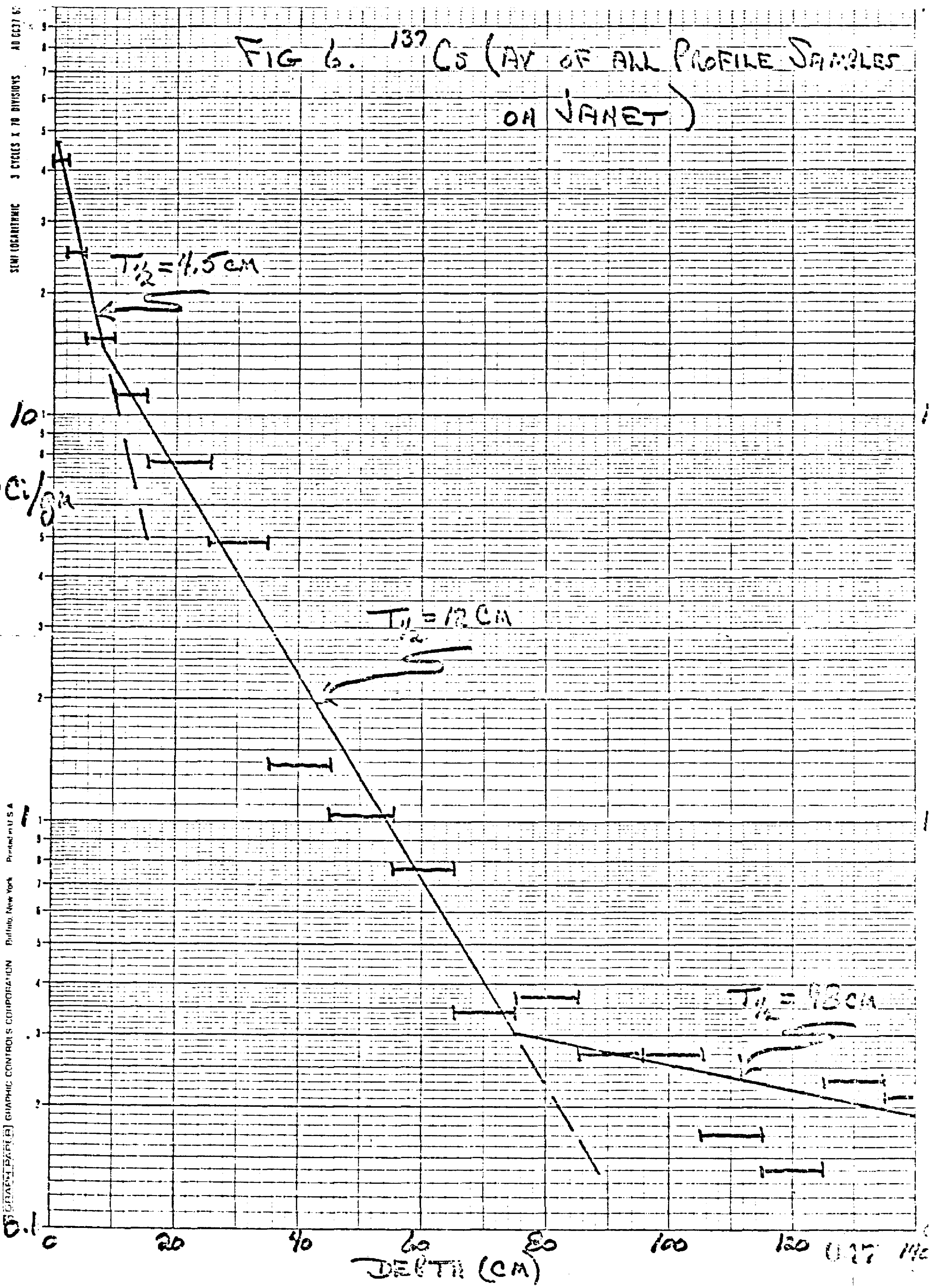


FIG 5. 90Sr (AV OF "SUBSISTENCE AGRICULTURE" PROFILE SAMPLES ON JANET)
pCi/gm
T1/2 = 4 cm
DEPTH (cm)
0
20
40
60
80
100
120
140
1
10
100
1000
SEMI-LOGARITHMIC 3 CYCLES X 70 DIVISIONS
GRAPH PAPER GRAPHIC CONTROLS CORPORATION Buffalo, New York

FIG 6. ^{137}Cs (AV OF ALL PROFILE SAMPLES
ON JANET)



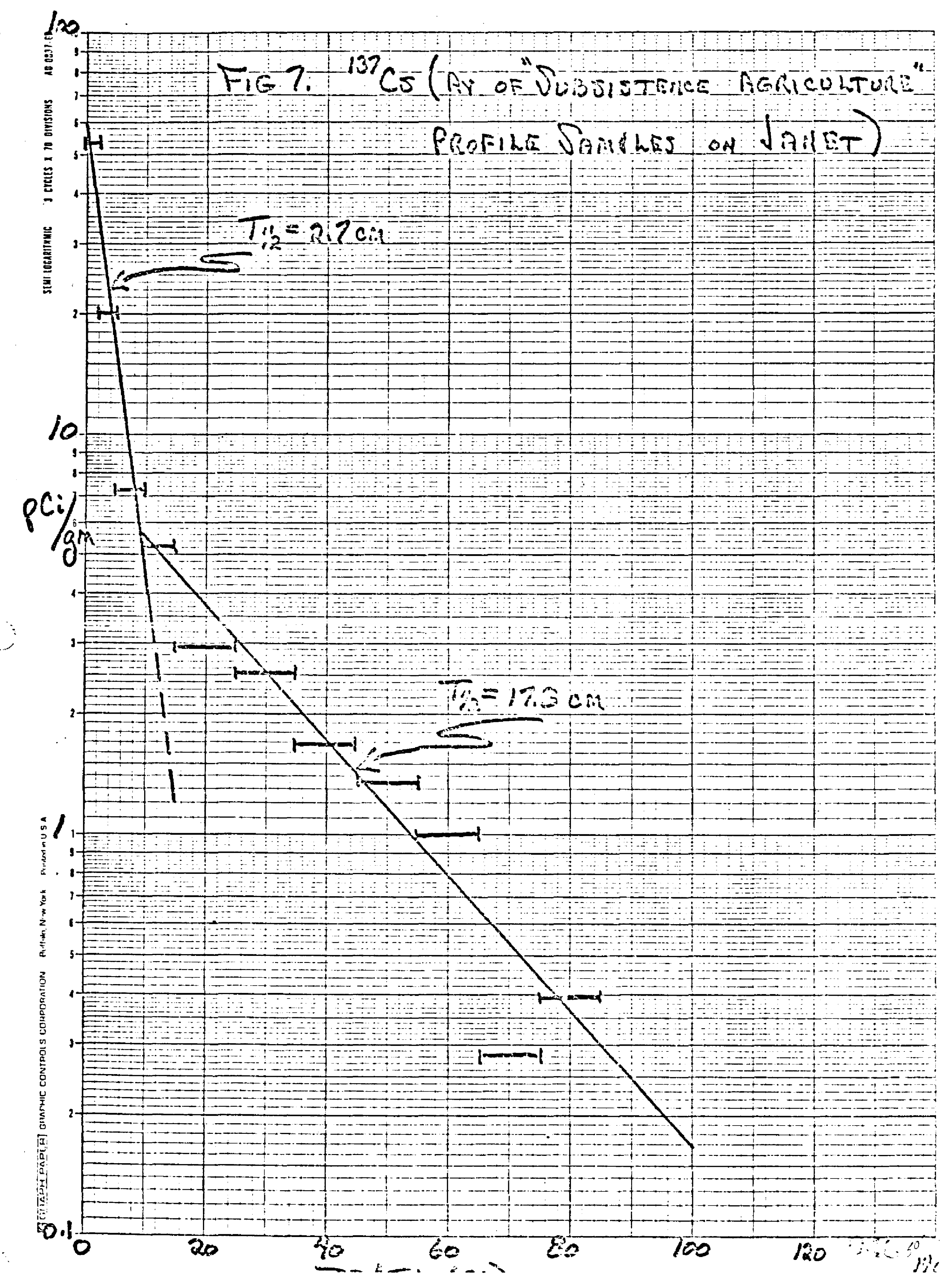


FIG 7. 137Cs (AV OF "SUBSISTENCE AGRICULTURE" PROFILE SAMPLES ON JANET)
T½ = 2.7 cm
T½ = 17.3 cm
pCi/gm
100
10
1
0.1
0
20
40
60
80
100
120

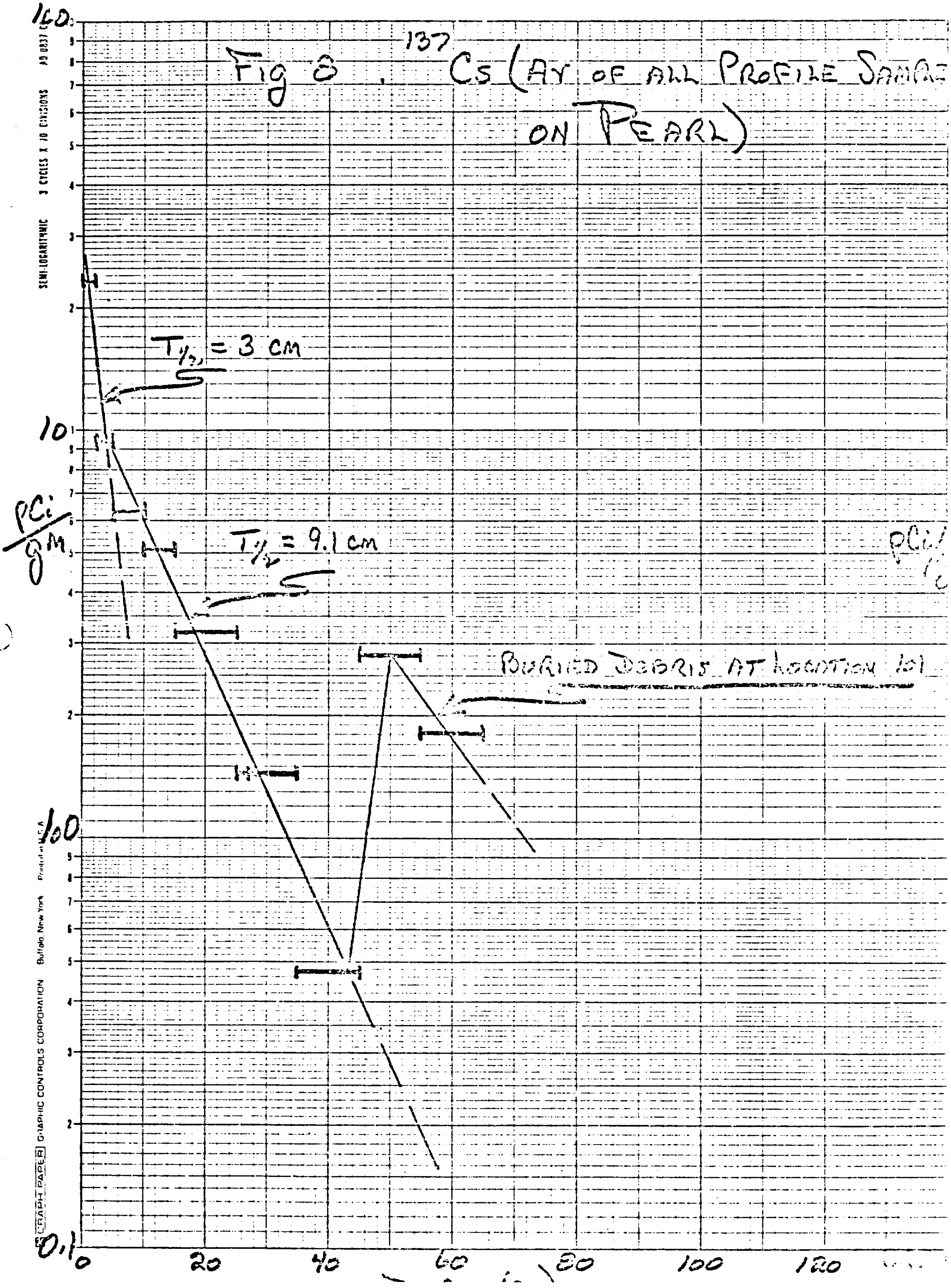
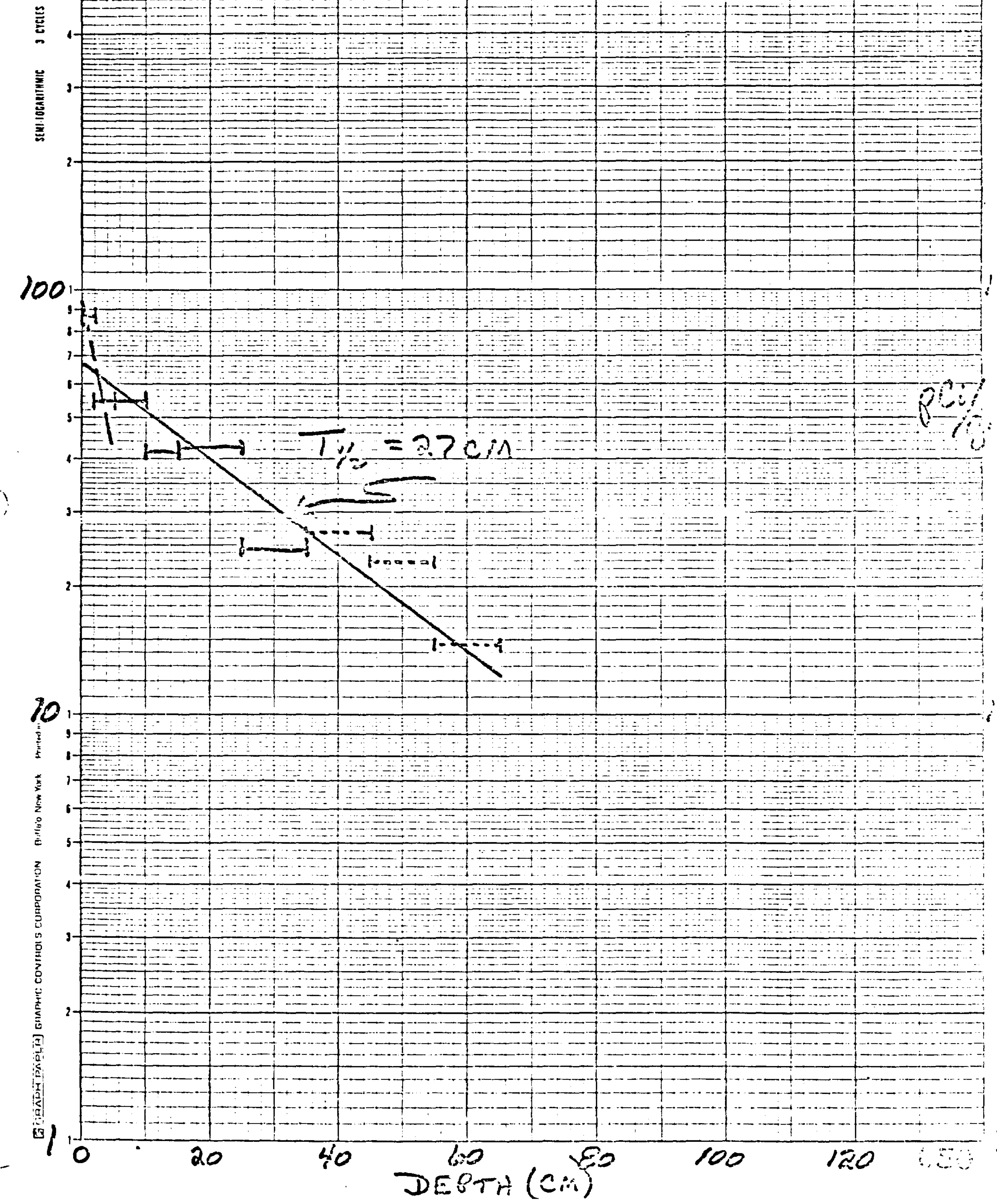


Fig 8, 137Cs (AV OF ALL PROFILE SAMP
ON PEARL)
T½ = 3 cm
T½ = 9.1 cm
BURIED DEBRIS AT LOCATION 101
pCi/gM
100
10
1.0
0.1
0
20
40
60
80
100
120
SEMI-LOGARITHMIC 3 CYCLES X 70 DIVISIONS
GRAPHIC CONTROLS CORPORATION Buffalo, New York
GRAPH PAPER

FIG 9. ^{137}Cs (AV OF ALL PROFILE SAMPLES ON ALICE)



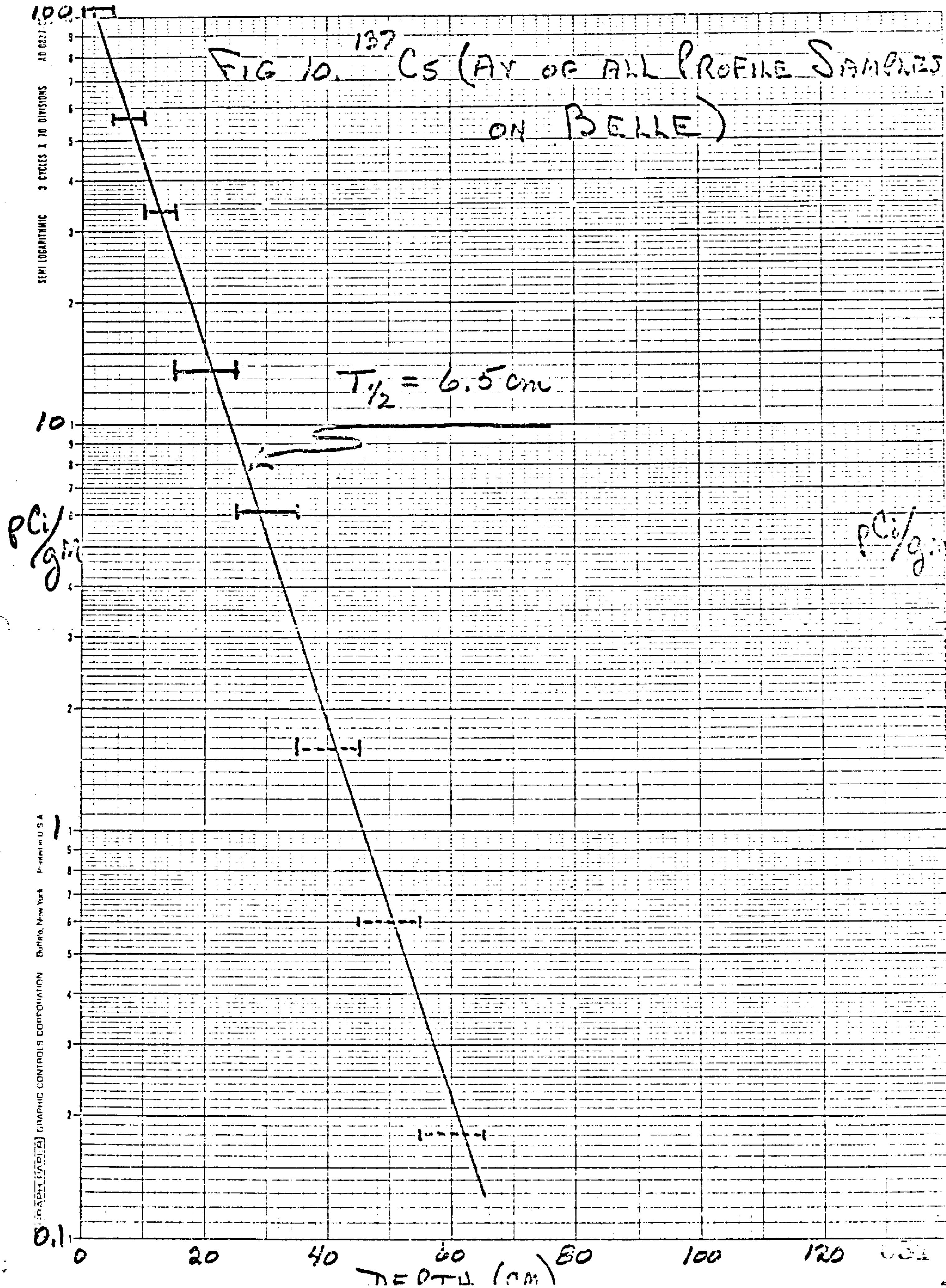


FIG 10. ^{137}Cs (AV OF ALL PROFILE SAMPLES ON BELLE)

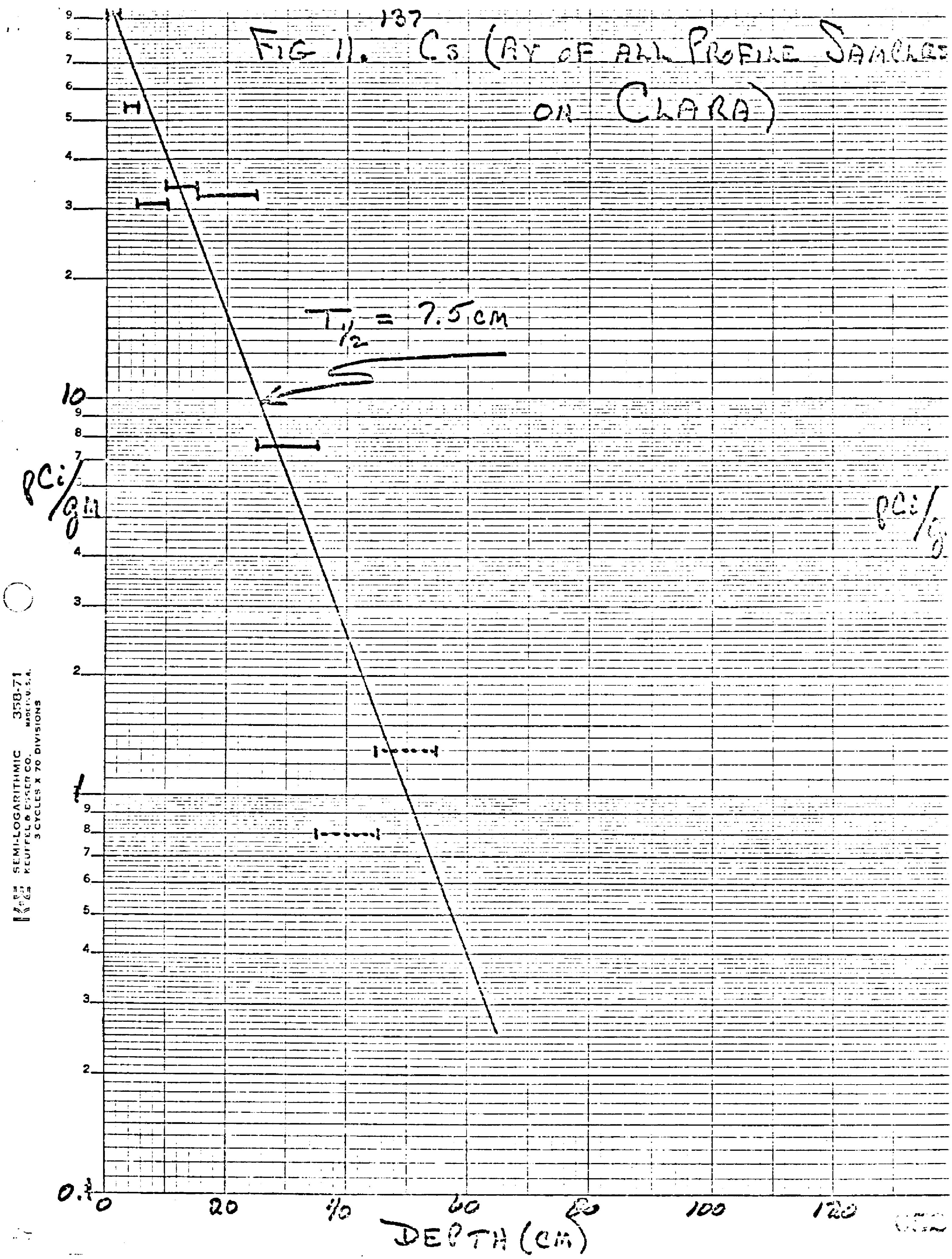


FIG 11. 137 Cs (Av of all Profile Samples on Clara)

Appendix I
Enewetak Radiological Survey Report

Abstract

The AEC has conducted a survey of the total radiological environment of Enewetak Atoll in order to provide data for judgments as to whether or not all or any part of the Atoll can be safely reinhabited. More than 4500 samples from all parts of the marine, terrestrial, and atmospheric components of the Atoll environment were analyzed by instrumental and radiochemical methods. In addition, an aerial survey for gamma-radiation levels was conducted over all land areas.

^{90}Sr, ^{137}Cs, ^{60}Co, and ^{239}Pu are the predominant radioactive isotopes now present, but their distribution is far from uniform. Islands on the southern half of the Atoll from ALVIN to KEITH have levels of contamination comparable to or less than those due to world-wide fallout in the United States. On the northern half, islands ALICE to IRENE are most heavily contaminated, KATE to WILMA are least contaminated, and JANET is at an intermediate level.

These radiological data have been combined with the best information currently available on the expected diet of the Enewetak people to estimate potential whole-body and bone doses to the population for six living patterns at 5-, 10-, 30-, and 70-yr intervals after return. Thirty-year integral dose estimates for unmodified (i.e., current) conditions are shown in Table A.

Table A. The 30-yr integral dose for six living patterns, assuming unmodified conditions.

	30-year integral dose, rem Unmodified conditions									
Living pattern	Inhalation			External	Terrestrial		Marine		Total	
	Bone	Lung	Liver	Bone, W.B.	W.B.	Bone	W.B.	Bone	W.B.	Bone
I	7(-4)	9(-4)	4(-4)	0.83	0.14	2.1	0.053	0.84	1.0	3.8
II	0.029	0.036	0.016	1.6	2.7	33	0.053	0.84	4.4	35
III	0.10	0.13	0.056	4.0	6.1	75	0.053	0.84	11	80
IV	0.47	0.59	0.24	10	21	210	0.053	0.84	31	220
V	0.11	0.13	0.058	2.9	2.7	33	0.053	0.84	5.7	37
VI	0.090	0.11	0.049	4.4	9.6	130	0.053	0.84	14	135

Living pattern	Village island	Agriculture	Visitation
I	FRED/ELMER/DAVID	ALVIN through KEITH	Southern islands
II	FRED/ELMER/DAVID	KATE through WILMA plus LEROY	Northern islands
III	JANET	JANET	Northern islands
IV	BELLE	BELLE	Northern islands
V	JANET	KATE through WILMA plus LEROY	Northern islands
VI	JANET	ALICE through IRENE	Northern islands

The main contribution to the population dose comes through the terrestrial food pathway, followed in decreasing order of significance by the external gamma dose, marine, and inhalation pathways. In the terrestrial food pathway, the main contribution to both whole-body and bone dose is due to pandanus and breadfruit. Percentage contributions to the 30-yr integral dose for each of the terrestrial food items for a population engaged in agriculture on JANET are shown in Table B.

Corrective actions to reduce population doses will be most beneficial if they are directed at the primary contributors, i.e., pandanus and breadfruit in the diet and external gamma dose in the residence areas. Since neither pandanus nor breadfruit are now growing on the Atoll in sufficient amounts to provide a significant dietary component, control of the location and manner in which they are reestablished will have a direct influence on the population doses from these fruits. If their growth were limited to the southern islands, for example, and the population living on JANET were to import them rather than grow them locally, the expected 30-yr bone dose would be reduced from 80 to 25 rem and the whole-body dose from 11 to 6.5 rem. Similar results would be obtained if uncontaminated soil were imported to JANET for the establishment of these plants. Attempts to obtain the same results by removal of ^{90}Sr- and ^{137}Cs-contaminated soil from JANET would require denuding of the entire island because of the relatively uniform distribution of these isotopes over the land surface.

Table B. Percentage of total 30-yr terrestrial food dose to a population engaged in agriculture on JANET.

Food	^{90}Sr dose to bone, %	^{137}Cs dose to whole body, %
Domestic meat	17	26
Pandanus fruit	40	35
Breadfruit	34	29
Wild birds	0.005	0.003
Bird eggs	0.05	0.002
Arrowroot	2	0.3
Coconut meat	6	9
Coconut milk	0.9	1

Significant reduction of the external gamma dose may be achieved by placing a 2-in. layer of clean gravel in the village areas and by plowing the agricultural areas. On JANET, for example, use of these procedures reduces the expected 30-yr external dose from 4.0 to 1.7 rem.

Thus, from Table A it is clear that a very broad range of population doses may be expected, depending on village island, agricultural island, and living pattern. It is equally clear that substantial reductions of the higher doses can be achieved through relatively simple modification of the agricultural practices and of the soil. Table C summarizes the reduction that could be expected from these actions for a population living on JANET.

The island of YVONNE presents a unique hazard on Enewetak Atoll. Pure plutonium particles are present on or close to the ground surface, randomly scattered in "hot spots" over most of the area from the tower to CACTUS crater. Examination of these "hot spots" has revealed the presence of occasional milligram-size pieces of plutonium metal, as well as smaller pieces which are physically indistinguishable in size from the surrounding coral matrix. Given these current conditions, it must be assumed that pure plutonium particles of respirable size are now also present on the surface or may be present in the future as weathering effects oxidize and break down the larger particles. Lung dose assessments for this area, therefore, must be based on inhalation of pure plutonium particles rather than those having the average plutonium content of the soil.

The potential health hazard via the inhalation pathway is sufficiently great to dictate two basic alternatives for remedial action for this island: (1) Make the entire island an exclusion area—off limits to all people, or (2) conduct a cleanup campaign which will eliminate the "hot-spot" plutonium problem and remove whatever amount of soil is necessary to reduce the soil plutonium concentration to a level comparable to other northern islands. As an indication of the volumes of soil involved, removal of a 10-cm thick layer of topsoil in the area in which "hot spots" have been detected involves approximately 17,000 m^3 of material. Further removal of soil to reduce the maximum plutonium contamination levels to 50 pCi/g or less involves an additional 25,000 m^3 of material.

Table C. 30-yr integral doses from all pathways compared to U.S. external background dose.

Location	30-yr integral dose, rem[a]			
	Unmodified soil case		Modified soil case[b]	
	W.B.	Bone	W.B.	Bone
Enewetak Atoll living pattern III (JANET-current conditions)	11	80	8.9	78
Enewetak Atoll living pattern III (JANET-pandanus and breadfruit imported)	6.5	25	4.2	23
Enewetak Atoll living pattern III (JANET-all agriculture confined to southern islands)	4.2	7.0	1.9	4.7
Enewetak Atoll living pattern I (southern islands)	1.0	3.8	1.0	3.8
U.S. background only[c]	3.0	3.0	3.0	3.0

[a]Sum of all pathways for the Enewetak living patterns (i.e., external, inhalation, marine, and terrestrial).

[b]Soil modified by placing 2 in. of clean gravel in the village area and plowing the agricultural area.

[c]Based upon background of 100 mrem/yr at sea level.

Appendix II
Enewetak Radiological Survey Report
Summary of Findings Chapter

W. Nervik, Lawrence Livermore Laboratory, Livermore, California

INTRODUCTION

It has been the purpose of this survey to gain a sufficient understanding of the total radiological environment of Enewetak Atoll to permit judgments as to whether or not all or any part of the Atoll can safely be reinhabited and, if so, what preliminary steps toward cleanup should be taken and what post-rehabilitation constraints must be imposed.

Enewetak Atoll has an extremely broad range of radiological conditions in a small land mass. To gain an understanding of the details of this range of conditions, it has been necessary to obtain and analyze a very large number of samples from all components of the environment. To gain an equivalent understanding of the implications of this range of conditions for rehabilitation of the Enewetak people, it has been necessary to postulate population distributions, life styles, and dietary habits – an endeavor fraught with uncertainties under the best of circumstances, but particularly so for the current, rapidly changing Marshallese culture.

This section is a summary of the data obtained from the Survey, the postulates used, and the population dose assessments derived from data plus postulates. The reader is cautioned against expecting or using a "simple" description of the radiological condition of Enewetak Atoll, because no single value of any component of the radiological condition is applicable to the entire Atoll without being misleading.

CURRENT RADIOLOGICAL CONDITION OF THE ATOLL

External Gamma Radiation Levels

Three independent techniques were used to measure external gamma radiation levels on the Atoll:

- LiF and CaF_2 thermoluminescent dosimeters (TLDs) were exposed for $3\frac{1}{2}$ months on seven of the northern islands.
- A measurement using a Baird-Atomic survey instrument was made at each soil-sampling location on each island.
- An aerial survey with NaI detectors was conducted over the entire surface area of every island.

All three techniques yield results which agree to within about 10%. ^{60}Co and ^{137}Cs contribute most of the total external gamma radiation, with the remainder due to small amounts of other gamma emitters such as ^{125}Sb, ^{155}Eu, and ^{241}Am. The amount of ^{60}Co relative to ^{137}Cs varies throughout the Atoll, with a range of values from about 0.5 on JANET to greater than 14 on JAMES. Average values for each isotope on each island are given in Table 214. For reference, a map of the Atoll is shown in Fig. 146.

Southern islands (SAM to KEITH) are characterized by low and more or less uniformly distributed gamma-radiation levels over the area of each island. As exposure levels increase, exposure gradients become severe, with beaches

Table 214. **Summary of average exposure rates for islands in Enewetak Atoll.**

Island	Average exposure rate, μR/hr at 1 m[a]			
	^{137}Cs	^{60}Co	Total γ (0-3 MeV)	Range[b]
ALICE	42	36	81	4-170
BELLE	61	50	115	5-200
CLARA	20	19	42	5-100
DAISY	6.8	14.4	21.3	5-140
EDNA	2.8	2.4	6	5-8
IRENE	14	63	80	3-560
JANET	25	13	40	2-150
KATE	11	7	19	3-22
LUCY	6	7	14	1-20
PERCY	2	2	5	2-11
MARY	5.5	4	10	2-12
NANCY	6	5	12	1-50
OLIVE	6.5	4.5	11	1-15
PEARL	12	45	70	1-400
RUBY	2	12	14	1-42
SALLY	3.5	3	7	3-110
TILDA	4	2	6	2-11
URSULA	3	1.8	5	1-7
VERA	2.8	2	5	1-6
WILMA	1	1	2	1-3
YVONNE	5.6	22.4	33	1-750
SAM	<0.3 (0.20)	<0.6 (0.11)	10.9	0-1
TOM	<0.3 (0.18)	<0.6 (0.13)	<0.9	0-1
URIAH	<0.3 (0.06)	<0.6 (0.43)	<0.9	0-1
VAN	<0.3 (0.08)	<0.6 (0.25)	<0.9	0-1
ALVIN	N. D. (0.06)	<0.6 (0.25)	<0.9	0-1
BRUCE	0.4 (0.22)	0.8 (0.34)	1.2	0-1
CLYDE	<0.3 (0.04)	<0.6 (0.11)	<0.9	0-1
DAVID	N. D. (0.21)	N. D. (0.10)	<0.9	0-5
REX	<0.3 (0.28)	<0.6 (0.25)	<0.9	0-1
ELMER	N. D. (0.19)	N. D. (0.12)	<0.09	0-2
WALT	<0.3 (0.08)	<0.6 (0.10)	<0.9	0-1
FRED	N. D. (0.14)	N. D. (0.12)	<0.9	0-1
GLENN	0.4 (0.33)	<0.6 (0.20)	<0.9	0-1
HENRY	<0.3 (0.14)	<0.6 (0.20)	<0.9	0-1
IRWIN	<0.3 (0.08)	<0.6 (0.46)	<0.9	0-1
JAMES	<0.3 (0.05)	2.8	3.0	0-5
KEITH	<0.3 (0.15)	<0.6 (0.49)	<0.9	0-2
LEROY	2.8	4.8	7.6	3-8

[a]Average dose rates given are derived from aerial survey data. On islands where activity levels are at the lower limit of sensitivity of the aerial survey equipment, dose rates derived from the soil sample data are given in parentheses.

