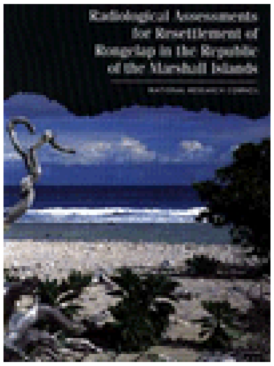

Radiological Assessments for the Resettlement of Rongelap in the Republic of the Marshall Islands

Committee on Radiological Safety in the Marshall Islands, National Research Council

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Committee on Radiological Safety in the Marshall Islands
Board on Radiation Effects Research
Commission on Life Sciences
National Research Council

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of the members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Committee on Radiological Safety in the Marshall Islands

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PREFACE

BACKGROUND

The Committee on Radiological Safety in the Marshall Islands was established by the National Research Council in response to a request from the U.S. Department of Energy (DOE) to assist the department in evaluating the radiological safety of the Marshall Islands, particularly Rongelap Atoll. The need for such an evaluation stems from questions over the possibility of meeting the radiological provisions of the memorandum of understanding (MOU) between the Republic of the Marshall Islands and the United States regarding the resettlement of Rongelap Atoll. The issue of resettlement itself originated in the desire of the Marshallese to return to the atolls from which they were evacuated as a consequence of nuclear-weapons testing by the United States during the 1940s and 1950s. The National Research Council was asked to review the scientific studies undertaken by DOE[1] to determine the potential radiological hazard, if any, to persons who might return to live on Rongelap Atoll.

A crucial provision of the MOU is that resettlement will occur only if *no person* returning to Rongelap and subsisting on a native-foods-only diet will receive a calculated annual whole-body radiation dose equivalent of more than 100 mrem above background. The scope of radiological studies needed to assure compliance with this MOU can be focused somewhat in the present context because of the radioactive decay and normal weathering processes that has taken place in the 40 years since the BRAVO detonation. At the present time, the only isotopes that contribute significantly to the dose on Rongelap are those of strontium-90, cesium-137, plutonium-239, plutonium-240, and americium-241. Of these, cesium-137 accounts for more than 90% of the estimated dose, strontium-90 is the second most significant contribution at 2-5%, and the transuranic nuclides contribute less that 5% to the total estimated dose (Kercher and Robison, 1993). This narrows considerably the effort to investigate and model the potential doses received from fallout radionuclides by those who might choose to resettle on Rongelap.

Another provision of the MOU that is of importance to the people of Rongelap as they consider resettlement is an action limit of 17 pCi/g for concentrations of plutonium in the island's soils. This action level in the MOU was based on a U. S. Environmental Protection Agency (EPA) action value of 0.2 $\mu Ci/m^2$ for protection of the public from radionuclides in the environment. The EPA action level was developed for application to recent contamination, thus all of the radioactivity was considered to be concentrated within the top 1 cm of the soil. The MOU action limit of 17 pCi/g was derived by DOE from this 0.2 $\mu Ci/cm^2$ EPA guideline

[1] Throughout this report, references to DOE and to work performed by DOE should be considered to include actions undertaken by DOE and its predecessors, including the Atomic Energy Commission and the Energy Research and Development Agency.

using a soil density of 1.2 g/cm^3 appropriate to Rongelap and assuming that the radioactivity was in the top 1 cm of soil. Because the contamination on Rongelap took place nearly 40 years ago the MOU considers the potential for subsequent radionuclide migration in the soil by providing provisions for averaging of the 17 pCi/g radionuclide concentration over the top 5 cm of soil.

In this report, the committee restricts its attention largely to the technical aspects of the issues surrounding resettlement of Rongelap Atoll. The committee recognizes, however, that major, and equally important, social, ethnological, and political elements will also influence resettlement decisions by the Rongelap people. It has, therefore, during its deliberations, tried to maintain due consideration of factors —such as physical, biological, logistical, cultural, and psychological factors —that may reasonably apply to or might come to bear on the resettlement of the Rongelap people and their continued well-being.

It is the desire of all parties that resettlement occur in a timely fashion but without sacrificing the ability of the Rongelap people to pursue their lives without an unacceptable risk from radiation. The proposed resettlement program is bilateral. Its success will depend on mutuality of purpose and intent. Integral to the program must be a commitment to information-sharing and to direct, unambiguous communication. The committee assumes DOE will ensure that all relevant information and documents in its possession are made available to the Rongelap people on request and that all recommendations by the present National Research Council committee will be forwarded to the Republic of the Marshall Islands and to the Rongelap Resettlement Project Scientific Peer Review Group.

Because of the many references made in this report to the provisions of the MOU between the United States and the Republic of the Marshall Islands, the full text of the MOU is provided as an appendix. It should be noted, however, that the committee was not asked to review or comment on the provisions of the MOU, as these are the result of international negotiations, and will do so only as it effects the scientific studies needed to provide assurances that its provisions can be met.

CHARGE TO THE COMMITTEE

DOE requested the assistance of a National Research Council committee to help it decide whether "good science" was being used in determining the appropriateness of resettlement of Marshall Islands atolls that were affected by the atmospheric fallout from nuclear weapons tested in the region in 1946-1958. The National Research Council appointed a group of eminent scientists to review and provide recommendations on radiological-health issues in the Marshall Islands. This group was to review and comment on the scientific and technical merit of the processes and procedures used by the DOE to evaluate the resettlement potential of Marshall Islands atolls affected by fallout and by actual detonations. The committee, established in the Board on Radiation Effects Research of the National Research Council, was asked to provide advice on the scientific validity of the technical studies, including comment on the methodologies of investigations of various kinds: determination of body burdens by bioassay, dose modeling for estimating ingestion and inhalation of radioactive materials, modeling and confirmatory assays of the soil-to-food pathway, remedial measures to reduce plant uptake of radioactive materials, and the application of current international standards for radiation dose limits in this particular environment. Particular emphasis was to be placed on the evaluation of procedures for environmental monitoring and dose assessment necessary to determine the doses to people who wished to return and to live in these atoll areas and to consume local-only foods from portions of Rongelap Atoll and surrounding atolls that can support a return to their native habits and ways of life. The committee was asked to review the DOE programs and accomplishments, compare them with current practices, and suggest where additional data might be required for prudent decision-making as to potential resettlement. The committee includes not only radiation scientists, but experts in anthropology, ecology, genetics, medicine, nutrition, psychology, and statistics.

Specifically, the committee was asked to carry out the following activities:

- Review and comment on the applicability of current International Commission on Radiological Protection (ICRP) recommendations on annual dose limits for general populations as they pertain to anticipated dose commitments after resettlement in potentially contaminated areas of the Marshall Islands.
- Evaluate and comment on the adequacy of followup analytical techniques such as whole-body counting techniques and urine assay, to measure the accumulation and elimination of internally deposited radioactive materials in people after resettlement in potentially contaminated areas.
- Review and evaluate methods to reduce the ingestion and inhalation of radioactive materials by inhabitants of the Marshall Islands, particularly persons that resettle Rongelap Island and other islands in the Rongelap Atoll.
- Evaluate the radiological implications of proposed dietary regimens for persons who resettle Rongelap Atoll, taking into account both native and imported foodstuffs and the range of variation in diet among individuals, including persons of different age groups and both sexes.
- Advise on the long-term health consequences of various remedial actions directed at the physical environment that might be proposed to improve the habitability of islands in the Rongelap Atoll.
- Evaluate metabolic and dosimetry models for ingested radioactive materials to determine which are the most valid for application to inhabitants of the Marshall Islands.

To make those assessments, the committee was asked to review recent ICRP reports, technical documents, and other data relevant to the environmental assessment of Rongelap Atoll and, to the extent necessary, draw on reports of experience in other Marshall Islands areas. The committee was also asked to review the scientific literature on bioassay methods and, by interview or other means, gather the views of scientists and other persons familiar with the needs of the Marshallese. The overall aim of the committee's activities was to review and evaluate the procedures that DOE scientists use in technical assessments concerning the potential resettlement of islands in the Rongelap Atoll and, as required, other Marshall Island atolls affected by the atmospheric nuclear-weapons tests.

In meeting its charge, the committee had access to reports (both internal and published) prepared by DOE contractor staff that covered the wide range and varied aspects of the radiological assessments being conducted in the Republic of the Marshall Islands (RMI). In addition, the committee members visited DOE contractor laboratories to observe the procedures and facilities developed and applied in their radiological studies, conducted numerous discussions with DOE contractor staff and with other scientists actively engaged in the investigation of conditions in the Marshall Islands. Finally, committee members visited the Marshall Islands to better connect the written reports with first-hand insights from a close look at the sites of current radiological studies on Bikini and Rongelap and to observe the conditions on the islands of Mejatto and Ebeye, where many of the previous residents of Rongelap now reside. Discussions were conducted both at the National Academy of Sciences facilities in Washington, D.C., and on Mejatto with the leaders of the people of Rongelap who wish to resettle. The committee also was provided with detailed information on the studies being conducted by the Nationwide Radiological Study of the RMI and the Rongelap Resettlement Project, both directed by Dr. S. L. Simon. Dr. Simon is a radiation scientist who has been employed by the Republic of the Marshall Islands to lead these projects.

This report is organized to reflect study of the characteristics of the land and people, elements of environmental and dose modeling, characteristics of potential remediation activities, the applicability of dose limits, and recommendations for post-resettlement monitoring. Chapter 1 is an introductory discussion of the environmental and cultural factors that underlie the desires of the people of Rongelap to resettle their island homes; it also provides a general discussion of the sources and measurements of radiation up to the present time. Chapters 2-6 evaluate the technical activities that have been undertaken to assess the radiological conditions on Rongelap. Chapter 7 addresses the applicability of dose limits in discussions of resettlement. Chapter 8 considers the applicability of possible remedial actions as they might apply to Rongelap. Chapter 9 considers the applicability of current technology to support the post-resettlement environmental and biological monitoring required to meet the conditions specified in the MOU that was signed by representatives of the people of Rongelap, the Republic of the Marshall Islands, DOE, and the U.S. Department of the Interior.

ACKNOWLEDGEMENTS

The committee's work was greatly facilitated by a number of people and organizations. Within the U.S., we are primarily grateful to Dr. William Robison of the Lawrence Livermore National Laboratory and Drs. L. C. Sun, A. Moorthy, E. Kaplan, and C. B. Meinhold of the Brookhaven National Laboratory. On the Marshall Islands trip, Dr. Keith Baverstock and Dr. Steven Simon, Director Nationwide Radiological Study, Republic of the Marshall Islands, were instrumental to the committee's scientific activities, and Mr. Kent Hiner of Raytheon to its physical needs; Dr. Robison provided an excellent description of his environmental studies underway on Bikini; and Mr. Randy Thomas, who accompanied our group as a representative of the Rongelap community, was instrumental in describing the importance of the islands to their way of life. The committee also benefited from numerous discussion with representatives of the Marshall Islands, both during their visits to the U.S. and in the Marshall Islands, including Mr. Peter Oliver, Under Secretary, Minister of Foreign Affairs, Republic of the Marshall Islands; Senator Johnsay Riklon, Rongelap/Utirik Atoll Local Government Council; Mayor Billiet Edmond, Rongelap Atoll Local Government Council; and others. The necessary contacts with, and briefings by, the Department of Energy were ably handled by Mr. Thomas Bell and Dr. Harry Pettengill. Dr. Douglas Grahn, liaison with the Board on Radiation Effects Research, contributed materially to our activities. Finally, in the persons of Drs. Dennis Mahlum, Larry Toburen, Evan Douple, and Ms. Doris Taylor, the committee enjoyed excellent staff support.

CONTENTS

Radiological Assessments for Resettlement of Rongelap in the Republic of the Marshall Islands

EXECUTIVE SUMMARY

The Committee on Radiological Safety in the Marshall Islands was established by the National Research Council in response to a request from the U.S. Department of Energy (DOE) to assist the department in evaluating radiological conditions on certain atolls in the Republic of the Marshall Islands, especially Rongelap Atoll. The need stems from the provisions of a memorandum of understanding (MOU) established between the Republic of the Marshall Islands and the United States in 1992. That agreement sets out criteria and stipulations pertaining to the resettlement of Rongelap Atoll. The issue of resettlement itself originated in the desire for the people of the Marshall Islands to return to the atolls from which they were evacuated as a consequence of nuclear-weapons testing by the United States during the 1940s and 1950s. The National Research Council was asked to review the scientific studies undertaken by the U. S. Department of Energy to determine if reliable and modem scientific methodology was being used to assess the potential hazard, if any, to persons who might return to live on Rongelap Atoll. A crucial provision of the MOU is that resettlement will occur only if *no person* returning to Rongelap and subsisting on a native-foods-only diet will receive a calculated annual whole-body radiation dose equivalent of more than 100 mrem above background. The MOU also presents an action level of 17 pCi/g for the concentration of transuranic contamination, i.e., plutonium and americium, in soils below which mitigation will be considered unnecessary.

The assessment of the radiological conditions on Rongelap resulting from the U. S. testing program is narrowed somewhat by the weathering processes and nuclear-decay that has transpired during the 40 years since the atoll was contaminated. At the present time, the isotopes that would contribute significantly to the dose to individuals who might reside on Rongelap are those of strontium-90, cesium-137, plutonium-239, plutonium-240, and americium-241. Of these, cesium-137 accounts for more than 90% of the estimated dose, strontium-90 provides the second most significant contribution at 2-5%, and the transuranic nuclides contribute less that 5% to the total estimated dose.

Resettlement of the northern Marshall Islands is a precedent-setting activity. As far as this committee is aware, the current efforts to resettle the Marshallese are among the first in which a government has undertaken to facilitate and monitor the return of a population that was displaced because of concerns for radiation exposure. The utility of the criteria and procedures used and the resulting protocol might extend well beyond the present situation. The people of Rongelap resettled their homeland in 1957 only to leave again in 1985 "on the belief that Rongelap was unsafe and that DOE had not told the truth about radiation —either with respect to its contamination of the lands and environment of Rongelap Atoll, or as to its impact upon the people."[1] It is important that the current effort to assess the radiological conditions and their potential impacts on the people of Rongelap avoid the problems of the past.