[b]As measured with the Baird-Atomic instrument.

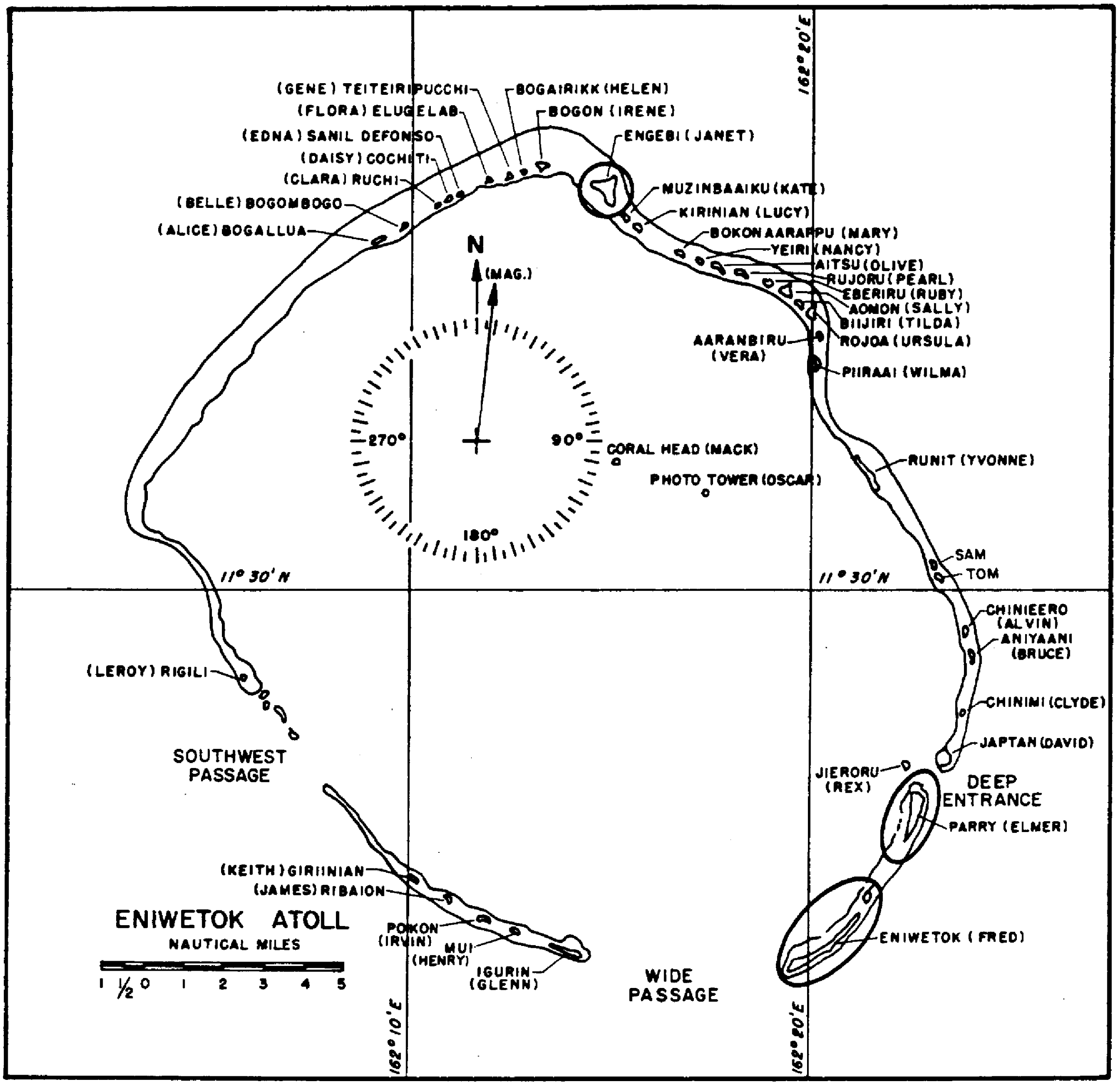


Fig. 146. Islands (those circled) requested as village locations by the Enewetak people.

generally at or very near expected background levels; the highest levels are found in heavy vegetation at island centers or near ground zero sites. "Average" values for islands with relatively high dose levels include a broad range of values for specific areas and should therefore be used with caution.

Radioactivity Levels in Enewetak Soil

Approximately 3000 samples of Enewetak soil were analyzed by germanium gamma-spectroscopic (GeLi) and wet-chemistry techniques to determine the distribution of radioactive species on islands in the Atoll. Samples were taken on every island, but emphasis was given to – and proportionately larger numbers of samples taken on – those islands which were known to have been sites for nuclear testing activity or to have been subjected to large amounts of fallout from such activity.

Two types of soil samples were taken on each island: "surface" and "profile." At "surface" sampling locations, two samples were taken – one a 30-cm^2 × 15-cm-deep core, and the second a composite of two 30-cm^2 × 5-cm-deep cores. At "profile" sampling locations, 100-cm^2 samples were taken from the side wall of a trench dug for the purpose. Nominal depth increments for the profile samples were 0 to 2, 2 to 5, 5 to 10, 10 to 15, 15 to 25, and 25 to 35 cm, and at 10-cm increments to total depth. Total depth for profile samples varied from 35 to 185 cm, depending on the distribution expected from the testing history of the island being sampled.

In general, the predominant species found in the soil samples are ^{90}Sr, ^{137}Cs, ^{239}Pu, and ^{60}Co. ^{40}K, ^{55}Fe, ^{101}Rh, ^{102m}Rh, ^{125}Sb, ^{133}Ba, ^{134}Cs, ^{152}Eu, ^{154}Eu, ^{155}Eu, ^{207}Bi, ^{226}Ra, ^{235}U, ^{238}Pu, and ^{241}Am are also present in some or all of the samples. As was the case for external gamma levels, small amounts of radioactive species on the southern islands (SAM to KEITH) are distributed more or less uniformly over the entire land area. On islands where larger amounts of activity are present, the highest levels of all species are found at the island centers or in proximity to ground-zero sites, usually related in a direct way to the vegetation density in the immediate area. As an example of the kind of data obtained for each of the predominant isotopes on each of the islands, ^{90}Sr values for 0-15 cm core samples on JANET are plotted in Fig. 147.

Table 215 presents geometric mean values and ranges for the four predominant radionuclides on islands from ALICE through WILMA. On islands where there are significant differences in activity levels between densely and sparsely vegetated areas, data for both are given. Similar data for groups of southern islands are shown in Table 216.

"Profile" samples showed a wide range of activity distributions as a function of depth on different parts of the Atoll. Examples of the types found are given in Figs. 148-151. Although generalizations in this area are not very meaningful, Fig. 148 shows the profile distribution normally found on the southern islands. Here the activity levels are usually low through the full range of depths sampled. Some sampling locations show concentrations decreasing somewhat from the surface through the first 10 or 20 cm of soil. Figure 149 shows the type of distribution often found inland on islands subjected to fallout but not to construction or other ground-zero earthmoving activities – i. e., a rapid and fairly steady decrease of activity levels from the surface to total depth. Figure 150 shows the distribution found on beaches and exposed areas on these same islands – i. e., uniform or slowly decreasing activity levels from the surface to total depth. Figure 151 shows a distribution pattern found occasionally on islands which have been the sites for tests or have been subjected to construction and earthmoving activities (primarily IRENE, JANET, PEARL,

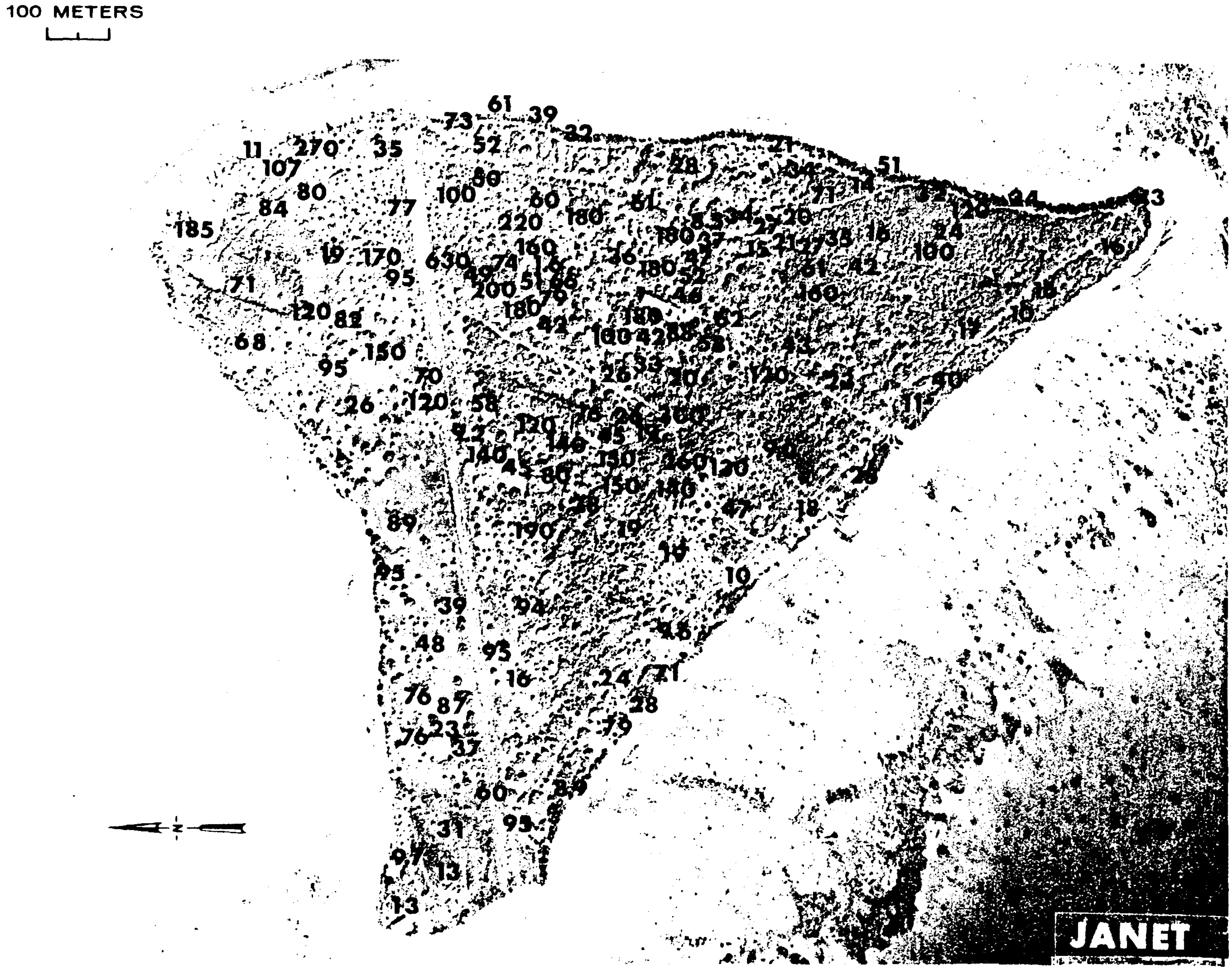


Fig. 147. The average ^{90}Sr activities (pCi/gm) in soil samples collected to a depth of 15 cm.

Table 215. Enewetak soil data, "northern islands" (pCi/g in top 15 cm).

		^{90}Sr		^{137}Cs		^{239}Pu		^{60}Co	
		Mean	Range	Mean	Range	Mean	Range	Mean	Range
ALICE		80	14-430	36	5.6-141	12	3.9-68	5.9	1.4-33
BELLE	Dense	123	14-670	48	14-170	26	7.2-130	10	3.1-30
	Sparse	44	35-130	8.6	3.3-44	11	5.8-26	4.6	2.4-9.6
CLARA		65	13-310	26	5.6-110	22	3.5-88	6.4	0.91-20
DAISY	Dense	190	100-380	11	3.4-33	41	22-98	11	6.4-26
	Sparse	32	16-120	3.8	0.86-9.0	15	3.8-33	0.85	0.37-7.4
EDNA		46	30-220	4.2	2.7-6.4	18	13-24	0.43	0.33-0.63
IRENE		30	5.9-570	3.2	0.22-41	11	2.4-280	5.4	0.12-520
JANET		44	1.6-630	16	0.57-180	8.5	0.08-170	1.9	0.02-33
KATE	Dense	67	37-200	24	18-37	17	8.6-50	2.7	1.6-5.8
	Sparse	11	1.6-49	4.8	1.8-16	2.3	0.17-14	0.46	0.03-3.5
LUCY		32	10-83	11	2.2-25	7.7	2.4-22	1.5	0.26-3.8
MARY		29	11-140	9.9	5.6-26	8.0	2.0-35	1.5	0.74-4.8
NANCY		36	16-110	12	6.0-28	9.1	2.3-28	1.6	0.56-5.3
PERCY		13	3.6-73	0.94	0.12-17	3.5	1.5-23	0.47	0.08-2.9
OLIVE	Dense	22	4.6-70	8.5	3.5-28	7.7	2.2-30	1.5	0.65-4.1
	Sparse	4.5	2.0-11	0.16	0.07-11	2.8	1.9-4.1	0.11	0.05-0.31
PEARL	Hot spot	62	35-140	19	7.4-55	51	15-530	12	3.6-70
	Remainder	17	3.2-61	7.6	1.2-34	11	0.85-100	4.1	0.49-49
RUBY		12	7.1-63	1.4	0.71-7.2	7.3	3.0-24	0.93	0.29-16
SALLY		8.4	0.87-140	3.0	0.03-30	4.3	0.21-130	0.54	0.05-69
TILDA	Dense	27	17-54	8.4	3.5-20	7.6	1.4-17	1.2	0.61-1.9
	Sparse	8.7	2.2-47	1.0	0.04-5.3	2.5	1.1-34	0.37	0.21-1.7
URSULA		6.8	2.0-19	1.7	0.13-7.8	1.3	0.26-7.3	0.31	0.05-1.7
VERA		6.3	1.1-68	2.0	0.03-12	2.5	0.60-25	0.30	0.02-2.2
WILMA		3.3	0.26-13	1.3	0.31-7.2	1.1	0.1-5.3	0.12	0.01-0.7
Southern YVONNE		1.7	0.09-20	0.40	0.02-3.6	3.2	0.02-50	0.64	0.01-20
Northern Beaches		6.4	1.2-30	0.30	0.03-9.0	2.7	0.34-18	0.13	0.03-1.6

YVONNE - Because of the complex distribution of activities on Northern YVONNE no single mean value for an isotope can be used for the island as a whole without being misleading. Readers should consult the YVONNE discussion in this section and the detailed data in Appendix II for information pertinent to their interests.

SALLY, and YVONNE). In these locations, activity levels below ground level are significantly higher than at the surface. Because of the observed variety of profile distributions, no "average vertical distribution" can be formulated which is applicable to the Atoll as a whole.

The land area which has the most severely nonuniform distribution of radioactive species on the Atoll is that

Table 216. Enewetak soil data, southern islands (pCi/g in top 15 cm).

	^{90}Sr		^{137}Cs		^{239}Pu		^{60}Co	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Group A (DAVID, ELMER, FRED)	0.41	0.02-4.8	0.21	0.01-2.1	0.04	0.004-0.31	0.03	0.01-0.15
Group B (All others except LEROY)[a]	0.52	0.03-3.9	0.14	0.004-1.8	0.07	0.004-1.1	0.06	0.007-63
Group C (LEROY)	11	1.6-34	3.2	0.5-10	0.63	0.02-2.0	0.58	0.04-5.0

[a]SAM, TOM, URIAH, VAN, ALVIN, BRUCE, CLYDE, REX, WALT, GLENN, HENRY, IRWIN, JAMES and KEITH.

part of YVONNE which lies north of the tower (Sta. 1310). This area includes the highest external gamma levels found on the Atoll, with levels of 500-750 μR/hr found over a five-acre site just south of the CACTUS crater. In addition, pieces of plutonium metal weighing as much as several milligrams are randomly scattered on or near the ground surface over most of the area from CACTUS crater to a line drawn across the island, about 60 m north of the tower. Construction and earthmoving activities during the testing period, for which we have no reliable record, served to redistribute the radioactivity in such a way that it is essentially impossible to get an accurate, detailed, three-dimensional survey of radioactive species present in this area now. Four hundred meters north of the tower, for about 100 m along the ocean-side embankment, for example, there is a visible layer of dark soil roughly 20 cm thick, 10 to 20 cm below the surface, which contains high concentrations of plutonium (3200 pCi/g in one sample).

In an effort to obtain a reasonable estimate of the three-dimensional distribution of radioactive material in this area, 45 profile locations (shown in Fig. 152) were sampled to 150-cm depths. Plutonium data for the profiles along the center of the island, and across the island at the position of the plutonium-bearing layer, are shown in Figs. 153-156. Data from all of the profile samples lead to the following observations:

- There were no large plutonium particles analyzed in any of these samples since the maximum specific activity found was ~800 pCi/g.
- Except for the area in the general vicinity of the exposed plutonium layer, there were few profile sampling locations where plutonium concentrations exceeded 100 pCi/g at <u>any</u> depth. Of the four that did, two had the high concentration in the top 10 cm of soil. Profile sampling locations where plutonium concentrations greater than 100

pCi/g were found at any depth are enclosed in cross-hatched areas in Fig. 152.

Thus it seems likely that soil bearing high concentrations of plutonium — as opposed to pieces of plutonium — is largely limited to a band roughly 350 m wide across the island, centered on the visible plutonium soil layer. Within this band, plutonium concentrations are greatest on the ocean side, less on the lagoon side, and least in the island center — a finding consistent with historical data which indicate that debris was bulldozed away from the shot point toward both shorelines after the event which produced these plutonium particles.

Except for this band across the island, there is no evidence which indicates that plutonium particles on or near the ground surface in the larger area shown in Fig. 152 are also found at any significant depth below the surface. Because of the discrete nature and random distribution of these particles, of course, the only way that their distribution could be further established would be by analysis of very large volumes of soil.

Radioactivity Levels in Enewetak Lagoon

Approximately 858 samples taken from the Enewetak lagoon environment were analyzed by germanium gamma-spectroscopic (GeLi) and wet-chemistry techniques to determine the distribution of radioactive species in the lagoon, including 345 sediment and bottom cores, 82 seawater and seawater filters, 21 algae, plankton, or coral, and 410 fish samples. Figure 157 shows the major sampling locations for this marine program.

Analysis of the sediment and core samples indicates the presence of ^{40}K, ^{60}Co, ^{90}Sr, ^{101}Rh, ^{102m}Rh, ^{106}Ru, ^{127}Sb, ^{137}Cs, ^{152}Eu, ^{154}Eu, ^{155}Eu, ^{207}Bi, ^{235}U, ^{238}Pu, ^{239,240}Pu, and ^{241}Am in some, but not necessarily all of the samples. Each nuclide is non-uniformly distributed over the lagoon floor, with the highest levels generally found in the northwest part of the lagoon, 2-3 km southeast of the islands ALICE through IRENE; the next highest levels are found in the area southwest of YVONNE; and the lowest levels are found south of a line extending across the lagoon from the Southwest Passage to TOM. Figure 158, for example, shows the distribution pattern for ^{90}Sr. Similar figures have been prepared for each of the predominant species found.

Many of the radionuclides found in the marine sediment and core samples were not detected in the water samples, including ^{102m}Rh, ^{106}Ru, ^{125}Sb, ^{152}Eu, and ^{235}U. In only 15 samples from the northern part of the lagoon were ^{60}Co, ^{155}Eu, ^{207}Bi, and ^{241}Am detected. ^{137}Cs and ^{239,240}Pu were positively identified in all samples. Table 217 gives the mean surface water concentration of ^{137}Cs and ^{239,240}Pu in the four quadrants of the lagoon, in the ocean close to the east side of the lagoon, and for several areas in other parts of the world for comparative purposes.

In the plankton samples, the most abundant isotopes observed were ^{90}Sr (av 0.86 pCi/g, wet wt) and ^{207}Bi (0.83 pCi/g), followed in decreasing order of abundance by ^{60}Co (0.68 pCi/g), ^{239,240}Pu (0.39 pCi/g), ^{155}Eu (0.24 pCi/g), ^{241}Am (0.23 pCi/g), and ^{137}Cs

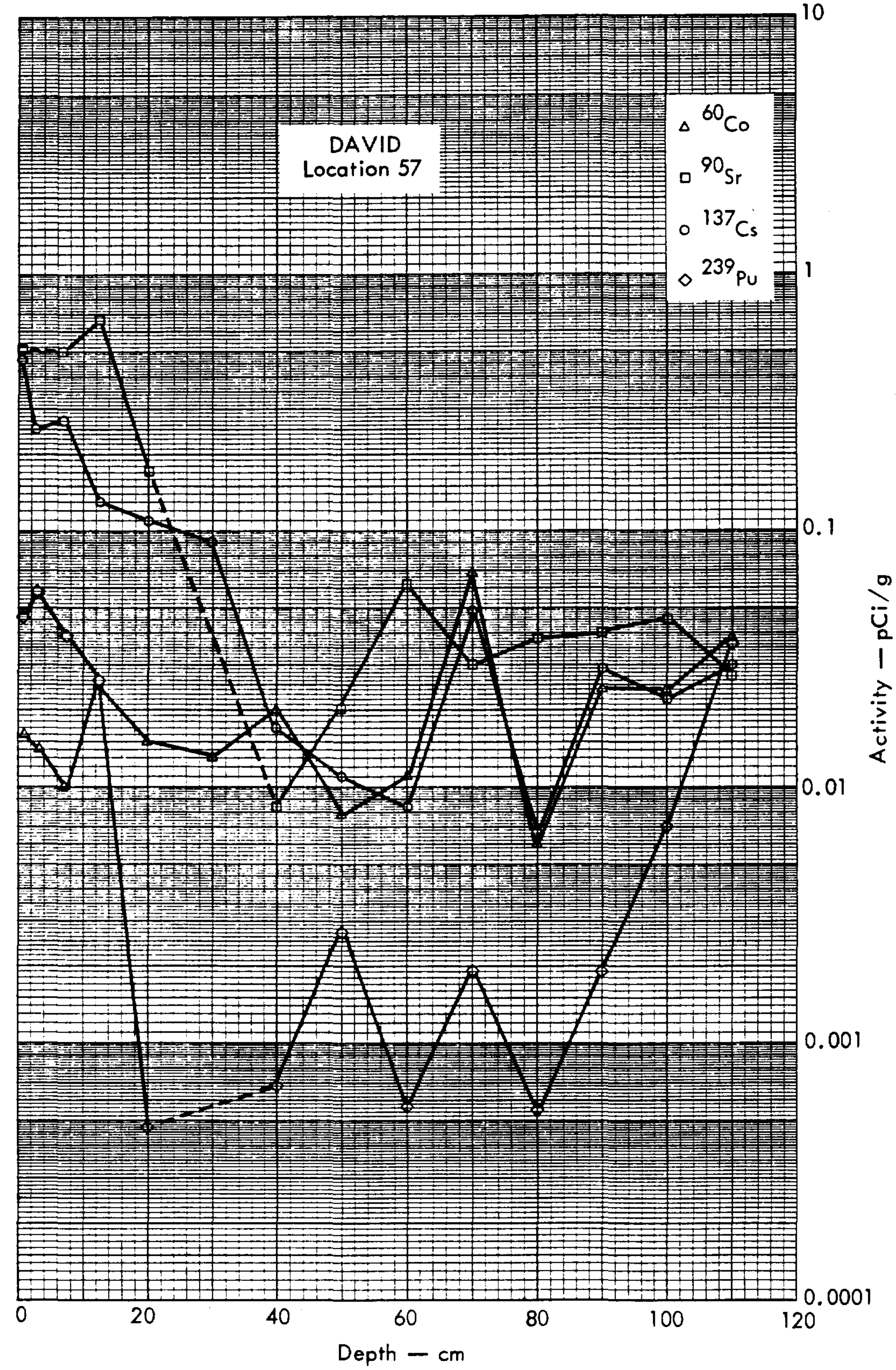


Fig. 148. Activities of selected radionuclides as a function of soil depth.

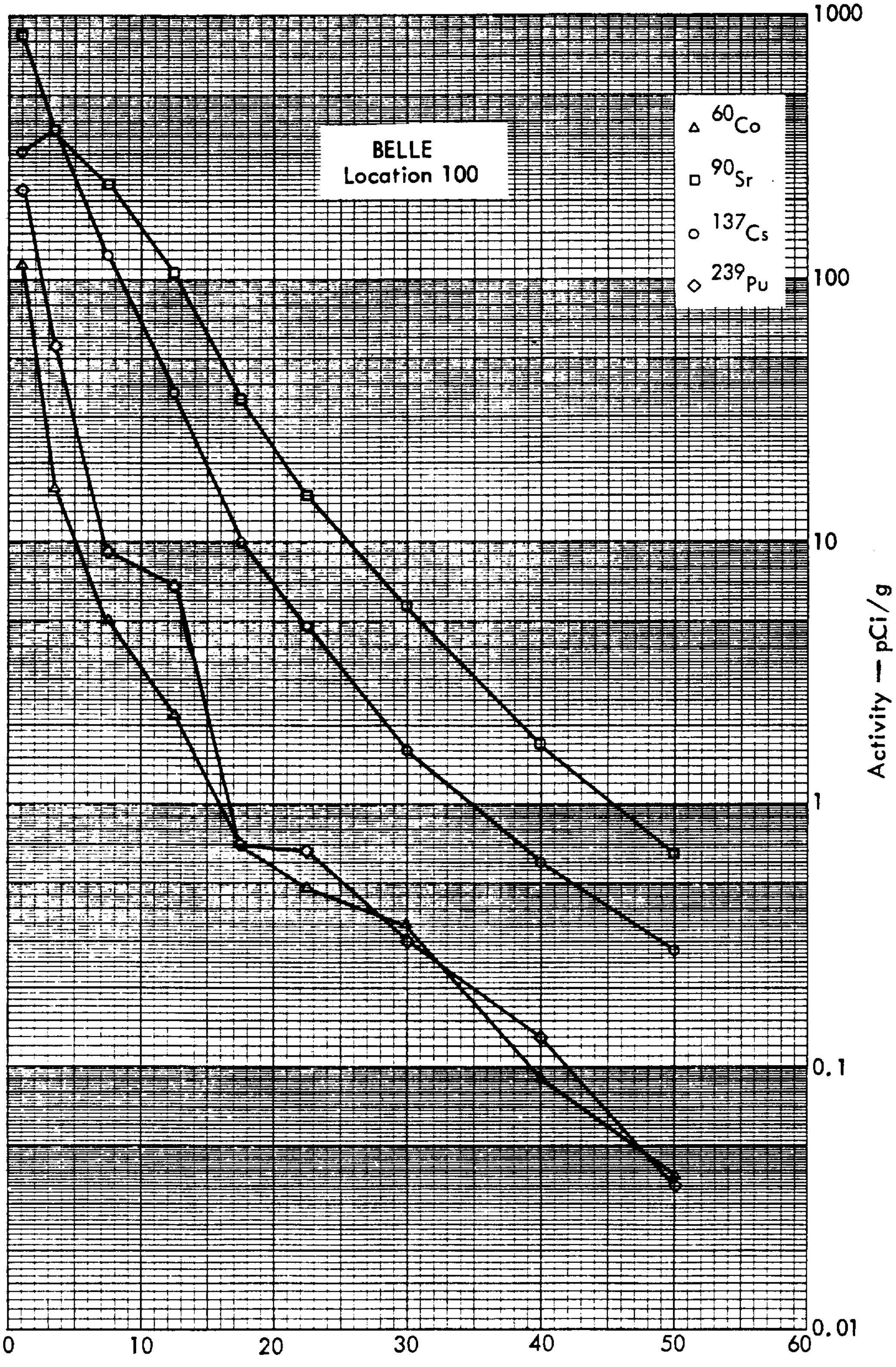


Fig. 149. Activities of selected radionuclides as a function of soil depth.

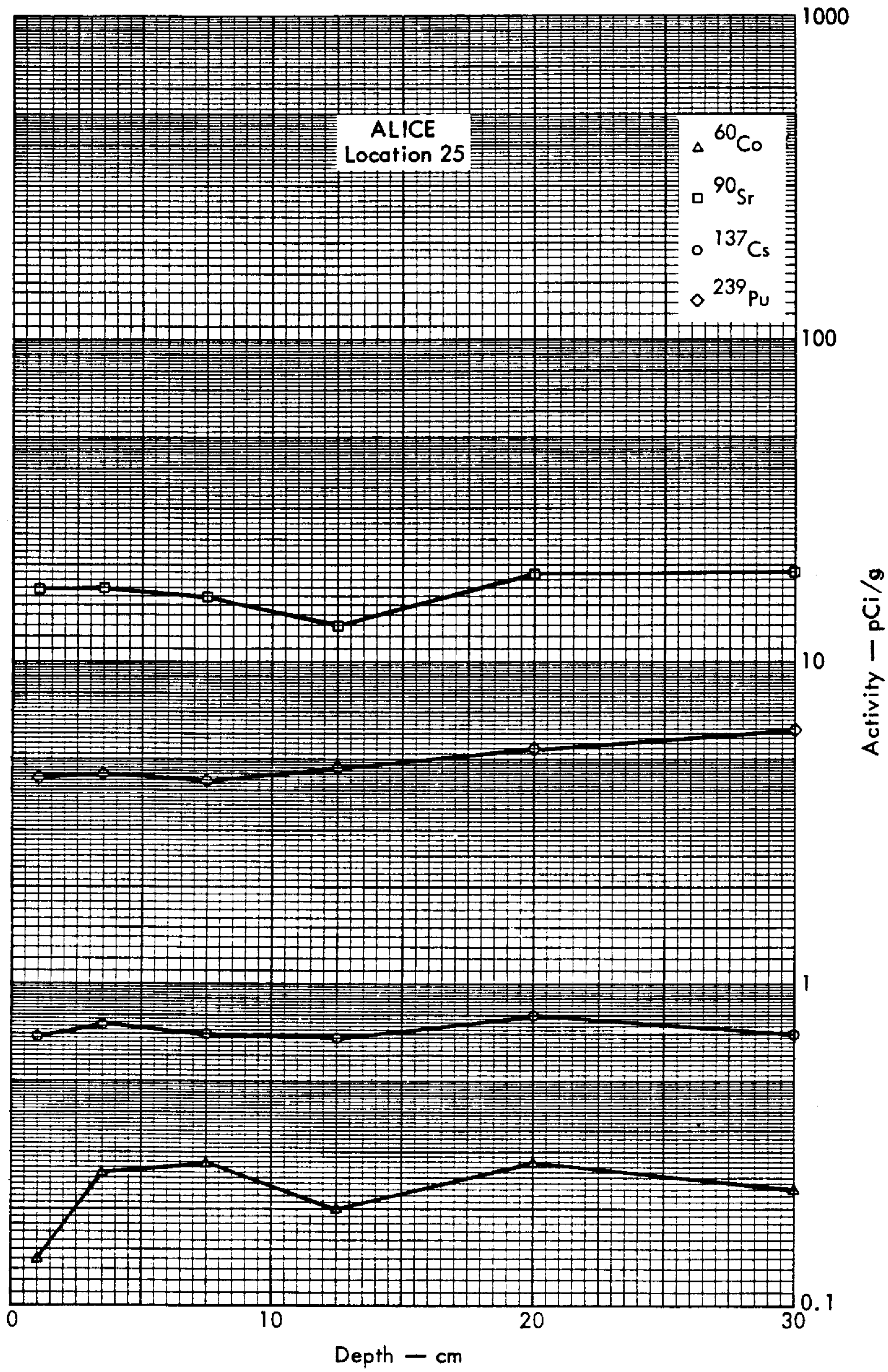


Fig. 150. Activities of selected radionuclides as a function of soil depth.

d. Recovery of plutonium soil concentrations greater than 400 pCI/g ^{239}, Pu at any depth these levels are found. The justification is that plutonium at some depth may one day be at the surface. Also, recovery of contaminated soil sufficient to reduce surface levels to a value well below 40 pCi/g ^{239,240}Pu. The justification is to keep air concentrations of resuspended plutonium to levels well within national and international standards. After soil removal, all areas should be resurveyed to ensure no pieces or hot spots of plutonium remain.

e. The area observed to have pieces of plutonium and the highest soil concentrations is the interior and shoreline of the island beginning at a line drawn from the ocean reef to lagoon 60 meters north of the tower (Hardtack Station 1310) to CACTUS Crater.

8. Plutonium contaminated soil on IRENE should be handled the same as on YVONNE and using the same criteria for removal except it is not expected that pieces of plutonium metal will be found.

9. Test plantings of pandanus, breadfruit, coconut, and arrowroot should be made, as soon as growth can be assured, on each of the islands on which these plants are to be grown. As edible parts of these plants become available, their concentration of ^{90}Sr, ^{137}Cs, ^{239,240}Pu and any other significant radionuclides should be measured and compared with the Radiological Survey predictions. These studies will provide for a determination to be made of the earliest time at which planting of food and commercial crops can be made.

10. An underground lens water sampling and analysis program should be conducted in which samples are taken over a period of at least 12

calendar months. Bacterial content, salinity, and radionuclide content should be measured, but primary emphasis of the program should be placed on development of an understanding of processes which are operating - or which can be made to operate - to reduce the ecological half-life of ^{90}Sr and ^{137}Cs below the radioactive half-life on the northe[rn] islands, especially JANET.

11. An air sampling program should be conducted during cleanup in support of cleanup operations and to add to the body of available information on radioactivity levels in air.

12. Base-line surveys of body burdens and urine content of ^{137}Cs and ^{90}Sr should be made for the Enewetak people prior to return to Enewetak Atoll, after the first year of residence, and as appropriate thereafter. Resurveys of the environmental radiation and radioactivity levels should be made starting in the first year of return and repeated every other year. To be determined is the adequacy of the diet and the actual average daily dietary intake of radioactivity for various age groups for comparison with estimated levels and how radioactivity levels in water, air, soil, plants, and animals are changing with time. (Included should be collection of additional information on the chemical form and size distribution of ^{239}Pu particle[s] in the air.) Information from such surveys will provide a continuing ch[eck] of the radiological status of the people and the environment and will assure that the exposure criteria is not being approached or exceeded.

13. Considering that the method of disposal of plutonium contaminated soil and scrap has not yet been decided, that not enough information is available to determine whether it is feasible to remove plutonium from the soil to reduce the amount of material requiring disposal, and not

wanting such problems to delay cleanup and rehabililatien of the atoll, the Task Group recommends the following:

a. At a minimum, cleanup should accomplish the recovery of plutonium contaiminated soil and scrap into storage on YVONNE,

b. The YVONNE quarantine should remain in effect with access controlled and all visitors monitored as for a radiation control zone.

c. If disposal is deferred for further study, such study should be planned and conducted promptly.

14. The cleanup phase of rehabitation, i.e., removal and disposal of contaminated scrap, debris, and soil, should be carefully documented in a comprehensive final report from these conducting the cleanup operation.

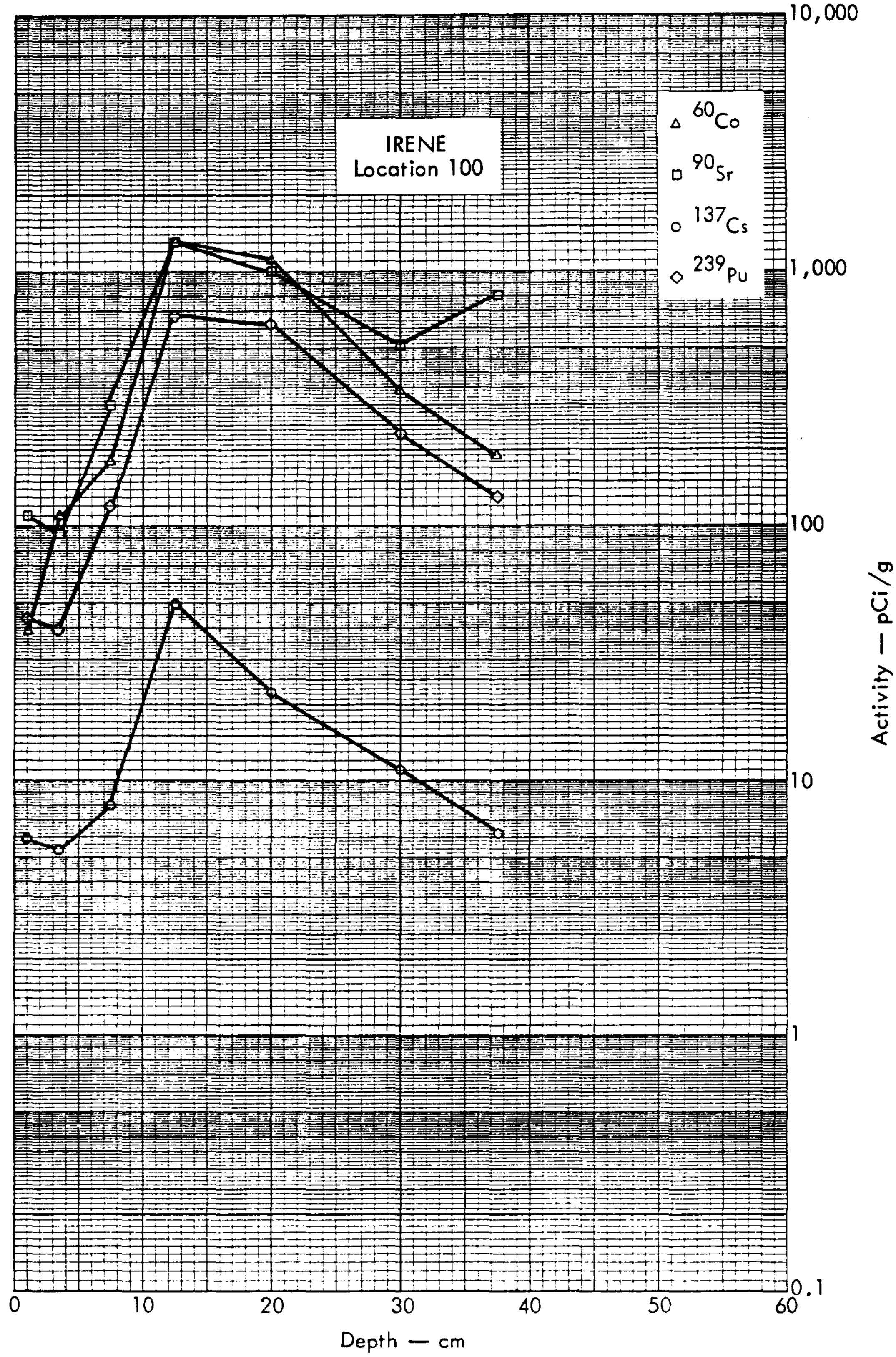


Fig. 151. Activities of selected radionuclides as a function of soil depth.

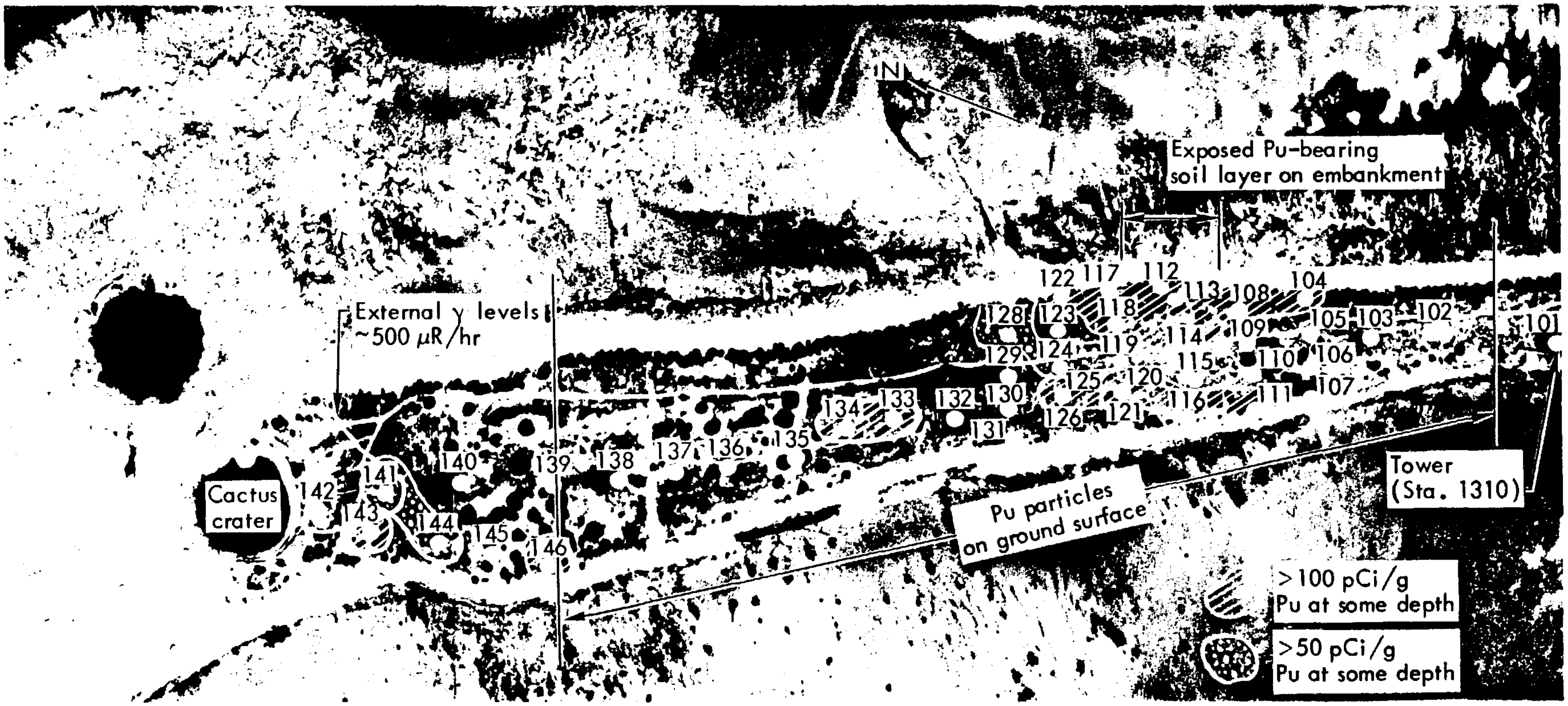


Fig. 152. Soil-profile locations which were sampled to 150-cm depths, YVONNE.

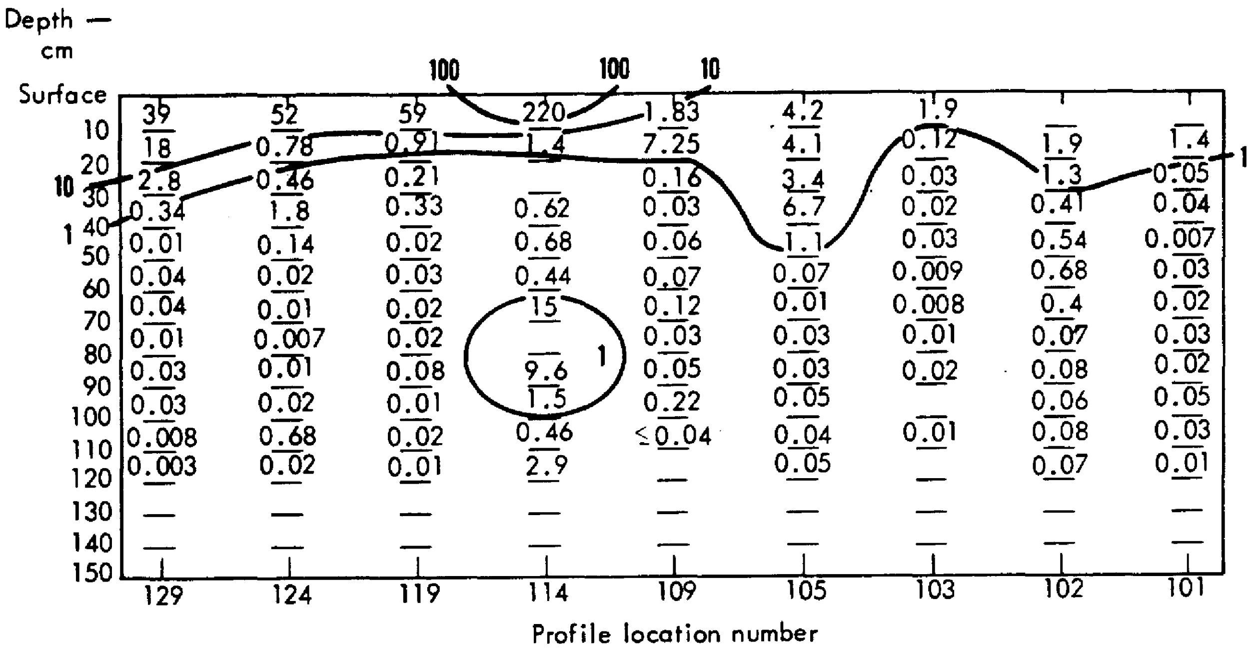


Fig. 153. Plutonium profile data, Locations 101-103, 105, 109, 114, 119, 124, and 129, YVONNE.

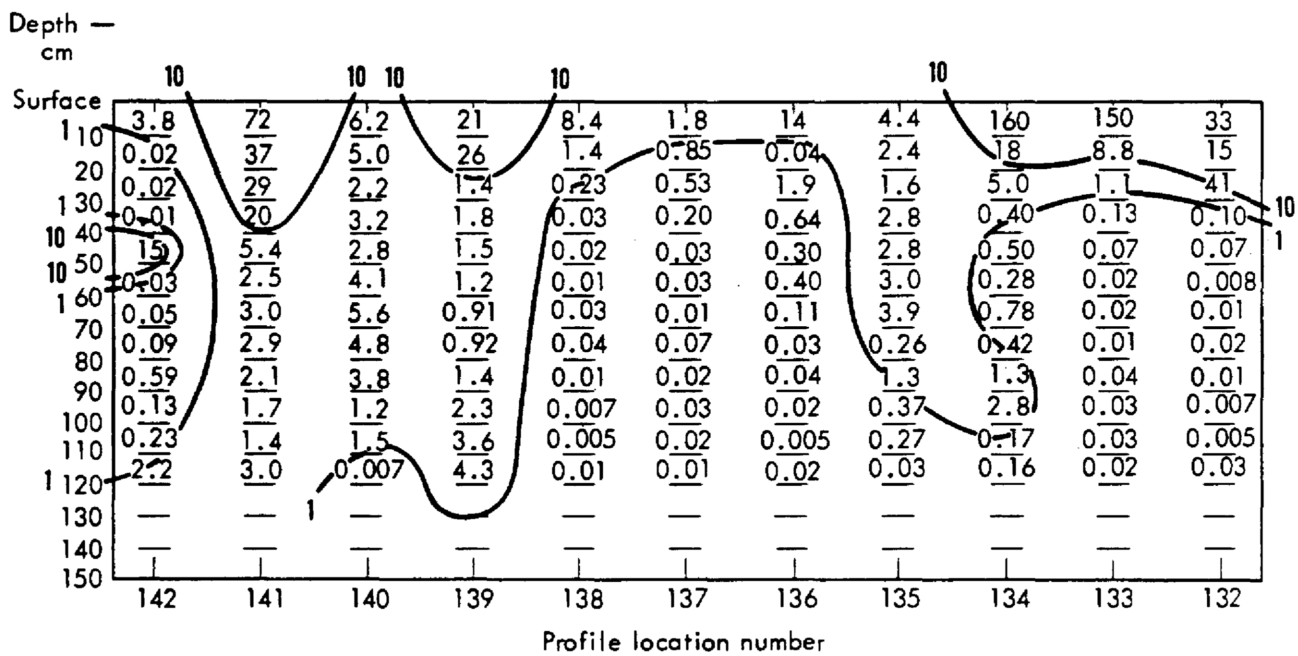


Fig. 154. Plutonium profile data, Locations 132-142, YVONNE.

(0.07 pCi/g). Comparison of these data with similar data obtained in 1964 indicates that, in addition to physical decay, ^{60}Co and ^{137}Cs are being lost from the lagoon with mean residence half-times of 3.3 and 4.1 yr, respectively, while ^{207}Bi appears to be decreasing at approximately its radioactive decay rate. ^{90}Sr,

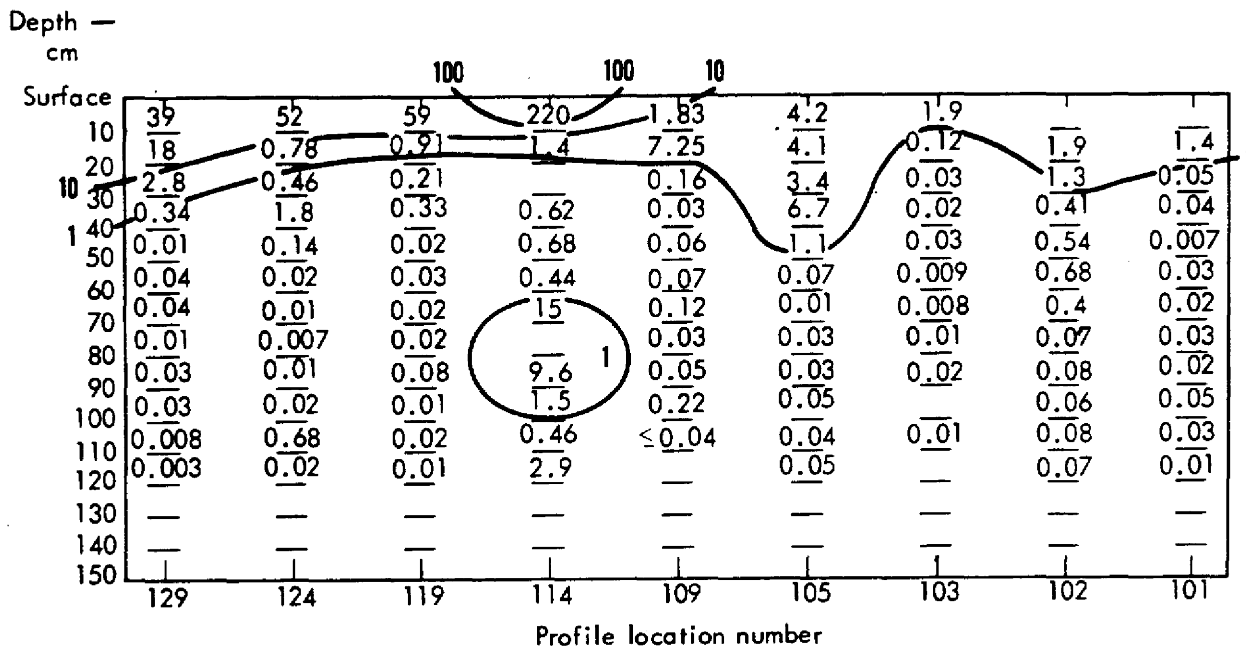


Fig. 153. Plutonium profile data, Locations 101-103, 105, 109, 114, 119, 124, and 129, YVONNE.

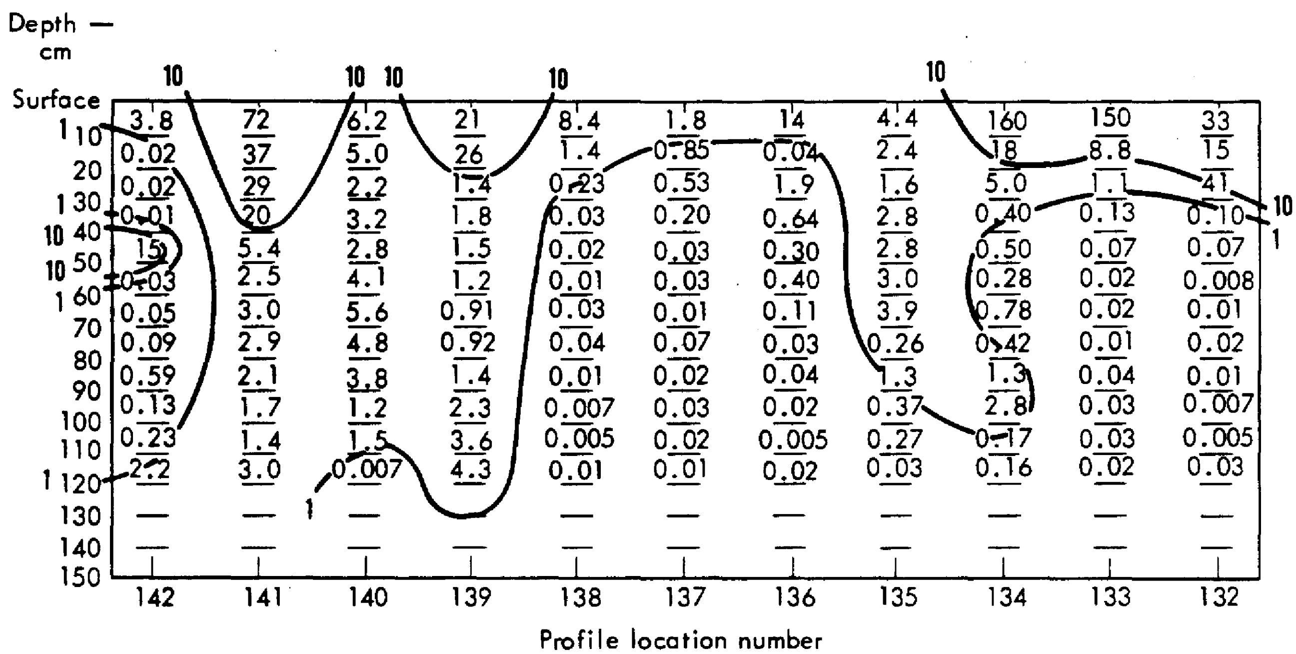


Fig. 154. Plutonium profile data, Locations 132-142, YVONNE.

(0.07 pCi/g). Comparison of these data with similar data obtained in 1964 indicates that, in addition to physical decay, ^{60}Co and ^{137}Cs are being lost from the lagoon with mean residence half-times of 3.3 and 4.1 yr, respectively, while ^{207}Bi appears to be decreasing at approximately its radioactive decay rate. ^{90}Sr,

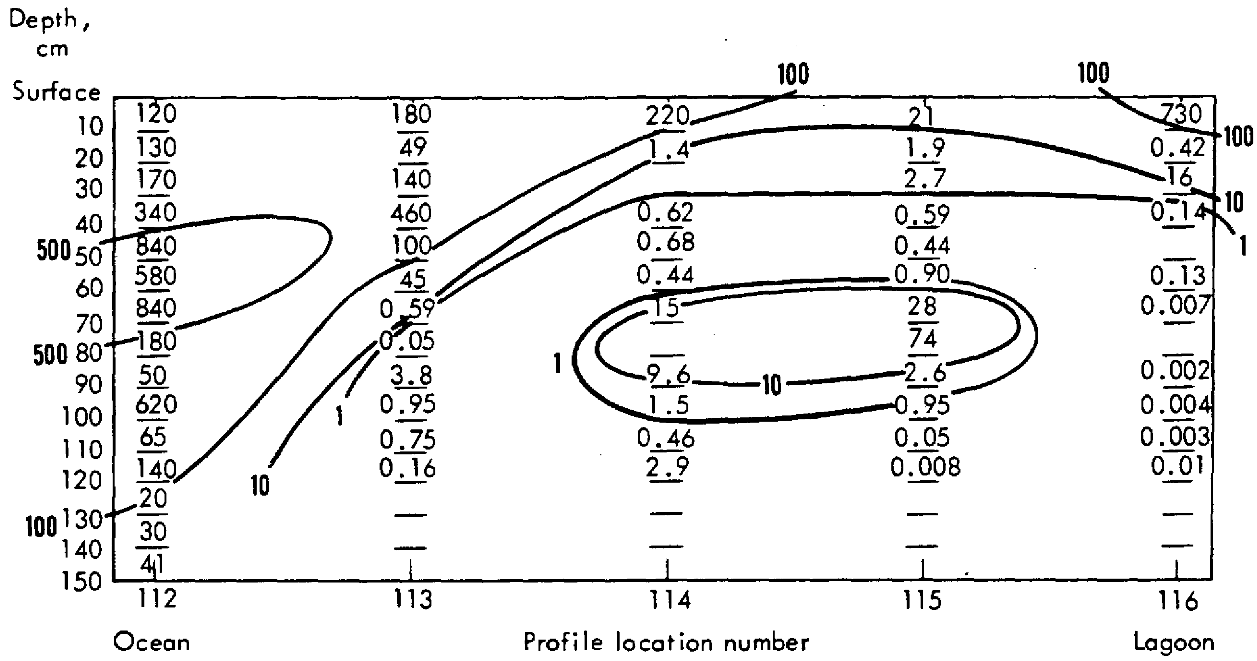


Fig. 155. Plutonium profile data, Locations 112-116, YVONNE.

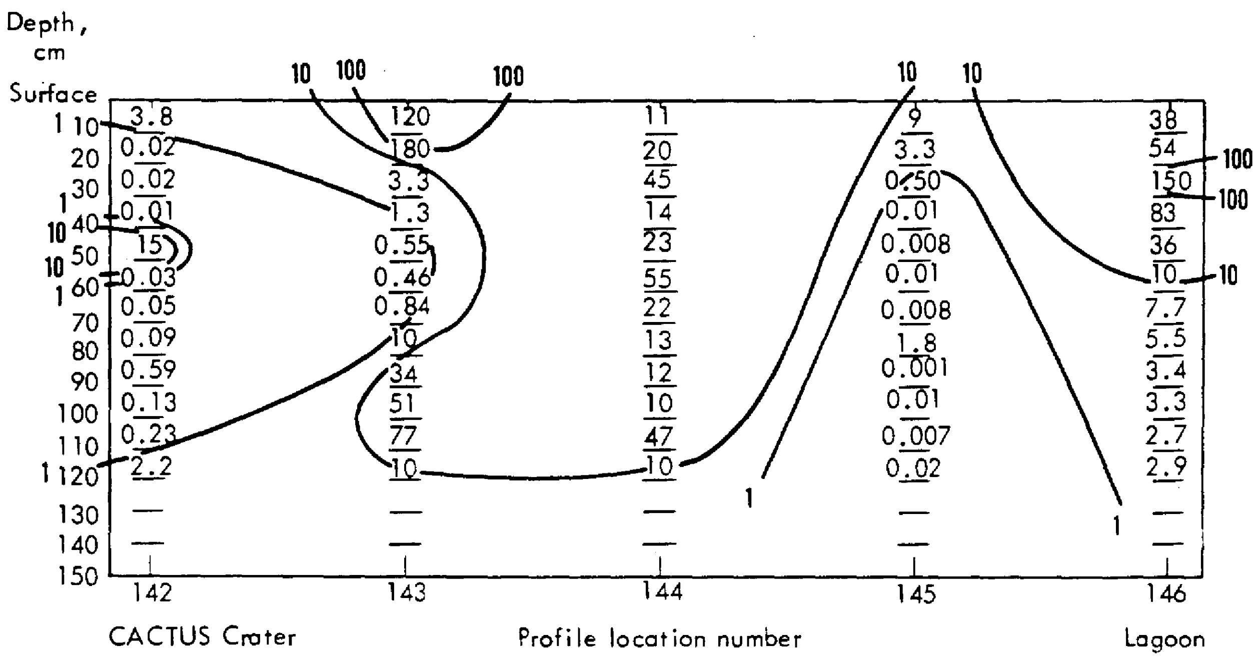


Fig. 156. Plutonium profile data, Locations 142-146, YVONNE.

$^{239,240}Pu$, ^{155}Eu, and ^{241}Am were not reported in 1964.

Of the more than 700 species of fish at Enewetak Atoll, the species selected for this survey were chosen for one or more of the following reasons: (1) They are commonly eaten by the Marshallese; (2) they are relatively abundant at most of the

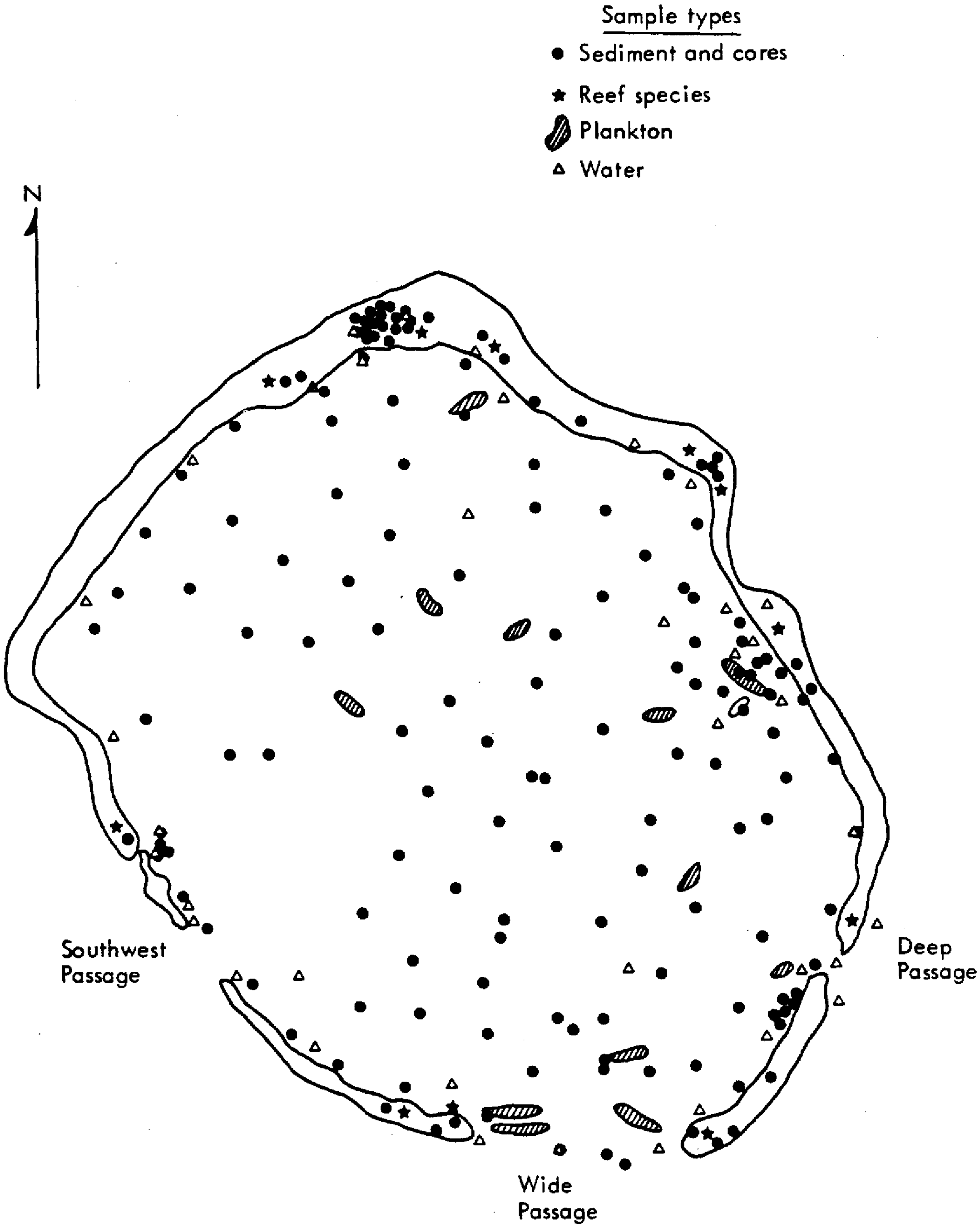


Fig. 157. Enewetak marine program sampling locations.

collection sites; (3) they are representative of a feeding habit; or (4) there is previous relevant radiometric information about the species. The species of reef fishes selected as being representative of feeding habits include the mullet (a plankton and detritus feeder), convict surgeon (a grazing herbivore), goatfish (a bottom-feeding carnivore), and parrotfish (a coral eater). The tunas, jacks, and dolphins – pelagic fish – and the snappers and groupers – benthic fish – which were also

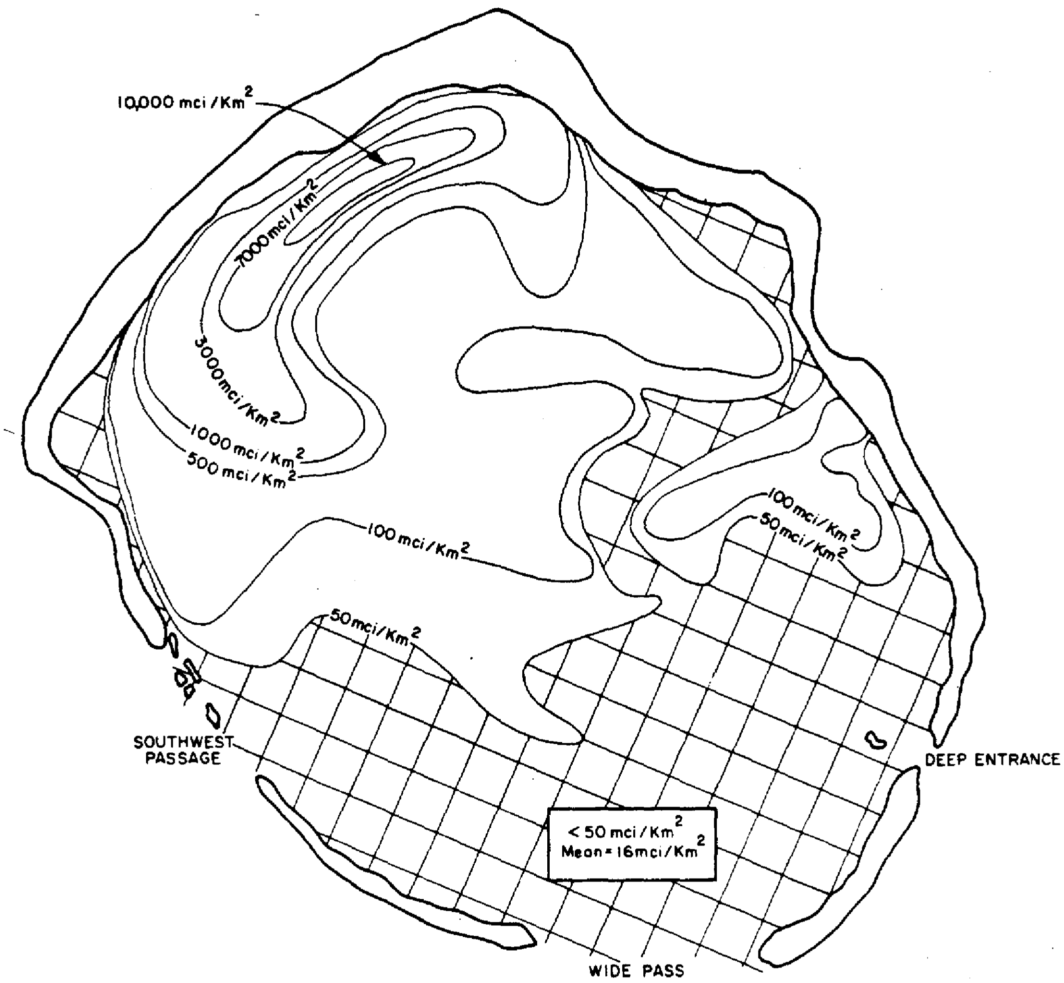


Fig. 158. Activity levels of ^{90}Sr deposited in the sediments of Enewetak Lagoon.

collected are carnivores of high order in the food chain leading to man.

The number and kind of marine organisms collected at near-shore sites at Enewetak Atoll and at Kwajalein Atoll, where "control" samples were taken, are shown in Table 218. Similar information for the carnivorous fish is given in Table 219.

^{40}K, ^{55}Fe, and ^{60}Co were the predominant radioactive nuclides found in all fish, although ^{65}Zn, ^{90}Sr, ^{101}Rh, ^{102m}Rh, ^{108m}Ag, ^{125}Sb, ^{137}Cs, ^{152}Eu, ^{155}Eu, ^{207}Bi, $^{239,240}Pu$, and ^{241}Am were also present in some or all samples.

Table 217. Concentration of ^{137}Cs and ^{239}Pu in comparative, surface water samples.

Location	Concentration, fCi/liter ^{137}Cs	Concentration, fCi/liter ^{239}Pu
Enewetak Lagoon		
SE quadrant	226	9.1
NE quadrant	334	42.6
NW quadrant	579	33.4
SW quadrant	332	21.6
Ocean, east of Enewetak Atoll	89	0.3
Lake Michigan (1971)	88	1.1
Humboldt Bay, Calif. (1973)	300	
14°N 180°W (1972)	143	0.44
12°N 170°E (1972)	170	0.35
Windscale vicinity (1969)	105,000	
Mean surface, Atlantic 0-31°N (1968)		0.7

Table 218. Number of organisms collected at Enewetak Atoll and Kwajalein Atoll near-shore sites, October to December 1972.

Collection site	Mullet	Goatfish	Convict surgeon	Parrot-fish	Other reef fish	Tridacna	Sea cucumber[a]	Other inverte-brates	Approx total
	Organism								
Enewetak Atoll									
GLENN-HENRY	~25	11	~50	2	10	6	4	6[b]	114
LEROY	~50	9	34	3	1	1	0	~10[c]	108
FRED	0	~20	~50	9	7	3	2		91
DAVID	0	25	~50	12	2	4	1		94
BELLE	~50	3	30	1	3	10	0		97
IRENE	2	3	12	0	8	0	0		25
JANET	~50	3	~40	1	0	4	0		98
TILDA-URSULA	~35	11	~50	2	3	3	3		107
YVONNE	10	~15	~55	10	3	0	3	6[d]	105
Kwajalein Atoll	–	–	~30	1	5	5			41
Approximate Total	~220	~100	~400	41	42	36	13	25	870

[a]The number given is the number of collections from a given site.
[b]Pencil urchins.
[c]Top snails.
[d]Spiny lobster.