In its charge to the committee, DOE directed the committee to review and comment on the scientific and technical merit of the processes and procedures used by DOE and its contractors in its evaluation of the radiological conditions on Rongelap and, in short, to determine whether its assessments meet the standards of good science. The committee was asked to give attention specifically to several subjects, including: the appropriateness of application of the International Commission on Radiological Protection's (ICRP) annual radiation dose limits to the dose commitments expected to follow resettlement; the applicability of metabolic and dosimetry models for ingested radioactive materials; the implications of proposed dietary regimens for calculated dose projections; the effect of variations in the native-to-imported food ratio and differences in diet due to sex, age, or individual preference; the methods proposed to reduce exposure to radioactive materials by inhalation or ingestion; the adequacy of follow-up analytical techniques; and the long-term consequences to health of proposed remediation of the environment.

In meeting its charge, the committee had access to reports (both internal, many in draft form, and published) prepared by DOE contractor staff that covered the wide range and varied aspects of the radiological assessments being conducted in the Marshall Islands. In addition, the committee members visited DOE contractor laboratories to observe the procedures and facilities developed and applied in studies of the radiological conditions in the Marshall Islands, conducted numerous discussions with DOE contractor staff and with other scientists actively investigating the conditions in the Marshall Islands, and traveled to the Marshall Islands for a close look at the sites of current radiological studies on Bikini and Rongelap and to observe the conditions on the islands of Mejatto and Ebeye, where many of the previous residents of Rongelap now reside. Discussions were conducted at the National Academy of Sciences facilities in Washington, D.C., and on Mejatto with the leaders of the people of Rongelap who wish to resettle. The committee also was provided with detailed information on the studies being conducted by the Nationwide Radiological Study and the Rongelap Resettlement Project, both of which are under the direction of Dr. S. L. Simon, a health physicist employed by the Republic of the Marshall Islands.

The committee conducted a comperhensive review and evaluation of the data available to it regarding the investigative procedures and models used in the assessment of the potential doses that might be incurred by those individuals who choose to return and live on Rongelap. In many instances the committee had to rely on discussions with the investigators, and unpublished procedures and results provided in internal reports in its investigation; it seems not to have been the tradition of these DOE programs to publish extensively in the peer reviewed literature. Based on its experiences, the committee would recommend that in the future the Department of Energy place greater emphasis on publishing results obtained in its programs in the peer-reviewed literature.

[1] Quoted from the testimony of Senator Jeton Anjain, Marshall Islands, on behalf of the people of Rongelap, before the House Committee on Appropriations, Subcommittee on Interior and Related Agencies, The Honorable Sidney R. Yates, Chairman, May 9, 1991.

The MOU that was negotiated between the governments of the United States and the Republic of the Marshall Islands includes a rather unusual requirement in its presentation of a radiation dose limit in terms of the dose to the *maximally exposed* resident. In general, the techniques of radiation dosimetry are not developed for determination of dose to the maximally exposed individual; it is particularly difficult for a population of limited size where the statistical power for determining doses at the extremes of dose distributions is limited. In addition, this population has the potential to gather food from other islands that may have higher radiation burdens, and individuals may "binge" on foods of higher than average radionuclide concentration, e.g., coconut crab. These possibilities make estimates of the dose to the maximally exposed resident highly uncertain. The committee would prefer that the MOU conform to more common radiation protection practices in stating dose limits, however it was not within the charge to the committee to implement or recommend changes to the MOU; these provisions stem from a previously negotiated international agreement. Therefore, assessment of dose estimates and application of dose modeling must be considered within the context of the provisions of the MOU. Although the available data and the standard procedures in radiation protection do not lend themselves to an accurate evaluation of the dose to the *maximally exposed* resident, the committee presents an assessment of the use of statistics, and of scenarios, in the report in an attempt to address this issue.

CONCLUSIONS

The following summarizes the committee's conclusions based on its review of all the material acquired during the course of its deliberations concerning the points enumerated in the committee's charge.

1. *Applicability of ICRP recommendations on annual dose limits*. The committee was asked to comment on the ICRP recommendations for general populations as related to the resettlement of Rongelap and other Marshall Islands populations. Because the ICRP recommendations were not developed with the present situation in mind and annual dose limits have already been negotiated for the resettlement of Rongelap and formalized in the MOU, the committee did not feel that it would serve a useful purpose to undertake a detailed discussion of exposure standards. Although the ICRP dose limits applicable to the public were not designed for application to resettlement of previously contaminated land, the ICRP recognizes the use of numerical criteria, action levels as defined in the MOU, as useful tools in decision making. This issue is discussed in Chapter 7.
2. *Environmental sampling and analysis*. The programs for systematic environmental sampling and radioassay of soil, vegetation, water, and foodstuffs on Rongelap have been broad in scope and of very high quality. The major focus of these studies has been on the concentrations of cesium in the soil, breadfruit, coconuts, and pandanus and the concentrations of transuranic elements in the soil as the primary radionuclides of interest in this environment. The rigid application of reliable laboratory techniques by the scientists of the Lawrence Livermore National Laboratory (LLNL), a DOE laboratory, has provided a substantial

background of information useful in the estimation of potential radiation doses to the resettlement population from exposure to radiation in the environment or through ingestion.

3. "*Hot Spots*". The potential for radionuclide hot spots in unsampled regions of the island has been of notable concern to the Rongelap community. However, given the relatively uniform distribution of radionuclides observed in the LLNL grid used to sample soil for radioactivity on Rongelap and the nature of the source contamination, the committee sees little reason to suspect the existence of localized high concentrations of radionuclides (plutonium, cesium, etc.) that would contribute to "hot spots." (The committee has accepted the definition of a "hot spot" as a local region in which the radionuclide concentration has a value of 10 or more times the mean of the present observations.)
4. *Dietary models*. The information obtained from a number of dietary surveys does not appear adequate to provide a reasonable estimate of either current or indigenous diets for the Rongelap community. *Based on the available information, however, the committee estimates that a sizeable fraction of the persons on a purely native diet, or any other diet that includes a large intake of coconuts, could exceed the 100-mrem, above normal background, annual dose equivalent limit specified in the MOU*. The effects of these uncertainties in the diet models are also discussed in conclusions 6 and 7 below.
5. *Measurements on humans*. The whole-body counting system currently used in the Marshall Islands by DOE contractor staff of the Brookhaven National Laboratory (BNL) is practical and reliable for measuring cesium-137 body burdens. To monitor the Rongelap population adequately for whole-body burdens, so that sufficiently accurate information is obtained to assure compliance with the MOU, it will be necessary to follow individuals in the resettlement population systematically for an indefinite period of time. In the environment of Rongelap, strontium-90, plutonium-239, and plutonium-240 are expected to make only a very minor contribution to doses received from the long-term exposure. The accurate measurement of plutonium-239 and plutonium-240 in the urine at the expected very-low levels is extremely difficult, if possible, using current techniques. The problems in accurately measuring and interpreting concentrations of plutonium in urine need to be addressed, improvements documented, and practical considerations and limitations understood in any program that might be set up to monitor plutonium intake.
6. *Dosimetry and its application*. Dose estimates have been made by DOE contractor personnel in accordance with accepted methods put forth by the ICRP. External-dose estimates are accurate and sufficiently comprehensive. Internal dose estimates —those related to doses received through inhalation, ingestion, and absorption —are less complete because age-specific estimates are absent. This is not a serious deficiency within the context of the present situation, because estimates for cumulative dose based on the "reference adult" tend to be conservative. In addition, uncertainties introduced by dosimetric techniques are, in general, small relative to those related to dietary information and individual variability.

7. *Uncertainty in dose projections*. Two generally accepted methods are used to estimate doses to the maximally exposed individual. One is the probabilistic approach that uses the means and variances of the radiological components used in modeling. The other is the scenario approach, which specifies characteristics of some maximally exposed resident, such as age, sex, residence, and diet. The LLNL dose projections principally used a sophisticated probabilistic approach, but their validity is limited by the small number of samples available for estimating distributions of dietary radionuclide intake and retention. On the basis of using a scenario approach, the present committee estimates that the *average* individual consuming a local-foods-only diet could receive an annual dose of 92-106 mrem/y, depending on the choice of diet; this estimated range is based on what the committee feels is the most likely combination of local foods and energy intake (see Chapter 5, Table 5-4). Uncertainty in the dose estimate for a particular scenario depends on the uncertainty in environmental sampling data and uncertainty in the dosimetry. Uncertainty in the probabilistic approach also depends on those sources of uncertainty, as well as uncertainty in the dietary intake and in other individual characteristics.
8. *Health effects of remedial actions*. The committee believes that the major environmental remedial action now under consideration, the use of potassium fertilizer, would not adversely affect the health of those residing on Rongelap and in fact, to the extent that it increased cultivar yields, would improve the nutrition of the population. Potassium chloride is a fertilizer commonly used in the United States with no known acute or chronic health hazards when used for this purpose. A second, more local remedial action, clearing contaminated soil from the village area, would likewise pose no adverse health effects. The Committee felt that stripping the island of the organic soil to remove contamination in the upper portions of the soil would, however, be unwise owing to the fragile ecology of the island and the long time required for regeneration of the organic topsoil.

Based on the committee's review of the scientific data, the potential radiation doses from the different sources of exposure that might accrue to those who choose to return to live on Rongelap are summarized in Table 1. Here we present dose contributions from two of the several possible diet scenarios that were discussed in the text, namely those provided by the local-plus-imported-available diet (scenario A) presented by Robison et al. (1993), and the local-foods-only diet of Robison et al. (1993), but with the caloric intake adjusted to reflect what the committee feels is a more appropriate energy intake for an active population, i.e., the same calorie intake as obtained for the local-plus-imported-foods diet (scenario C).

Table 1. Summary of projected Average Radiation Exposures to Rongelap Residents

	Contributions to Dose		mSv/y	(mrem/y)		
I.	NATURAL BACKGROUND RADIATION					
	A. External Exposure[a]		0.22	(22)		
	B. Internal Radionuclides[b]		2.0	(200)		
	Subtotal		2.22	(222)		
II.	ATTRIBUTABLE TO FALLOUT[c]	Scenario A[d]			Scenario C[e]	
	A. External exposure	0.11	(11)		0.11	(11)
	B. Internal Exposure					
	1. Ingestion	0.17	(17)		0.95	(95)
	2. Inhalation	0.0043	(0.43)		0.0043	(0.43)
	Subtotal	0.29	(29)		1.06	(106)
TOTAL: NATURAL AND FALLOUT		2.51	(251)		3.28	(328)

[a] Primarily cosmic radiation; external background radiation from natural terrestrial sources is very low in the northern Marshall Islands (Robison et al., 1993)

[b] From naturally-occurring radionuclides, such as potassium-40, polonium-210, and lead-210 in a diet high in fish content (Robison et al., 1993).

[c] Projected for 1995.

[d] Scenario A is based on a diet that includes the availability of imported foods; this diet, from the work of Robison et al., (1993), contains a caloric intake of 3208/d.

[e] Scenario C is composed of the *local-foods-only* diet described by Robison et al. (1993), but adjusted by the committee to contain the same caloric intake as scenario A.

RECOMMENDATIONS

On the basis of its review, the committee offers the following recommendations.

1. Because of the substantial uncertainties in this complex and unprecedented situation, the committee recommends that no categorical assurances be given concerning the MOU requirement that no individual receive a calculated annual radiation dose equivalent of more than 100 mrem above background. Some people returning to Rongelap and subsisting on a local-food-only diet might receive an annual dose in excess of 100 mrem above background if there is no remedial action.
2. If the citizens of Rongelap decide to accept the uncertainties in dose estimates and return to Rongelap, the Committee endorses two, possibly temporary, remedial actions:

- The immediate and, as appropriate, continuing application of potassium chloride as a fertilizer to decrease uptake of cesium in foods wherever there are coconut palms or pandanus trees on the island.

- On resettlement, acceptance of an initial diet in which about half the calories are derived from non-native foods (which might be necessary in any case to support the population while it attempts to re-establish the island's economy).

These remedial actions can be regarded as temporary measures in the sense that both might be relaxed if monitoring results in appropriate assurance that the dose limits negotiated in the MOU can be met.

3. To provide reassurance to the people of Rongelap that the limits of the MOU are being met, the committee recommends that, until experience dictates otherwise, every member of the resettled community receive a whole-body count for radionuclide burden and provide a urine sample sufficient for analysis for plutonium before resettlement and each year thereafter. In addition, a cohort of approximately 80 persons (assuming a total resettlement population of approximately 400 people) stratified by age and sex should be examined four times a year in the same fashion to establish seasonal fluctuations, which must be understood if annual doses to the most heavily exposed are to be calculated.
4. The committee recommends that at the outset, to meet the terms of the MOU, the northern islands of Rongelap and Rongerik Atolls be considered "off limits" for food-gathering. This constraint may be relaxed if the experience of the first several years indicates that the 100-mrem standard would be met even if food-gathering were extended to the northern islands. The environmental sampling program conducted on Rongelap has provided an appropriate background of information for estimating the potential doses for the resettlement of Rongelap Island. The committee recommends that a continued effort be made to characterize the other islands in the atoll that may be used for food gathering in the future. This data is needed to provide detailed estimates of doses that may occur as a consequence of such activities. Such a research effort should be carefully designed with goals established in concert with the needs of the people of the region and in consultation with experts in environmental monitoring and dose assessment. In addition, the committee recommends that environmental monitoring of edible fruits be continued with a focus on determining the biological retention of radionuclides in the environment.
5. The committee recommends that medical services, with comprehensive medical-record maintenance, be initiated to permit continuing evaluation of the health status of the returning population. This recommendation is not in anticipation of radiogenic illness among those persons, but rather is intended to meet the need for factual information if the community becomes concerned about radiogenic consequences.
6. The committee recommends that a more formal coordination of the radiological-assessment activities of BNL and LLNL be established than has existed in the past. Similarly, these activities should be coordinated with those of the Scientific Management Team of the Nationwide Radiological Study of the RMI.