Table 219. Number of carnivorous fish collected from the Enewetak and Kwajalein off-shore lagoon sites, October to December 1972.

Collection site	Yellowfin tuna	Skipjack	Mackerel	Dolphin	Snapper	Grouper	Ulua	Total
		Organism						
Enewetak	2	9	3	2	8	8	8	40
Kwajalein	3	1				2		6
Total	5	10	3	2	8	10	8	46

Figures 159-161 show the average concentrations of predominant radionuclides found in convict surgeon samples taken at each of the collection sites around the lagoon. Similar data were obtained from the mullet, goatfish, and parrotfish samples.

Average radionuclide content of light muscle, dark muscle, and liver of skipjack collected in Enewetak lagoon are shown in Fig. 162. In general, ^{55}Fe levels in the large pelagic fish were higher than levels found in other fish types, while other nuclides were present at levels comparable to or lower than those found in the reef fish.

Of the samples collected at Kwajalein, ^{40}K was present at normal background

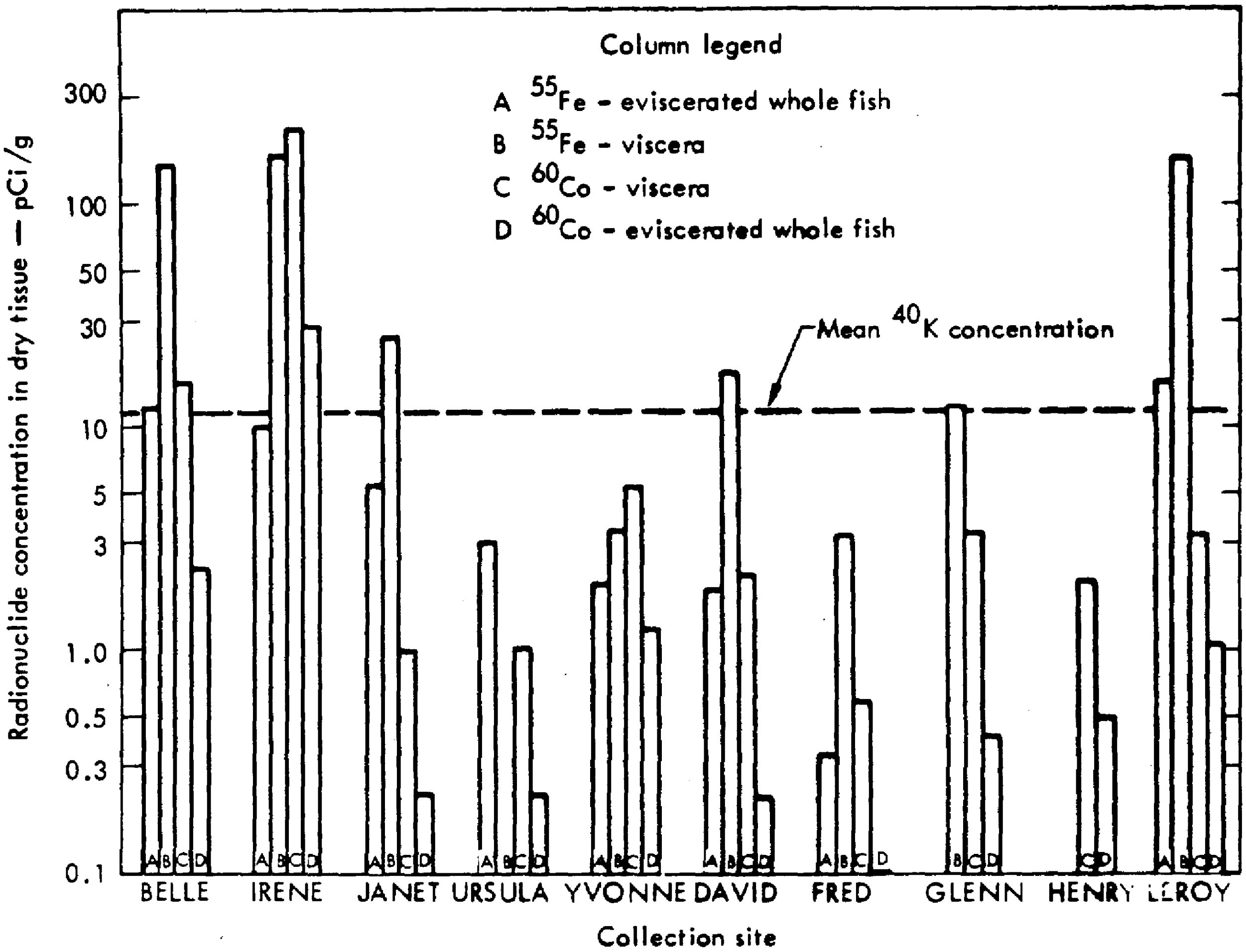


Fig. 159. Average ^{40}K, ^{55}Fe, ^{60}Co concentration in convict surgeon from Enewetak Atoll, October to December, 1972. The ^{40}K value is the mean for all convict surgeon samples.

Table 220. Comparison of ^{60}Co and ^{207}Bi in the viscera of convict surgeon collected in 1964 and 1972.

	^{60}Co in pCi/g, dry			^{207}Bi in pCi/g, dry		
Island	1964	1972	Fraction remaining	1964	1972	Fraction remaining
BELLE	120	16	0.13	8.0	2.0	0.25
JANET	8.3	0.96	0.12	1.2	0.2	0.17
GLENN	19	3.3	0.17	2.6	0.7	0.27
LEROY	56	3.4	0.06	5.2	3.1	0.59
YVONNE	64	5.2	0.08	-	-	-
Average			0.11			0.32

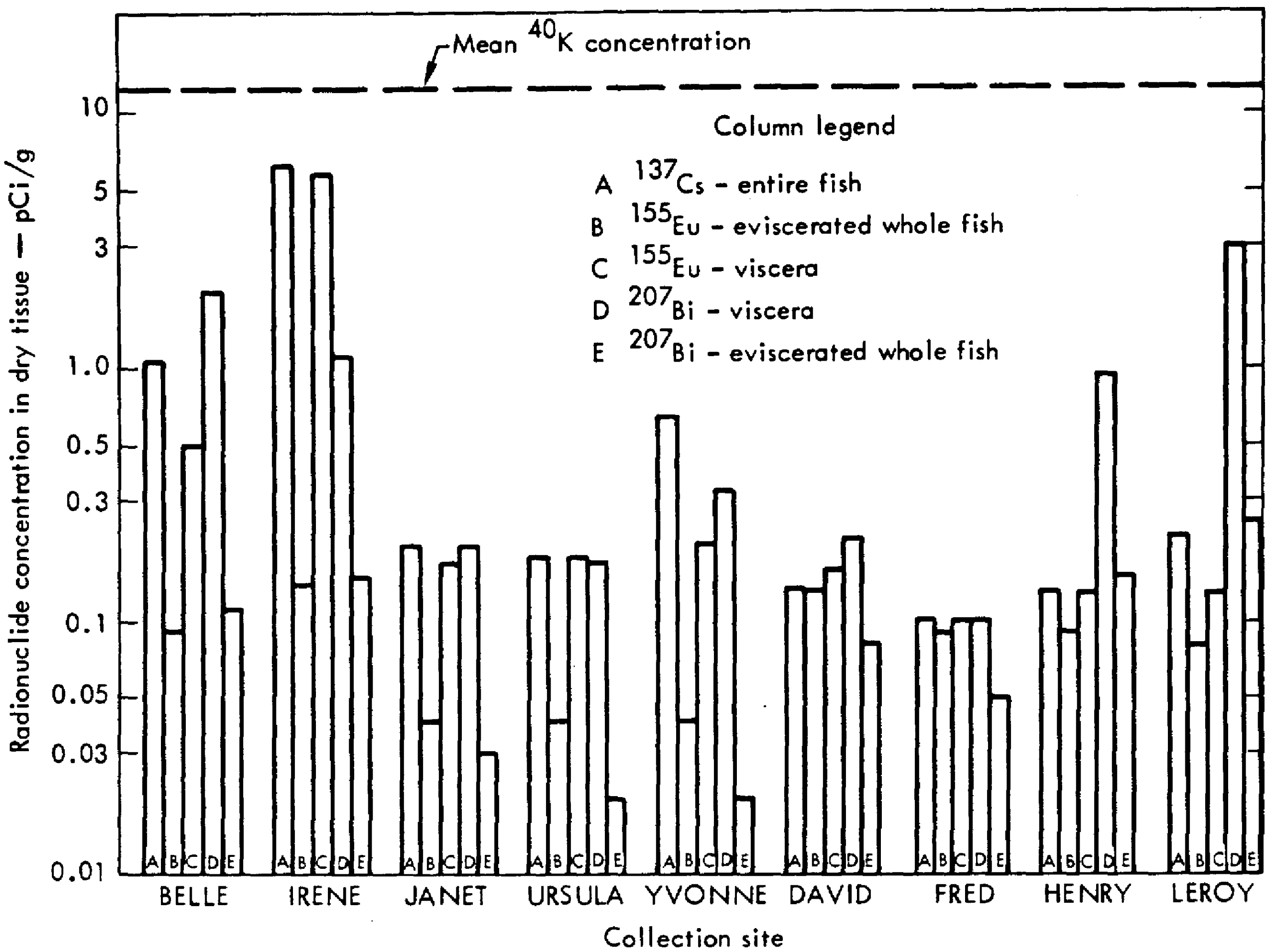


Fig. 160. Average ^{137}Cs, ^{155}Eu, and ^{207}Bi concentration in convict surgeon from Enewetak Atoll, October to December, 1972. The ^{40}K value is the mean for all convict surgeon samples.

levels (av 15 pCi/g). No ^{60}Co, ^{207}Bi, or ^{155}Eu were observed, but ^{55}Fe, ^{137}Cs, ^{90}Sr, and $^{239,240}Pu$ were found in some or all of the samples, usually at levels comparable to the lower values found at Enewetak.

As with the plankton, comparison of data obtained from this survey with similar data from samples taken in 1964 indicates that, for some nuclides at least, there are processes operating to reduce concentrations in the lagoon faster than is expected from radioactive decay alone. Table 220, for example, presents a comparison of ^{60}Co and ^{207}Bi data for the two collection periods. The effective half-life of 2.7 yr for ^{60}Co (radioactive decay half-life 5.24 yr) and 5.1 yr for ^{207}Bi (radioactive decay half-life 30 yr) implies an effective half-life in the ecosystem for both isotopes of about 5-6 yr.

Of the marine invertebrates present at Enewetak, tridacna clams, sea cucumbers, spiny lobster, and top snails were collected and analyzed. In the tridacna, ^{60}Co was the most abundant radioisotope found, and it was present in higher amounts in the kidney than in the viscera,

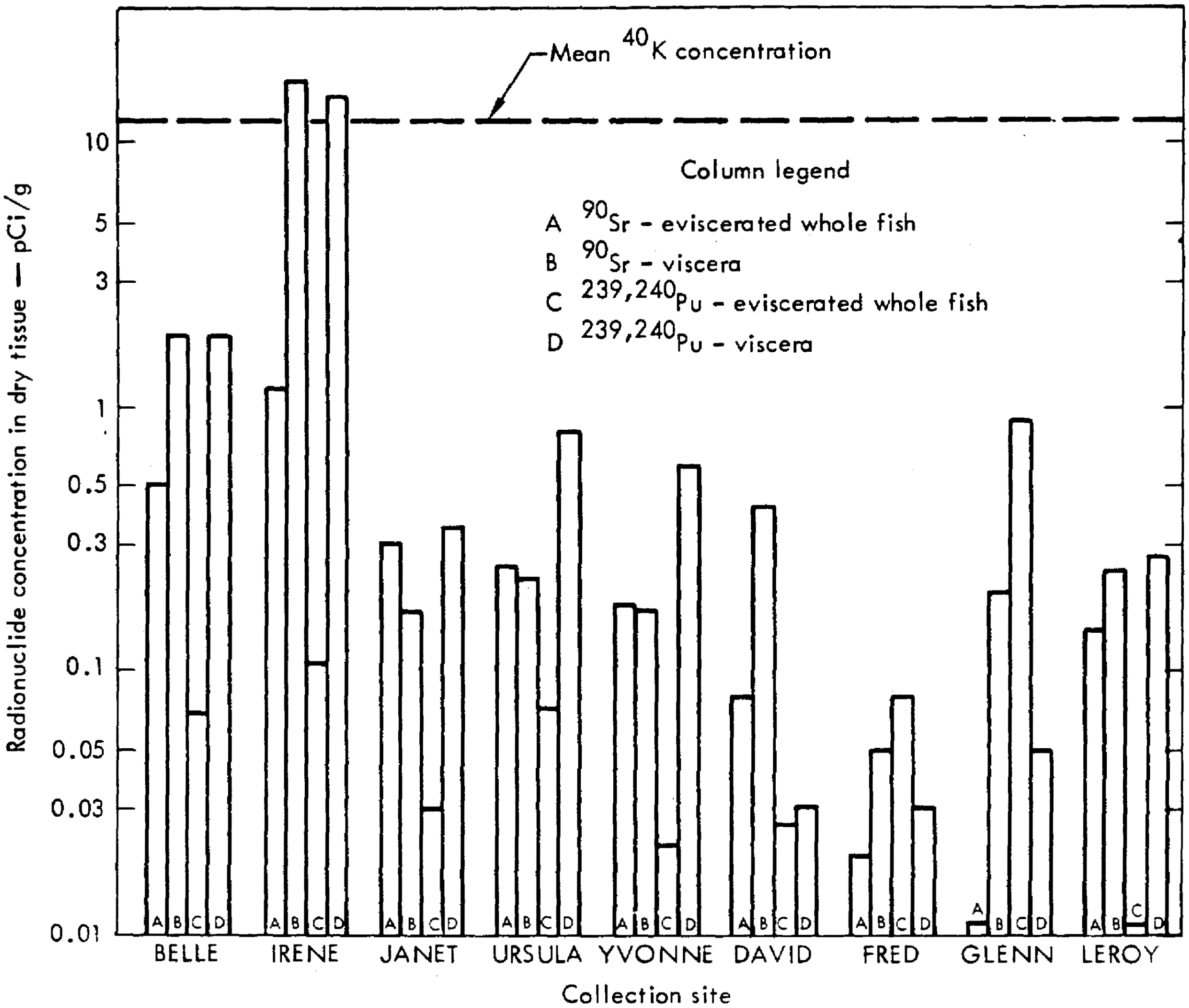


Fig. 161. Average ^{90}Sr and $^{239,240}Pu$ concentration in convict surgeon from Enewetak Atoll, October to December, 1972. The ^{40}K value is the mean for all convict surgeon samples.

mantle, or muscle. Figures 163-165 present the average radionuclide concentrations of these tissues for the Enewetak locations at which tridacna samples were taken.

Radionuclide distributions for sea cucumbers, spiny lobsters, and top snails were similar to those found for the tridacna, except that high concentrations were not observed in the kidney.

Radioactivity Levels in Enewetak Terrestrial Biota

The terrestrial biota survey had as its objective the collection and analysis of all available terrestrial vegetation and animal species which could be used as a basis for estimating population doses through dietary pathways. Not all vegetable and animal components of the Enewetakese diet are currently available

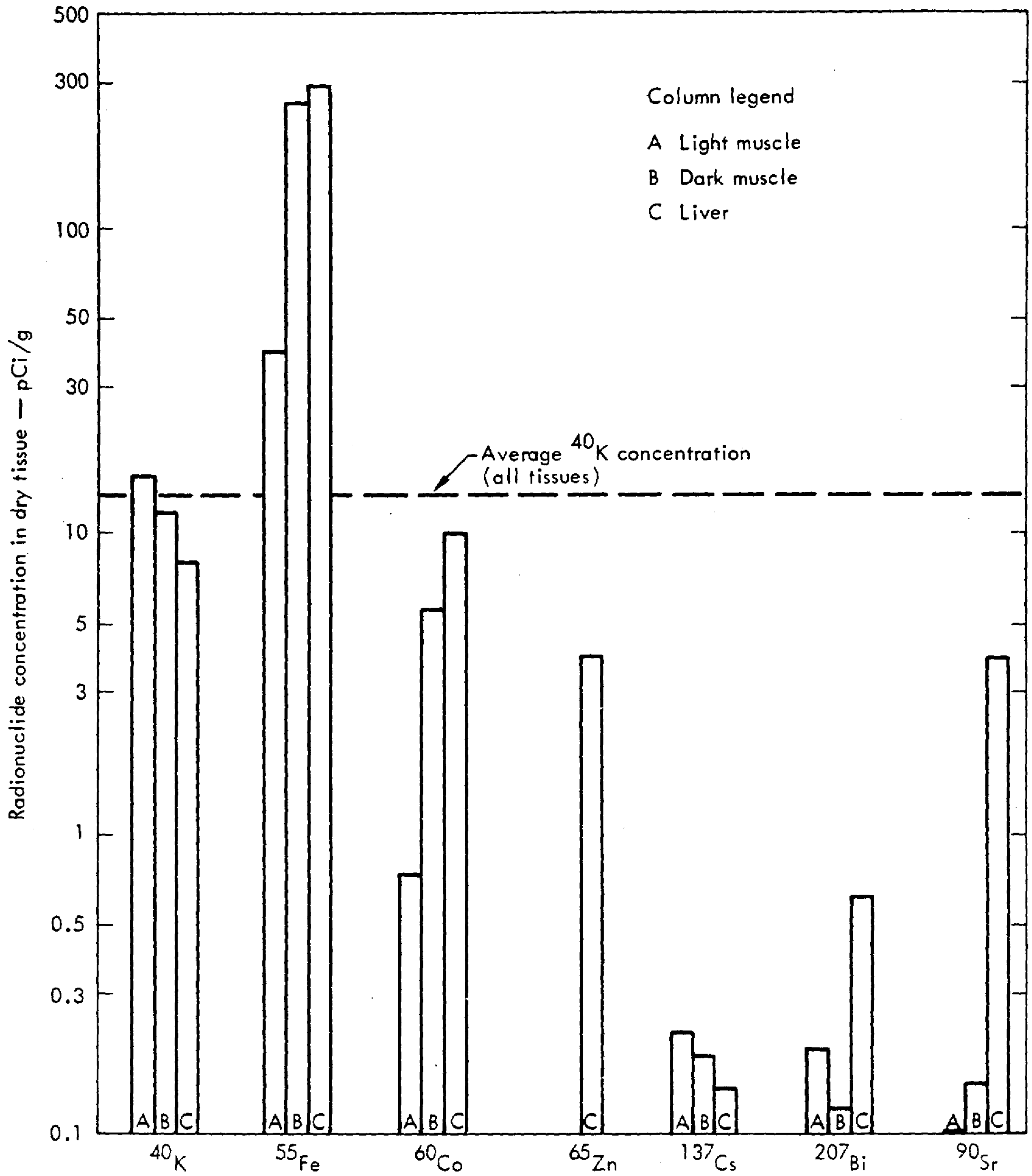


Fig. 162. Average concentration of seven radionuclides in the light muscle (A), dark muscle (B), and liver (C) of three skipjack from Enewetak Atoll, October to December, 1972.

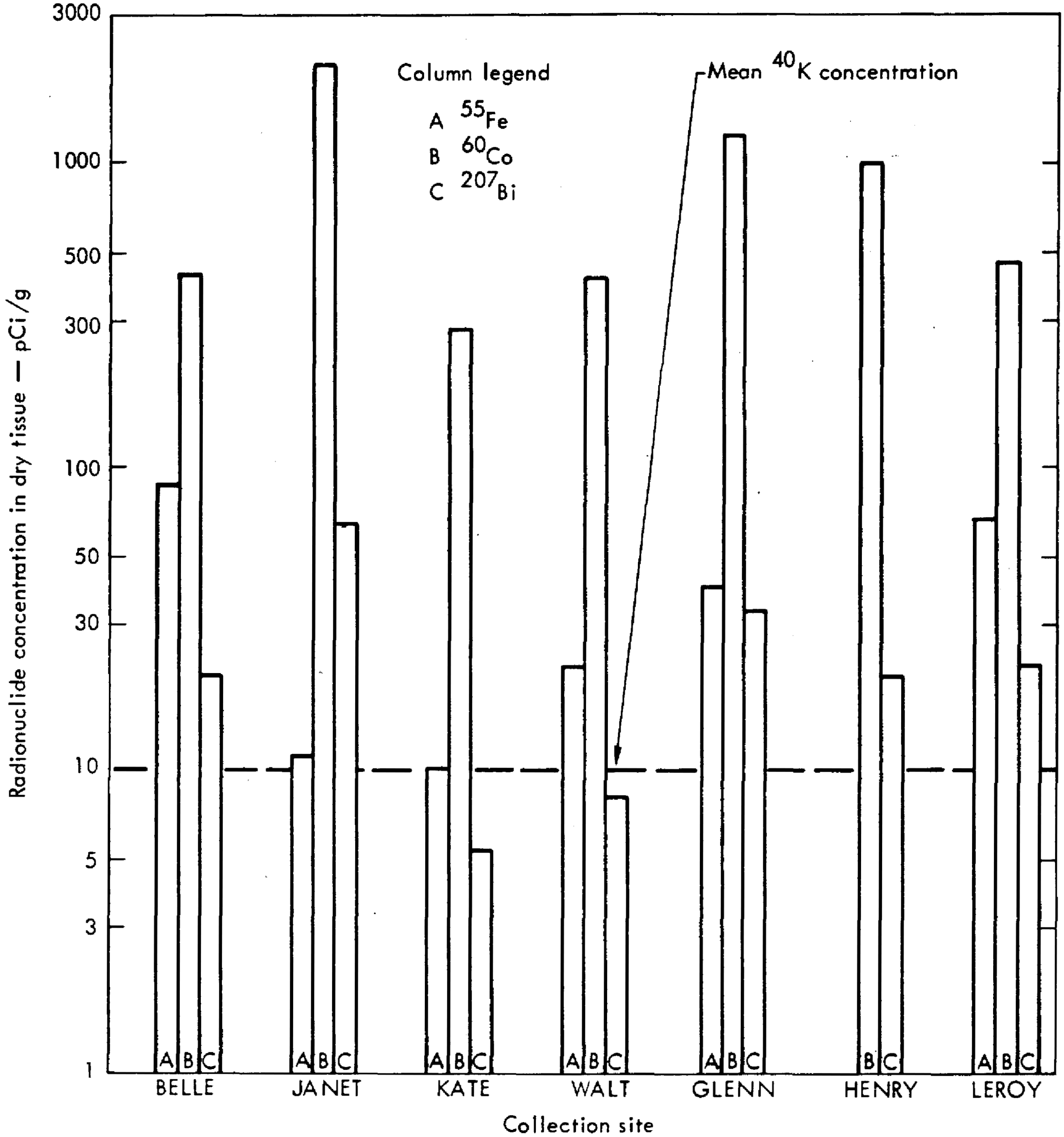


Fig. 163. Average ^{40}K, ^{55}Fe, ^{60}Co, and ^{207}Bi concentration in the kidney of Tridacna clams collected at Enewetak Atoll, October to December, 1972. The ^{40}K value is the mean of all Tridacna samples.

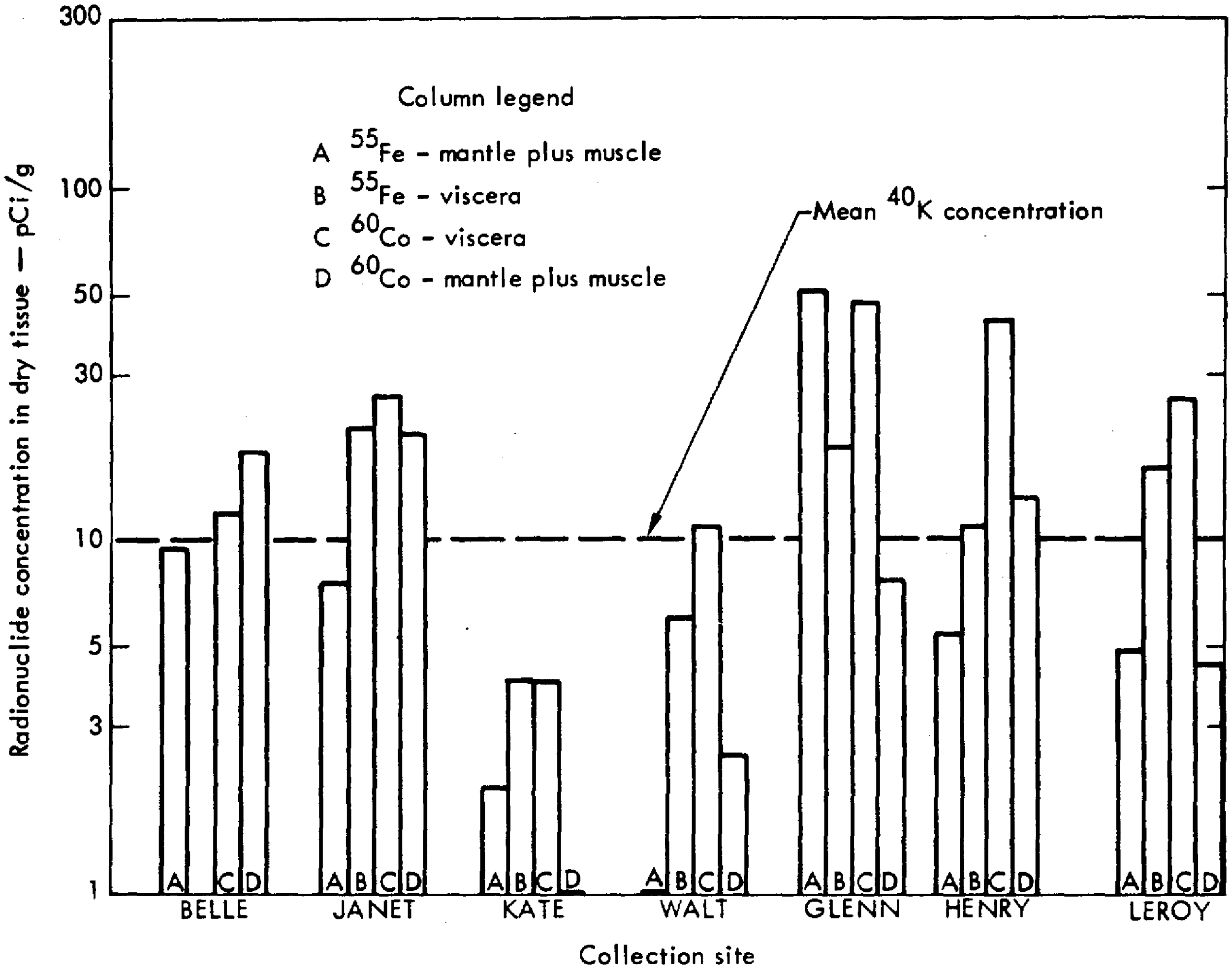


Fig. 164. Average ^{40}K, ^{55}Fe, and ^{60}Co concentration in the viscera, mantle, and muscle of Tridacna clams collected at Enewetak Atoll, October to December, 1972. The ^{40}K value is the mean of all Tridacna samples.

on the Atoll; of those that are, not all are available on every island.

A total of 1103 specimens were collected in the field as part of the terrestrial biota survey, distributed as follows:

Soils	42
Plants	208
Birds	116
Eggs	217
Rats	249
Crabs	271
Total	1103

The geographical distribution of specimen collection sites is shown in Fig. 166 and the types of edible sample collected on each island are listed in Table 221.

^{90}Sr and ^{137}Cs were observed in essentially all of the plant, rat, and crab samples and in many of the bird and egg samples. ^{55}Fe, ^{60}Co, and $^{239,240}Pu$ were observed less frequently, and isotopes such as ^{207}Bi, ^{152}Eu, and ^{151}Sm were observed occasionally.

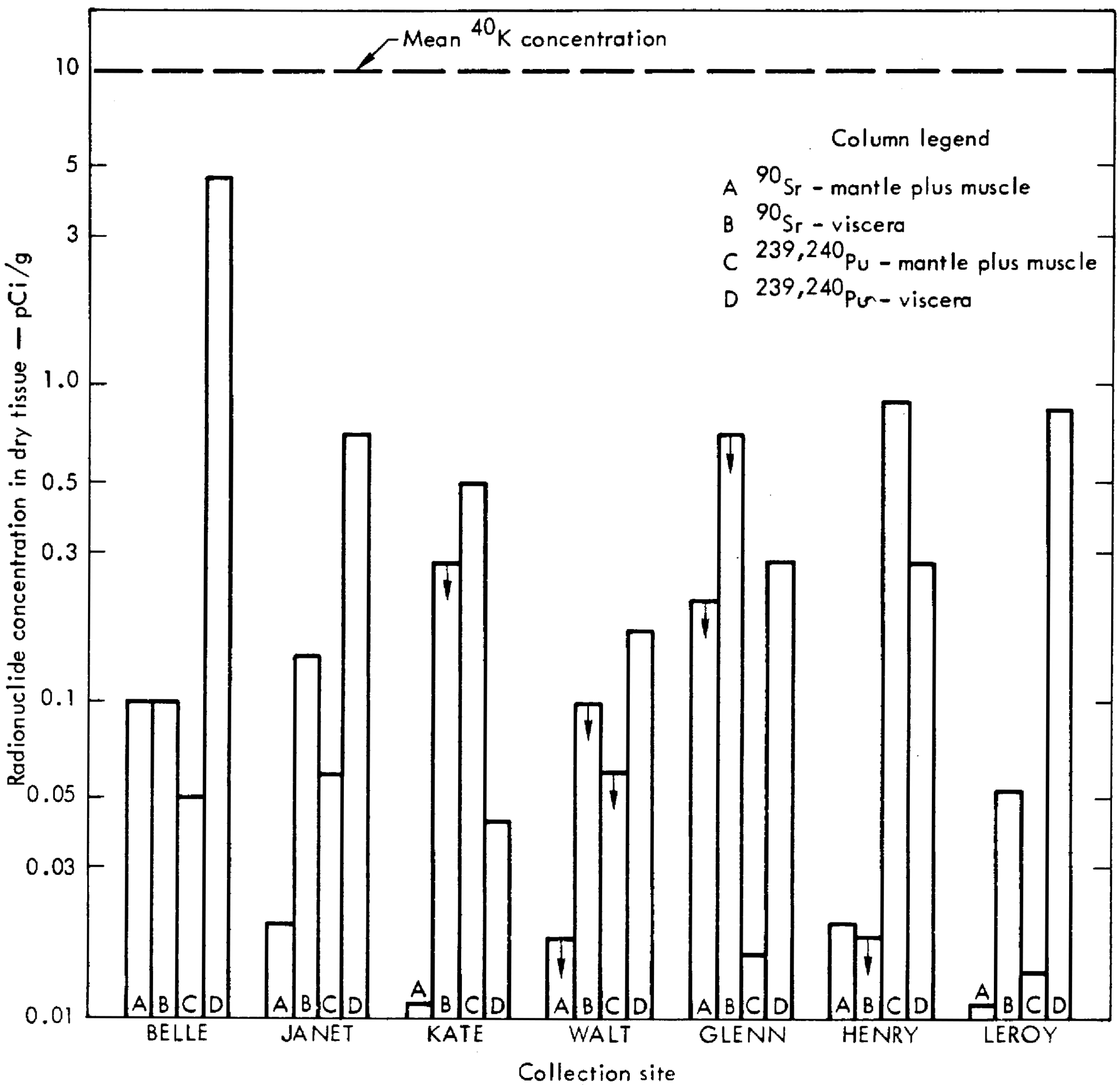


Fig. 165. Average ^{90}Sr and ^{239,240}Pu concentration in the viscera, mantle, and muscle of Tridacna clams collected at Enewetak Atoll, October to December, 1972. The ^{40}K value is the mean for all Tridacna samples.

Table 221. Terrestrial biota survey. Edible plants and edible animals sampled.

Island No.	Island	Coconut meat	Coconut milk	Pandanus fruit	Pandanus leaves[a]	Tacca corm	Birds	Bird eggs	Coconut crab	Rat[b]
1.	ALICE						x			
2.	BELLE			x	x					
4.	DAISY	x	x							
9.	IRENE	x	x				x	x		
10.	JANET	x	x		x		x	x		x
12.	LUCY						x			
14.	MARY	x	x				x			
15.	NANCY	x	x							
16.	OLIVE						x			
17.	PEARL						x			x
19.	SALLY				x		x	x		x
20.	TILDA				x					
21.	URSULA									x
22.	VERA	x			x					
24.	YVONNE	x					x	x		x
29.	VAN						x			
30.	ALVIN						x			
31.	BRUCE	x					x		x	
32.	CLYDE						x	x		x
33.	DAVID	x	x		x	x	x			x
34.	REX						x	x		
35.	ELMER	x			x					x
37.	FRED	x			x					
38.	GLENN	x							x	x
39.	HENRY	x						x		
40.	IRWIN	x					x	x		
41.	JAMES								x	
42.	KEITH	x		x	x		x		x	
43.	LEROY	x			x		x		x	

[a]Pandanus leaves are not eaten but serve as indicators for pandanus fruit.

[b]Rats are not eaten but serve as indicators for poultry and swine.

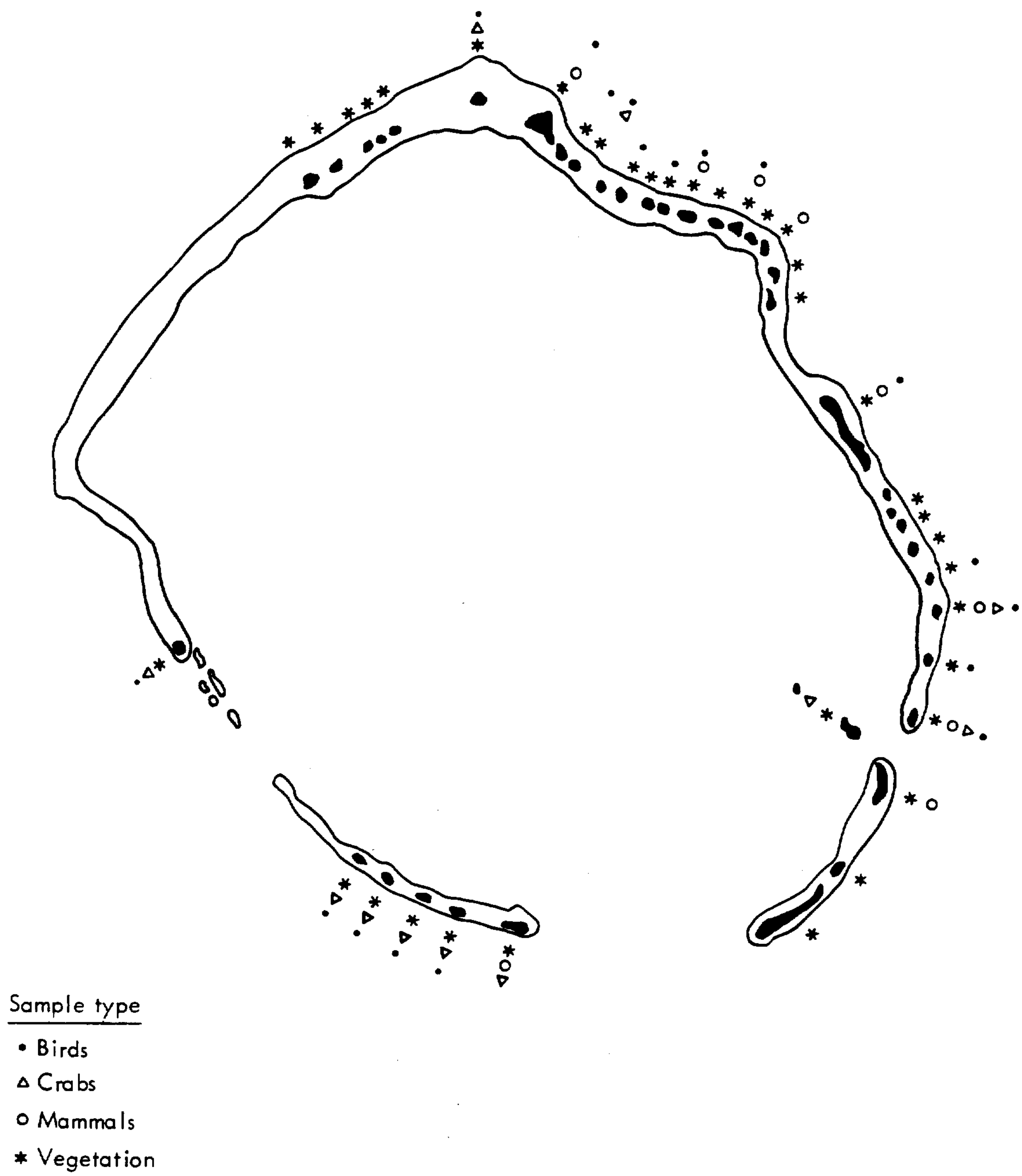


Fig. 166. Terrestrial biota program sampling locations.