1.

Introduction

The physical and cultural characteristics of the people of Rongelap, their diet, and their customs —as distinct from environmental factors —are important in estimating potential radiation doses after return to their native atoll. The Rongelap people are culturally and ethnically distinct. Some of their physiological characteristics might also differ from those of the "standard" American and might be closer to those of the reference "Asian man" than to those of the ICRP standard "reference man" (Griffith, 1994), on which much of our information for radiation-protection standards is based. The committee is aware of those differences and has attempted to keep them and the concerns of the Rongelap community uppermost in mind during its deliberations.

Concerns of the committee regarding the settlement of Rongelap are both general and specific. Examples of general concerns are the protection of people from needless above-background radiation exposure; the use of universally accepted dosimetry methods; and the proper application of the most current statistical, environmental, and body-burden modeling procedures in estimating potential radiation doses. Specific issues are more variable and often intangible and must be considered in relation to individual and group needs. They include the spiritual confluence that the Rongelap people feel with their atoll home, their intimate daily interaction with their environment, and the variations in their diet. The people of Rongelap are highly mobile, and their dietary pattern reflects their movements and activities. In body type, the average Rongelap native is short and tends to be slender until marriage, after which the cultural value placed on being well fed becomes apparent. Given those conditions, predicting and monitoring radiation exposure must take into account age, sex, and activity pattern and must also focus on context-specific biophysical and metabolic profiles, which include the ratio of locally produced to imported food and other dietary variables.

The people of Rongelap have obviously been traumatized by their involuntary involvement in nuclear testing. Their first exile occurred in 1954, 2 days after the U.S. nuclear test BRAVO resulted in widespread contamination of their island home. They returned in 1957 with assurances that the radiation levels on their atoll were safe. But in 1985 they became convinced that radiation contamination on Rongelap was contributing to medical problems, and they again moved from their home, this time to exile on the island of Mejatto in the Kwajalein Atoll. Since that time, they have attempted to determine whether the environment of Rongelap Atoll —soil, birds, fish, and other foodstuffs —is safe and the atoll therefore habitable. They still do not have a definitive answer; in fact, the Rongelap community expresses a degree of distrust of information received from DOE. Members of this NRC committee hope —indeed, anticipate —that the concerns of the Rongelap people will, to a great extent, be allayed by the knowledge that the scientific activities of the DOE have been given a thorough review during the course of this committee's deliberations.

This chapter presents an overview of the cultural and environmental factors that affect the resettlement of Rongelap, including their potential effect on the estimation of radiation doses of returning Rongelap people. Both the composition of the island soils and the local climate affect weathering and the dispersal of radioactive contamination, and the availability of native food sources and the dietary habits of the people are also important. This chapter draws heavily on several reviews of the geology and cultural history of the Marshall Islands (Mason, 1947; Wiens, 1957; Fosberg and Carrol, 1965; Amerson, 1969; Hezel, 1983; Bendure and Friary, 1992; Simon et al., 1993).

ENVIRONMENT

The map shown in Figure 1 illustrates the location of the Republic of the Marshall Islands (RMI) relative to the other islands, island groups, and larger land masses in the Pacific Ocean. Figure 2 shows the position of the different island chains, atolls, and islands of the RMI (in this report the RMI will often be referred to simply as the "Marshall Islands", as has become common practice). The Marshall Islands consists of two chains of atolls running north-northwest to south-southeast: the western, Ralik ("sunset") chain and the eastern Ratak ("sunrise") chain are clearly differentiated in Fig. 2. The number of islands in the republic exceeds 1,200. Only five are considered single islands; the others are sets of islets grouped into 29 atolls, of which Rongelap Atoll is one. The areas of the various atolls range from about 0.5 to 16 km^2, and those of the lagoons from about 8.5 to 2,500 km^2. The capital of the republic, Majuro, is on an atoll that lies approximately 3,800 km southwest of Honolulu and 2,700 km north of Fiji.

The climate of the Marshall Islands is tropical. The average daily temperature is 27ºC (81ºF), and the typical relative humidity is about 80%. The islands are low-lying and therefore do not influence local weather patterns substantially. Rainfall has a wide gradient, from 350 cm (138 in.) a year in the southern islands to only about 110 cm (43 in.) in the northernmost; this accounts for the heavier vegetation in the South. The wettest months are September through November, the driest January through March. During the wet season, intense rain squalls are frequent. Full-blown tropical storms and typhoons are rare, but they can be devastating when they do occur and cross these unprotected islands.

The soils and vegetation of the Marshall Islands have been studied extensively (see, e.g., Fosberg and Carroll, 1965). Virtually all the islands have white sand (coral) beaches. Soils of the deep-ocean atolls consist almost solely of sandy and coarser particles of calcium carbonate as calcite and aragonite and contain small amounts of substituted magnesium and strontium. Silicate clays appear undetectable, although trace amounts presumably occur from accumulation of global dust. Organic matter is relatively high in the surface layer but decreases abruptly through a narrow transition zone. The organic content of the surface layer varies from a trace to more than 10% and is the sole source of cation-exchange capacity. Calculated ratios of the carbon to nitrogen content of the soils vary from about 10:1 to 13:1 and indicate advanced stages of organic decomposition. Phosphorus content represents input by nesting sea birds at some time in the past and varies highly in amount from site to site. The make-up of the island soils and sub-soils contribute to very low natural background radiation exposure rates; there are no naturally occurring rock formations that would contribute to such

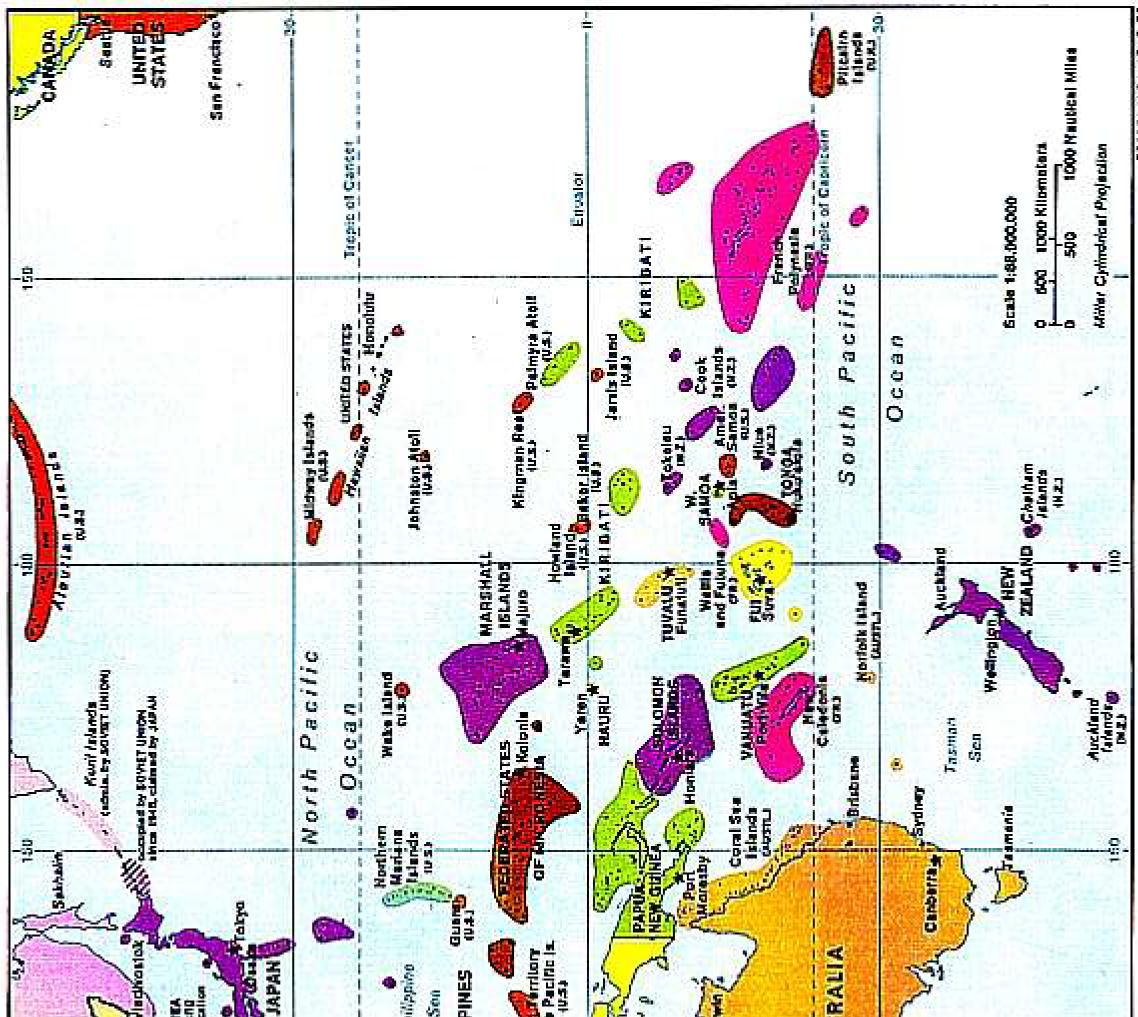


Figure 1. Central Pacific Ocean.

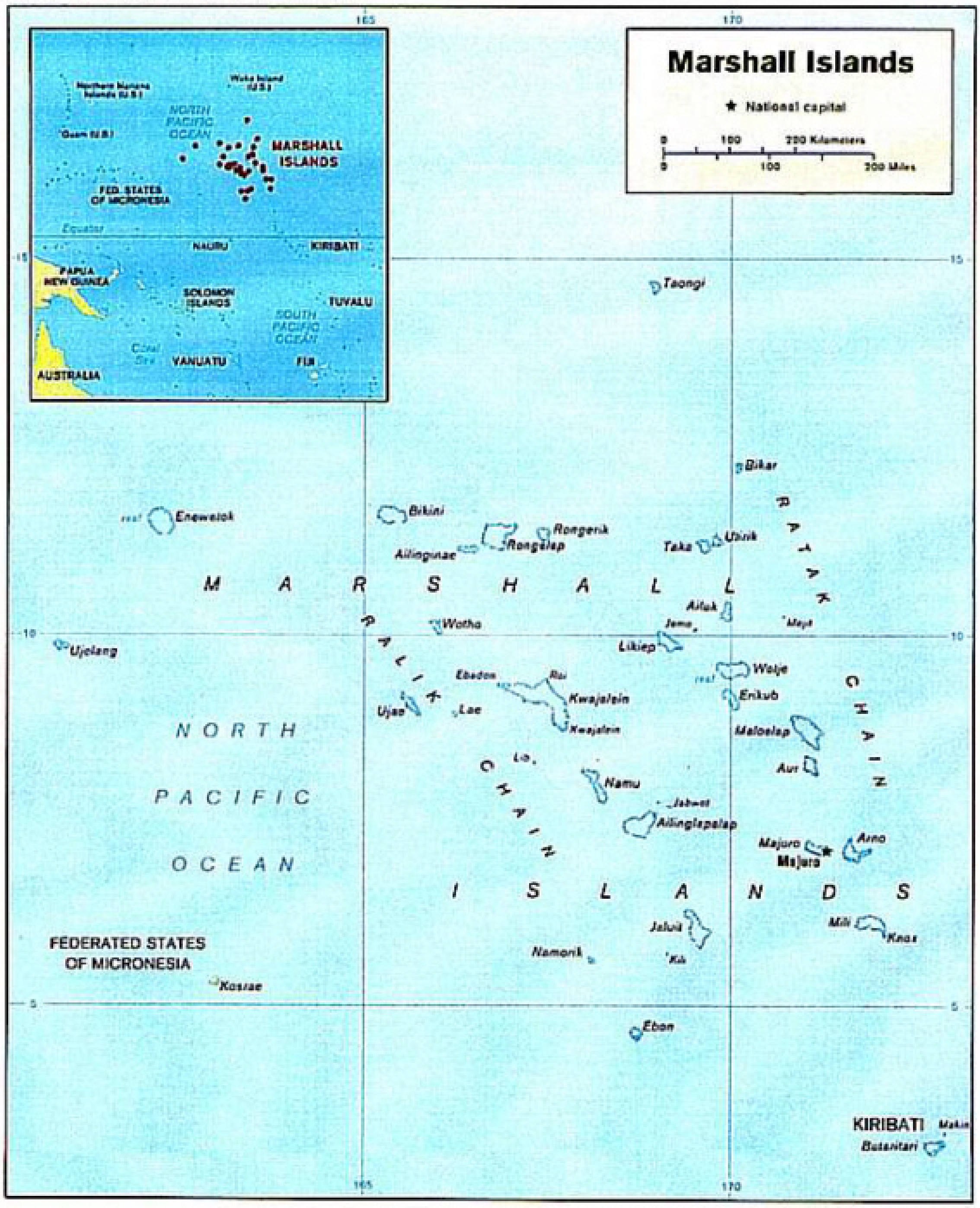


Figure 2. Republic of the Marshall Islands

otherwise commonly occurring radiation backgrounds such as that due to radon.

Most of the original vegetation of the northern Marshall Islands, especially the larger islands, has been replaced by coconut plantations. These plantations range in density from almost complete cover in the moister regions to sparseness in the dry northern atolls. The ground cover under the trees ranges from grass and other herbs to a thick tangle of bushes, vines, and trees, depending on the particular atoll climate and how diligently the plantations are tended. A belt of scrub forest is sometimes left around the plantations for protection from wind and salt spray. The thick scrub forests along the fringe of the islands can give the appearance of impenetrability. In undisturbed areas, pure stands of the soft-wooded trees *Pisonia, Pandanus*, or umbrella-like *Ochrosia* are found with mixed stands of several hardwood species. The forests usually have dense canopies and little undergrowth.

Rongelap Atoll is in the Ratak Chain about 670 km northwest of Majuro and about 200 km southeast of Bikini Atoll. It comprises about 50 low-lying islands with a total area of about 9 km^2 surrounding a lagoon of about 1,000 km^2. The largest and by far the most important island is Rongelap, with an area of about 0.8 km^2. The atoll has moderate yearly rainfall, about 150-180 cm (60-70 in.). The mean air temperature is about 27ºC (82ºF), and the prevailing wind is east to north. The islands are covered with vegetation —some coconuts and much native brush and woodland; however, the lack of rainfall during the long dry season limits the kinds of plants that can be grown. Fourteen bird species are known on Rongelap Atoll: eight sea birds, four shore birds, one heron, and one domestic fowl (Amerson, 1969).

CULTURE

Anthropologists estimate that the residents of the Republic of the Marshall Islands first arrived on the shores of their coral-atoll homes about 2,000 years ago. Until the latter half of the nineteenth century, they subsisted on seafoods and breadfruit, pandanus, coconut, and arrowroot. The Marshall Islands were never unified under a single leader, although one chief often controlled several atolls, and at times virtually the entire Ralik chain was under a single chief. Chiefs had absolute authority, but their wealth and power depended on the loyalty and tribute payments of the commoners.

European cultural influences were absent from the islands until Alvaro de Saavedra landed in the western part of the Marshall Islands in 1529. Although other Spanish expeditions landed in the Marshall Islands during the 1500s, Spain did not attempt to colonize the area actively. Substantial interest in the area by British and Europeans generally was not shown until the 1830s and 1840s, when whalers began to frequent the area. The islands are named after the English sea captain John Marshall, who visited the islands in 1788, but it was the Russian explorer Otto von Kotzebue who was chiefly responsible for extensive exploration of the region between 1815 and 1825 and whose efforts resulted in the first good maps of the islands.

Whalers and traders began to expand their efforts in the Pacific early in the 1800s, but tended to avoid the Marshall Islands because of its widespread reputation for violence. Responding to European and American abuse of island women and to the killing of sacred chiefs and valued commoners, the previously friendly Marshall Islands natives became, for westerners, the most feared people in Micronesia. Violence was declining, however, by the westerners, the most feared people in Micronesia. Violence was declining, however, by the time the first Protestant missionaries arrived on Ebon Atoll in the 1850s. Missionaries were given a mixed reception by local people but within a few years had attracted a core of converts. In the 1860s and 1870s, copra production replaced whaling as the primary European industrial interest in the area. The copra industry employed local chiefs as intermediaries and greatly increased their power, stability, and influence (Carucci, 1988).

Germany purchased the Marshall Islands from Spain in 1885 and left the administration of island affairs to a group of German trading companies that further stabilized the position of the ruling chiefs. German government officials did not arrive on the scene until 1906. In the interim, a series of struggles over the terms of western domination took place between American missionaries, German traders, and independent "local" European traders. In 1917, the Japanese took control of the Marshall Islands under a League of Nations mandate. They assumed control of the copra business and, unlike the Germans, purchased copra directly from the people, using groups of resident Japanese traders, rather than relying solely on local chiefs. This policy, with the Japanese institutionalization of positions for a group of local political elites, began to undermine the unquestioned authority that island chiefs had gained during the copra era. In 1933, when it broke from the League of Nations, Japan declared ownership of Micronesia. It developed and fortified large military bases on several atolls, using local labor from throughout the Marshall Islands and Korean and Okinawan expatriates. The United States defeated Japan in decisive battles on Kwajalein and Enewetok Atolls in 1944 liberating the Marshall Islands, and ruled the area through a naval military government until it was given authority by the United Nations after World War II to administer the scattered islands and atolls of Micronesia as the Trust Territory of the Pacific Islands. Administration of the trust territory shifted from the U.S. Navy to the Department of the Interior in 1951 and remained in effect until the Republic of the Marshall Islands gained political, if not economic, independence under the Compact of Free Association that was signed with the United States in 1983 and approved under U.S. Public Law 99-239 on January 14, 1986.

Ebon, Jaluit, Majuro, Kwajalein, and Enewetok were Marshall Islands locations of interest to Japanese, European, and American colonizers from the 1850s to the 1950s, but it was not until the U.S. nuclear-testing era after World War II that Rongelap, Bikini, and Utirik joined Enewetok as locations of major consideration. The United States began nuclear tests in 1946 on Bikini Atoll and expanded them to Enewetok late in 1947.

The consequences of the contamination of Rongelap Atoll and exposure of its inhabitants owing to substantial amounts of radiation from radioactive fallout on the life-style of the people of Rongelap are summarized in Table 1-1. On March 1, 1954, the BRAVO test on Bikini exploded with 3 times the projected intensity. The unexpectedly extensive fallout traveled eastward of the test site and subjected the residents of Rongelap Atoll (including Ailinginae and Rongerik) and Utirik Atoll to substantial amounts of radioactive contamination. Within about 5 h after the nuclear test, a fine white powdery substance began to rain on Rongelap and its inhabitants. There had been no warning, so the children were allowed to play in the "snow"; only later did the inhabitants of Rongelap learn that this "snow" was dangerously radioactive. On March 3, 1954, 2 days after the test, 64 residents of Rongelap and 18 of Ailinginae were evacuated to Kwajalein; then on March 4, 159 residents of Utirik were evacuated. Including fetuses, 252 residents of these Atolls suffered whole-body exposure, with the people of Rongelap receiving estimated external gamma-ray doses of 190 rem and substantial internal and external exposure from beta-emitting radionuclides (Conard, 1992). The later development of nodular thyroid diseases, including some malignancies, resulted in understandable concern in Rongelap community about long-term health.

Table 1-1. Summary of Residences of Rongelap Community Since BRAVO Test

Dates	Residences
March 1954	Fallout from BRAVO test occurs on March 1; residents are evacuated to Kwajalein Atoll on March 3
1954-1957	Rongelap community lives on Ejet Island, Majuro Atoll
1957-1985	Rongelap community returns to Rongelap Atoll in June 1957 and lives there until May 1985
May 1985	Rongelap community moves from Rongelap to Mejatto Island, Kwajalein Atoll, on May 22
1985 to present	Rongelap community lives on Mejatto Island while awaiting resettlement to Rongelap Atoll

The people of Rongelap returned to their home atoll on June 29, 1957, after a decision was made that it was safe for them to return under continuing radiological surveillance. Later, they came to feel that "safe" was relative when unanticipated medical problems began to surface.[2] Concern was intensified by release of additional government reports, including a Marshallese language discussion of the radiation levels in the Northern molls of the Marshall Island (Bair, et al., 1982), that the people of Rongelap interpreted as indicating greater levels of contamination on their homelands than they had previously been made aware of by the U. S. Department of Energy. This report was interpreted as indicating that their atoll was contaminated to the same degree as Bikini which was generally considered "unsafe" for habitation. In addition to these concerns, urine samples analyzed by Brookhaven National Laboratory in 1984 had shown higher levels of plutonium than had been expected (Conard, 1992). On May 22, 1985, the Rongelap people, having lost confidence in the advice provided

[2] According to testimony of Senator Jeton Anjain before the Subcommittee on Insular and International Affairs, Washington, D.C., November 16, 1989.

by the department of Energy,[3] left their home atoll for a new location on Mejatto Island in Kwajalein Atoll. The increased plutonium concentrations now appear to have resulted from urine-collection procedures that resulted in spurious high plutonium levels (Conard, 1992) and the levels of radionuclide contamination on Rongelap have proven to be lower than those on Bikini. However, the Rongelap people now wish to eliminate all doubts about the habitability of their homeland before they return and have chosen to stay on Mejatto Island until they are assured of the radiological safety of Rongelap Island.

The review of DOE's effort in the radiological assessment of Rongelap by this National Research Council committee is aimed at determining whether the methods and practices undertaken by DOE and its contractors are scientifically sound.

RADIATION EXPOSURE AND DOSE

Radiation doses that might be received in the future by persons of all ages are important issues related to the resettlement of the Rongelap people. Assessments of these doses provide important bases for estimating the possible health risks associated with residual radionuclides on Rongelap Island. Sources of radiation can be external, internal, or both. For example, some of the Rongelap inhabitants exposed directly to the BRAVO fallout material in March 1954 received, in a matter of a few days, bums on their skin as a result of beta radiation emitted by radionuclides deposited on skin, whereas other effects of the early exposures, such as damage to the thyroid, were not manifest for several years. Effects on the thyroid, including cancer, were produced by radionuclides of iodine (^{131}I, ^{133}I, and ^{135}I) that were absorbed into the body, were deposited preferentially in the thyroidal tissue, and became sources of chronic internal radiation exposure.

Because of radioactive decay and natural weathering, many of the radionuclides in the initial fallout material are no longer present. Resettlement decisions must include consideration of which radionuclides are present and the extent to which current and future radionuclide inventories will contribute to radiation doses that the Rongelap people might receive from external and internal sources. Of the radionuclides originally deposited as fallout from the BRAVO detonation, only 5 radionuclides are still present in sufficient quantities to contribute significant doses to individuals. These include cesium-137, strontium-90, plutonium-239, plutonium-240, and americium-241. Of the total dose estimated for residents resettling the atolls, 90% is from cesium-137 and over 70% of that will come from ingestion of the native foods (Kercher and Robison, 1993). Possible exposure pathways by which radiation doses might be received are listed in Table 3. Strontium is the second most significant nuclide contributing to the estimated dose, also from ingestion in foodstuffs, and might account for as much as 2-5% of the dose. The transuranic radionuclides are estimated to contribute less than 5% of the estimated dose over 50 and 70 y. Estimated doses from stochastic source terms and the uncertainties in such calculations have recently been discussed in detail by Kercher and Robison (1993).

[3] As related by Senator Anjain in his testimony to the House Committee on Appropriations, May 9, 1991.

Table 1-2. Pathways of Exposure to Radiation

I.	NATURAL BACKGROUND RADIATION
	A External exposure[a]
	B. Internal exposure[b]
II.	RADIATION FROM FALLOUT RADIONUCLIDES
	A. External exposure
	B. Internal Exposure due to Intake via
	1. Ingestion[c]
	2. Inhalation

[a] Annual external dose from cosmic radiation is 0.22 mSv (22 mrem). External background radiation from terrestrial sources is very low in northern Marshall Islands (Robison et al., 1993).
[b] Annual internal equivalent dose is about 2 mSv (200 mrem) per year from naturally occurring radionuclides, such as potassium-40, polonium-210, and lead-210 in the diet (Robison et al., 1993).
[c] Ingestion includes uptake from terrestrial foods, marine foods, drinking water, and soil.

Measurements and analyses of the exposure pathways and the wide array of factors that can influence both the exposures and the radiation doses received from these exposures have been made by several different organizations during the last 40 years. Periodic medical examinations of the Rongelap people began soon after their evacuation in March 1954; the examinations have been carried out by medical staff of BNL and health-service personnel from the Marshall Islands. In addition to performing medical examinations on persons exposed to the initial BRAVO fallout, the BNL medical staff initiated, in 1958, periodic whole-body counting to determine the extent to which photon-emitting radionuclides from the internal exposure sources shown in Table 1-2 were being incorporated in people. Responsibility for monitoring internal deposition of radionuclides was transferred in 1978 to the BNL Safety and Environmental Protection Division, which continues to carry out whole-body counting and radionuclide-content analysis of urine and feces.

On-site environmental surveys have also involved several other organizations. Most of the early surveys were conducted by personnel of the U.S. Naval Radiological Defense Laboratory and the Radiation Ecology Laboratory of the University of Washington College of Fisheries. In 1978, personnel from EG&G Corporation performed an extensive airborne radiological survey of the northern Marshall Islands in the BRAVO fallout path; in conjunction with this extensive survey program, scientists from LLNL conducted land-based environmental surveys of water, soil, vegetation, and marine species. Additional sampling trips were made in 1986-1993.

This committee has focused in large part on requirements specified in the MOU related to annual radiation doses, soil concentrations of transuranic radionuclides (alpha radiation), and measurements needed before and after resettlement. Thus, the measurements, analyses, and dose estimates made by scientists from LLNL and BNL lie at the heart of the committee's concerns and responsibilities. The approaches used by both organizations are illustrated in

Fig. 3. LLNL scientists obtain information on the radionuclide content of the various samples shown, and then calculate possible radionuclide intakes on the basis of the amounts of intake of air, water, and food. This information is then coupled with models of radionuclide metabolism and dosimetry to calculate the internal deposition and retention of these radionuclides and the resulting internal radiation dose. Such an approach makes it possible to estimate the accumulation of radionuclides and the consequent internal dose in the Rongelap people after resettlement.

The measurements on individuals by BNL scientists provide direct information on the presence of radionuclides in the body. Whole-body counting provides information on the total-body content of radionuclides that emit photons of sufficient energy to escape the body and be detected by the whole-body counter. Analyses of radionuclides excreted in urine and feces indicate which radionuclides are present in the body on a given day, regardless of whether they emit alpha, beta, or gamma radiation. Metabolic models are used to compute the total-body content of each radionuclide measured. Once the total-body content has been estimated by whole-body counting or excretion analyses, metabolic and dosimetric models are used to compute the radiation dose resulting from this body burden.