For a given sample type, the radionuclide content generally corresponded with levels of soil contamination found on the Atoll. Data for ^{90}Sr and ^{137}Cs in coconut meat versus island sampling location, for example, are plotted in Fig. 167 and it is apparent that concentrations are significantly higher on the northern islands (islands 1-24) than on those on the southern part of the Atoll.

Since the main vegetation components in the human diet (coconut, pandanus,

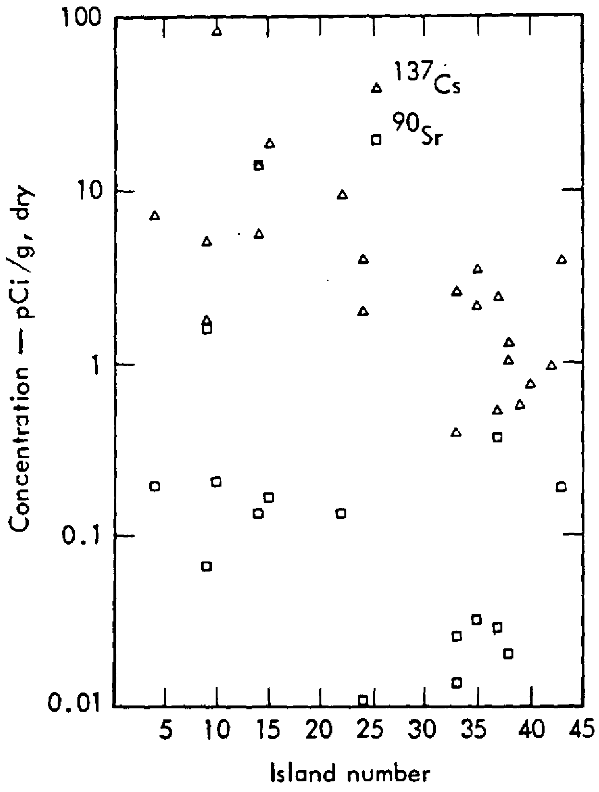


Fig. 167. Concentrations of ^{90}Sr and ^{137}Cs in coconut meat.

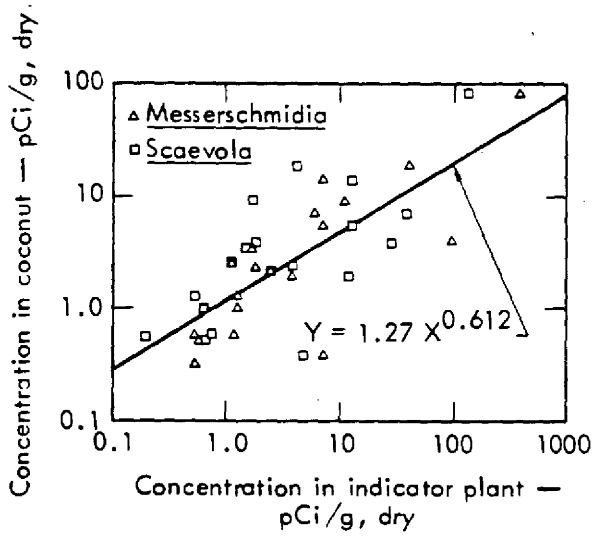


Fig. 168. Statistical correlation between ^{137}Cs in coconut meat and ^{137}Cs in Messerchmidia and Scaevola.

and breadfruit) are not growing now on all of the northern islands, the ubiquitous Messerschmidia and Scaevola were sampled and analyzed extensively with the intent that they be used as "indicator species" for estimating doses from the edible plants should they become available. The correspondence between ^{137}Cs activity in coconut meat and Messerschmidia and/or Scaevola from the same location is shown in Fig. 168.

To increase accuracy, dose estimates to the human population through the terrestrial vegetation pathway should be based on the geographical distribution of radionuclides. In order to do this, however, a correlation between nuclide content of vegetation and nuclide content of soil must be established. As an example of the correlations that have been developed, data for ^{137}Cs in Messerschmidia and Scaevola vs ^{137}Cs in soil are shown in Fig. 169.

Similarly, data obtained from rats — the only mammals now found on the Atoll — were found to correlate with the vegetation radionuclide levels. For example, correlations for ^{137}Cs in rat muscle vs Messerschmidia/Scaevola are shown in Fig. 170, and for ^{90}Sr in rat bone vs Messerschmidia/Scaevola are shown in Fig. 171.

Three classes of data obtained from the terrestrial biota survey, therefore, have been used to estimate potential human doses through the terrestrial food pathway:

- Data obtained from the edible organisms where they were available.
- Data obtained from the correlation between edible plants — indicator

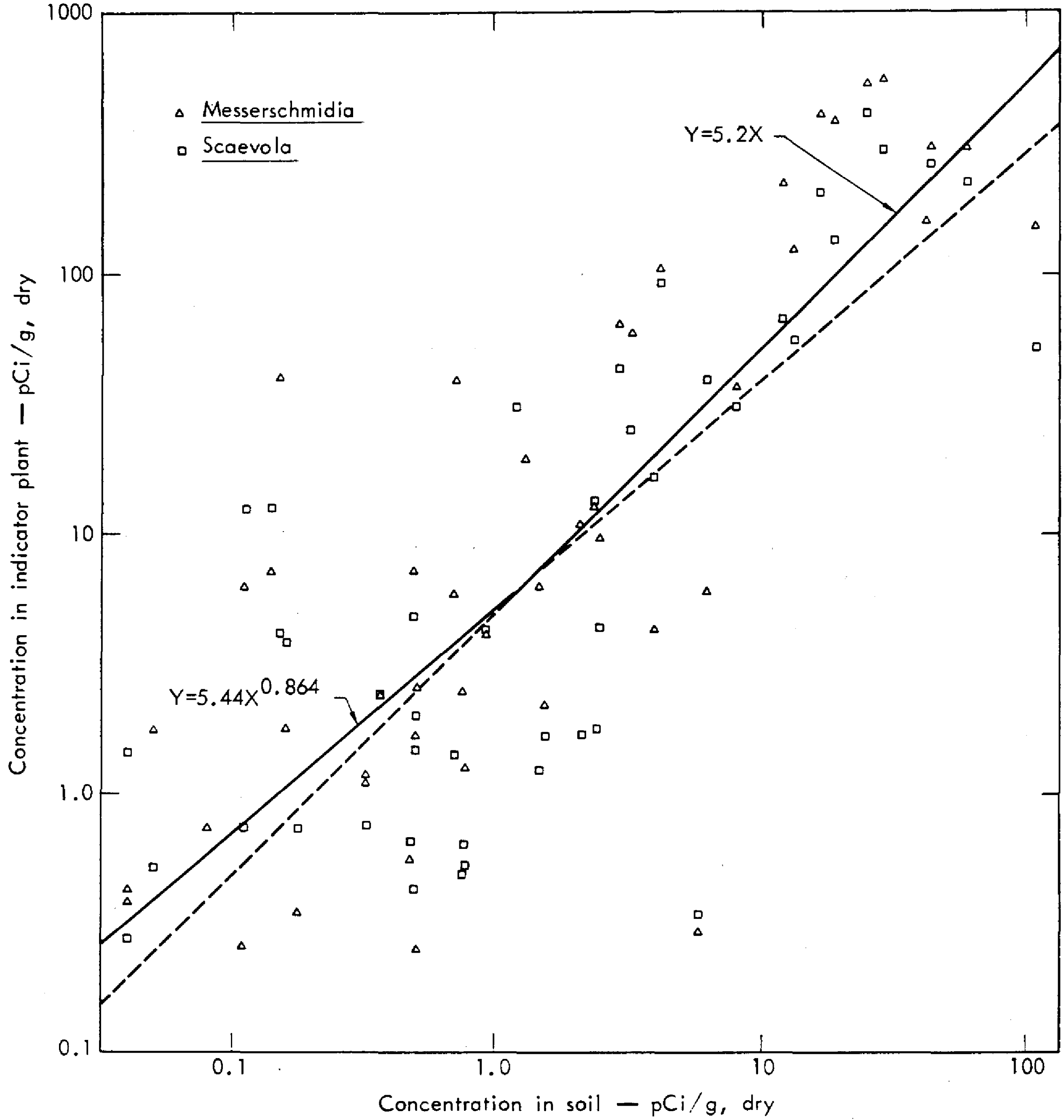


Fig. 169. Statistical correlation between ^{137}Cs in Messerschmidia and Scaevola and ^{137}Cs in soil.

plants – soil and applied to the plant component of the diet.

- Data obtained from the correlation between rats – indicator plants – soil and applied to the meat component of the diet.

Radioactivity Levels in Enewetak Air

A total of 32 samples of airborne Enewetak particulate debris have been analyzed to determine inhalation exposures likely to be encountered by residents of

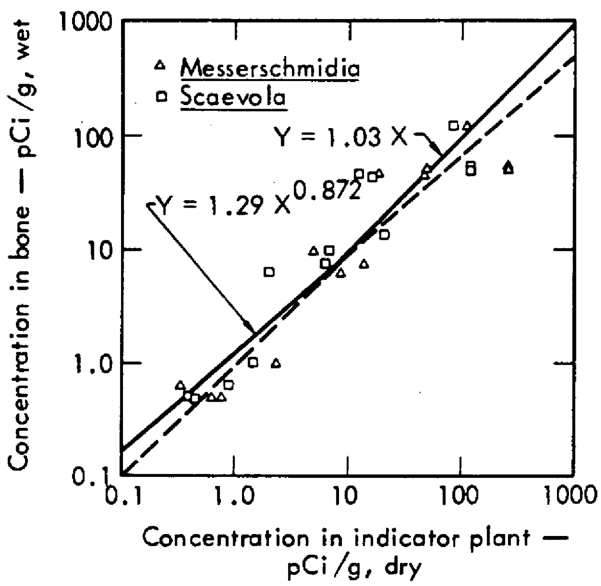


Fig. 170. Statistical correlation between ^{90}Sr in rat bone and ^{90}Sr in Messerschmidia and Scaevola.

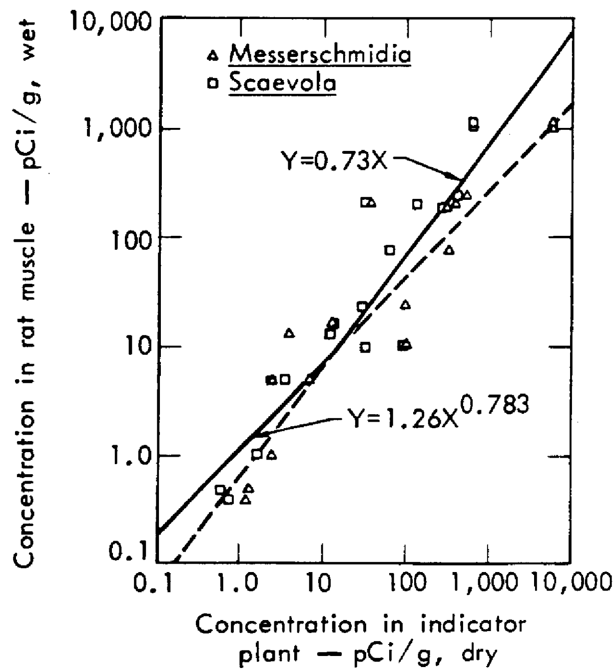


Fig. 171. Statistical correlation between ^{137}Cs in rat muscle and ^{137}Cs in Messerschmidia and Scaevola.

the Atoll. Samples were taken using the following three types of equipment:

- Ultra High-Volume Air Sampler (UHVS) – Used to sample large volumes of air in short time intervals. Typical samples were taken at a rate of 2000 m^3/hr for a continuous 24-hr period.
- Low-Volume Air Sampler (VCS) – Used to sample for extended periods. Typical samples were taken at a rate between 8 and 20 m^3/hr for a continuous 7-day period.
- Anderson Cascade Impactors (ACI)– Used to obtain data on the particle-size distribution of airborne radioactivity. These samplers operated at a throughput rate of 34 m^3/hr, sampled for 7- to 10-day periods, and separated each sample into the following particle-size ranges: 0.1-1.1, 1.1-2.0, 2.0-3.3, 3.3-7.0, and >7 μm.

Air samples were taken on FRED, DAVID, SALLY, JANET, and YVONNE, which are islands that include the full range of airborne activity levels likely to be found on the Atoll.

A number of radionuclides were detected in the surface air, including ^{7}Be (53 day), ^{40}K (1.26×10^9 yr), ^{54}Mn (303 day), ^{95}Zr (65 day), ^{103}Ru (39.6 day), ^{106}Ru (1.0 yr), ^{125}Sb (2.7 yr), ^{137}Cs (30 yr), ^{144}Ce (285 day), ^{239}Pu (2.4×10^4 yr), ^{238}Pu (86 yr), and ^{241}Am (458 yr). ^{7}Be and ^{40}K are naturally occurring activities. ^{54}Mn, ^{95}Zr, ^{103}Ru, ^{106}Ru, ^{125}Sb, and ^{144}Ce are intermediate-life activation and fission products found in current worldwide fallout, but present in Enewetak soils in only very reduced quantities due to radioactive decay in the long interval since testing ended. Longer-life ^{137}Cs,

Table 222. Comparison of radionuclides in surface air (fCi/m^3) on Enewetak, Livermore, California, and Balboa, Panama.

Nuclide	YVONNE	Remainder of Enewetak Atoll	Livermore, Calif., 1972	Balboa, Panama, 9°N 79°W, 1972-1973
^{7}Be	<49-193	<6-116	90-250	43-143[c]
54Mn	<0.6-2.1	<0.14-4.0	-	-
^{95}Zr	<0.4-0.4[a]	0.03-0.3	0.005-0.4	<0.9-8.5
^{103}Ru	<5.5-5.5[a]	NDET[b]	0.29-3.4	-
^{125}Sb	<0.27-0.27[a]	NDET	0.04-0.23	-
^{106}Ru	<0.9-2.6	<0.2-1.6	0.14-2.9	-
^{137}Cs	<0.49-0.82	<0.04-2.5	0.63-3.2	0.09-1.7
^{144}Ce	<2.5-3.7	<0.22-1.9	0.24-3.1	0.7-11.2
^{239,240}Pu	<0.03-2.6	<0.001-0.025	0.01-0.05	<0.001-0.030
^{238}Pu	<0.04-0.13	<0.0028-0.008	0.001-0.005	<0.001-0.003
^{241}Am	<0.3-0.30[a]	NDET	NDET	NDET

[a]Detected only one sample.
[b]Not detected.
[c]Oct.-Dec. 1972 range.

^{238}Pu, ^{239}Pu, and ^{241}Am in air could be from either local resuspension or from worldwide fallout. A comparison of activity levels at Enewetak with those observed at Livermore, California, and Balboa, Panama is shown in Table 222. It appears that, with the exception of the single sample on which 5.5 fCi/m^3 of ^{103}Ru was observed, the only airborne radionuclides present at levels consistently higher than those at the other two locations were the Pu-Am species on YVONNE, a result not too surprising, considering the known soil contamination levels on that island.

Of the 32 air samples, four were taken in October 1972 before typhoon Olga struck, and the remainder were taken between November 28 and December 19, 1972. Wind speeds were almost always greater than 10 knots and often greater than 20 knots at all sampling locations. In addition, frequent light rain showers served to keep the ground surface damp. Table 223 presents climatological data which have been published for Enewetak and Kwajalein. It is apparent that December represents a fairly average month as far as total rainfall and rainfall frequency are concerned, while average windspeeds are higher than those observed most of the year.

Radioactive Scrap and Buried Debris

Holmes and Narver, Inc., as part of the engineering survey they conducted

Table 223. Climatological data for Kwajalein and Enewetak.[a]

	Percentage of total time at each wind-speed interval												
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Av
Wind speed, knots[b]													
0-3	1	1	1	0	1	1	6	10	16	9	3	1	4.2
4-10	15	12	22	20	27	27	49	60	59	63	42	20	34.7
11-21	68	80	70	75	69	70	44	29	24	28	53	70	56.7
22-33	15	7	7	5	3	2	1	1	1	0	2	9	4.4
>33	1	0	0	0	0	0	0	0	0	0	0	0	0
Prevailing wind direction and	NE	NE	NE	NE	NE	NE	E/NE	E	NE	NE	NE	NE	--
frequency[b]	86%	87%	81%	77%	67%	64%	36% each	31%	27%	33%	55%	74%	--

Precipitation[c]	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Yr	Yr. of record
Av. amount, in.	1.02	1.84	1.86	1.28	4.57	3.37	6.45	6.81	6.24	9.09	6.30	2.63	51.46	30
Greatest amount, in.	1.95	10.21	7.33	3.86	8.38	7.03	15.35	14.41	13.17	18.07	17.38	9.18	69.86	13
Least amount, in.	0.12	0.40	0.37	0.49	0.37	1.33	1.36	4.22	1.53	2.60	1.94	0.86	24.42	13
Mean number of days, 0.01 in. or more.	11	10	13	13	16	16	21	21	20	21	21	16	198	10

[a]U. S. Hydrographic Office, Sailing Directions for the Pacific Islands, H. O. Pub. No. 82, Vol. 1, Second Edition (1964), updated to Dec. 5, 1970.

[b]Wind data for Kwajalein.

[c]Precipitation data for Enewetak.

for DNA,* estimated that there were approximately 7200 yd^3 of contaminated metal and concrete present on Enewetak Atoll in December 1972. AEC radiation monitors accompanied the H&N crews in order to identify the radioactive material. Table 224 shows the distribution of this debris on islands where this type of survey was conducted. The amounts of material listed should be taken only as an approximate lower limit, particularly on islands such as PEARL, where very heavy underbrush prevented the survey party from covering all parts of the island. In addition, it is conceivable that radioactive scrap material may be found on the other northern islands (KATE, LUCY, MARY, NANCY, OLIVE, URSULA, VERA, and WILMA), even though none of them contains ground-zero sites, and neither the aerial radiological survey nor the ground survey parties detected this type of debris.

On the southern islands, there were four locations where radioactive scrap material was found:

- On the north end of ELMER (in the "C" level area of Fig. B.37.1.b in Appendix II) there are several pieces of scrap iron with activity levels above local background.
- In the central part of ELMER (the large "E" level area of Fig. B.39.1.b) a partially shielded ^{60}Co source was found in a small storage building.

*Engineering Study for a Cleanup Plan, Enewetak Atoll-Marshall Islands, Holmes and Narver, Repts. HN-1348.1 and HN-1348.2 (1973).

Table 224. Contaminated metal and concrete scrap on Enewetak Atoll.

Island	Approximate scrap quantities	Remarks
ALICE	10 yd^3	Background is up to 170 μR/hr. An M-boat wreck on beach reads 8 mR/hr.
BELLE	Small (< 10 yd^3)	Background up to 250 μR/hr.
CLARA	Small (< 10 yd^3)	Background up to 100 μR/hr.
DAISY	Small (< 10 yd^3)	Background up to 140 μR/hr.
EDNA	None	Sandbar
IRENE	Moderate[a]	Up to 1.2 mr/hr.
JANET	568 yd^3	Activated scrap metal in all sizes can be found in piles or individual pieces scattered over the island at levels up to 8 mr/hr.
PEARL	317 yd^3	Confined to SGZ area. Levels up to 5 mr/hr.
RUBY	196 yd^3	
SALLY	2106 yd^3	Scrap-metal activity levels up to 0.12 mr/hr. Alpha levels on concrete surfaces up to 10^3 dpm/50 cm^2.
TILDA	1 yd^3	
YVONNE	4064 yd^3	Activity levels up to 60 mr/hr.
Total	7262 yd^3	

[a]Reference does not identify volume.

- In the south-central part of ELMER (the small "E" level area of Fig. B.39.1.b) there appears to be scrap metal or other radioactive debris on, or just below, the ground surface in heavy underbrush.
- On the north-central shore of GLENN (the "C" area of Fig. B.48.1.b) there is a derelict barge which is contaminated with detectable amounts of ^{207}Bi.

Because of the extremely low ambient radiation levels on the southern islands and the sensitivity of the aerial survey equipment, we can be reasonably confident that we have found all material above ground with activity levels greater than a few microroentgens per hour. On FRED, for example, the highest radiation level found (the "D" area in Fig. B.46.1.b) proved to be coming from barrels of fly ash stored in a warehouse intended to be

Table 225. Living patterns describing the geographical locations for activities involved in daily living.

	Pattern I	Pattern II
Residence	FRED, ELMER, or DAVID	FRED, ELMER, or DAVID
Agriculture	ALVIN through KEITH	KATE through WILMA + LEROY
Fishing	Entire Atoll	Entire Atoll
	Pattern III	**Pattern IV**
Residence	JANET	BELLE
Agriculture	JANET	BELLE
Fishing	Entire Atoll	Entire Atoll
	Pattern V	**Pattern VI**
Residence	JANET	JANET
Agriculture	KATE through WILMA + LEROY	ALICE through IRENE
Fishing	Entire Atoll	Entire Atoll

used for PACE drilling operations. Similarly, the nearby "C" level area proved to be a ^{60}Co source stored in a lead container in a locked building properly labeled, but of which we were unaware before the survey started.

POPULATION DOSE ASSESSMENT

The total radiation dose to the Enewetak people returning to Enewetak Atoll is determined by the sum of the contributions of each of the exposure pathways; i. e.,

$$\text{Dose} = D_{\text{inhalation}} + D_{\text{external gamma}} + D_{\text{marine food chain}} + D_{\text{terrestrial food chain}}$$

The contribution of each pathway to the total dose for an individual depends on living patterns and diet. Six living patterns, shown in Tables 225 and 226, have been selected for the dose assessment on the basis of statements made by the Enewetak people as to how and where they would like to live after they return. Similarly, the diets shown in Table 227 have been selected on the basis of the best current information on the dietary habits of the Enewetak people, the curren distribution of edible species on the Atoll and growth periods before harvest for edible species which will have to be established after return. In addition, these assessments assume that the Enewetak people will continue their current practice of using catchment rainwater for drinking and that underground

Table 226a. Estimated time distribution (in percent) for men, women, children, and infants, with emphasis on residence island. Pattern A.

	Village area	Beaches	Interior	Lagoon	Other islands
Men	50	5	15	10	20
Women	60	10	10	0	20
Children	55	10	15	5	15
Infants	85	5	0	0	10

lens water, where available, will not be a significant part of the diet.

$D_{inhalation}$

$^{239,240}Pu$ has been found to be the only significant contributor to inhalation doses on Enewetak Atoll. Airborne radioactive species observed during the survey, however, were identified as originating almost entirely from world-wide fallout or cosmic-ray activity. In order to make a conservative estimate of inhalation dosages, it has been assumed that the returning population will be exposed to air with an average dust loading of 100 $\mu g/m^3$, with the same $^{239,240}Pu$ content as the local soil, all 0.4 μm in diameter and low in solubility.

Using these assumptions and $^{239,240}Pu$ concentrations obtained from the soil samples, inhalation doses to bone, liver, and lung for each of the six living patterns have been estimated and are shown in Tables 228-230.

The "unmodified" cases represent calculations based on the $^{239,240}Pu$ content of the top 2 cm of soil, while the "modified" cases represent calculations based on the average $^{239,240}Pu$ content of the top 15 cm of soil. The latter condition would obtain if the soils were plowed or mixed during the replanting operations.

$D_{external\ gamma}$

Using gamma levels obtained from the aerial survey, estimates of the external gamma dose associated with each of the living patterns have been calculated (Table 231). In this table the "unmodified"

Table 226b. Estimated time distribution (in percent) for men, women, children, and infants with emphasis on additional time spent on nonresidence islands. Pattern B.

	Village area	Beaches	Interior	Lagoon	Other islands
Men	40	5	20	10	25
Women	50	5	15	5	25
Children	50	5	15	10	20
Infants	70	5	5	0	20

Table 227. Postulated diet for the returning adult Enewetak population for time of return and for 10 yr after initial return.

Food item	Diet, g/day: At time of return,	Diet, g/day: 10 yr after return
Fish	600	600
Domestic meat	60	100
Pandanus fruit	0	200
Breadfruit	0	150
Wild birds	100	20
Bird eggs	20	10
Arrowroot	0	40
Coconut	100	100
Coconut milk	100	300
Coconut crabs	25	25
Clams	25	25
Garden vegetables	0	0
Imports	200-1000	200-1000
	1030 plus imports	1570 plus imports

Table 228. Cumulative rems to organs from ^{239,240}Pu via inhalation pathway, bone.

LIVING PATTERN		PCI/G IN SOIL	5 YRS	EXPOSED 10 YRS	30 YRS	50 YRS	70 YRS
I.	MODIFIED	0.05	0.0000	0.0000	0.0003	0.0009	0.0018
	UNMODIFIED	0.12	0.0000	0.0001	0.0007	0.0022	0.0043
II.	MODIFIED	2.00	0.0001	0.0008	0.0122	0.0360	0.0720
	UNMODIFIED	4.70	0.0003	0.0020	0.0287	0.0846	0.1692
III.	MODIFIED	7.30	0.0004	0.0031	0.0445	0.1314	0.2628
	UNMODIFIED	17.00	0.0010	0.0071	0.1037	0.3060	0.6120
IV.	MODIFIED	15.00	0.0009	0.0063	0.0915	0.2700	0.5400
	UNMODIFIED	77.00	0.0046	0.0323	0.4697	1.3860	2.7720
V.	MODIFIED	7.30	0.0004	0.0031	0.0445	0.1314	0.2628
	UNMODIFIED	17.60	0.0011	0.0074	0.1074	0.3168	0.6336
VI.	MODIFIED	9.50	0.0006	0.0040	0.0579	0.1710	0.3420
	UNMODIFIED	14.70	0.0009	0.0062	0.0897	0.2646	0.5292

Table 229. Cumulative rems to organs from $^{239,240}Pu$ via inhalation pathway, liver.

LIVING PATTERN	PCI/G IN SOIL	5 YRS	EXPOSED 10 YRS	30 YRS	50 YRS	70 YRS
I. MODIFIED	0.05	0.0000	0.0000	0.0002	0.0005	0.0008
UNMODIFIED	0.12	0.0000	0.0000	0.0004	0.0011	0.0030
II. MODIFIED	2.00	0.0001	0.0005	0.0066	0.0186	0.0340
UNMODIFIED	4.70	0.0002	0.0011	0.0155	0.0437	0.0799
III. MODIFIED	7.30	0.0003	0.0018	0.0241	0.0679	0.1241
UNMODIFIED	17.00	0.0007	0.0041	0.0561	0.1581	0.2890
IV. MODIFIED	15.00	0.0006	0.0036	0.0495	0.1395	0.2550
UNMODIFIED	77.00	0.0031	0.0185	0.2541	0.7161	1.3090
V. MODIFIED	7.30	0.0003	0.0018	0.0241	0.0679	0.1241
UNMODIFIED	17.60	0.0007	0.0042	0.0581	0.1637	0.2992
VI. MODIFIED	9.50	0.0004	0.0023	0.0313	0.0883	0.1615
UNMODIFIED	14.70	0.0006	0.0035	0.0485	0.1367	0.2499

case represents the current conditions; "village graveled" shows the effect of placing a 5-cm gravel layer in the village area; and "__________ plowed" indicates the effect of thoroughly mixing the top 30 cm of soil in the specified area.

$D_{\text{marine food chain}}$

Doses via the marine and terrestrial food chains were estimated using the following differential equation to describe the intake and retention by man:

$$\frac{dC_{man}}{dt} = \frac{I\, f_{man}\, C}{M} - \lambda_{man}\, C_{man} \qquad (3)$$

where

C_{man} = concentration of nuclide in man, pCi/g

I = food intake, g/day,

f_{man} = fraction of nuclide ingested reaching the organ of reference,

C = concentration of nuclide in food product, pCi/g, (i.e., fish, shellfish, coconut, land crab, etc.),

M = mass of the organ of reference, (g),

and

λ_{man} = effective elimination rate of nuclide from man, (day^{-1}).

$$(\lambda_{man} = \lambda_{biological} + \lambda_{radioactive})$$

The concentration C in the food products is calculated assuming that the nuclide

Table 230. Cumulative rems to organs from $^{239,240}Pu$ via inhalation pathway, lung.

LIVING PATTERN	PCI/G IN SOIL	5 YRS	EXPOSED 10 YRS	30 YRS	50 YRS	70 YRS
I. MODIFIED	0.05	0.0000	0.0001	0.0004	0.0006	0.0009
UNMODIFIED	0.12	0.0001	0.0003	0.0009	0.0016	0.0022
II. MODIFIED	2.00	0.0017	0.0044	0.0152	0.0260	0.0360
UNMODIFIED	4.70	0.0040	0.0103	0.0357	0.0611	0.0846
III. MODIFIED	7.30	0.0063	0.0161	0.0555	0.0949	0.1314
UNMODIFIED	17.00	0.0146	0.0374	0.1292	0.2210	0.3060
IV. MODIFIED	15.00	0.0129	0.0330	0.1140	0.1950	0.2700
UNMODIFIED	77.00	0.0662	0.1694	0.5852	1.0010	1.3860
V. MODIFIED	7.30	0.0063	0.0161	0.0555	0.0949	0.1314
UNMODIFIED	17.60	0.0151	0.0387	0.1338	0.2288	0.3168
VI. MODIFIED	9.50	0.0082	0.0209	0.0722	0.1235	0.1710
UNMODIFIED	14.70	0.0126	0.0323	0.1117	0.1911	0.2646

disappears only by radioactive decay, i. e., that no other processes are in operation which reduce the nuclide availability in the food chain. Therefore $C = C_o e^{-\lambda_r t}$, where C_o is the concentration observed at the time of the survey and λ_r is the radioactive decay constant. The concentration in man at any time t after initial consumption of the food is:

$$C_{man} = \frac{I f_{man} C_o}{M(\lambda_{man} - \lambda_r)} \times \left(e^{-\lambda_r t} - e^{-\lambda_{man} t}\right), \text{ pCi/g.} \quad (4)$$

The dose at any time t after initial consumption is

$$\text{Dose (rem)} = KE\int_0^t C_{man}\, dt$$

$$= KE\int_0^t \frac{I f_{man} C_o}{M(\lambda_{man} \lambda_r)} \times \left(e^{-\lambda_r t} - e^{-\lambda_{man} t}\right) dt, \quad (5)$$

where K is a conversion constant from pCi/g to rem and equals 5.1×10^{-5} $\frac{\text{disintegrations} \cdot \text{g} \cdot \text{rem}}{\text{pCi} \cdot \text{MeV} \cdot \text{day}}$ and E is the disintegration energy of the nuclide in MeV, including a factor for relative biological effectiveness (RBE). The final dose is then determined from the integration of the equation, i. e.,

$$\text{Dose} = \frac{KEIf_{man}C_o}{M(\lambda_{man} - \lambda_r)} \times \left[\frac{1 - e^{-\lambda_r t}}{\lambda_r} - \frac{1 - e^{-\lambda_{man} t}}{\lambda_{man}}\right], \text{ rem.} \quad (6)$$

Table 232 lists the f_{man} (FMAN), $\lambda_{radioactive}$ (LR), λ_{man} (LMAN), and disintegration energy (E) values for all of the isotopes in the dose calculations.

Fish and marine organism data from the survey have been found not to have any statistically significant differences for dose estimation purposes between samples taken in different parts of the lagoon. The radionuclide concentration, C_o, used in the marine food chain dose assessment, therefore, is the average value for all fish from the entire Atoll determined from the survey and is listed in Tables 233 and 234 for each nuclide. The average values for radionuclide concentrations listed in the tables are in pCi per gram dry weight, with data corrected to pCi per gram wet

Table 231. Estimated integral external free-air gamma doses.

Case	Living pattern	Gamma dose, rad — Time interval, yr: 5	10	30	70
I	Village: FRED/ELMER/DAVID Visits to ALVIN-KEITH Time distribution: Table 137				
Unmodified		0.14	0.28	0.83	1.92
II	Village: FRED/ELMER/DAVID Visits to ALICE-WILMA Time distribution: Table 137				
Unmodified		0.38	0.68	1.59	2.97
3.	Northern islands plowed	(0.22)	(0.41)	(1.08)	(2.26)
III	Village: JANET No visits to other islands Time distribution: Table 137 with "other islands" time spent in interior of JANET				
Unmodified		0.94	1.71	3.95	6.66
1.	Village graveled	(0.82)	(1.49)	(3.48)	(5.96)
2.	JANET plowed	(0.36)	(0.68)	(1.70)	(3.24)
IV	Village: BELLE Visits to ALICE-WILMA Time distribution: Table 137				
Unmodified		2.72	4.78	10.06	15.50
1.	Village graveled	(1.78)	(3.14)	(6.69)	(10.53)
2.	Plus BELLE plowed	(0.83)	(1.47)	(3.26)	(5.47)
3.	Plus Northern islands plowed	(0.68)	(1.23)	(2.77)	(4.76)

Table 231 (continued).