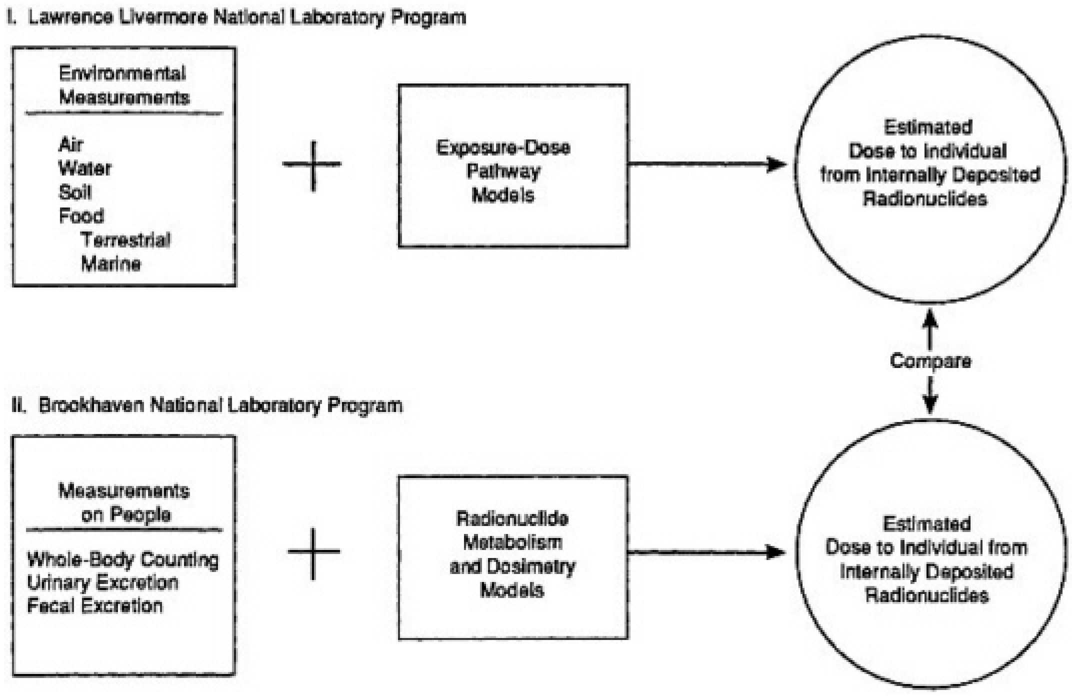


Figure 3. Internal dose assessments for Rongelap people.

The LLNL approach can be used to estimate either past or future environmental exposure of persons on Rongelap Atoll; the BNL measurements provide estimates of the current body content of radionuclides of interest. The measurements and modeling approaches used by the two laboratories are related and can be used to obtain comparable data. The BNL measurements of total-body radionuclide content at a reference time should provide dose estimates that agree with the prediction for the same time yielded by the LLNL models based on environmental pathways.

It is obvious that many scientific variables are associated with each approach. To provide the best information on radionuclide exposure and radiation dose, these variables must be dealt with in scientifically acceptable and defensible ways. This committee has reviewed what has been done about dose assessment in the past and what further should be done before resettlement of the Rongelap people. In particular, the Committee has directed its efforts to five related subjects:

- Environmental sampling and analysis.
- Diet models.
- Measurements on humans.
- Dosimetry and its application.
- Uncertainty and variability in dose projection.

Each of those subjects is explored in detail in subsequent chapters of this report.

2.

ENVIRONMENTAL SAMPLING AND ANALYSIS

SAMPLING TECHNIQUES

This chapter describes and evaluates the LLNL environmental sampling program. The assessment is based on a 1.5-d visit in October 1993 by two committee members to review the environmental laboratory directed by W. L. Robison at LLNL, on evaluation of data provided directly to the committee by W. L. Robison, and on evaluation of the procedures described by W. L. Robison in his publications (see, for example, Robison et al, 1993).

Description of the LLNL environmental sampling program

The LLNL environmental program has sampled soil, vegetation, water, and foodstuffs on several islands of Rongelap Atoll and numerous other islands and atolls in the Marshall Islands. These measurements provide information on the radionuclide content of components of the projected Rongelap diet and on material, such as soil, that might be inadvertently ingested. LLNL has also estimated whole-body exposure from external sources of radiation. Our review focuses on soil sampling because soils are the major source of exposure to plutonium and on the sampling of three foodstuffs —coconut, breadfruit, and pandanus fruits —because these are the primary sources of cesium-137 exposure and are major components of both the imported-foods-available and local-foods-only diets (W. Robison et al. 1993). Inhalation and ingestion via water do not appear as significant sources of internal radiation exposure.

The nature ofthe sampling program has changed over time. The initial 1978 sampling program, which complemented the EG&G Corporation's aerial gamma-ray spectroscopy survey, was undertaken to characterize the distribution and amounts of radionuclides on many of the northern Marshall Islands, not just those of Rongelap Atoll (Robison et al., 1993). That characterization sampling was not designed to estimate the statistical distributions of radionuclides on the island; instead, the focus was on estimating the radionuclide concentrations in selected soils and vegetation and the depth profiles of radionuclides in the soil. On Rongelap Island, soil and foodstuff samples were collected at arbitrary locations along the length of the island. Later trips used a variety of sampling designs to characterize different aspects of radionuclide distribution on Rongelap. Some samples were collected by walking along transects; others were collected at arbitrarily chosen locations. Fine-scale spatial variation within a 1 x 1-m area was sampled in one region of the island with relatively high activity. The region around the village on Rongelap Island was extensively sampled. Such characterization sampling provides information about the locations actually sampled, but there is no statistically reliable method to draw conclusions about unsampled areas from such sampling.

In the last few years, LLNL has conducted systematic sampling from a 100-m sampling grid, illustrated in Fig. 4, that covers the vegetated area of the island. The grid was oriented parallel to the rows of trees in the coconut plantation, and the grid origin was defined as the northernmost coconut tree. For each point in the systematic sampling grid at which there was a coconut, breadfruit, or pandanus tree, a soil-depth profile was determined by digging a soil pit and collecting soil from depths of 0-5 cm, 5-10 cm, 10-15 cm, 15-25 cm, 25-40 cm, and 40-60 cm. Deeper soil fractions were not sampled, because observed activities in the samples from 40-60 cm were low. In the case of a few grid locations, no foodstuff was nearby and no soil profile was collected at these points. If there was a coconut, breadfruit, or pandanus tree close to the sampling point, nuts and fruits were also collected. Because of the widespread planting of coconuts across the island, coconuts were usually found close to the designated sampling points, but breadfruit and pandanus trees are less frequent and more scattered across the island. The staff that performed the field sampling appear to have taken considerable effort to follow the systematic sampling plan. On the committee's visit to Rongelap, a number of sites were observed where access paths were cut through the thick scrub to reach sampling points. In Robison's opinion (W. L. Robison, personal communication, 1993), all breadfruit and pandanus trees in the vicinity of the deserted village on Rongelap Island have been sampled.

Evaluation of the LLNL environmental sampling program

In general, the goal of any statistical sampling program is to draw conclusions about some general population from a set of observed values. A statistical sampling program can be evaluated by considering four questions:

- What population is being described and is that choice appropriate?
- Are sample locations chosen with an appropriate technique?
- Is the number of samples sufficient to obtain the desired precision?
- Are appropriate techniques used to draw conclusions from the results of sampling?

As noted above, there have been two sampling programs on Rongelap: the initial characterization sampling at arbitrarily chosen positions and a more recent systematic sampling based on a 100-m grid. The characterization sampling cannot be used to draw conclusions about unsampled locations, because the probability that an individual location or source of vegetation was sampled is unknown and arbitrary. We focus on the systematic sampling because it can be used to draw conclusions about unsampled locations. We consider soil sampling and foodstuff sampling separately because their goals are slightly different.

Soil sampling

The goal of the soil-sampling program that was conducted by LLNL was to draw conclusions about soil radionuclide concentrations at any location on Rongelap. It should be noted, however, that the only soils sampled were from locations in the vicinity of foodstuff trees. Such a protocol is conservative and is likely to overestimate soil transuranic concentrations, inasmuch as there is some evidence that the unsampled areas (between trees) are likely to have lower concentrations of transuranics than the sampled areas (W. L. Robison,

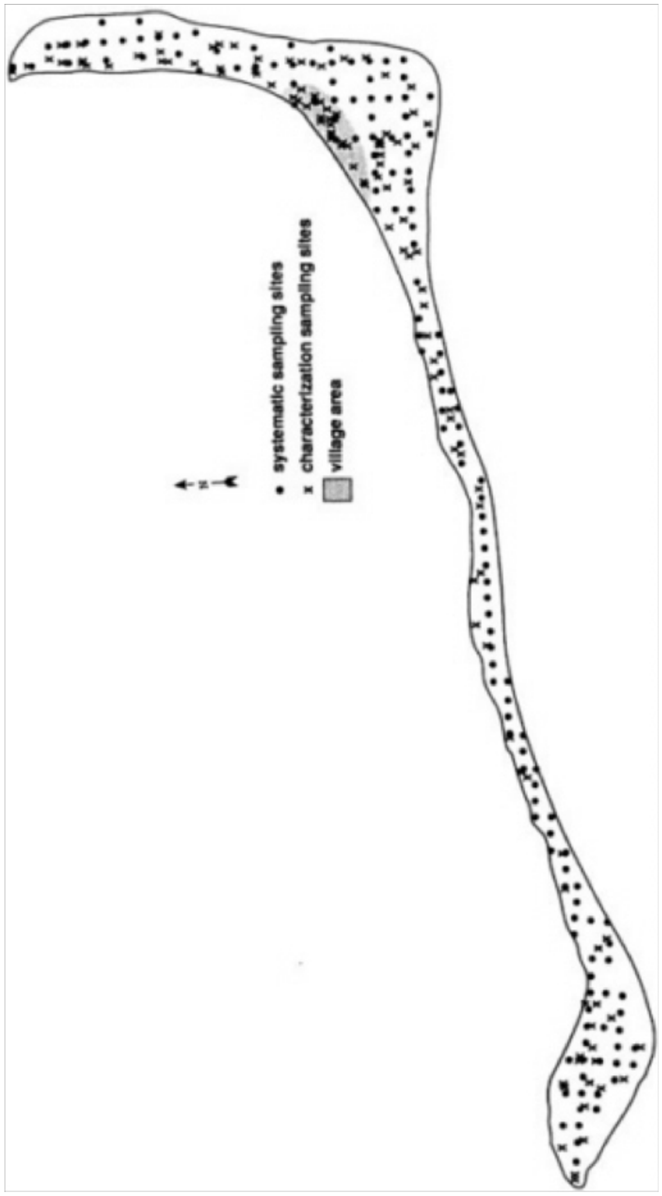


Figure 4. Map of Rongelap Island with sampling locations indicated.

personal communication, 1993).

The preferred method to draw a systematic sample is to choose a starting point randomly. The LLNL grid was started at the northernmost coconut tree. Because the island has an irregular shape, that can be considered as an acceptable choice of starting point and equivalent to a random start.

There are two separate issues concerning contributions of soil radionuclides to the total dose: the exposure from "average" conditions and the probability that there are local regions of high concentrations of radionuclides, commonly referred to as "hot spots." The estimated contributions of soil ingestion and inhalation to the total dose are considered small —1.6% for all isotopes (Tables 6 and 12 in Robison et al., 1993). The concern with hot spots is that a chance encounter with an unusually high concentration of radionuclides might contribute a substantial dose; this issue is of concern mostly for plutonium and americium isotopes because of their longevity, although their contribution to the total average dose is normally very small. In the context of this report and for the form of radionuclide contamination on Rongelap, a hot spot refers to the possibility of finding a small area with substantially higher radionuclide concentration than the measured average, not to a hot particle as might occur from fallout from a reactor accident. In its deliberations the committee has arbitrarily defined a hot spot to be a small region with radionuclide concentration of more than 10 times the measured average.

The probability that a hot spot is sampled on a systematic sampling grid depends on the size and shape of the hot spot and the spacing of the sampling grid (Gilbert, 1987). Given a single circular hot spot of radius r and a square grid of spacing s, the probability that a grid location falls within the hot spot can be derived to be

$$P = \frac{\pi r^2}{s^2} \qquad (1)$$

for s > 2r. Hot-spot sampling probabilities for a selection of grid spacings and three radii are given in Table 2-1.

The 100-m grid used on Rongelap Island has a moderate probability of sampling a large (28-m) hot spot, but a very low probability of sampling smaller hot spots. However, an extremely fine grid would be needed to sample small (10-m or 5-m) hot spots reliably. For a given area to be sampled, the number of samples required increases as grid spacing is reduced. For example, a 20-m grid requires 25 times as many samples as a 100-m grid. The probabilities in Table 2-1 were derived for circular hot spots; the detection probabilities are different for square or rectangular hot spots, but the shape of hot spot does not affect the basic conclusions of the sampling program.

Any reasonable sampling grid is unlikely to detect a very small, very hot area that might be randomly placed on Rongelap Island. However, two considerations suggest that the probability of there being such a hot spot is small: the BRAVO fallout precipitated from a relatively high elevation and was finely dispersed. One statistical consequence is a small-scale spatial correlation between radionuclide concentrations in nearby samples (this is discussed in greater detail later).

Table 2-1. Probability That a Single Circular Hot Spot of Selected Radius Is Sampled by a Grid of Selected Spacing

Grid Spacing	Probability of sampling a hot spot of radius:		
	28 m[a]	10 m	5 m
200 m	0.062	0.008	0.002
100 m[b]	0.250	0.008	0.008
50 m	>0.990	0.03	0.03
25 m	>0.990	0.12	0.12
20 m	>0.990	0.20	0.20

[a] Circle of radius 28 m covers about 1/4 ha.
[b] Grid used by LLNL sampling program.

The previous analysis of the probability of sampling hot spots did not incorporate any information from the *observed* amounts of radionuclides in Rongelap soil. A second approach to evaluating the probability of there being hot spots is to specify a radionuclide concentration that defines a hot spot, and then ask, what is the probability that there might be such a concentration in a small randomly chosen area based on observed distributions. The committee agrees that a concentration 10-times the observed mean level is a reasonable definition of a hot spot. For Rongelap Island, this level of concentration for plutonium would be about 35 pCi/g. The observed data for soil concentrations can then be used to estimate the probability that the soil plutonium concentration in a small area might exceed 35 pCi/g.