Case	Living pattern	Gamma dose, rad — Time interval, yr: 5	10	30	70
V	Village: JANET				
	Visits to KATE-WILMA				
	Time distribution: Table 137				
Unmodified		0.71	1.28	2.94	5.06
	1. Village graveled	(0.59)	(1.07)	(2.48)	(4.36)
	2. Plus JANET plowed	(0.36)	(0.66)	(1.59)	(3.02)
	3. Plus KATE-WILMA plowed	(0.29)	(0.54)	(1.36)	(2.71)
VI	Village: JANET				
	Visits to ALICE-IRENE				
	Time distribution: Table 137				
Unmodified		1.15	2.03	4.39	7.13
	1. Village graveled	(1.02)	(1.81)	(3.93)	(6.43)
	2. Plus JANET plowed	(0.80)	(1.41)	(3.05)	(5.09)
	3. Plus ALICE-IRENE plowed	(0.43)	(0.78)	(1.85)	(3.39)
VIa	Village: JANET				
	Visits to ALICE-WILMA				
	Time distribution: Table 136				
Unmodified		0.76	1.37	3.12	5.33
	1. Village graveled	(0.62)	(1.12)	(2.58)	(4.51)
	2. Plus JANET plowed	(0.41)	(0.75)	(1.77)	(3.27)
	3. Plus Northern islands plowed	(0.30)	(0.56)	(1.40)	(2.76)
VIb	Village: JANET				
	Visits to ALVIN-KEITH				
	Time distribution: Table 136				
Unmodified		0.60	1.10	2.60	4.60
	1. Village graveled	(0.48)	(0.88)	(2.14)	(3.90)
	2. Plus JANET plowed	(0.25)	(0.48)	(1.26)	(2.56)
Mean population dose					
(Average of Cases I, II, III, V, and VI)					
Unmodified		0.66	1.20	2.74	4.75
	1. Village graveled	(0.59)	(1.07)	(2.46)	(4.33)
	2. Plus JANET plowed	(0.41)	(0.74)	(1.75)	(3.25)
	3. Plus All Northern islands plowed	(0.29)	(0.54)	(1.36)	(2.70)
Sea level, U.S.A.					
(80 mrad/yr) Typical		0.40	0.80	2.40	5.60

Table 232. The disintegration energy E and the radioactive half-life LR are listed for each radionuclide. The effective biological half-time LMan and the fraction of ingested isotope reaching the organ of reference FMan are listed for three receptor organs, bone, liver, and whole body.

1

NUCLIDE	E	LR	BONE MASS= 5.000E+03 -LMAN-	-FMAN-	LIVER MASS= 1.800E+03 -LMAN-	-FMAN-	WHOLEBODY MASS= 7.000E+04 -LMAN-	-FMAN-
3 H	6.287E-03	1.549E-04	5.790E-02	9.100E-02	5.790E-02	2.600E-02	5.790E-02	1.000E+00
14 C	6.087E-02	3.314E-07	1.733E-02	2.500E-02	6.930E-02	2.600E-02	6.930E-02	1.000E+00
55FE	6.540E-03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
60CO	[illegible]	[illegible]	[illegible]	[illegible]	8.191E-03	[illegible]	[illegible]	[illegible]
63NI	1.780E-02	[illegible]	[illegible]	1.500E-01	[illegible]	2.000E-02	[illegible]	[illegible]
90SR	5.500E+00	[illegible]	[illegible]	3.000E-01	1.156E-01	[illegible]	[illegible]	3.000E-01
106RU	1.400E+00	[illegible]	[illegible]	3.000E-02	[illegible]	[illegible]	[illegible]	3.000E-01
102RH	1.020E+00	6.541E-04	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.000E-01
113CD	1.800E-01	[illegible]	5.911E-03	9.000E-03	3.601E-02	[illegible]	[illegible]	5.900E-02
125SB	3.600E-01	[illegible]	7.633E-03	3.000E-03	[illegible]	6.000E-03	[illegible]	[illegible]
129 I	7.686E-02	[illegible]	4.950E-02	7.000E-02	9.986E-02	1.200E-01	[illegible]	1.000E+00
133BA	3.940E-01	[illegible]	1.093E-02	[illegible]	5.745E-04	3.000E-05	1.093E-02	5.000E-02
137CS	5.900E-01	6.329E-03	[illegible]	9.100E-02	6.383E-03	2.600E-02	7.143E-03	1.000E+00
144CE	3.754E+00	2.432E-03	2.894E-03	3.000E-05	4.797E-03	2.500E-05	3.662E-03	1.000E-04
147PM	2.297E+00	7.032E-04	1.165E-03	3.500E-05	1.760E-03	6.000E-06	1.160E-03	1.000E-04
151SM	1.523E-02	2.110E-05	4.831E-04	3.500E-05	3.727E-03	3.500E-05	1.077E-03	1.000E-04
152EU	6.600E-01	1.531E-04	3.379E-04	3.600E-05	5.610E-03	2.500E-05	3.779E-04	1.000E-04
155EU	1.600E-01	1.055E-03	1.240E-03	3.600E-05	6.511E-03	2.500E-05	1.248E-03	1.000E-04
207BI	1.000E+00	6.322E-05	5.217E-02	3.000E-04	4.026E-02	1.500E-03	1.387E-01	1.000E-02
235 U	4.600E+00	[illegible]	[illegible]	5.400E-05	1.899E-06	[illegible]	[illegible]	1.000E-04
238PU	4.600E+01	2.134E-05	[illegible]	1.350E-05	2.323E-05	1.230E-05	[illegible]	3.000E-05
239PU	5.300E+01	[illegible]	1.909E-05	1.350E-05	[illegible]	1.200E-05	[illegible]	3.000E-05
240PU	5.300E+01	[illegible]	[illegible]	[illegible]	[illegible]	1.200E-05	[illegible]	3.000E-05
241AM	5.700E+01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 233. Average concentration, number of samples in the average, standard deviation, and high and low of the range for all fish in the entire Enewetak Atoll.

NUCLIDE	TISSUE	NO. OF SAMPLES	AVERAGE PCI/GRAM*	STANDARD DEVIATION	RANGE PCI/GRAM HIGH	LOW	AVERAGE PCI/GRAM**	LOGNORMAL MEDIAN PCI/GRAM
01003	MUSCLE	9	3.955E-01	1.517E-01	7.189E-01	1.845E-01	3.955E-01	3.712E-01
19040	MUSCLE	116	1.189E+01	5.277E+00	2.697E+01	2.982E+00	1.189E+01	1.075E+01
26055	MUSCLE	123	1.574E+01	4.108E+01	3.833E+02	1.577E-01	1.566E+01	5.063E+00
27060	MUSCLE	128	2.005E+00	5.377E+00	3.827E+01	4.063E-02	1.958E+00	5.974E-01
38090	MUSCLE	125	1.562E-01	2.460E-01	1.541E+00	1.051E-03	1.177E-01	6.308E-02
44106	MUSCLE	88	8.085E-01	4.558E-01	2.237E+00	3.017E-01	0.	7.058E-01
45102	MUSCLE	128	9.044E-02	6.601E-02	3.729E-01	1.805E-02	0.	7.165E-02
48113	MUSCLE	1	2.635E-01	0.	2.635E-01	2.635E-01	2.635E-01	2.635E-01
51125	MUSCLE	128	2.449E-01	2.581E-01	2.096E+00	7.734E-02	3.910E-02	1.970E-01
55137	MUSCLE	128	3.897E-01	7.940E-01	6.779E+00	2.636E-02	3.493E-01	1.955E-01
56133	MUSCLE	104	1.431E-01	1.205E-01	7.631E-01	2.445E-02	1.598E-02	1.004E-01
58144	MUSCLE	4	2.822E-01	1.269E-02	2.975E-01	2.699E-01	0.	2.829E-01
63152	MUSCLE	128	7.826E-02	5.899E-02	3.415E-01	2.779E-02	0.	6.329E-02
63155	MUSCLE	128	1.107E-01	7.631E-02	5.212E-01	3.097E-02	1.411E-02	9.242E-02
83207	MUSCLE	128	2.409E+00	2.233E+01	2.527E+02	1.965E-02	2.372E+00	1.350E-01
92235	MUSCLE	122	7.932E-02	4.723E-02	2.547E-01	2.271E-02	0.	6.563E-02
94000	MUSCLE	123	2.477E-01	2.003E+00	2.306E+01	4.820E-04	2.444E-01	1.257E-02
94238	MUSCLE	64	1.390E-02	2.175E-02	1.140E-01	1.802E-03	5.241E-03	7.679E-03
95241	MUSCLE	128	1.144E-01	8.463E-02	8.023E-01	2.232E-02	2.771E-03	9.298E-02

*AVERAGE (IF NON-DETECTED, CONCENTRATION SET EQUAL TO DETECTION LIMIT) PCI/GRAM
**AVERAGE (IF NON-DETECTED, CONCENTRATION SET EQUAL TO ZERO) PCI/GRAM

Table 234. Radionuclide concentrations in fish (January 1972).

Nuclide	Sample	No. of Samples	Concentration, pCi/g dry weight Average	High	Low
^{137}Cs	All fish[a]	128	0.39	6.8	0.026
^{60}Co	All fish[a]	128	2.0	38	0.041
^{90}Sr	All fish[a]	125	0.16	1.5	0.0010
^{90}Sr	Eviscerated whole fish	74	0.21	---	---
^{90}Sr	Fish muscle only	51	0.075	---	---

[a]All fish includes eviscerated whole fish and those fish where muscle was separated from bone and only the muscle was analyzed.

weight for use in the dose code by dividing by 3.5, the average wet-to-dry ratio for fish from the Atoll.

Integral doses calculated from the marine survey data are listed in Table 235 for the whole body and bone for 5, 10, 30 and 70 yr. The major contribution to the whole-body dose comes from ^{137}Cs and ^{60}Co, while the bone dose comes from ^{90}Sr, as well as from ^{137}Cs and ^{60}Co. The third line of the table gives the summation of the dose to each organ from the three isotopes. The bottom entry in the table lists the dose from all radionuclides listed in the Table 235 footnote.

D terrestrial food chain

Evaluation of the potential dose to the returning population via the terrestrial food chain has been structured on the basis of the living patterns in Table 225. The quantity of radionuclides ingested via terrestrial foods was computed from the measured and predicted concentration of activities according to the expected daily diets listed in Table 227. Except for coconut and arrowroot, the daily intake of the food items listed in this table refers to g/day of fresh food. The g/day intakes listed for coconut and arrowroot refer to the dry weight intake of coconut meat (copra) and processed arrowroot starch. Inferred initial ingestion rates assuming the diet at time of return are shown in Table 236. This diet contains only foods that are available on islands of the group at the time of return, i.e., domestic meat, birds, bird eggs, coconut crabs, and, in the case of the southern islands, coconut meat and coconut milk.

The 30- and 70-yr integral doses were calculated assuming the 10-yr post-return diet. In addition to the foods that are available at the time of return, the 10-yr post-return diet includes pandanus fruit, breadfruit, arrowroot, coconut meat, and coconut milk for all islands. The initial rates of ingestion for each island group assuming the 10-yr post-return diet are listed in Table 237. These values are presented in two parts; the rates of ingestion for the foods immediately available are presented on the left side of Table 237 under January 1, 1974, while the rates of ingestion for the foods that are to become available 8 yr after return

Table 235. Integral dose[a] for 5, 10, 30, and 70 yr from the marine food chain.

	Integral dose, rem[b]							
	5 yr		10 yr		30 yr		70 yr	
Nuclide	W. B.	Bone	W. B.	Bone	W. B.	Bone	W. B.	Bone
^{137}Cs	0.0061	0.0061	0.012	0.012	0.030	0.030	0.049	0.049
^{60}Co	0.0078	0.0078	0.012	0.012	0.017	0.017	0.017	0.017
^{90}Sr	---	0.13	---	0.31	---	0.77	--	1.3
Sum	0.014	0.14	0.024	0.33	0.047	0.82	0.066	1.4
All nuclides[c]	0.016	0.14	0.028	0.34	0.053	0.84	0.089	1.6

[a]The dose is based upon the average concentration for fish from the entire Atoll and upon a dietary fish intake of 600 g/day. These doses apply to all six living patterns.

[b]The concentration data were corrected to January 1974, the earliest possible return date to the Atoll; all integral doses are calculated for periods which begin on January 1974.

[c]Isotopes included in the "All nuclides" calculation:

^{3}H	^{60}Co	^{102}Rh	^{137}Cs	^{152}Eu	^{235}U
^{14}C	^{90}Sr	^{113}Cd	^{133}Ba	^{155}Eu	^{238}Pu
^{55}Fe	^{106}Ru	^{125}Sb	^{144}Ce	^{207}Bi	^{239}Pu
					^{241}Am

are presented on the right side of Table 237 under the 8-yr post-return date, January 1, 1982. In essence, the foods immediately available are assumed to contribute to the diet beginning January 1, 1974, and the edible plants that are yet to be established are assumed to contribute to the diet beginning January 1, 1982.

Using these data, plus the integrated dose per unit rate of ingestion to whole body and bone shown in Table 238, the integral 5- and 10-yr doses shown in Table 239 have been calculated. The 5- and 10-yr dosages particularly relate to the situation during the initial few years following return.

In computing the bone dose, the whole-body dose from ^{137}Cs and the other non-bone seekers has been added to the bone dose from ^{90}Sr and $^{239,240}Pu$. The whole-body dose has been computed as the sum of the whole-body dosages from the non-bone seekers.

Similarly, integral 30- and 70-yr doses have been calculated assuming the 10-yr post-return diet (Table 240).

Total Dose

The total 30-yr integral dose predicted for whole body and for bone for the six living patterns are listed in Table 241. This table includes the contributions from each pathway and, for

Table 236. Rate of ingestion of radionuclides from terrestrial foods assuming diet at time of return (Jan. 1, 1974).

	Ingestion rate, pCi/day					
Food item	^{3}H	^{55}Fe	^{60}Co	^{90}Sr	^{137}Cs	$^{239,240}Pu$
A. Island group ALICE-IRENE						
Pork and chicken				185	3100	
Wild birds		984	6.21	1.21	<2.4	0.143
Bird eggs		69	<0.29	0.45	<0.24	0.0074
Total		1050	6.35	187	3100	0.150
B. Island group BELLF						
Pork and chicken				302	6960	
Total				302	6960	
C. Island group JANET						
Pork and chicken				108	2320	
Wild birds		1800	7.70	0.29	2.5	0.100
Bird eggs		171	<0.39	0.97	0.6	0.074
Total		1970	7.89	109	2320	0.174
D. Island group KATE-WILMA, LEROY						
Pork and chicken				47.4	858	
Wild birds		1800	7.70	0.29	2.50	0.100
Bird eggs		113	<0.28	0.02	<0.25	0.077
Coconut crabs	0.480		1.03	1.96	7.59	0.0035
Total	0.480	1900	8.87	49.7	868	0.180
E. Island group ALVIN-KEITH						
Pork and chicken				6.18	50.9	
Wild birds		1700	6.41	0.37	2.55	0.704
Bird eggs		131	<0.35	0.02	<0.35	0.003
Coconut	29.3	<23	<2.9	3.35	68.7	<0.259
Coconut milk	14.9	<11	<1.42	0.17	3.44	<0.129
Coconut crabs	2.91		4.23	2.58	9.31	0.023
Total	47.1	1850	13.7	12.7	135	0.99

Table 237. Rate of ingestion of radionuclides from terrestrial foods assuming 10-yr post-return diet.

Food item	Ingestion rate, pCi/day											
	January 1, 1974						January 1, 1982					
	^{3}H	^{55}Fe	^{60}Co	^{90}Sr	^{137}Cs	$^{239,240}Pu$	^{3}H	^{55}Fe	^{60}Co	^{90}Sr	^{137}Cs	$^{239,240}Pu$
A. Island group ALICE-IRENE												
Domestic meat				308	5170							
Pandanus fruit										941	8840	
Breadfruit										807	7570	
Wild birds		197	1.24	0.242	<0.5	0.0286						
Bird eggs		34.5	<0.14	0.226	<0.1	0.0037						
Arrowroot										47	71	
Coconut meat							23.7	664	<16.3	135	2210	18.1
Coconut milk							35.6	<37	<8.5	20	331	<1.7
Total		231	1.31	308	5170	0.0323	59.3	683	12.4	1950	19000	19
B. Island group BELLE												
Domestic meat				504	11600							
Pandanus fruit								1.34	<1.46	1540	19800	<9.5
Breadfruit								1.15	<1.25	1320	17000	<8.1
Arrowroot										77	159	
Coconut meat										221	4960	
Coconut milk										33	743	
Total				504	11600			2.50	1.35	3180	42700	8.8
C. Island group JANET												
Domestic meat				180	3870							
Pandanus fruit								7.12	<1.25	550	6610	0.082
Breadfruit								6.10	<1.07	471	5560	0.071
Wild birds		360	1.54	0.058	0.50	0.020						
Bird eggs		85.5	<0.19	0.482	0.29	0.037						
Arrowroot										28	53	
Coconut meat									<1.85	79	1650	
Coconut milk								<2.54	<2.27	12	248	<1.31
Total		445	1.64	181	3870	0.057		14.5	3.22	1140	14100	0.81

Table 237 (Continued).

Food item	Ingestion rate, pCi/day											
	January 1, 1974						January 1, 1982					
	^{3}H	^{55}Fe	^{60}Co	^{90}Sr	^{137}Cs	$^{239,240}Pu$	^{3}H	^{55}Fe	^{60}Co	^{90}Sr	^{137}Cs	$^{239,240}Pu$
D. Island group KATE-WILMA + LEROY												
Domestic meat				79	1430							
Pandanus fruit								3.94	<13.8	241	2480	0.316
Breadfruit								3.38	<11.8	207	2120	0.271
Wild birds		360	1.54	0.058	0.50	0.020						
Bird eggs		56	<0.14	0.01	<0.12	0.039						
Arrowroot										12	20	
Coconut meat							19.0	204	<1.05	34.7	619	<8.64
Coconut milk							28.5	<6.44	<2.27	5.2	93	<0.38
Coconut crabs	0.480		1.03	1.96	7.59	0.003						
Total	0.480	416	2.59	81	1440	0.062	47.5	215	14.4	500	5330	5.0
E. Island group ALVIN-KEITH												
Domestic meat				10.3	84.9							
Pandanus fruit								1.33	<0.65	9.44	85.4	0.156
Breadfruit								1.14	<0.56	8.09	73.2	0.134
Wild birds		340	1.28	0.073	0.51	0.141						
Bird eggs		65	<0.17	0.009	<0.17	0.002						
Arrowroot	Not available									0.47	0.68	
Coconut meat	29.3	<23	<2.9	3.35	68.7	<0.259						
Coconut milk	44.6	<33	<4.2	0.50	10.3	<0.386						
Coconut crabs	2.91		4.23	2.58	9.3	0.023						
Total	76.8	433	9.17	16.8	174	0.488		2.48	0.60	18.0	159	0.290

Table 238. Integrated dose per unit rate of ingestion to whole body and bone.

Nuclide	Organ	D_T, rem/pCi/day Period of integration 2 yr	5 yr	10 yr	22 yr	30 yr	62 yr	70 yr
^{3}H	Whole body	4.51(-8)[a]	1.05(-7)	1.85(-7)	3.05(-7)	3.51(-7)	4.17(-7)	4.23(-7)
^{55}Fe	Whole body	7.50(-8)	2.35(-7)	3.73(-7)	4.29(-7)	4.32(-7)	4.32(-7)	4.32(-7)
^{60}Co	Whole body	1.27(-5)	2.96(-5)	4.65(-5)	6.09(-5)	6.33(-5)	6.46(-5)	6.46(-5)
^{90}Sr	Bone	2.87(-3)	1.08(-2)	2.39(-2)	4.99(-2)	6.33(-2)	9.70(-2)	1.02(-1)
^{137}Cs	Whole body	3.49(-5)	9.62(-5)	1.89(-4)	3.74(-4)	4.71(-4)	7.22(-4)	7.61(-4)
$^{239,240}Pu$	Bone	1.51(-6)	9.39(-6)	3.71(-5)	1.75(-4)	3.19(-4)	1.27(-3)	1.59(-3)

[a] The number within parentheses denotes the power of 10. Thus, 4.51(-8) is a contraction of 4.51×10^{-8} rem/pCi/day.

Table 239. Prediction of the dosage from ingestion of terrestrial foods assuming diet at the time of return.

	Isotope	5-yr dose, rem		10-yr dose, rem	
		Whole body	Bone	Whole body	Bone
A. Island group ALICE-IRENE					
	^{3}H			2.7(-6)	
	^{55}Fe	2.5(-4)[a]		4.4(-4)	
	^{60}Co	1.9(-4)		4.5(-4)	
	^{90}Sr		2.02		10.1
	^{137}Cs	0.298		1.25	
	$^{239,240}Pu$		1.4(-6)		3.4(-5)
	Subtotal	0.298	2.02	1.25	10.1
	Total 5-yr whole-body dose		0.30 rem	Total 10-yr whole-body dose	1.25 rem
	Total 5-yr bone dose		2.32 rem	Total 10-yr bone dose	11.3 rem
B. Island group BELLE					
	^{55}Fe			1.9(-7)	
	^{60}Co			1.7(-5)	
	^{90}Sr		3.26		16.3
	^{137}Cs	0.669		2.81	
	$^{239,240}Pu$				1.3(-5)
	Subtotal	0.67	3.26	2.81	16.3
	Total 5-yr whole-body dose		0.67 rem	Total 10-yr whole-body dose	2.81 rem
	Total 5-yr bone dose		3.93 rem	Total 10-yr bone dose	19.2 rem

Table 239 (Continued).

	Isotope	5-yr dose, rem Whole body	5-yr dose, rem Bone	10-yr dose, rem Whole body	10-yr dose, rem Bone
C. Island group JANET					
	^{55}Fe	4.6(-4)		7.4(-4)	
	^{60}Co	2.3(-4)		4.1(-4)	
	^{90}Sr		1.18		5.88
	^{137}Cs	0.223		0.831	
	^{239,240}Pu		1.6(-6)		7.6(-6)
	Subtotal	0.224	1.18	0.932	5.88
	Total 5-yr whole-body dose	0.22 rem		Total 10-yr whole-body dose	0.93 rem
	Total 5-yr bone dose	1.40 rem		Total 10-yr bone dose	6.82 rem
D. Island group KATE-WILMA + LEROY					
	^{3}H	5.0(-8)		2.2(-6)	
	^{55}Fe	4.5(-4)		7.3(-4)	
	^{60}Co	2.6(-4)		6.0(-4)	
	^{90}Sr		0.536		2.62
	^{137}Cs	0.0835		0.350	
	^{239,240}Pu		1.7(-6)		1.4(-5)
	Subtotal	0.0842	0.536	0.351	2.62
	Total 5-yr whole-body dose	0.084 rem		Total 10-yr whole-body dose	0.351 rem
	Total 5-yr bone dose	0.620 rem		Total 10-yr bone dose	2.97 rem

Table 239 (Continued)

	Isotope	5-yr dose, rem		10-yr dose, rem	
		Whole body	Bone	Whole body	Bone
E. Island group ALVIN-KEITH					
	^{3}H	4.9(-6)		8.7(-6)	
	^{55}Fe	4.4(-4)		6.9(-4)	
	^{60}Co	4.1(-4)		6.5(-4)	
	^{90}Sr		0.137		0.355
	^{137}Cs	0.0130		0.0311	
	$^{239,240}Pu$		9.3(-6)	0.0324	3.7(-5)
	Subtotal	0.0138	0.137	0.0324	0.303
	Total 5-yr whole-body dose	0.014 rem		Total 10-yr whole-body dose	0.032 rem
	Total 5-yr bone dose	0.151 rem		Total 10-yr bone dose	0.387 rem

[a]The number within parentheses denotes the power of 10. Thus, 2.5(-4) is a contraction of 2.5×10^{-4}.

Table 240. Prediction of the dosage from ingestion of terrestrial foods assuming 10-yr post-return diet.

Isotope	Ingestion rate, pCi/day January 1, 1974	30-yr dose, rem		70-yr dose, rem		Ingestion rate, pCi/day January 1, 1984	22-yr dose, rem		62-yr dose, rem	
		Whole body	Bone	Whole body	Bone		Whole body	Bone	Whole body	Bone
A. Island group										
ALICE-IRENE										
^{3}H						59.3	1.8(-5)		2.5(-5)	
^{55}Fe	231	1.0(-4)[a]		1.0(-4)		683	0.0003		0.0003	
^{60}Co	1.31	8.3(-5)		8.5(-5)		12.4	0.0008		0.0008	
^{90}Sr	308		19.5		31.5	1950		97.3		190
^{137}Cs	5170	2.44		3.93		19,000	7.11		13.7	
$^{239,240}Pu$	0.0323		1.0(-5)		5.1(-5)	19		0.003		0.024
Subtotal		2.44	19.5	3.93	31.5		7.11	97.3	13.7	190
Total 30-yr whole-body dose		9.55 rem				Total 70-yr whole-body dose		17.7 rem		
Total 30-yr bone dose		126 rem				Total 70-yr bone dose		239 rem		
B. Island group										
BELLE										
^{55}Fe						2.50	1.1(-6)		1.1(-6)	
^{60}Co						1.35	8.2(-5)		8.7(-5)	
^{90}Sr	504		31.9		51.4	3180		159		309
^{137}Cs	11,600	5.46		8.83		42,700	16.0		30.8	
$^{239,240}Pu$						8.8		1.5(-3)		1.1(-2)
Subtotal		5.46	31.9	8.83	51.4		16.0	159	30.8	309
Total 30-yr whole-body dose		21.4 rem				Total 70-yr whole-body dose		39.6 rem		
Total 30-yr bone dose		212 rem				Total 70-yr bone dose		400 rem		

Table 240 (Continued).

Isotope	Ingestion rate, pCi/day January 1, 1974	30-yr dose, rem Whole body	30-yr dose, rem Bone	70-yr dose, rem Whole body	70-yr dose, rem Bone	Ingestion rate, pCi/day January 1, 1984	22-yr dose, rem Whole body	22-yr dose, rem Bone	62-yr dose, rem Whole body	62-yr dose, rem Bone
C. Island group JANET										
^{55}Fe	445	1.9(-4)		1.9(-4)		14.5	6.2(-6)		6.2(-6)	
^{60}Co	1.64	1.0(-4)		1.1(-4)		3.22	2.0(-4)		2.1(-4)	
^{90}Sr	181		11.4		18.4	1140		56.9		111
^{137}Cs	3870	1.82		2.95		14,100	5.28		10.2	
$^{239,240}Pu$	0.057		1.8(-5)		9.1(-5)	0.806		1.4(-4)		1.0(-3)
Subtotal		1.82	11.4	2.95	18.4		5.28	56.9	10.2	111
Total 30-yr whole-body dose		7.10 rem				Total 70-yr whole-body dose	13.1 rem			
Total 30-yr bone dose		75.4 rem				Total 70-yr bone dose	142 rem			
D. Island group KATE-WILMA + LEROY										
^{3}H	0.480	2(-7)		2.0(-7)		47.5	1.5(-5)		2.0(-5)	
^{55}Fe	416	1.8(-4)		1.8(-4)		215	9.2(-5)		9.3(-5)	
^{60}Co	2.59	1.6(-4)		1.7(-4)		14.4	8.8(-4)		9.3(-4)	
^{90}Sr	81.0		5.13		8.26	500		24.9		48.5
^{137}Cs	1440	0.677		1.09		5330	1.99		3.85	
$^{239,240}Pu$	0.062		2.0(-5)		9.8(-5)	4.96		8.7(-4)		6.3(-3)
Subtotal		0.677	5.13	1.09	8.26		1.99	24.9	3.85	48.5
Total 30-yr whole-body dose		2.67 rem				Total 70-yr whole-body dose	4.94 rem			
Total 30-yr bone dose		32.7 rem				Total 70-yr bone dose	61.7 rem			

Table 240 (Continued).

Isotope	Ingestion rate, pCi/day January 1, 1974	30-yr dose, rem Whole body	30-yr dose, rem Bone	70-yr dose, rem Whole body	70-yr dose, rem Bone	Ingestion rate, pCi/day January 1, 1984	22-yr dose, rem Whole body	22-yr dose, rem Bone	62-yr dose, rem Whole body	62-yr dose, rem Bone
E. Island group										
ALVIN-KEITH										
^{3}H	76.8	1.3(-5)		3.3(-5)						
^{55}Fe	433	1.9(-4)		1.9(-4)		2.48	1.1(-6)		1.1(-6)	
^{60}Co	9.17	5.8(-4)		5.9(-4)		0.60	3.7(-5)		3.9(-5)	
^{90}Sr	16.8		1.07		1.72	18.0		0.898		1.75
^{137}Cs	174	0.0819		0.132		159	0.0596		0.115	
$^{239,240}Pu$	0.49		1.6(-4)		7.8(-4)	0.290		1.8(-4)		1.3(-3)
Subtotal		0.0826	1.07	0.133	1.72		0.0596	0.898	0.115	1.75
Total 30-yr whole-body dose		0.142 rem				Total 70-yr whole-body dose		0.248 rem		
Total 30-yr bone dose		2.11 rem				Total 70-yr bone dose		3.71 rem		

[a]The number within parentheses denotes the power of 10; thus, 1.0(-4) is a contraction of 1.0×10^{-4}.

Table 241. The 30-yr integral dose for the six living patterns assuming unmodified conditions.

	30-yr integral dose, rem — Unmodified conditions									
	Inhalation			External	Terrestrial[b]		Marine[b]		Total	
Living pattern	Bone	Lung	Liver	Bone,[a] W.B.	W.B.	Bone	W.B.	Bone	W.B.	Bone
I	7(-4)	9(-4)	4(-4)	0.83	0.14	2.1	0.053	0.84	1.0	3.8
II	0.029	0.036	0.016	1.6	2.7	33	0.053	0.84	4.4	35
III	0.10	0.13	0.056	4.0	7.1	75	0.053	0.84	11	80
IV	0.47	0.59	0.25	10	21	210	0.053	0.84	31	220
V	0.11	0.13	0.058	2.9	2.7	33	0.053	0.84	5.7	37
VI	0.090	0.11	0.049	4.4	9.6	130	0.053	0.84	14	135

Living pattern	Village island	Agriculture	Visitation
I	Enewetak-Parry	ALVIN-KEITH	Southern Is.
II	Enewetak-Parry	KATE-WILMA + LEROY	Northern Is.
III	JANET	JANET	Northern Is.
IV	BELLE	BELLE	Northern Is.
V	JANET	KATE-WILMA + LEROY	Northern Is.
VI	JANET	ALICE-IRENE	Northern Is.

[a]Taken from the chapter on external dose estimates, Table 22.
[b]Based upon diet 10 yr after return, as described in the dietary and living patterns chapter.

the external dose assessment, is based upon the unmodified conditions for the village island. The largest contribution to the whole-body and bone doses comes from the terrestrial food chain, the external dose pathway is the next highest contributor, and the marine food chain and inhalation pathway contribute the least.* The relative contributions of each diet component to the terrestrial pathway dose is shown in Tables 242 and 243.

In general, living on JANET, visiting northern islands, and maintaining agriculture on northern islands (living patterns III, V, and VI) lead to significantly higher doses than if the village and agriculture are located on islands in the southern half of the Atoll (living pattern I). Doses for these same patterns have been calculated for 5, 10, and 70 yr and are shown in Table 244.

The most significant contribution via the terrestrial food chain is the dose to bone resulting from ^{90}Sr uptake via pandanus fruit and breadfruit. For living pattern III, for example, the total terrestrial bone dose is 75 rem, of which 74% is derived from the intake of breadfruit and pandanus. It is important to note, however, that the large contribution to the bone dose via these fruits occurs only when they are grown on northern islands. Pandanus and breadfruit grown on the less contaminated southern islands lead to much lower dose commitments.

Table 245 shows the 30-yr integral dose for the six living patterns for the modified soil condition, i. e., where the village area has 5 cm of gravel and the village island is plowed. Table 246 shows the 5-, 10-, 30-, and 70-yr dose estimates for the same conditions.

Table 247 shows the additional effect on the 30-yr integral dose of limiting growth of pandanus, breadfruit, coconut, and tacca to the southern islands, while Table 248 shows the effect of limiting all terrestrial foods to the southern islands. The effect of the combination of these preventive measures reduces the dose for living pattern III from 11 rem to 1.9 rem for whole body and from 80 to 4.7 rem for bone.

A comparison of the 30-yr integral dose for living patterns I and III relative to the average United States external background dose over 30 yr is shown in Table 249.

Plutonium isotopes, because of their long half-lives, will still be present when the other major isotopes observed at the Atoll have decayed away; therefore, Tables 250 and 251 are included to show the predicted doses from plutonium to the three major receptor organs (lung, liver, and bone) via the three relevant exposure pathways.

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*As indicated earlier, these dose calculations assume that the Enewetak people will continue their current practice of using catchment rain water for drinking and that the underground lens water supply will not be a part of their diet. An indication of doses that are to be expected from lens water may be obtained from four water samples taken on JANET in July 1971. These samples, two each from each of two 2.5-m-deep holes about 100 m from the lagoon shore, gave average concentrations of 130 pCi/liter for ^{90}Sr, and 400 pCi/liter for ^{137}Cs. ^{239}Pu concentrations were scattered (<0.03, 21, <0.03, and 17 pCi/liter) but, for our current purpose, we will assume an average value of 20 pCi/liter.

Using these concentrations, and assuming an average daily intake of 100 ml of lens water, the resulting 30-yr doses would be 0.83 rem due to ^{90}Sr, 0.019 rem due to ^{137}Cs, and 0.00082 rem due to ^{239}Pu.

The island of YVONNE presents a unique hazard on Enewetak Atoll. Pure plutonium particles are present on or close to the ground surface, randomly scattered in "hot spots" over most of the area from the tower to CACTUS crater. Examination of these "hot spots" has revealed the presence of occasional milligram-size pieces of plutonium metal, as well as smaller pieces which are physically indistinguishable in size from the surrounding coral matrix. Given these current conditions, it must be assumed that pure plutonium particles of respirable size are now also present on the surface or may be present in the future as weathering effects oxidize and break down the larger particles. Lung dose assessments for this area, therefore, must be based on inhalation of pure plutonium particles rather than those having the average plutonium content of the soil.

The potential health hazard via the inhalation pathway is sufficiently great to dictate two basic alternatives for remedial action for this island: (1) Make the entire island an exclusion area – off limits to all people, or (2) conduct a cleanup campaign which will eliminate the "hot-spot" plutonium problem and remove whatever amount of soil is necessary to reduce the soil plutonium concentration to a level comparable to other northern islands. As an indication of the volumes of soil involved, removal of a 10-cm-thick layer of topsoil in the area in which "hot spots" have been detected involves approximately 17,000 m^3 of material. Further removal of soil to reduce the maximum plutonium contamination levels to 50 pCi/g or less involves an additional 25,000 m^3 of material.

Table 242. Relative contributions of terrestrial foods to the integral dose assuming diet at time of return.