If soil plutonium concentrations were known to be normally distributed, the desired probability of a given concentration can be calculated from the cumulative distribution function of the normal distribution. However, probability plots of the soil plutonium data (e.g., Robison et al., 1993, Fig. 10) suggest that neither a normal nor a lognormal distribution is appropriate to estimate probabilities in the extreme upper tail of the distribution. One solution to this problem is to find a transformation of the data that optimally fits a normal distribution, then estimate probabilities using the transformed distribution. One broad class of transformations that can be used is the class of power transformations:

$$Y = \begin{cases} \ln(x), & \lambda = 0 \\ \dfrac{X^{\lambda}-1}{\lambda}, & \lambda \neq 0 \end{cases} \tag{2}$$

A log transformation corresponds to $\lambda = 0$, the square-root transformation corresponds to $\lambda = 0.5$, and no transformation corresponds to $\lambda = 1$. The optimal transformation to normality can be defined as 1) the λ that maximizes the correlation between the transformed data and normal order scores (Stoline, 1991), or 2) the λ that produces transformed data with a skewness closest to 0. These approaches are used with two samples of soil plutonium data: the 22 observations from the systematic sampling grid and 110 observations from mapped locations across Rongelap.

Because the mean and standard deviation are estimated from the data, there is some sampling variation in the estimated probabilities. This sampling variation is smaller in larger samples. An upper confidence bound on the hot spot probability can be calculated using tables based on non-central t distributions (Owen and Hua, 1977).

The optimal transformations to normality are different for the two groups of data. Both the correlation and skewness criteria indicate the same choice of transformation: $\lambda = 0.8$ is the optimal transformation for the grid data, while $\lambda = 0.4$ is the optimal transformation for the larger data set (Table 2-2). Both sets of data indicate that the probability of a hot spot is extremely small, 1 in 100,000 or less. Upper 99% confidence bounds on the hot spot probabilities are also small, 40 in 100,000 or 13 in 100,000, depending on the choice of data set (Table 2-2). The exact values of the hot spot probabilities and upper confidence bounds do depend slightly on the choice of transformation, but they are all small. If the observed values of soil plutonium concentrations are taken as representative of soil plutonium concentrations in unobserved areas of Rongelap Island, then the probability that a small area contains a high concentration of plutonium is extremely small. The numerical values of hot spot probabilities depend on the extrapolation from the distribution of observed data to the distribution of high concentrations. Because the assumed critical value (35 pCi/g) is much greater than the largest observed value, some form of extrapolation is necessary to make the calculation, but it is very difficult to verify the validity of the extrapolation.

Foodstuffs

The sampling of foodstuff on Rongelap is more difficult to evaluate because no quantitative goal specified the precision required for the sampling program. For example, a survey to estimate the mean concentration of plutonium in soil might specify that the standard error of the mean is to be less than 1 pCi/m^2, and this required precision could then be used to calculate the required number of samples. The quality-assurance plan for the LLNL program (W. L. Robison, personal communication, 1993) specified acceptable counting errors for each sample, but these provided no specification of the desired accuracy for estimates of population parameters. The population parameters used in the dose assessment are the mean, variance, and type of distribution of radionuclide concentrations in foodstuffs. Sample numbers of foodstuff and soils are shown in Table 2-3.

Attention is focused on sample sizes to estimate the cesium concentration in foodstuffs because, according to the dose assessment, cesium in foodstuffs contributes a large fraction of the total dose (Robison et al., 1993). The committee estimated mean concentrations because the dose to the maximally exposed resident depends more on the mean cesium concentration and on differences in diet and individual physiology among the Rongelap natives than on the variance in cesium concentration in foodstuffs (Robison et al. 1993).

Table 2-2. Probability of hot spots exceeding 35 pCi/g of Pu on Rongelap.

Data from 100 m grid on Rongelap (n = 22).			
λ*	r**	Estimated probability	upper 99% confidence bound
optimal transformation to normality:			
0.8	0.986	0.00000	0.0004
other candidate transformations to normality:			
0.6	0.981	0.00000	0.0020
0.7	0.985	0.00000	0.0009
0.9	0.984	0.00000	0.0002
1.0	0.981	0.00000	0.0001
Data from all locations on Rongelap (n = 110)			
λ*	r**	Estimated probability	upper 99% confidence bound
optimal transformation to normality:			
0.4	0.996	0.00001	0.00013
other candidate transformations to normality:			
0.2	0.989	0.00039	0.00292
0.3	0.994	0.00006	0.00093
0.5	0.995	0.00001	0.00002
0.6	0.992	0.00000	0.00000

* λ specifices the transformation to normality.
** r is the correlation between the transformed data and normal order scores; values closer to 1 indicate better fit to a normal distribution.

The expected width of a 95% confidence interval for the mean is one of several approaches to determining an adequate sample size. One criterion might be that the sample be large enough for the expected width to be smaller than the population standard deviation. A stricter criterion might be that the expected width be smaller than half the population standard deviation.

Table 2-3. Environmental Samples and Interviews Contributing to Rongelap Diet Information

Environmental samples analyzed by LLNL as of October 1993*		
	Total	On sampling grid
Cs in drinking-coconut meat	293 trees	134 trees
Cs in pandanus	77 trees	22 trees
Cs in soils (0-5 cm)	659 samples	186 samples
Pu in soils (0-5 cm)	208 samples	22 samples
Samples used to estimate variability among individuals:		
Diet	34 Ujelang women	
Biological half-life (cesium)	23 Marshallese men	

* Numbers may vary from Robison et al., 1993, because some trees have been sampled more than once.

The expected width of a confidence interval depends on the variance of the sample mean, which depends on the sample size and properties of the population. The variance of the mean from a systematic sample can be written as

$$s_{\bar{x}}^2 = \left(1 - \frac{n}{N}\right) \frac{\sigma_x^2}{n} \left[1 + (n - 1)\rho_w\right] , \qquad (3)$$

where n is the sample size, N is the population size, σ_x^2 is the population variance, and ρ_w S the correlation among values in a systematic sample. The correlation ρ_w is usually unknown, but if the population is in random order, $\rho_w = 0$. The number of coconut trees on Rongelap (N) is about 10,000, much larger than the sample size. Hence, the sampling variance simplifies to that for random-sampling:

$$S_{\bar{x}}^2 = \frac{\sigma_x^2}{n} . \qquad (4)$$

If the data can be transformed to a normal distribution, then the width of a 95% confidence interval for the transformed mean is given by

$$2t_{0.975,\, n-1}\, s_{\bar{x}} , \qquad (5)$$

where $t_{0.975,\, n-1}$ is the 97.5 percentile of a student t distribution with n-1 degrees of freedom.

The sample standard deviation is a slightly biased estimator of σ, but an unbiased estimate can be obtained by multiplying s by a correction factor (Gurland and Tripathi 1971) to get the expected widths shown in Table 2-4. The expected widths in Table 2-4 are calculated for simple random samples of various sample sizes from an infinite population and are expressed relative to the population standard deviation. Expected widths are slightly smaller for finite populations. At least 19 samples are needed for the expected width to be less than the population standard deviation. At least 65 samples are needed to meet the stricter criterion of a width less than σ/2. With 150 samples, the expected width is about σ/3 (Table 2-4).

The number of samples of drinking coconuts from the 100-m systematic grid is large enough to provide a reasonably precise estimate of mean cesium. The expected width of the 95% confidence interval is σ/3. The number of pandanus and breadfruit on Rongelap is smaller; however, in the vicinity of the village all or most of these trees have been sampled. In this case, the sample estimates are also precise estimates of the population mean, although the sample sizes are smaller. It is difficult to evaluate the precision of the estimated cesium concentrations in the other foodstuffs used in the dose assessment because there was no probability sampling and the population sizes are generally unknown.

The mean cesium-137 concentration in many foodstuffs is likely to be poorly estimated because of the small sample sizes. For example, there are 5 samples of arrowroot, 7 samples of pork muscle, 6 samples of pork liver, and 4 samples of pork heart (Robison et al., 1993; Tables 20 and B-1). Because standard deviations are not computed by Robison et al. (1993; Table 20), it appears that there are even smaller numbers of samples, perhaps only one each, of papaya, chicken muscle, chicken liver and chicken gizzard. Chapter 6 on uncertainty and variability in dose projection explores some of the consequences of the small sample sizes.

An alternative criterion to assess a sampling plan is that it provide sufficiently accurate estimates of extreme values in a population. This criterion is especially relevant to Rongelap resettlement, where the MOU is concerned with the dose to the maximally exposed resident. One statistical evaluation of whether extreme values are adequately sampled is based on confidence bounds on the proportion of a population that exceeds the largest sample value. These can be calculated without assuming that values in a population have a specific distributional form (e.g., normal) by using nonparametric tolerance bounds (Hahn and Meeker, 1991). The tolerance bound that is relevant here is the estimate, with given confidence, of the proportion of the population that exceeds the largest observed value in a sample.

For an infinite population, a 95% upper confidence bound on the proportion of individuals that exceeds the largest sample value is given by

$$1 - \frac{n}{n + F_{0.05,\,2,\,2n}}\,, \qquad (6)$$

where n is the sample size and F is the 95th percentile of an F distribution with 2, 2n degrees of freedom (Hahn and Meeker 1991). For a finite population of size N, the upper 95% confidence bound can be expressed as a number of persons. It is given by the smallest number, k, that satisfies the following expression:

Table 2-4. Expected Widths of 95% Confidence Intervals for the Mean and Nonparametric 95% Confidence Bounds on the Number (in the Population) that Exceed the Largest Observation in the Sample

sample size	Expected width	Number in the population (size N) that exceed the largest observed value in the sample (size n)			
n	(σ)	N = 50	N = 100	N = 200	N[a] = ∞
5	2.6	22	45	90	45.1
10	1.5	12	25	51	25.9
15	1.12	8	17	35	18.1
20	0.94	6	13	27	13.9
25	0.84	5	10	22	11.3
50	0.56	0	5	11	5.8
75	0.43		3	7	3.9
100	0.40		0	5	3.0
150	0.32			3	2.0
200	0.28			0	1.5
500	0.17				0.6

[a] in percent of total

$$\binom{N-k}{n} \Big/ \binom{N}{n} \leq 0.05 \;. \qquad (7)$$

The maximum observed concentration of cesium-137 in the meat of drinking coconuts —those harvested at the proper time for drinking the liquid in the coconut —was 14.7 pCi/g (decay corrected to 1995). It is reasonable to treat the populations of soil and coconut trees as having an infinite size because there are many more locations and coconut trees than were sampled. According to Table 2-4 and the sample sizes given in Table 2-3, it is unlikely that the meat from any drinking coconuts will be as large as the maximum observed, 14.7 pCi/g, but it is reasonably certain that no more than 2% of the coconut trees will have values larger than that. If one assumes that there are about 100 pandanus trees on Rongelap, it is reasonably certain that the fruits of very few trees (no more than three) have cesium concentrations larger than 33.3 pCi/g, the highest concentration found in the 77 measured trees.

In contrast, measurements of the diet and biological characteristics of the Rongelap people provide much less precise estimates of mean or extreme values. Diet estimates are based on 34 women; biological half-life estimates of cesium are based on 23 men. The expected widths of confidence intervals for the means are 75-85% of the population standard deviation (Table

2-4). If the population size is taken to be 200, there are likely to be about 22 people (about 10% of the population) with diets or biological half-lives more extreme than the largest values found in the sample. Samples of about 25 persons of a population of this size do not provide good estimates of either the mean or the maximum.

The results from a systematic sample are commonly treated as though the sample was a simple random sample. This is true of the LLNL Rongelap dose assessment, the work plan of the Rongelap Atoll Resettlement Project (S. Simon, personal communication, 1994), and our analysis illustrated in Table 3-1. Analyzing data from a systematic sample as though they came from a simple random sample is statistically justifiable if three conditions are met (Gilbert, 1987):

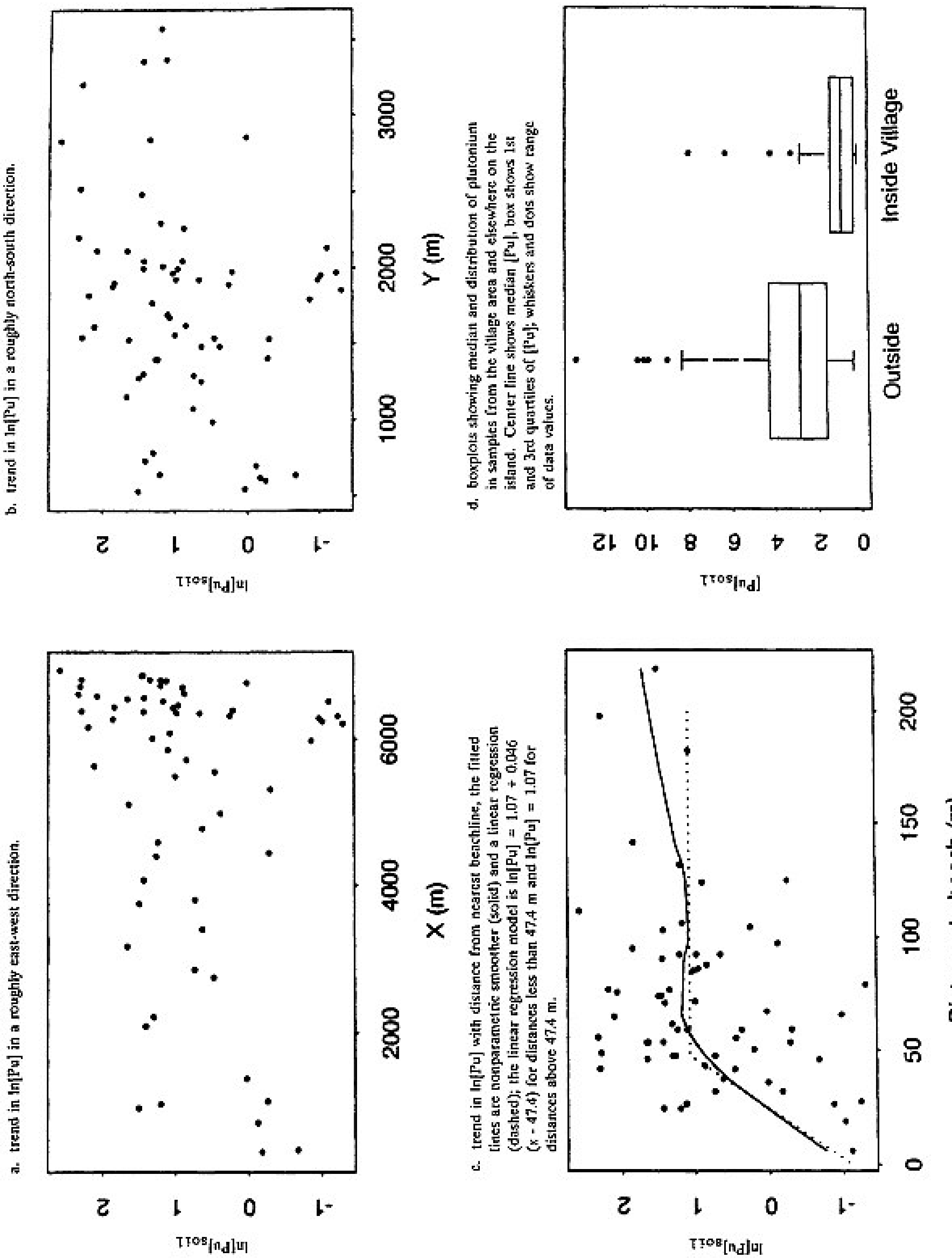
- There is no trend in the population.
- There are no strata in the population.
- Values are uncorrelated across space.