Food item	Percentage of total 5-yr		Percentage of total 10-yr	
	^{90}Sr dose to bone	^{137}Cs dose whole body	^{90}Sr dose to bone	^{137}Cs dose whole body
A. Island group ALICE-IRENE				
Domestic meat	98.9	100	43.9	46.9
Pandanus fruit			26.8	24.7
Breadfruit			23.1	21.1
Wild birds	0.65	<0.08	0.29	0.04
Bird eggs	0.24	<0.008	0.11	0.004
Arrowroot			1.3	0.20
Coconut meat			3.9	6.2
Coconut milk			0.57	0.93
B. Island group BELLE				
Domestic meat	100	100	44.2	47.1
Pandanus fruit			27.0	24.6
Breadfruit			23.2	21.1
Arrowroot			1.4	0.20
Coconut meat			3.9	6.2
Coconut milk			0.58	0.92

Table 242 (continued)

Food item	Percentage of total 5-yr		Percentage of total 10-yr	
	^{90}Sr dose to bone	^{137}Cs dose whole body	^{90}Sr dose to bone	^{137}Cs dose whole body
C. Island group JANET				
Domestic meat	99.1	100	43.9	47.0
Pandanus fruit			26.9	24.8
Breadfruit			22.9	20.8
Wild birds	0.27	0.11	0.12	0.05
Bird eggs	0.89	0.03	0.39	0.01
Arrowroot			1.4	0.20
Coconut meat			3.9	6.2
Coconut milk			0.59	0.93
D. Island group KATE-WILMA + LEROY				
Domestic meat	95.4	98.8	43.1	46.3
Pandanus fruit			26.4	24.7
Breadfruit			22.7	21.1
Wild birds	0.58	0.29	0.26	0.14
Bird eggs	0.04	<0.03	0.02	0.01
Arrowroot			1.3	0.20
Coconut meat			3.8	6.2
Coconut milk			0.57	0.93
Coconut crabs	3.9	0.87	2.4	0.41
E. Island group ALVIN-KEITH				
Domestic meat	48.7	37.7	41.7	30.9
Pandanus fruit			7.6	9.6
Breadfruit			6.5	8.2
Wild birds	2.9	1.9	2.5	1.5
Bird eggs	0.2	<0.26	0.13	0.21
Arrowroot			0.38	0.08
Coconut meat	26.4	50.9	22.6	41.8
Coconut milk	1.4	2.5	1.1	2.1
Coconut crabs	20.3	6.9	17.4	5.6

Table 243. Relative contributions of terrestrial foods to the integral dose assuming 10-yr post-return diet.

	Percentage of total 30-yr dose				Percentage of total 70-yr dose			
	^{90}Sr dose to bone		^{137}Cs dose to whole body		^{90}Sr dose to bone		^{137}Cs dose to whole body	
	Commencement date		Commencement date		Commencement date		Commencement date	
Food item	1/1/74	1/1/82	1/1/74	1/1/82	1/1/74	1/1/82	1/1/74	1/1/82
A. Island group ALICE-IRENE								
Domestic meat	16.7		25.5		14.2		22.3	
Pandanus fruit		40.2		34.7		41.4		36.2
Breadfruit		34.5		29.6		35.5		31.0
Wild birds	0.01		<0.002		0.01		<0.002	
Bird eggs	0.01		<0.0005		0.01		<0.004	
Arrowroot		2.0		0.28		2.1		0.29
Coconut meat		5.8		8.7		5.9		9.1
Coconut milk		0.85		1.3		0.88		1.4
Subtotal	17	83	26	74	14	86	22	78
B. Island group BELLE								
Domestic meat	16.7		25.4		14.3		22.3	
Pandanus fruit		40.2		34.5		41.5		36.1
Breadfruit		34.5		29.6		35.6		31.0
Arrowroot		2.0		0.27		2.1		0.29
Coconut meat		5.8		8.7		6.0		9.0
Coconut milk		0.86		1.3		0.89		1.4
Subtotal	17	83	25	75	14	86	22	78

Table 243 (Continued).

Food item	Percentage of total 30-yr dose: ^{90}Sr dose to bone, Commencement date 1/1/74	1/1/82	^{137}Cs dose to whole body, Commencement date 1/1/74	1/1/82	Percentage of total 70-yr dose: ^{90}Sr dose to bone, Commencement date 1/1/74	1/1/82	^{137}Cs dose to whole body, Commencement date 1/1/74	1/1/82
C. Island group JANET								
Domestic meat	16.7		25.7		14.2		22.6	
Pandanus fruit		39.6		34.8		41.2		36.6
Breadfruit		34.4		29.3		35.3		30.7
Wild birds	0.005		0.003		0.005		0.003	
Bird eggs	0.05		0.002		0.04		0.002	
Arrowroot		2.0		0.28		2.1		0.29
Coconut meat		5.8		8.7		5.9		9.1
Coconut milk		0.88		1.3		0.90		1.4
Subtotal	17	83	26	74	14	86	23	77
D. Island group KATE-WILMA + LEROY								
Domestic meat	16.6		25.2		14.2		22.0	
Pandanus fruit		39.8		34.8		41.2		36.2
Breadfruit		34.2		29.7		35.4		30.9
Wild birds	0.01		0.009		0.01		0.008	
Bird eggs	0.002		0.003		0.002		0.002	
Arrowroot		2.0		0.28		2.0		0.29
Coconut meat		5.7		8.7		5.9		9.0
Coconut milk		0.86		1.3		0.89		1.4
Coconut crabs	0.41		0.13		0.35		0.12	
Subtotal	17	83	25	75	15	85	22	78

Table 243 (Continued).

	Percentage of total 30-yr dose				Percentage of total 70-yr dose			
	^{90}Sr dose to bone		^{137}Cs dose to whole body		^{90}Sr dose to bone		^{137}Cs dose to whole body	
	Commencement date		Commencement date		Commencement date		Commencement date	
Food item	1/1/74	1/1/82	1/1/74	1/1/82	1/1/74	1/1/82	1/1/74	1/1/82
E. Island group ALVIN-KEITH								
Domestic meat	33.3		28.3		30.3		26.2	
Pandanus fruit		24.1		22.5		26.5		25.0
Breadfruit		20.6		19.4		22.7		21.4
Wild birds	0.24		0.17		0.22		0.16	
Bird eggs	0.03		0.06		0.03		0.05	
Arrowroot		1.2		0.18		1.3		0.20
Coconut meat	10.8		22.9		9.9		21.2	
Coconut milk	1.6		3.4		1.5		3.2	
Coconut crabs	8.3		3.1		7.6		2.9	
Subtotal	54	46	58	42	50	50	54	46

Table 244. The 5-, 10-, 30-, and 70-yr doses for the six living patterns assuming unmodified conditions.

Living pattern	5 yr W. B.	5 yr Bone	10 yr W. B.	10 yr Bone	30 yr W. B.	30 yr Bone	70 yr W. B.	70 yr Bone
	Total integral dose, rem Unmodified conditions							
I	0.17	0.58	0.35	1.4	1.0	3.8	2.3	8.5
II	0.48	1.3	1.1	4.3	4.4	35	8.0	68
III	1.2	2.6	2.7	9.2	11	80	20	150
IV	3.4	6.9	7.6	25	31	220	56	420
V	0.81	1.6	1.7	4.9	5.7	37	10	71
VI	1.5	3.8	3.3	14	14	135	25	250

Table 245. The 30-yr integral dose for the six living patterns assuming modified conditions.

Living pattern	Inhalation Bone	Inhalation Lung	Inhalation Liver	External Bone, W.B.	Terrestrial W.B.	Terrestrial Bone	Marine W.B.	Marine Bone	Total W.B.	Total Bone
	30-yr integral dose, rem Modified conditions[a]									
I	3(-4)	4(-4)	2(-4)	0.83	0.14	2.1	0.053	0.84	1.0	3.8
II	0.012	0.015	6.6(-3)	1.1	2.7	33	0.053	0.84	3.9	35
III	0.045	0.056	0.024	1.7	7.1	75	0.053	0.84	8.9	78
IV	0.092	0.11	0.050	3.3	21	210	0.053	0.84	24	215
V	0.045	0.056	0.024	1.6	2.7	33	0.053	0.84	4.4	35
VI	0.058	0.072	0.031	3.1	9.6	130	0.053	0.84	13	135

[a]Modified by graveling the village area and by plowing the village island.

Table 246. The 5-, 10-, 30-, and 70-yr doses for the six living patterns assuming modified conditions.

	Total integral dose, rem Modified conditions[a]							
Living pattern	5 yr		10 yr		30 yr		70 yr	
	W. B.	Bone	W. B.	Bone	W. B.	Bone	W. B.	Bone
I	0.17	0.58	0.35	1.4	1.0	3.8	2.3	8.5
II	0.48	1.3	1.1	4.3	3.9	35	8.0	68
III	0.60	2.1	1.7	8.2	8.9	78	16	150
IV	1.5	5.0	4.3	22	24	215	46	410
V	0.46	1.3	1.0	4.3	4.4	35	8.0	68
VI	1.1	3.4	2.7	13	13	135	23	250

[a]Modified by gravelling the village area and plowing the village island.

Table 247. The 30-yr integral dose for the six living patterns assuming modified conditions and agriculture on the southern islands.

	30-yr integral dose, rem Modified conditions[a] and pandanus, breadfruit, coconut, and tacca grown on southern islands									
	Inhalation			External	Terrestrial[c]		Marine		Total	
Living pattern	Bone	Lung	Liver	Bone, W.B.	W.B.	Bone	W.B.	Bone	W.B.	Bone
I	3(-4)	4(-4)	2(-4)	0.83	0.14	2.1	0.053	0.84	1.0	3.8
II	0.012	0.015	0.0066	1.1	0.77	7.1	0.053	0.84	1.9	9.1
III	0.045	0.056	0.024	1.7	1.9	15	0.053	0.84	3.7	18
IV	0.092	0.11	0.050	3.3	5.7	39	0.053	0.84	9.1	43
V	0.045	0.056	0.024	1.6	0.77	7.1	0.053	0.84	2.4	9.6
VI	0.058	0.072	0.031	3.1	2.5	23	0.053	0.84	5.7	27

[a]Modified by graveling the village area and by plowing the village island.

Table 248. The 30-yr integral dose for the six living patterns assuming modified conditions and agriculture on the southern islands.

Living pattern	Inhalation			External	Terrestrial		Marine		Total	
	30-yr integral dose, rem Modified conditions[a] and agriculture on southern islands									
	Bone	Lung	Liver	Bone, W.B.	W.B.	Bone	W.B.	Bone	W.B.	Bone
I	3(-4)	4(-4)	2(-4)	0.83	0.14	2.1	0.053	0.84	1.0	3.8
II	0.012	0.015	0.0066	1.1	0.14	2.1	0.053	0.84	1.3	4.1
III	0.045	0.056	0.024	1.7	0.14	2.1	0.053	0.84	1.9	4.7
IV	0.092	0.11	0.050	3.3	0.14	2.1	0.053	0.84	3.5	6.3
V	0.045	0.056	0.024	1.6	0.14	2.1	0.053	0.84	1.8	4.6
VI	0.058	0.072	0.031	3.1	0.14	2.1	0.053	0.84	3.3	6.1

[a]Modified by graveling the village area and by plowing the village island.

Table 249. The 30-yr integral dose from all pathways compared to U. S. external background dose.

Location	30-yr integral dose,[a] rem			
	Unmodified case		Modified case	
	Whole body	Bone	Whole body	Bone
Enewetak Atoll Living pattern I	1.0	3.8	1.0	3.8
Enewetak Atoll Living pattern III	11	80	8.9	78
Enewetak Atoll Living pattern III, agriculture confined to southern islands	4.2	7.0	1.9	4.7
U. S. background only[b]	3.0	3.0	3.0	3.0

[a]Sum of all pathways for the Enewetak living patterns (i.e., external, inhalation, marine, and terrestrial).
[b]Based upon background of 100 mrem/yr at sea level.

Table 250. The plutonium 30-yr integral dose to bone, liver, and lung via the three exposure pathways. This table assumes unmodified conditions on the village island.

Plutonium 30-yr integral dose, rem
Unmodified conditions

Living pattern	Marine			Terrestrial			Inhalation			Total		
	Bone	Liver	Lung	Bone	Liver	Lung	Bone	Liver	Lung	Bone	Liver	Lung
I	0.018	0.047	-	5.0(-5)	1.8(-4)	-	7(-4)	4(-4)	9(-4)	0.018	0.048	9(-4)
II	0.018	0.047	-	1.5(-3)	5.0(-3)	-	0.029	0.016	0.036	0.049	0.068	0.036
III	0.018	0.047	-	6.9(-3)	5.3(-3)	-	0.10	0.056	0.13	0.12	0.11	0.13
IV	0.018	0.047	-	3.0(-3)	0.010	-	0.47	0.25	0.59	0.49	0.31	0.59
V	0.018	0.047	-	5.0(-5)	1.8(-4)	-	0.11	0.058	0.13	0.13	0.11	0.13
VI	0.018	0.047	-	3.0(-3)	0.010	-	0.090	0.049	0.11	0.11	0.11	0.11

Table 251. The plutonium 30-yr integral dose to bone, liver, and lung via the three exposure pathways. This table assumes modified conditions.

Plutonium 30-yr integral dose, rem
Modified conditions

Living pattern	Marine			Terrestrial			Inhalation			Total		
	Bone	Liver	Lung	Bone	Liver	Lung	Bone	Liver	Lung	Bone	Liver	Lung
I	0.018	0.047	-	5.0(-5)	1.8(-4)	-	3(-4)	2(-4)	4(-4)	0.018	0.047	4(-4)
II	0.018	0.047	-	1.5(-3)	5.0(-3)	-	0.012	0.0066	0.015	0.032	0.057	0.015
III	0.018	0.047	-	6.9(-3)	5.3(-3)	-	0.045	0.024	0.056	0.070	0.076	0.056
IV	0.018	0.047	-	3.0(-3)	0.010	-	0.092	0.050	0.11	0.11	0.11	0.11
V	0.018	0.047	-	5.0(-5)	1.8(-4)	-	0.045	0.024	0.056	0.063	0.071	0.056
VI	0.018	0.047	-	3.0(-3)	0.010	-	0.058	0.031	0.072	0.079	0.088	0.072

APPENDIX III

REVIEW OF RADIATION PROTECTION STANDARDS

The Task Group has considered a number of concepts in devising an approach to guidance for cleanup and rehabilitation of Enewetak Atoll, accepting some and rejecting others. The concept that AEC recommendations should consists of a series of alternatives or fall back positions with the degree or level of radiation exposure reduction ultimately determined by some later deliberation based on factors such as availability of funds or reaction by others was rejected. The consensus of the Task Group opinion was that these recommendations should be specific and unequivocal, and should establish a clear position on what is needed. To do less would be unfair to the federal agencies who have accepted responsibilities to perform the rehabilitations and to the Enewetak people who are looking to this agency for advise.

The judgment of the Task Group is that rehabilitation must conform with current radiation standards and with good health physics practice in implementing these standards. A summary of current radiation protection standards and material related to health risks that may be associated with standards reviewed and radiation criteria recommended by the Task Group follows.

A. <u>Federal Radiation Council (FRC)</u>

Basic FRC numerical guidance and health protection philosophy are similar to those of the ICRP and NCRP. Radiation Protection Guides (RPG's) are provided which deal with exposures of individuals and of population groups. Actions are to be directed primarily toward control of the sources of radioactivity to restrict entry into the environment but also toward control of radioactive materials after entry into the environment in order to limit intake by humans. The RPG's express the dose that should not be exceeded without careful consideration of the reasons for doing so. Every effort should be made to encourage the maintenance of radiation doses as far below this guide as practicable. The RPG's are intended for use with normal peacetime operations. There should be no man-made radiation exposure without expectation of benefits from such exposure. Considering such benefits, exposure at the level of the RPG is considered as an acceptable risk for a lifetime. The RPG's for the population are expressed in terms of annual exposure, except for the gonads, where the ICRP recommended value of 5 rems in 30 years is used. FRC states that the operational mechanism described for application of criteria to limit the whole body dose for individuals to 0.5 rem per year and to limit exposure of a suitable sample of the population to 0.17 rem per year is likely to assure that the gonadal exposure guide will not be exceeded.

The child, infant, and unborn infant are identified as being more sensitive to radiation than the adult. Exposures to be compared with the guidance are to be derived for the most sensitive members in the population. The guide for the individual applies when individual exposures are known;

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Basic FRC numerical guidance and health protection philosophy are similar to those of the ICRP and NCRP. Radiation Protection Guides (RPG's) are provided which deal with exposures of individuals and of population groups. Actions are to be directed primarily toward control of the sources of radioactivity to restrict entry into the environment but also toward control of radioactive materials after entry into the environment in order to limit intake by humans. The RPG's express the dose that should not be exceeded without careful consideration of the reasons for doing so. Every effort should be made to encourage the maintenance of radiation doses as far below this guide as practicable. The RPG's are intended for use with normal peacetime operations. There should be no man-made radiation exposure without expectation of benefits from such exposure. Considering such benefits, exposure at the level of the RPG is considered as an acceptable risk for a lifetime. The RPG's for the population are expressed in terms of annual exposure, except for the gonads, where the ICRP recommended value of 5 rems in 30 years is used. FRC states that the operational mechanism described for application of criteria to limit the whole body dose for individuals to 0.5 rem per year and to limit exposure of a suitable sample of the population to 0.17 rem per year is likely to assure that the gonadal exposure guide will not be exceeded.

The child, infant, and unborn infant are identified as being more sensitive to radiation than the adult. Exposures to be compared with the guidance are to be derived for the most sensitive members in the population. The guide for the individual applies when individual exposures are known;

otherwise, the guide for a suitable sample (one-third the guide for the individual) is to be used. This operational technique may be modified to meet special situations.

The FRC primary numerical guides, expressed in rem, are provided in two reports, FRC Nos. 1 and 2, summarized in Table I. Secondary numerical guides developed by FRC are expressed in terms of daily intake of specific radionuclides corresponding to the annual RPG's. Consideration is given to all radionuclides through all pathways to derive a total annual exposure for comparison with FRC guides. However, for many practical situations a relatively few radionuclides yield the major contribution to total exposure; by comparison, exposures from others are very small.

TABLE I

FRC RADIATION PROTECTION GUIDES 1/

	Individual	Population Group
Whole body	0.5 rem/yr	0.17 rem/yr
Gonads	-	5 rems/30 yrs
Thyroid 2/	1.5 rems/yr	0.5 rem/yr
Bone marrow	0.5 rem/yr	0.17 rem/yr
Bone	1.5 rems/yr	0.5 rem/yr
Bone (alternate 3/ guide)	0.003 μg of ^{226}Ra in adult skeleton	0.001 γg of ^{226}Ra in adult skeleton

1/ For conditions and qualifications see FRC Report Nos. 1 and 2.
2/ Based upon a childs thyroid, 2 gms in weight and other factors listed in paragraphs 2.10-2.14 of FRC Report No. 2.
3/ Or the biological equivalents of these amounts of ^{226}Ra.

B. <u>The International Commission on Radiological Protection (ICRP)</u>

The ICRP originated in the Second International Congress of Radiology in 1928. It has been looked to as the appropriate body to give general guidance on widespread use of radiation sources caused by rapid developments in the field of nuclear energy. ICRP recommendations deal with the basic principles of radiation protection. To the various national protection bodies is left the responsibility for introducing the detailed technical regulations, recommendations, or codes of practice best suited to their countries. Recommendations are intended to guide the experts responsible for radiation protection practice.

ICRP states that the objectives of radiation protection are to prevent acute radiation effects and to limit the risks of late effects to an acceptable level. It holds that it is unknown whether a threshold exists, and it is assumed that even the smallest doses involve a proportionately small risk. No practical alternative was found to assuming a linear relationship between dose and effect. This implies that there is no wholly "safe" dose of radiation.

Exposure to natural background radiation carries a probability of causing some somatic or hereditary injury. However, the Commission believes that the risk resulting from exposures received from natural background should not affect the justification of an additional risk from man-made exposures. Accordingly, any dose limitations recommended by the Commission refer only to exposure resulting from technical practices that add to natural background radiation. These dose limitations exclude exposures received in the course of medical procedures. (These same qualifications with regard to natural background and medical procedures are applied to NCRP and FRC recommendations.

ICRP developed the concept of "acceptable risk." Unless man wishes to dispense with activities involving exposures to ionizing radiation, he must recognize that there is a degree of risk and must limit the radiation dose to a level at which the assumed risk is deemed to be acceptable to the individual and to society in view of the benefits derived from such activities.

For planned or controlled exposures of individuals and populations, the ICRP has recommended the term "dose limit." Recommended dose limits are thought to be associated with a very low degree of risk. For unplanned exposures from uncontrolled sources the term "action level" is recommended. In general it will be appropriate to institute countermeasures only when their social cost and risk will be less than those resulting from the exposure. Setting of action levels is the responsibility of national authorities.

It is not desirable to exposure members of the public to doses as high as those considered to be acceptable for radiation workers because children are involved, members of the public do not make the choice to be exposed, and members of the public are not subject to selection, supervision and monitoring, and are exposed to the risks of their own occupations. For planning purposes, dose limits for members of the public are set a factor of ten below those for radiation workers.

The ICRP dose limits for individual members of the public are presented in Table II. No maximum "somatically significant" dose for a population is given. The genetic dose to the population should be kept to the minimum amount consistent with necessity and should not exceed 5 rems in 30 years from all sources other than natural background and medical procedures. No single type of population exposure should take up a disproportionate share of the total of the recommended dose limit.

TABLE II

ICRP DOSE LIMITS 1/

	Individuals	Population
Gonads, red bone-marrow	0.5 rem/yr	-
Skin, bone, thyroid	3.0 rems/yr 2/	-
Hands and forearms; feet and ankles	7.5 rems/yr	-
Other single organs	1.5 rems/yr	-
Genetic dose 3/	-	5 rems/30 yrs

1/ For conditions and qualifications see ICRP Publication 9.
2/ 1.5 rems/yr to thyroid of children up to 16 years of age.
3/ See paragraphs 84, 85, and 86, ICRP Publication 9.

C. <u>National Council on Radiation Protection and Measurements* (NCRP)</u>

The NCRP position is that the rational use of radiation should conform to levels of safety to users and the public which are at least as stringent as those achieved for other powerful agents. Continuing and chronic exposure attributable to peaceful uses of ionizing radiation are assumed.

The NCRP has adopted the assumption of no-threshold dose-effects relationship and uses the term "dose limits" in providing guidance on population exposures. All radiation exposures are to be kept as low as practicable. The numerical values of exposure as presented are to be interpreted as recommendations, not regulations. Use of the no-threshold concept involves the thesis that there is no exposure limit free from some degree of risk.

To establish criteria, NCRP uses the concept of "acceptable risk" (where the risk is compensated by a demonstrable benefit) broken down to fit classes of individuals or population groups exposed for various purposes to different quantities of radiation. Numerical recommendations for dose limits are necessarily arbitrary because of their mixed technical value-judgment foundation. The dose limits for individual members of the public and for the average population recommended by NCRP represent a level of risk considered to be so small compared with other hazards of life, and

*Formerly known as the National Committee on Radiation Protection and Measurements.

so well offset by perceptible benefits when used as intended, that public approbation will be achieved when the informed public review process is completed.

For peaceful uses of radiation, NCRP provides yearly numerical dose limits for individual members of the public, considering possible somatic effects, and strongly advocates maintenance of lowest practicable exposure levels, especially for infants and the unborn. NCRP also recommends yearly dose limits for the average population based upon somatic and genetic considerations and recommends the same value as ICRP of 5 rems in 30 years for gonadal exposure of the U.S. population. Table III contains a summary of recommended values. NCRP Report No. 39 entitled, "Basic Radiation Protection Criteria," dated January 15, 1971, contains the most recent updating of NCRP recommendations for protection of the public.

TABLE III

NCRP DOSE LIMITS 1/

	Individual	Population
Whole body	0.5 rem/yr	0.17 rem/yr
Gonads	-	0.17 rem/yr 2/
Gonads (alternative 3/ objective)		5.0 rems/30 yrs

1/ For conditions and qualifications on application, see NCRP Report No. 39, "Basic Radiation Protection Criteria."
2/ To be applied as the average yearly value for the population of the United States as a whole. See paragraph 247, NCRP Report No. 39.
3/ See paragraph 247, NCRP Report No. 39.

D. Criteria Against Which Survey Findings and Alternative Measures Will Be Evaluated

The Task Group approached the question of radiation dose criteria from two directions. First, FRC, ICRP, and NCRP recommendations reviewed above were judged as to applicability in this situation. Second, a risk approach was reviewed using information from ICRP, UNSCEAR, and the National Academy of Science BEIR Committee. The results of this latter effort are summarized in Part E which follows.

The radiological survey of Enewetak Atoll provides a comprehensive data base needed to derive recommendations relative to the radiologically safe return of the Enewetak people. These recommendations are to be based on an evaluation of the significance of all radioactivity on the Atoll in terms of the total exposure to be expected in the returning population, and on consideration of those reasonable actions and constraints which, where made, will result in minimum exposures.

The guidelines used in deriving these recommendations can be summarized as two interdependent considerations:

1. Expected exposures should be minimized and should fall in a range consistent with guidance put forward by the Federal Radiation Council (FRC).
2. Actions taken to reduce exposures should be those which show promise of significant exposure reduction when weighed against total expected exposures and the "costs" of the actions. "Costs," in this context, are measured primarily in terms of costs to the Enewetak people as constraints on their activities or as dollar costs for cleanup or remedial action.

In these evaluations, it should be emphasized that dosages through various pathways are estimated on the basis of environmental data and considerations of expected living patterns and dietary habits. While "radiation standards" do not exist for environmental contamination levels in substances such as soil and foodstuffs, there is general agreement in terms of conservative models of these pathways and the relationships between a certain level in the environment and the likely dose to result from the pathway exposure.

The area of plutonium in soils, however, is one for which there is no general agreement as to the quantitative relationship between levels in soils and dosages to be expected through the inhalation pathway, the primary one through which man can receive a significant dose from plutonium. The ICRP recommends a maximum permissible average concentration (MPC) of 1 picocurie per cubic meter (pCi/m^3) of air for "insoluble" plutonium and 0.06 pCi/m^3 for "soluble" plutonium for unrestricted areas. While the plutonium in the soil at Enewetak is thought to be typical of world-wide fallout, and therefore insoluble, 0.06 pCi/m^3 will be used for the sake of conservatism.

Appendix A of Enewetak Radiological Survey, NVO-140, presents two possible methods for deriving the exposures that may occur through the inhalation pathway for plutonium in soil. (This is the pathway of interest for the present although it is reorganized that for the very distant future, ingestion may become more important by comparison. Table 250 of Appendix II shows that exposure to bone, liver, and lung from ^{239}Pu are expected to be a few hundredths of a rem in 30 years for pathways other than inhalation.) This material is produced as Attachment I of this section.

The two methods presented are the "resuspension-factor" approach and the mass-loading" approach. Soil concentrations of ^{239}Pu that would be associated with the standard for ^{239}Pu in air (0.06 pCi/m^3) by the two methods are:

Resuspension-factor approach . . . . . . 1,000 pCi/g

Mass-loading approach . . . . 600 pCi/g

A recent report, A Proposed Interim Standard for Plutonium in Soils LA-5483-MS, presents recommendations derived from estimates of exposure through inhalation considering the concentration of ^{239}Pu in the very top surface soil. The following values were recommended:

400 pCi/g - For all particle sizes provided no more than 200 pCi/g in < 100/mm size fraction.

A revised Maximum Permissible Concentration, MPC, of 0.3 pCi/m^3 for individuals was used in these determinations. The estimates apply to large area contamination. Levels several times larger could be permitted for localized deposition.

The Task Group recognizes that the islands of Enewetak Atoll are small and that the areas of highest ^{239}Pu in soil on these islands are smaller still. On the other hand the people live close to the soil. It is also recognized that experts are not in agreement as to the critical organ for inhaled plutonium, whether to use an average dose for this organ, or the model to be used to predict dose. In the interest of seeking a conservative yet flexible approach to considerations of criteria to treat the problem of ^{239}Pu in Enewetak soil, the Task Group recommends the following:

1. Any areas or locations where soil concentrations of ^{239}Pu are greater than 400 pCi/g should receive corrective action with contaminated soil removed for disposal.

2. Situations with soil levels in the 40 to 400 pCi/g range may receive corrective action with each area or location evaluated on a case by case basis.

The following guidance is provided for this evaluation:

a. Islands with soil levels in the above range may be divided into two categories, those of sufficient size for construction of permanent houses, and those that are not.

b. Removal of ^{239}Pu contaminated soil is better justified within the range above for the larger islands such as JANET or SALLY where permanent housing may someday be located and for near surface locations on the larger islands.

c. The smaller islands may be considered of less concern. Their longterm outlook is uncertain since they are sometimes increasing in size and sometimes erroding away. Small islands may be washed over by storm waves and are not a safe site for permanent housing. From that viewpoint, they are in the same category as unnamed sandbars along the reef where other islands may have disappeared or be forming.

d. The amount of effort that properly may be given to soil removal in this range increases as the soil concentration increases.

e. Once a soil removal action is to be taken, the objective is to achieve a substantial reduction in plutonium soil concentrations, and further, to reduce concentrations to the lowest practicable level, not to reduce them to some prescribed numerical value.

3. Areas or locations showing less than 40 pCi/g do not require corrective action because of the presence of plutonium alone.

The Task Group views these recommendations as the best current approach for obtaining acceptable actions against plutonium in soil at Enewetak Atoll. These are interium criteria to the extent that there does not appear to be either adequate physical or biological basis on which to establish firm and durable standards for cleanup of plutonium contaminated soil.

E. Recommended Guides

The standards issued by FRC are recommended as the basic guidance for evaluation of exposures to individuals to Enewetak. This is recommended with provisos that:

1. The full amount of the numerical values should not be used for evaluating exposures from a single man-made source, in this case radioactivity from weapons tests. This is applied so that the Enewetak people will not be denied benefits of future nuclear technology because they are receiving exposures from man-made radiation at the maximum level of acceptable standards.
2. Environmental followup surveys and studies of radioactivity levels in people are performed such that the full range of radiation exposures of individual members of the Enewetak population will be known.
3. Exposures of the Enewetak people are kept to the minimum practicable level.

Survey, Cleanup, and Rehabilitation Evaluation

It is recommended in this context that:

1. The FRC Radiation Protection Guide (RPG's) for individuals should be used as the basic standard. The requirement is to assure that exposures for continuous residence in Enewetak Atoll will be well within the annual and 30 year criterion. While these are conservative standards from a health view point, there is no builtin conservatism to account for uncertainty in prediction of annual exposures to individuals. Because of the complex circumstances of exposure and the many pathways, each with its uncertainty, the Task Group recommends use of 50 percent

of the FRC annual standards for evaluation of the many cleanup and rehabilitation alternatives at Enewetak Atoll. This is not to be viewed as an attempt to establish new standards but is considered to be a necessary precaution in the application of current standards. The following values apply for evaluation of alternatives:

Whole body	0.25 Rem/yr
Bone marrow	0.25 Rem/yr
Bone	0.75 Rem/yr
Thyroid	0.75 Rem/yr

2. The Task Group recommends use of 100 percent of the FRC RPG's to evaluate post cleanup and rehabilitation and post return conditions wherein direct measurement of levels of radiation and radioactivity in foods and in people are made. Under such conditions, dose estimates should be subject to much less uncertainty. The requirement is to assure that exposures are well within the FRC standards. See Section A. of this Appendix for the FRC RPG's.

3. The criteria for evaluating gonadal exposures at Enewetak Atoll should be 4 rems in 30 years. The requirement is to assure that long term exposures will be well within this criteria. The Task Group feels justified in using 80 percent rather than 50 percent of the FRC standard since there will be ample time to verify exposure estimates using actual sampling of the diet and time to follow the changing pattern of exposures of people.

4. The recommended guidance for ^{239}Pu in soil is:

a. <40 pCi/g - corrective action not required.

b. 40 to 400 pCi/g - corrective action may be needed. Action to be taken should be determined on a case-by-case basis.

c. >400 pCi/g - corrective action required.

In applying the criteria for bone and bone marrow in part 1 above, it is assumed that if annual exposures do not exceed the applicable criteria in the year of highest dose, there will not be a requirement for limiting longer term cumulative exposures. On the other hand, implementation of the "lowest practicable" concept will require considerations of effectiveness of remedial measures to reduce both annual and longer term exposures to the extent practicable.

F. Risk Considerations

The Task Group and its technical advisors have reviewed the available information from ICRP, UNSCEAR, and the National Academy of Science BEIR Committee that could be used to estimate the health risk that may be associated with long term exposures at the level of the radiation dose and soil removal criteria being recommended. It is clear from this review that knowledge of the relationship between radiation dose and effects of that dose on man as characterized in dose-effect curves is incomplete even for external radiation exposures. For internal emitters and particularly for plutonium, the situation is even less satisfactory. UNSCEAR has summarized their fundings by stating that one should not extrapolate in a linear fashion from effects seen at high doses and dose rates to effects at low doses and dose rates since there is strong likelyhood of recovery and repair. The BEIR Committee, using only human data, concluded that since the low dose data were incomplete, one should conservatively assume a linear no-threshold dose-affect curve drawn through data obtained at high doses and dose rates. The Committee further suggested that if this linear no-threshold curve is assumed to be correct, it follows that 6,000 cases of cancer would be produced each year in a population of 200,000,000 people exposed at a rate of 0.17 Rem/yr. (This is the FRC RPG for population groups - see Table I.) For the Enewetak population of less than 500 exposed at the same level, one can make the following estimate:

$$\frac{6 \times 10^{3} \text{ cases/yr} \times 500 \text{ people}}{2 \times 10^{8} \text{ people}} = 1.5 \times 10^{-2} \text{ cases of cancer/yr}$$

Exposure at the level of the recommended criterion of 0.25 Rem/yr would give twice the above value using a linear dose-effect curve or 3×10^{-2} cases per year. The Task Group views this as a pessimistic upper limit of risk. It could be inferred that there may be between zero and three cases of cancer in 100 years if the entire Enewetak population were continuously exposed to 0.25 Rem/yr over that time period.

Lack of confidence in extrapolation of high dose and dose rate effects into the very low dose and low dose rate situation, consideration of the fact that for alternatives being considered for cleanup and rehabilitation, most of the exposure to whole body and in fact to all organs comes from internal emitters wherein the shape of the dose-effect curve is most uncertain, and lack of confidence in the statistics and risk estimate drawn therefrom have led the Task Group to have serious reservations about their validity. The Task Group holds the opinion that such estimates can not be used in any definative way to draw conclusions on whether current radiation standards are too high or too low or as a basis for decision making relative to resettlement of Enewetak Atoll. While the risk associated with doses at the level of current standards is possibly not zero, it is viewed as being very low as described by FRC, ICRP, and NCRP. The basic FRC standards, conservatively applied, are viewed as suitable for Enewetak rehabilitation provided there is also a serious and concerted effort to keep exposures as low as practicable.

A T T A C H M E N T I

RELATIONSHIP BETWEEN RESUSPENDED PLUTONIUM

IN AIR AND PLUTONIUM IN SOILS

Relationship Between Resuspended Plutonium in Air and Plutonium in Soil

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There are no general models that may be used with confidence to predict the resuspended air activity in the vicinity of an area contaminated with plutonium.

However, two approximate methods may be used — the resuspension factor approach and an argument based upon ambient air particulate concentrations, with the assumption that the particulates are derived from the contaminated surface. The former method has been frequently used, but almost always in the context of a fresh surface deposit. The latter method is inappropriate to the fresh deposit situation, but should be reasonably valid after enough time has elapsed for the surface-deposited material to become fairly well mixed with a few centimeters of the soil surface.