Each of those issues can be examined with the available data. We concentrate on plutonium in the soil, because of its interest to the people of Rongelap, and cesium in the soil, pandanus, and drinking coconuts, because it contributes the major fraction of the calculated dose. Pandanus and drinking coconuts were chosen because they are large components of the diet and have relatively high cesium content, according to the LLNL diet model and dose assessment.

Three possible trends were considered: variations in concentrations of radionuclides across the island in a roughly east-west direction, across the island in a roughly north-south direction, and from the beachline to the center of the island, measured by the distance from a sampling point to the nearest beach. None of the four variables (plutonium in soil or cesium in soil, pandanus, or drinking coconuts) shows any trends in mean concentration in the east-west north-south directions (Figs.5, 6, 7, and 8). However, the variance in cesium in coconuts is higher at the eastern and western ends of the island than in the center of the island. Except for cesium in pandanus, the concentrations increase with distance from the beach.

The structure of the soil in the village area is quite different from that in the coconut groves. In the village, the soil has much less organic matter, has been disturbed by construction, and often is covered with layers of crushed coral. Soil surface concentrations of cesium and plutonium are significantly lower in the village area than in the coconut groves (Figs. 5 and 6). A small number of pandanus and other trees grow in the vicinity of the village. The concentrations of cesium in these trees are similar to those found in other areas of the island.

The only set of data that can be used to draw conclusions about unsampled places on Rongelap is the systematic sample, because there are notable trends and strata across the island. Mean cesium and plutonium concentrations calculated from all tree and soil samples differ from those calculated from the sampling grid alone. Sites and trees on the sampling grid cover all areas of the island with about equal probability. The characterization samples cover some areas of the island excessively, such as the village area (for soils) and the center of the island (for trees). Oversampling in this manner biases the mean. For example, oversampling of village areas, as was the case for cesium and plutonium measurements, can reduce the overall



a. trend in ln[Pu] in a roughly east-west direction.

b. trend in ln[Pu] in a roughly north-south direction.

c. trend in ln[Pu] with distance from nearest beachline, the fitted lines are nonparametric smoother (solid) and a linear regression (dashed); the linear regression model is ln[Pu] = 1.07 + 0.046 (x - 47.4) for distances less than 47.4 m and ln[Pu] = 1.07 for distances above 47.4 m.

d. boxplots showing median and distribution of plutonium in samples from the village area and elsewhere on the island. Center line shows median [Pu], box shows 1st and 3rd quartiles of [Pu]; whiskers and dots show range of data values.

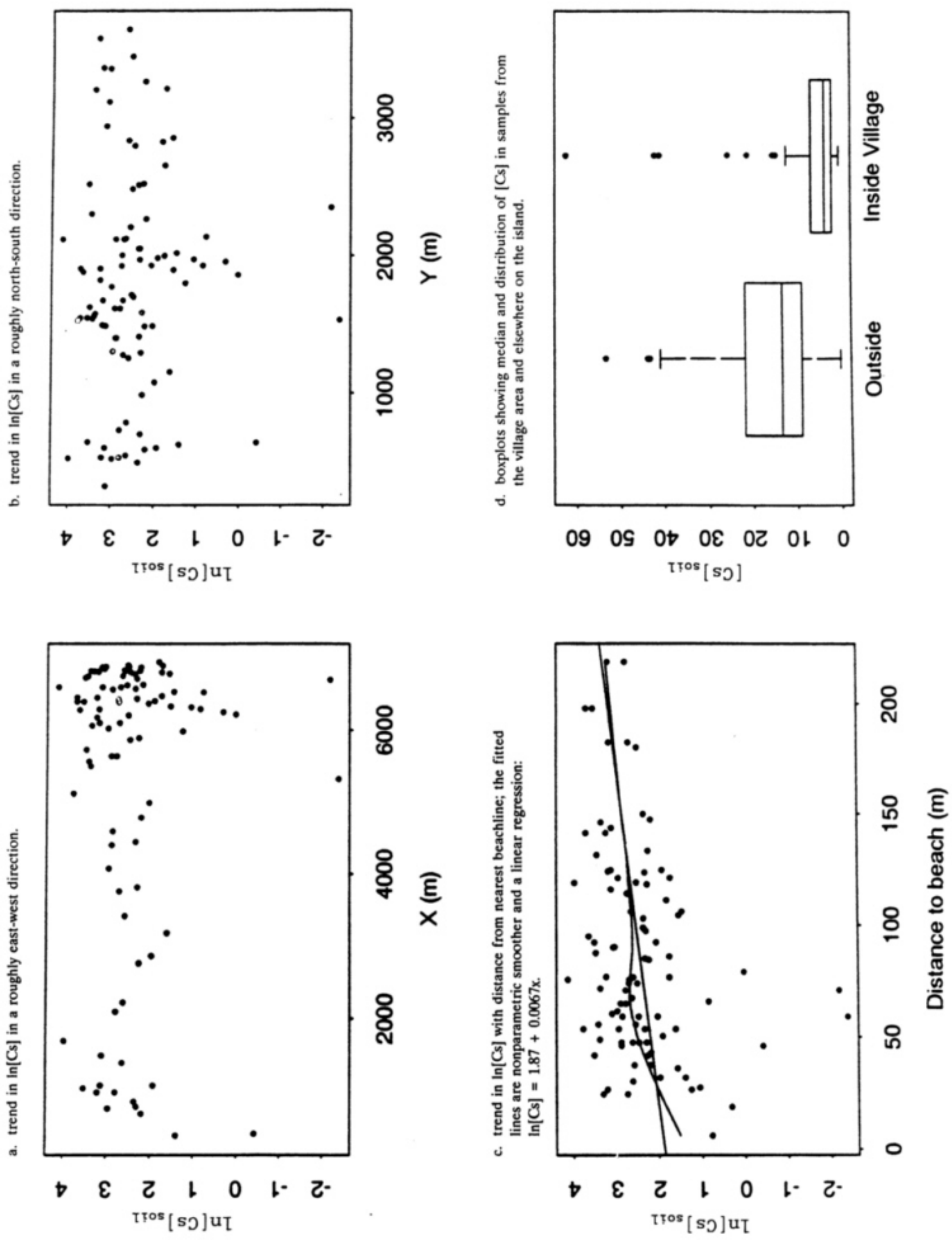


Figure 6. Trends in soil cesium concentration (0-5 cm) on Rongelap; [Cs] in pCi/g.

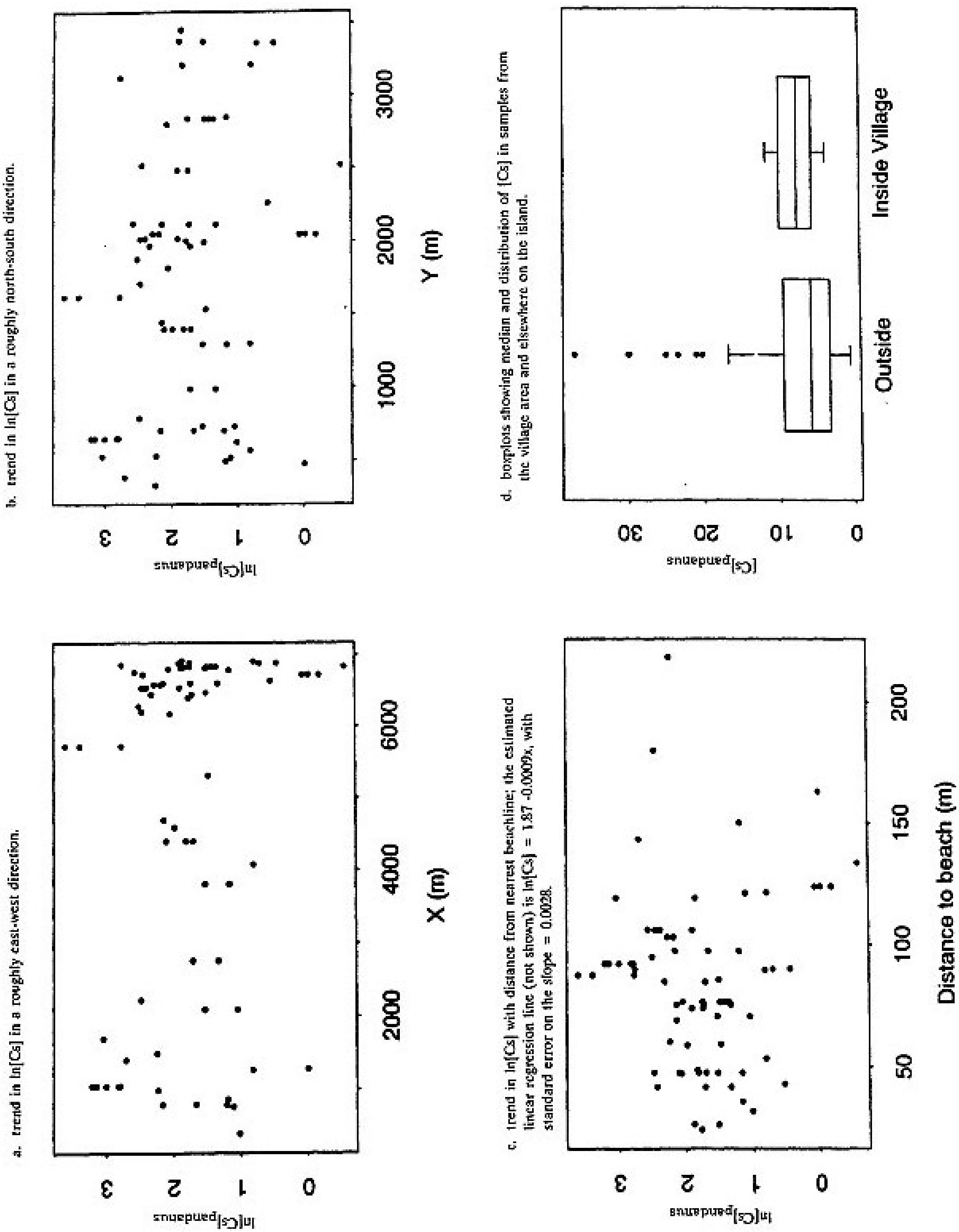


Figure 7. Trends in pandanus Cs concentration on Rongelap; [Cs] in pCi/g.