Resuspension Factor Approach

The resuspension factor, K, is defined as

$$K = \frac{\text{Air concentration } (Ci/m^3)}{\text{Surface deposition } (Ci/m^2)},$$

and thus has units of m^{-1}. It is almost always implied that both measurements are made at the same location. The difficulties with this approach are fairly obvious — no allowance is made for the geometrical configuration of the source, the particle-size distributions of the contaminant and the soil surface, vegetation cover, etc. Stewart[1] and Mishima[2] have tabulated values of K from many experiments including those involving laboratory floors as well as native soils. As would be expected, the tabulated values cover an enormous range and vary from 10^{-2} to 10^{-13}/m. Most of the high values, however, are derived from experiments with laboratory floor surfaces and/or with artificial disturbance.

For outdoor situations, Stewart[1] suggests as a guide for planning purposes that a value for K of 10^{-6}/m be used "under quiescent conditions, or after administrative control has been established in the case of an accident." A value of 10^{-5}/m is suggested under conditions of moderate activity. Stewart states, however, that exceptionally higher values (mean of 10^{-5}/m) were observed during the Hurricane Trial (Monte Bello Islands) and credited this to the nature of the small islands exposed to sea breezes. Values approaching 10^{-3}/m when dust is raised by pedestrians and vehicles are also reported by Stewart.

Kathren[3] has also considered the resuspension factor approach and has recommended the use of 10^{-4}/m as a conservative but appropriate value for setting standards for PuO_2 surface contamination.

Langham[4, 5] has suggested that a value of 10^{-6}/m is a reasonable average value to use in estimating the potential hazard of occupancy of a plutonium-contaminated area. At the same time, however, Langham notes that many measured values lie in the range of 10^{-5} to 10^{-7}/m and reports that his own measurements in 1956 produced a value of 7×10^{-5}/m.

These recommended values, however, are all intended for application during the time period immediately following deposition. Numerous studies[1, 5-8] have shown that air concentrations of resuspended materials decrease with time. With the assumption that this decrease can be represented by a single exponential function, half-times of 35 to 70 days have been reported[5, 7, 8]. This decrease in air activity is not explainable by the relatively minor loss of material from the initial site of deposition[1, 6], but is presumably caused by the migration of the initial surface-deposited material into the soil.

Attempts to use the resuspension factor approach to derive acceptable levels of soil surface contamination have included this "attenuation factor" as a simple exponential function with half-times of 35 or 45 days[3,4]. There are major uncertainties in such a formulation, however. The longest study of this decrease with time extended to only 11 mo following the initial deposition[8], which is extremely short compared to the half-life of a radionuclide such as ^{239}Pu. There are also published reports which indicate on experimental and theoretical bases that the decrease with time will not be adequately represented by a single exponential function, but that the rate of decrease itself will also decrease with time[1,6]. Fortunately, the exact nature of this time dependence is not critical in determining the integrated exposure from the time of initial deposition due to the fairly well-documented rapid decrease at early times. However, it is obviously the controlling factor for questions concerning the reoccupation of areas many years after the contaminating event.

As an illustration, the most conservative published model (Kathren[3]) may be used to calculate a resuspension rate for material 15 yr after deposition:

$$K = \frac{10^{-4}}{m} \exp\left(\frac{-0.693 \times 15y \times 365d}{45d \qquad y}\right)$$

$$\simeq 10^{-41}/m.$$

If, however, the resuspension rate asymptotically approached some finite value 10^{-6} of the original, then the resuspension rate 15 yr later would obviously be 10^{-10}/m. However, the total integrated air activity (from t = 0 to ∞) for ^{239}Pu would be changed only by

$$A \times 10^{-4} \int_0^{\infty} \exp(-0.693t/45d)\, dt + A \times 10^{-10} \int_0^{\infty} \exp(-0.693t/24,400y)\, dt$$

$$= 6.5A \times 10^{-3} + 1.3A \times 10^{-3},$$

which is an increase of 20%, and more importantly, cannot be accumulated during an individual's life span.

Because the functional nature of the decrease in resuspension rate with time cannot be confidently extrapolated, previously published models should not be applied to the reoccupation of areas many years after the contaminating event.

The resuspension-factor approach can be applied in an approximate way, however, if resuspension factors are used which were derived from measurements over aged sources. Perhaps the most relevant data are unpublished results from current resuspension experiments at the GMX site in Area 5 of the Nevada Test Site. The ^{239}Pu at this location was deposited following 22 high-explosive detonations during the period from December 1954 to February 1956. Measurements of resuspended air activity levels at this site during 1971-1973 appear to be the only available data concerning resuspension of ^{239}Pu from a source of this age.

Data from two types of measurements are available and can be used to derive average resuspension factors. The first type of measurement[9] was accomplished by placing five high-volume cascade impactors[10] within the most highly contaminated area, and running them for

36 days, from July 7 to August 12, 1972. The collected $^{239,240}Pu$ activity was distributed lognormally with particle size with an activity median aerodynamic diameter (AMAD) of 3.0 μm and a geometric standard deviation of 8.2. The $^{239,240}Pu$ concentration varied from 1.0×10^{-14} to 3.9×10^{-14} $\mu Ci/cm^3$, with an average of 2.3×10^{-14} $\mu Ci/cm^3$ for the five samplers. At the present time only limited data are available regarding the soil activity in the area. Four soil samples of depth 0-3 cm from approximately the same location have been analyzed with results[11] of 2060 to 3550 dpm/g, with a mean of 2700 dpm/g. Profile data from other locations at the same general site indicate that about 90% of the total deposition is contained within the top 2.5 cm of the soil[12]. Measurements of soil density in the area average 1.8 g/cm^3 [9]. The resuspension factor is therefore

$$\frac{2.3 \times 10^{-14}\ \mu Ci}{cm^3} \times \frac{g}{2700\ dpm} \times \frac{cm^3}{1.8\ g} \times \frac{0.9}{3\ cm} \times \frac{10^2\ cm}{m} \times \frac{2.22 \times 10^6\ dpm}{\mu Ci}$$

$$= 3 \times 10^{-10}/m.$$

Additional air samples were taken by the Reynolds Electrical and Engineering Co. (REECo) on the edge of the contaminated area during the period of February 1971 to July 1972, with a sampling time of approximately 48 hr[13]. Measurements were made at four locations, but the most pertinent is the one which was most frequently in the direction of strong winds from the strongly contaminated area and where the highest air activities were recorded. Here, 254 individual air-filter samples were collected and detectable results reported for 236. $^{239,240}Pu$ concentrations ranged from 3.5×10^{-17} to 6.3×10^{-13} $\mu Ci/cm^3$, with arithmetic and geometric means of 6.6×10^{-15} and 7.9×10^{-16} $\mu Ci/cm^3$, respectively. Results for four soil samples taken from approximately the same location range from 128 to 202 dpm/g, with a mean of 160 dpm/g[11]. Because the arithmetic mean is a better representation of average lung exposure, it is used to derive a resuspension factor at this site:

$$\frac{6.6 \times 10^{-15}\ \mu Ci}{cm^3} \times \frac{g}{160\ dpm} \times \frac{cm^3}{1.8\ g} \times \frac{0.9}{3\ cm} \times \frac{10^2\ cm}{m} \times \frac{2.22 \times 10^6\ dpm}{\mu Ci}$$

$$= 2 \times 10^{-9}/m.$$

This value is nearly an order of magnitude higher than the one previously calculated, and reflects some of the inherent difficulties in the resuspension-factor approach, i.e., that no allowance is made for the geometrical configuration of the source and that higher ground activities may be present upwind.

It is obvious that this approach is subject to major uncertainties, but does serve as an order-of-magnitude indication of the resuspended air activities that may arise from a $^{239,240}Pu$ contaminated area which has weathered for 15 to 20 yr. The data discussed above also demonstrate unequivocally that resuspension of $^{239,240}Pu$ does in fact occur from such aged deposits and at levels many orders of magnitude higher than would be expected if the often noted decrease with time were represented by a single exponential function with a half-time of 35 to 70 days.

Mass-Loading Approach

The other approximate prediction method is based upon measured or assumed levels of particulate matter in ambient air with the assumption that this material is derived from the contaminated soil. For fresh deposits this approach is not valid because the freshly deposited debris is much more likely to be resuspended than the remainder of the weathered soil surface. After many years of weathering since the initial deposition, however, the contaminating material should be reasonably well mixed with a centimeter or two of soil, such that the contaminant activity per gram of airborne particulate should approximate that in the upper soil. However, a major difficulty could arise if, for example, $^{239,240}Pu$ were preferentially associated with the smaller particle sizes more likely to become airborne. For the Nevada Test Site, such is not the case as determined by soil analyses[14] and by the high-volume cascade impactor study. The latter study found an AMAD of 3.0 μm for $^{239,240}Pu$, whereas the total mass median aerodynamic diameter was 1.7 μm. The specific activity of the material collected on each stage can also be examined for a preferential association of plutonium with particle size. Average data from all five samplers are:

Size, μm	$^{239,240}Pu$, dpm/g
>7	950
3.3 to 7	700
2.0 to 3.3	1030
1.1 to 2.0	1300
0.01 to 1.1	480
All stages	890
(Soil)	(2700)

Although there is considerable spread in these data, there is no indication of a preferential association of $^{239,240}Pu$ with a particular particle size; as would be expected as a result of dilution by inert aerosol, the specific activity is lower than that of the soil.

If we assume that this is generally true, a general and conservative method of predicting resuspended air concentrations of contaminants would be to simply multiply the ambient air mass loading by the contaminant concentration in soil. A factor of some uncertainty for a specific calculation is what value to use for the ambient air mass loading in the absence of specific data. This becomes even more uncertain because of the possibility that the people involved may be highly correlated with the source in the sense that children playing in sand, adults cultivating crops, etc., may generate their own "ambient air" which contains much more mass than would be recorded by a remote stationary sampler.

The lower and upper bounds of ambient air mass loading can be fixed rather easily for any site. There has been considerable interest in establishing a "background level" of mass loading, and this is generally believed to be about 10 $\mu g/m^3$ (15). The upper bound can be established in a reasonable way by the levels found in mine atmospheres which have led to a considerable prevalence of pneumoconiosis in the affected workers[16]. Examination of these data indicate that current standards for occupational dust exposure ($\sim$1-10 mg/m^3) have a very small, or perhaps no margin of safety, such that a reasonable upper bound can be taken as 1 mg/m^3. British data[17] indicate that if the general public were exposed to dust levels in excess of 1 mg/m^3, the public health problem from the dust alone might be enormous. The reasonableness of the upper limit value of 1 mg/m^3 is also demonstrated by data which indicate that nonurban ambient air mass concentrations this high are usually associated with conditions described as dust storms[18,19].

Measurements of ambient air mass loading can be used to further define a reasonable estimate for predictive purposes. The National Air Surveillance Network (NASN) has reported such results for several years. Data[20] for 1966 show that there were 217 urban and 30 nonurban stations reporting. The annual arithmetic average for the urban stations ranged from 33 (St. Petersburg, Florida) to 254 $\mu g/m^3$ (Steubenville, Ohio), with a mean arithmetic average for all 217 stations of 102 $\mu g/m^3$. For the nonurban stations, the range was from 9 (White Pine County, Nevada) to 79 $\mu g/m^3$ (Curry County, Oregon), with a mean arithmetic average for all 30 stations of 38 $\mu g/m^3$. No data in this report are available for nonurban locations on small islands similar to the Enewetak group; perhaps the closest analog is the urban station at Honolulu, Hawaii, which had an annual arithmetic average of 35 $\mu g/m^3$.

More pertinent, but limited, data have recently been published for the island of Hawaii[21, 22]. Data are given for three locations: Mauna Loa Observatory located at a height of 3400 m, Cape Kumukahi, and the city of Hilo. NASN data for Hilo (for an unspecified period) are given as 18 $\mu g/m^3$, and nephelometer measurements varied from 18 $\mu g/m^3$ during the day to 26 $\mu g/m^3$ at night. At Cape Kumukahi the nephelometer measurement was 9.2 $\mu g/m^3$. The greatest amount of data is available for Mauna Loa Observatory. Here, the NASN measurement was 3 $\mu g/m^3$, and the nephelometer measurements varied from 1.7 $\mu g/m^3$ at night to 6.5 $\mu g/m^3$ during the day. Additional measurements made by the USAEC Health and Safety Laboratory (HASL) were 3 $\mu g/m^3$. It is of interest in the present context that Simpson[22] made the following comment concerning the HASL measurements: "The HASL filter samples contain substantial dust (3-5 $\mu g/m^3$ of air sampled) because of the fact that the filter was located less than one meter above the ground surface near areas with substantial personnel activity at the observatory site." Thus, while this method of measurement may not have coincided with Simpson's interest, it does indicate that ambient air mass loadings may be very low on such remote islands even when considerable human activity is occurring nearby.

On the basis of the above data, it would appear reasonable to use a value of 100 $\mu g/m^3$ as an average ambient air mass loading for predictive purposes. Indications are that this value should be quite conservative for the Enewetak Islands, and therefore allows room for the uncertainty involved because the people themselves may generate a significant fraction of the total aerosol. Therefore, they may be exposed to higher particulate concentrations than would be measured by a stationary sampler.

Supporting evidence that 100 $\mu g/m^3$ is a reasonable value to use for predictive purposes is provided by the National Ambient Air Quality Standards[23]. Here ambient air is defined as "...that portion of the atmosphere, external to buildings, to which the general public has access." The primary ambient air standards define "levels which... are necessary, with an adequate margin of safety, to protect the public health." The secondary standards define "levels which...(are)...necessary to protect the public welfare from any known or anticipated adverse effects of a pollutant." These standards for particulate matter are given below:

National ambient air quality standards for particulate matter, $\mu g/m^3$.

Annual geometric mean	Max. 24-hr concentration not to be exceeded more than once a year
Primary:	
75	260
Secondary:	
60	150

Data to support these standards in terms of health effects, visibility restrictions, etc. have been provided[24].

An arithmetic mean would be more desirable for predictive purposes. Data from 1966[20] for nonurban locations indicate that the annual arithmetic mean is (on the average) 120% of the annual geometric mean.

Representative Calculations

Because one of the primary objects is to derive an acceptable soil level for the Enewetak Islands, the approaches developed above were used to derive such levels for both soluble and insoluble ^{239}Pu. The derived values are given in Table 151. The two methods agree within a factor of two, at least for soil distributions like those found at the Nevada Test Site. The ambient air mass loading at

Table 151. Acceptable soil levels of ^{239}Pu for a source which has weathered for several years. Values are approximate and are subject to uncertainty. Permissible Concentration in Air for 168-hr occupational exposure (MPC_a)25.

	Insoluble	Soluble
Acceptable air concentration, $\mu Ci/cm^3$	10^{-12}	6×10^{-14}
Resuspension-factor approach		
Assumed resuspension factor, m^{-1}	10^{-9}	10^{-9}
Acceptable soil deposition[a], $\mu Ci/m^2$	10^3	60
Acceptable soil concentration[b], nCi/g	20	1
Mass-loading approach		
Assumed mass loading, $\mu g/m^3$	10^2	10^2
Acceptable soil concentration, nCi/g	10	0.6

[a]Equivalent to approximately 10^4 μg of insoluble $^{239}Pu/m^2$.

[b]Assumes same distribution of ^{239}Pu with depth and soil density as measured at the Nevada Test Site.

NTS during the cascade impactor run was measured to be 70 $\mu g/m^3$.

Such derived values must, of course, be used with a great deal of discretion. They are based on simple model systems which are believed to be generally conservative, but individual situations can be imagined which could exceed the predictions.

Other Considerations

The above calculations relate only to the resuspended air activity in ambient air, and do not consider the additional problems of resuspension of material from contaminated clothing or the resuspension of material which has been transferred to homes.

Healy[26] has considered these and other problems, and has provided tables of "decision levels" for surface contamination levels and home transfer levels. A decision level is based upon National Council on Radiation Protection and Measurements (NCRP) recommended dose limitations. Because the derivations

Table 152. Decision levels[26] for soluble ^{239}Pu, and their equivalent in soil mass based upon the "acceptable soil concentration" from Table 151.

Pathway	Decision level	Mass equivalent
	A. Direct personal contamination	
Direct inhalation[a]	2×10^{-5} nCi/cm^2	1×10^{-5} g/cm^2
Direct ingestion[b]	0.2 nCi/cm^2	0.2 g/cm^2
Skin absorption[c]	8×10^{-4} μCi	0.8 g
	B. Transfer (to homes) levels	
Resuspension[d]	0.01 μCi/day	10 g/day
Direct inhalation	0.01 μCi/day	10 g/day
Direct ingestion	100 μCi/day	10^5 g/day
Skin absorption	0.03 μCi/day	30 g/day

[a] "The contamination level on clothing and skin that could result in inhalation of air at the MPC_a for the public."[26]

[b] "The contamination level on skin or clothing that could result in ingestion of a quantity of radioactive material equivalent to the ingestion of water at the MPC_w for an individual in the public."[26]

[c] "The total quantity of radioactive material maintained on the skin for 24 h/day that could result in absorption of a quantity equal to that which would be absorbed from the GI tract if water at the MPC_w for "soluble" isotopes for an individual in the public were ingested."[26]

[d] "The amount transferred per day that could result in air concentrations due to resuspension in a medium-sized home averaging at the MPC_a for an individual in the public."[26]

are rather tenuous, Healy has used the phrase decision level and states that its use is to serve as a signal that further careful investigation is warranted.

Healy's decision levels for soluble ^{239}Pu are given in column 1 of Table 152. The values in column 2 are derived from these and an acceptable soil concentration of 1 nCi/g from Table 151 to give equivalent dirt (soil) contamination and transfer levels. The results are interpreted as indicating that the potential exists for greater dose contributions from these infrequently considered pathways than from the usually considered pathway of resuspension as calculated for ambient air. This conclusion would be the same for insoluble ^{239}Pu. Therefore, if dose calculations based on the usual resuspension pathway should appear limiting compared to other pathways such as food-chain transfer, these pathways considered by Healy need to be carefully evaluated for the specific Enewetak situation.

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APPENDIX IV

Annual Bone and Whole-Body Doses

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1. Introduction

The purpose of this appendix is to evaluate the potential annual bone doses for adults and children for the six living patterns considered in the Enewetak Radiological Survey Report (NVO-140). The bone doses presented in NVO-140 were calculated for mineral bone for adults as integrated doses for 5-, 10-, 30-, and 70-yr periods. Bone and whole-body doses to children were not considered separately because in most cases the doses predicted for adults are usually a good estimate of the dose to children. For example, the external gamma contributes similarly to both adults and children. Strontium-90 and ^{137}Cs contribute over 95% of the food-chain dose and there is evidence to show that doses to children from ingestion of ^{137}Cs are usually less than those to adults. Strontium-90 differs from ^{137}Cs. Doses to children can exceed adult doses; however, the additional dose increment to children over the first 1 to 5 yr is not large and increases the integral 30- and 70-yr doses by only a few percent. With the uncertainties involved in other parts of the dose assessment, for example the actual diet at time of return, the differentiation between child and adult integrated doses was not included in the tables.

Because of the magnitude of some of the 30-yr integral bone doses, it was decided that annual bone doses should be evaluated to indicate the living patterns and agricultural situations which are within FRC guides for annual bone doses. The more detailed assessment of bone doses is directed at estimating the dose to the critical cell population at risk in bone - the bone marrow - rather than to the entire bone mass, as was calculated in the original report (NVO-140). In adopting this approach, we are following the recommendations of the ICRP (ICRP-11) and the approach of Spiers used by UNSCEAR (22).

The following text considers the information available for estimating the doses to the fetus, the newborn, and children relative to adults, and also the dietary changes which are assumed for children.

2. Dose to Fetus and Newborn Relative to Adults

The Sr/Ca ratio in the fetus and in mothers' milk is determined by the Sr/Ca ratio in the maternal blood. Sr/Ca discrimination across the placental barrier and across the mammary gland is nearly the same.[1,2] In fact, the observed ratio OR $\frac{\text{fetus or mothers' milk}}{\text{maternal blood}}$ $\left(OR = \frac{(\mu Ci\ ^{90}Sr/g\ Ca)\ \text{milk or fetus}}{(\mu Ci\ ^{90}Sr/g\ Ca)\ \text{maternal blood}}\right)$ is ~ 0.5.[1-3] Therefore, the Sr/Ca ratio of the fetus or newborn is very similar to that of the mothers' milk.

There is considerable evidence to show that the OR milk/diet for human breast milk is in the range of 0.1 to 0.16.[3,5] The same observed ratio exists for the fetus and newborn relative to the adult diet.[1,2] This ratio has been observed directly and can also be calculated from data which indicate that the average OR body/diet for adults is 0.25;[1,6] when this is combined with a further discrimination of approximately a factor of 2 across the placental or mammary membrane, the range of values of 0.1 to 0.16 for milk or fetus is obtained.

As a result, the Sr/Ca ratio in the fetus and newborn is approximately 1/8 to 1/10 that of the adult, and the resulting dose to the fetus is less than that to adults.

The dose to a young infant being breast fed will of course also be less than that calculated for adults. The OR body/diet for young infants is 0.9;[1,4] that is, the young infant nearly equilibrates with his diet. However, the mothers' milk, as discussed previously, has a Sr/Ca ratio ~ 0.1 that of the adult diet. The OR body/diet then decreases to 0.5 for a 1-year-old and by approximately 3 or 4 years of age has reached the adult value of 0.25.[2,4,6]

Similar data are available for ^{137}Cs. Cesium-137 is metabolized and turned over more rapidly in pregnant women than in nonpregnant women.[7,8] As a result, ^{137}Cs incorporation in the fetus and the resulting exposure are less than would be expected from normal retention times observed for adults. Experimental data further indicate that for the fetus and for breast-fed infants the concentration of ^{137}Cs and the resulting dose never exceeds that of the mother or of other adults.[9,10] Therefore, as indicated in reports by Rundo,[9] Iinuma et al.,[10] and Cook and Snyder,[11] the dose calculated for an adult for ^{137}Cs is a conservative estimate for the fetus and the newborn.

3. Dose to Children Relative to Adults

^{137}Cs — A considerable body of evidence is available which indicates that the half-time for ^{137}Cs in the body is a function of age, with a more rapid turnover for younger ages.[11-14] The biological half-time appears to be the order of 10-15 days for 1- to 2-year-old children and increases to ~ 100 days by age 20. It then remains reasonably constant throughout adult life. The body mass is less for the younger age groups, and these two factors tend to offset each other in dose calculations. Doses to children are generally less than for adults as a result of the combination of these two offsetting factors. When the relative dietary intake is included, children receive a lesser dose than adults. Therefore, dose estimates for adults are usually a conservative estimate for children.

^{90}Sr — Reports by Loutit,[15] Bennett,[16] and Rivera[17] indicate that the pCi ^{90}Sr/g Ca in human bone is greater for ages 1-5 than for ages greater than 6 yr, including adults. However, the turnover rate is much more rapid and the retention time much shorter for ^{90}Sr in ages 1-5. The combination of these two factors determines the bone burden, the annual dose, and the dose commitment resulting from a specified ingestion of ^{90}Sr. For children, these two factors tend to offset each other; the resulting dose to children, therefore, is not straightforward and is dependent upon the relative interaction of these two factors.[1] Any comparison with adults must therefore take into account the age dependence of these factors, as well as the difference in dietary intake. The model reported by Bennett[16] is therefore used for estimating the doses to children.

4. Dose Models and Diet

^{90}Sr — Models developed by ICRP for estimating the bone dose from ingested ^{90}Sr are considered to be age invariant.[18-20] A recent model from Bennett[16] does model the child separately from the adult, and this model is applied for estimating the bone doses to children.

The bone-marrow dose-rates to children are calculated by combining Bennett's model for children with the approach developed by Spiers[21] and used in the UNSCEAR report[22] for estimating bone-marrow dose from the mineral or matrix bone dose. The values used for converting D_o doses, to bone-marrow and endosteal cell doses, are 0.314 and 0.434 respectively. Bennett's model also extrapolates to the adult case and is combined with the Spiers approach for predicting the bone-marrow doses to adults.

The bone mass is assumed to correlate directly with body mass, and these data as a function of age are taken from Spiers.[21] These body masses are based upon average data from the U.S. population and a factor of 0.85 was incorporated to account for the smaller size of the Enewetakese. The calcium concentration in bone (gCa/g bone) as a function of age is taken from Bennett.[16]

In calculating the mineral bone dose (D_o dose) in NVO-140, the approach of ICRP[18] was followed, using a QF = 1 and n = 5. The doses calculated from this model are compared to the 3-rem/yr guide (ICRP 9)[23] for bone for general public. However, in assessing the annual dose to both children and adults, the bone marrow is taken as the critical organ, and the recommendations in ICRP 11[24] are used.

In this model the quality factor is still one (QF = 1), and the "n" factor is no longer applicable. The bone marrow is considered in the category of sensitive blood-forming organs, and the corresponding dose guide for such organs is 0.5 rem/yr rather than the 3 rem/yr for mineral bone.

^{137}Cs — In the dose model for ^{137}Cs, it is assumed that the loss of ^{137}Cs from the body can be described as an exponential loss with a turnover time that varies as a function of age.[10-14] The annual dose is calculated, always taking into account the residual body burden from the previous year. Body mass as a function of age is taken from Spiers.[21] Initial dietary intakes are calculated and doses are predicted, based upon the initial intake and the exponential loss of ^{137}Cs in the diet at a rate equal to the physical half-time of ^{137}Cs.

Diet — The diet for adults is that listed in the original report NVO-140. For children from ages 1 through 10, the intake of coconut milk and coconut meat is doubled to 600 and 200 g/day, respectively. These two products are the most likely to be consumed in greater quantity by children than by adults. The rest of the diet for children is assumed to be one-half of the adult diet.

At age 10, it is assumed that the child is on the full adult diet. From information available, this is a conservative assumption in that children are not usually considered to reach the average adult intake until age 14 or 15. However, because of the diet changes which occur at 10 yr (i.e., pandanus, breadfruit, coconut, etc., which become available) it is convenient to use this point for adjusting the child to the adult diet, and if anything, this adjustment produces a slightly conservative dose estimate for the children due to the high ^{90}Sr content in the adult diet.

5. Results

The results of the calculations based upon the models described above and upon the diets listed in NVO-140 and altered for children as previously discussed, are listed in Tables 1-8. The data are presented as maximum annual bone-marrow and whole-body doses. The living patterns are listed after Tables 1 and 6 for convenience of reference; they are the same as those listed in NVO-140.

The annual doses for external exposure and for food chain exposure from ^{137}Cs and ^{90}Sr are calculated for 70 yr, beginning at either age 1 or age 20. The three different components contributing to the dose produce a maximum dose at different times. The external component, for instance, is maximum at 1 yr and decreases thereafter with the physical half-life of ^{137}Cs and ^{60}Co; the effective decay depends on the particular percentage of each isotope in the soil. Strontium-90 delivers its maximum dose several years after intake of the nuclide begins. The year of maximum dosage depends upon whether an adult or child is considered and upon whether or not a diet change is involved at some point in time. The dosage from ^{137}Cs incorporated in man via food chains tends to peak early and decreases exponentially thereafter. The annual dose is then selected for the years at which the sum of these three components was maximum.

The maximum annual bone-marrow doses are listed in Table 1 for the case where no restrictions are placed upon the location of agriculture and source of the diet and no modifications are made for external gamma on the village island. Table 2 lists the results for the case where no restriction are placed upon the diet but where the village island has been modified by plowing and graveling. Living Pattern 1, where the home island and agriculture are on southern islands, is the only living pattern for these two situations where the total bone-marrow doses do not exceed 50% of the FRC guide; in this instance, it is less by a factor of 5. All other living patterns lead to an annual dose which for at least 1 yr, and in most cases several years, exceeds the FRC guide.

The results also indicate that there is not a great deal of difference between the predicted child and adult maximum annual doses. This is due in part to the assumed diets of adults and children and the large ^{90}Sr and ^{137}Cs intake via the food chains for such products as pandanus, breadfruit, coconut, and meat. For coconut milk and coconut meat, the children are assumed to have an intake twice that of the adults, but until age 10 the rest of the dietary intake is assumed to be one-half that of the adults.

Table 3 lists the results for the six living patterns when pandanus and breadfruit are grown on southern islands only. As a result of this action, three living patterns fall within 50% of the FRC guide — Patterns 1, 2, and 5. When pandanus, breadfruit, coconut, and tacca are all confined to southern islands, then Living Pattern 3 also falls within the guide (Table 4). If the total diet is confined to the southern islands, then all living patterns are within FRC guide, and the only variation among living patterns is the result of the difference in external exposure for each of the situations (Table 5). For all the cases where there is a restriction on the agriculture and diet, it is assumed the village island will be plowed and graveled.

Similar results for whole-body exposure for the four different agricultural situations are presented in Tables 6-10. With no restrictions on the diet, Living Patterns 1, 2, and 5 are under FRC guides. Therefore, the bone-marrow is the more limiting feature. When the other agricultural conditions are used, the living patterns which fall below the FRC guide are the same as those for the bone-marrow dose.

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Table 1. Maximum annual bonemarrow dose (rem).

No restrictions on diet

Village island unmodified for external gamma

Living Pattern	Start January 1974		Start January 1984	
	Child [a]	Adult [a]	Child [b]	Adult
1	0.047	0.045	0.047	0.043
2	0.314	0.294	0.282	0.290
3	0.790	0.760	0.759	0.754
4	2.27	2.15	2.17	2.13
5	0.361	0.348	0.333	0.344
6	1.10	1.04	1.03	1.02

Living Pattern	Village island	Agriculture	Visitation
1	(A) Enewetak-Parry	ALVIN-KEITH	Southern Is.
2	(B) Enewetak-Parry	KATE-WILMA + LEROY	Northern Is.
3	(D) JANET	JANET	Northern Is.
4	(F) BELLE	BELLE	Northern Is.
5	(C) JANET	KATE-WILMA + LEROY	Northern Is.
6	(E) JANET	ALICE-IRENE	Northern Is.

[a] Diet change at 10 yr., i.e., 1984.

[b] Diet change at 10 yr., i.e., 1994.

Table 2. Maximum annual bonemarrow dose (rem).

No restrictions on diet

Village island graveled and plowed

	Start January 1974		Start January 1984	
Living Pattern	Child [a]	Adult [a]	Child [b]	Adult
1	0.047	0.045	0.047	0.043
2	0.314	0.294	0.282	0.290
3	0.718	0.677	0.680	0.672
4	2.08	1.92	1.93	1.90
5	0.317	0.300	0.285	0.296
6	1.06	0.989	0.988	0.977

Table 3. Maximum annual bonemarrow dose (rem).

Pandanus and breadfruit from southern islands

Village island graveled and plowed

	Start January 1974		Start January 1984	
Living Pattern	Child [a]	Adult [a]	Child [b]	Adult
1	0.047	0.045	0.047	0.043
2	0.148	0.149	0.200	0.142
3	0.293	0.294	0.418	0.284
4	0.786	0.774	1.16	0.749
5	0.151	0.178	0.201	0.148
6	0.428	0.437	0.574	0.419

[a] Diet change at 10 yr., i.e., 1984.

[b] Diet change at 10 yr., i.e., 1994.

Table 4. Maximum annual bonemarrow dose (rem).

Pandanus, breadfruit, coconut, tacca from southern islands

Village island graveled and plowed

	Start January 1974		Start January 1984	
Living Pattern	Child [a]	Adult [a]	Child [b]	Adult
1	0.047	0.045	0.047	0.043
2	0.122	0.130	0.092	0.101
3	0.168	0.204	0.138	0.166
4	0.415	0.516	0.325	0.392
5	0.121	0.135	0.094	0.106
6	0.253	0.354	0.202	0.254

Table 5. Maximum annual bonemarrow dose (rem).

Total diet from southern islands

Village island graveled and plowed

	Start January 1974		Start January 1984	
Living Pattern	Child [a]	Adult [a]	Child [b]	Adult
1	0.047	0.045	0.047	0.043
2	0.097	0.091	0.071	0.069
3	0.094	0.094	0.077	0.079
4	0.199	0.193	0.133	0.129
5	0.096	0.096	0.074	0.074
6	0.189	0.213	0.123	0.134

[a] Diet change at 10 yr., i.e., 1984.

[b] Diet change at 10 yr., i.e., 1994.

Table 6. Maximum annual whole-body dose (rem).

No restrictions on diet

Village island unmodified for external gamma

Living Pattern	Start January 1974 Child[a]	Start January 1974 Adult[a]	Start January 1984 Child[b]	Start January 1984 Adult
1	0.039	0.039	0.038	0.039
2	0.234	0.236	0.200	0.233
3	0.619	0.630	0.531	0.628
4	1.81	1.80	1.54	1.79
5	0.285	0.291	0.252	0.291
6	0.798	0.812	0.674	0.802

Living Pattern		Village island	Agriculture	Visitation
1	(A)	Enewetak-Parry	ALVIN-KEITH	Southern Is.
2	(B)	Enewetak-Parry	KATE-WILMA + LEROY	Northern Is.
3	(D)	JANET	JANET	Northern Is.
4	(F)	BELLE	BELLE	Northern Is.
5	(C)	JANET	KATE-WILMA + LEROY	Northern Is.
6	(E)	JANET	ALICE-IRENE	Northern Is.

[a] Diet change at 10 yr., i.e., 1984.

[b] Diet change at 10 yr., i.e., 1994.

Table 7. Maximum annual whole-body dose (rem).

No restrictions on diet

Village island graveled and plowed

Living Pattern	Start January 1974 Child[a]	Adult[a]	Start January 1984 Child[b]	Adult
1	0.039	0.039	0.039	0.038
2	0.234	0.236	0.200	0.233
3	0.540	0.542	0.452	0.540
4	1.56	1.55	1.30	1.55
5	0.237	0.241	0.204	0.240
6	0.749	0.761	0.631	0.757

Table 8. Maximum annual whole-body dose (rem).

Pandanus and breadfruit from southern islands

Village island graveled and plowed

Living Pattern	Start January 1974 Child[a]	Adult[a]	Start January 1984 Child[b]	Adult
1	0.039	0.039	0.039	0.038
2	0.125	0.128	0.146	0.127
3	0.245	0.252	0.304	0.249
4	0.662	0.663	0.846	0.656
5	0.128	0.133	0.149	0.132
6	0.350	0.367	0.430	0.363

[a]Diet change at 10 yr., i.e., 1984.

[b]Diet change at 10 yr., i.e., 1994.

Table 9. Maximum annual whole-body dose (rem).

Pandanus, breadfruit, coconut, and tacca from southern islands

Village island graveled and plowed

Living Pattern	Start January 1974 Child[a]	Start January 1974 Adult[a]	Start January 1984 Child[b]	Start January 1984 Adult
1	0.040	0.039	0.039	0.039
2	0.091	0.122	0.078	0.093
3	0.146	0.187	0.119	0.151
4	0.357	0.475	0.280	0.355
5	0.093	0.127	0.080	0.098
6	0.246	0.328	0.160	0.241

Table 10. Maximum annual whole-body dose (rem).

Total diet from southern islands

Village island graveled and plowed

Living Pattern	Start January 1974 Child[a]	Start January 1974 Adult[a]	Start January 1984 Child[b]	Start January 1984 Adult
1	0.040	0.039	0.039	0.039
2	0.090	0.083	0.065	0.066
3	0.087	0.097	0.070	0.076
4	0.192	0.191	0.126	0.126
5	0.089	0.094	0.066	0.071
6	0.182	0.211	0.116	0.131

[a]Diet change at 10 yr., i.e., 1984.

[b]Diet change at 10 yr., i.e., 1994.