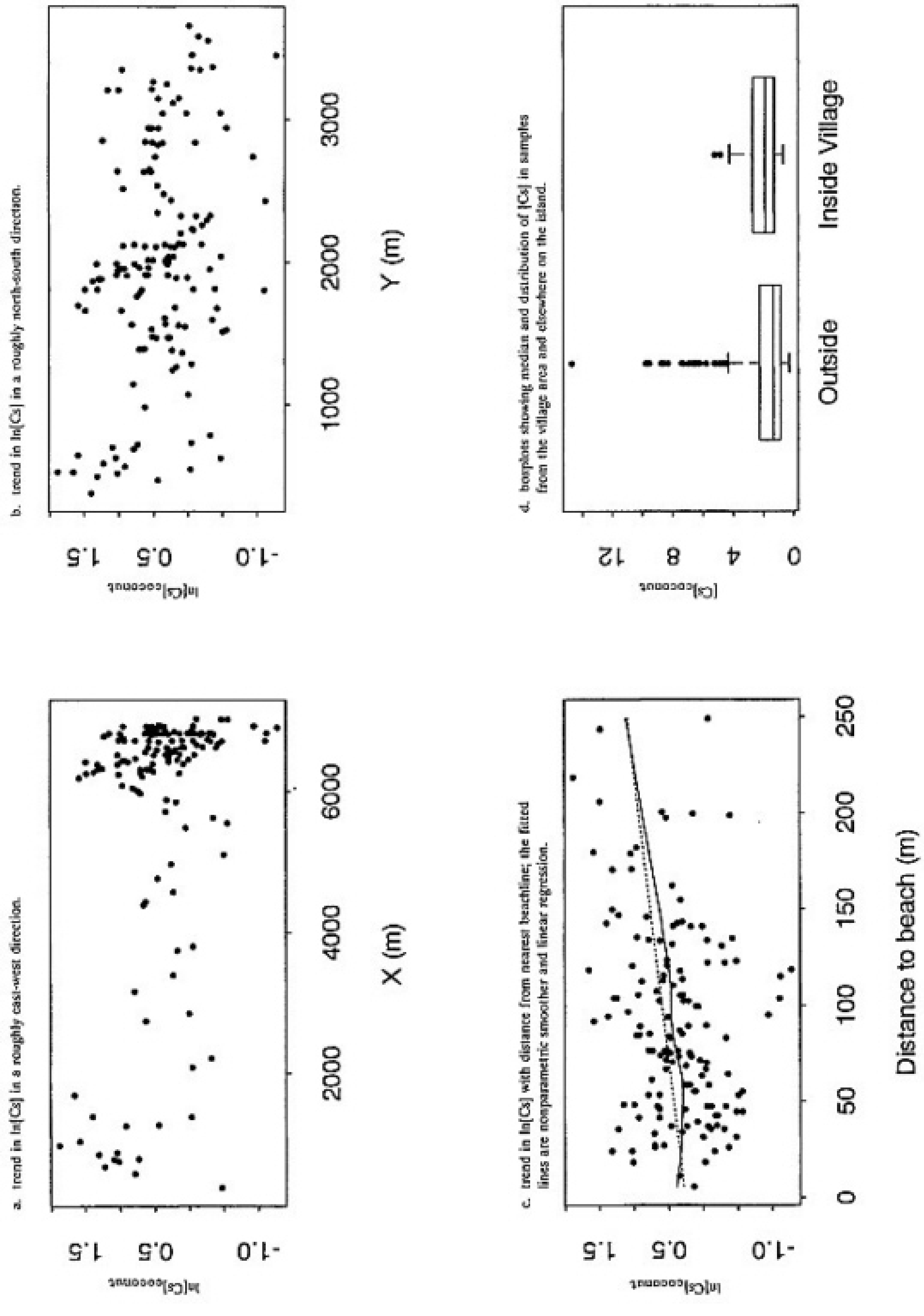


Figure 8. Trends in cesium concentration in meat of drinking coconuts on Rongelap; [Cs] in pCi/g.

mean by as much as 25%. The LLNL dose assessment should use either estimates calculated from just the sampling grid to describe radionuclide concentrations in the soil and coconut trees or use area-weighted averages. For pandanus, breadfruit, and other foodstuffs, for which most or all of the population has been sampled, it is appropriate to use all the available data.

Spatial correlation was examined on island-wide, 10-m, and 10-cm scales by estimating isotropic and anisotropic semivariograms. Semivariograms are commonly used to describe spatial variation in soil properties (for descriptions and uses of semivariograms, see, for example, Burrough, 1991; Cressie, 1991; and Warrick et al., 1986). In such plots, departure of the curve from the horizonal asymptote indicates a positive correlation. Small-scale cesium-concentration data are available from pit 22, a 1 x 1-m area in a region of the island with relatively high concentrations of cesium in the soil, and two 100 x 100-m sites. Within pit 22, soil samples were taken at 10-cm intervals in a square grid. In the other regions, soil samples were taken at 10-m intervals. One site was entirely in the coconut grove; the other crossed from the village to the coconut grove. Because of the differences in cesium concentrations in village and coconut-grove soil, only the first site can be used to estimate the spatial correlations. There was no detectable spatial correlation on the island-wide scale or the 10-m scale, but cesium concentrations showed substantial positive correlations in pit 22 (Fig. 9). Sites within 40 to 50 cm of one another have similar cesium concentrations. If the spatial correlation found in pit 22 is characteristic of the rest of the island, this small-scale positive correlation decreases the probability that a very small hot spot exists.

Conclusions

- The systematic sampling grid used by LLNL is a widely used, commonly accepted technique to sample environmental characteristics. Only the data from the sampling grid should be used, however, to estimate the mean and variance, unless most or all of the items on Rongelap are sampled, e.g., breadfruit and pandanus trees.
- The samples derived from the sampling grid are sufficient to provide reasonably precise estimates of the mean concentrations of radionuclides in the major foodstuffs. Estimates of the variance in the distributions of radionuclides in the environment are less accurate, but they have a much smaller impact on the conclusions of the dose assessment.
- There are trends in soil cesium and plutonium and coconut cesium concentrations from the beach to inland. Some care is needed to analyze these data because of the trends. The cesium concentration of pandanus can be analyzed as though the data were collected from an island-wide simple random sample.

ANALYTICAL TECHNIQUES

This section briefly evaluates the analytical methods used by LLNL to determine the concentration of radioactive isotopes of concern in soil, sediment, seawater, and biota samples from Rongelap Atoll. The procedures used are described in great detail in an LLNL report (Wong et al., 1994), and the method used for preconcentration of plutonium from large

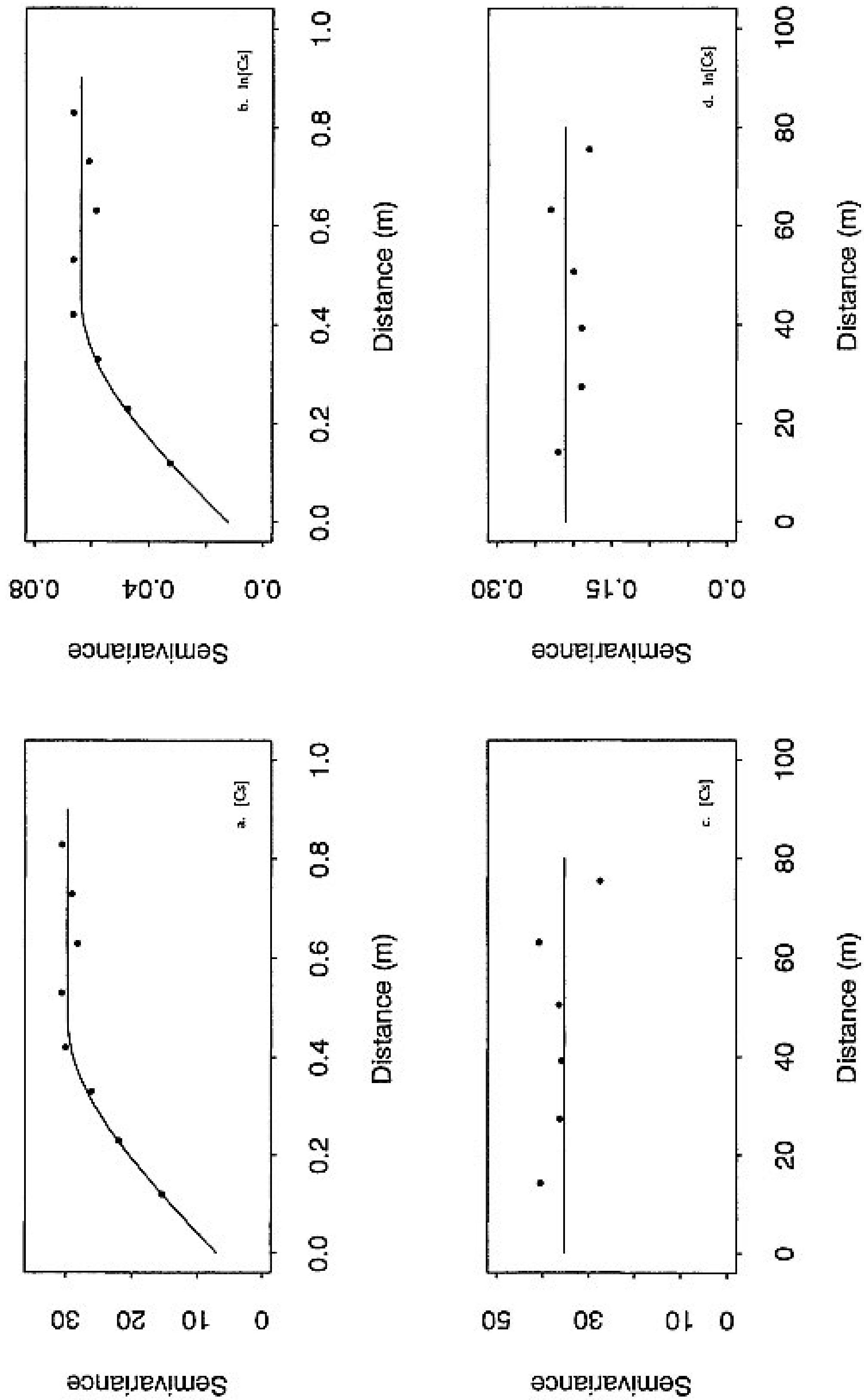


Figure 9. Semivariogram for cesium and in cesi-um concentration. Small-scale spatial correlation estimated from 10-cm grid samples in pit 22:a. [Cs]; b. In[Cs]. Medium-scale spatial correlation estimated from 12-m grid samples in coconut grove: c. [Cs]; d. In[Cs]. Lines show the fitted spherical semivariograms. Semivariances less than asymptotic semivariance indicate positive spatial correlation at that distance; [Cs] in pCi/g.

volumes of natural waters has been published (Wong et al., 1978). Much additional information was obtained from extensive discussions with W. L. Robison of the Health and Ecological Assessment Division of LLNL.

In general, standard well-proven procedures were used in analyses for the isotopes of concern. Internal standards and carriers were used as appropriate. Samples to be analyzed for plutonium were concentrated by manganese dioxide precipitation if they were aqueous (Wong et al., 1978) or ashed and digested in concentrated nitric acid if they were soil, sediment, or biota (Wong et al., 1994). After dissolution, the plutonium was separated by anion exchange (Dowex-1), electroplated onto a metal disc, and analyzed by alpha spectrometry. Sample preparation and analysis for americium were similar to those for plutonium, except that a chelating ion-exchange resin, octyl(phenyl)-N,N-diisobutylcarbamoylmethylphosphine oxide (TRU-Spec), was used instead of a strong-base anion-exchange resin. Again, the sample was electroplated and counted by alpha spectrometry.

The other two elements of primary concern are in these studies were cesium and strontium. Cesium-137 in aqueous samples was measured by extraction onto a microcrystalline ammonium phosphomolybdate cation-exchanger followed by purification from potassium and rubidium by sorption onto a strong-acid cation exchange resin (BIO-REX 40) and the precipitation of the cesium with chloroplatinic acid for beta counting. The cesium-137 content of most soil and biota samples can be determined directly by gamma-ray spectrometry without any preparation.

Determination of strontium-90 content of aqueous samples required preconcentration by coprecipitation with ammonium oxalate, dissolution in nitric acid and precipitation as strontium nitrate, dissolution in water, and precipitation of strontium carbonate. Pretreatment of soil and biota samples was the same as that of plutonium samples. The strontium should be present as a strontium nitrate precipitate in the nitric acid solution; it was separated, dissolved in water, and precipitated as strontium carbonate. After dissolution in hydrochloric acid, the strontium solutions were allowed to stand at least 18 d for the strontium-90-yttrium-90 equilibrium to be established and then counted on a low-background beta counter. The yttrium-90 content must also be considered in the determination of strontium-90 concentration.

Conclusions

The methods used in these analyses are well established, proven procedures, many of which were developed by LLNL and used there for a number of years. Where there are alterations in these procedures, they generally involve the use of new, more efficient ion-exchange resins and extraction solvents. The written procedures are very thorough, first describing the chemical basis for the method and then giving a careful, step-by-step set of instructions that are easy to understand and follow. Also, possible sources of error are recognized and cautioned against at appropriate points in the procedure, for example, the need for care in pipetting a tracer solution, to color-code wash bottles to avoid mistakes about what they contain, and to use a Teflon-coated stirring rod in transferring solutions. These might seem to be inconsequential points, but many analyses have been aborted by failure to observe such seemingly trivial points.

The analytical procedures were carried out under an extensive quality-assurance-quality control program (Mount et al., undated). In addition, a split-sample program was under way with the Nationwide Radiological Study of the Republic of the Marshall Islands (S. L. Simon, personal communication, 1994). Limited results (S. Duffy, personal communication, 1993) from the analysis of coconut milk and meat in this split-sample program indicate acceptable agreement between the two laboratories. Because of the sound chemistry and thoroughness of the analytical procedures, the effectiveness of the quality-control program, and the early data from the split-sample program, there is little reason to question the accuracy and precision of the LLNL analytical data.

Moreover, an earlier concern of the committee appears to have been eliminated. For a time, there was a considerable backlog of unanalyzed samples that were collected in a grid sampling program; lack of data on those samples would have impaired proper dose assessment on Rongelap. Fortunately, analysis of the samples is now essentially complete, and all the planned analytical results are available for use in dose assessment.

3.

DIETARY MODELS

The technical activities (environmental sampling and dose measurement) needed to support any decision on resettlement are themselves diverse and scientifically sophisticated. However, the integration and interpretation of the resulting data in a manner that permits reliable dose projections depend on the development of scientifically sound diet models appropriate to the population of concern.

The development of a model that provides useful predictions of dietary intake under a variety of life circumstances is not easy. Nevertheless, accurate estimates of exposure to radioactivity depend on a robust diet model, particularly in the northern Marshall Islands, where a large component of the radiation dose appears to be contributed by cesium-137, which is concentrated in common local foods. A number of groups have studied food habits in the Marshall Islands, including Kotzebue (1821, 1830), Paulding (1831), Finsch (1893), Snefft (1903), Kramer and Nevermann (1938), Lawrence (1943), Murdock (1943), Mason (1947, 1967), Tobin (1952, 1953), and Maramba (1960). However, the data from those sources have little value for use in dose projections because they are old (and, therefore, not in tune with changes in dietary habits) and generally not quantitative. The most recent information on diet that might be relevant to the resettlement of Rongelap comes from the Marshall Islands National Nutrition Survey of 1991, which focused on the growth of children and infant feeding practices (RMI Ministry of Health, 1991); it also does not provide quantitative estimates of food intakes.

Only two surveys have provided data that are of potential value in quantitatively estimating adult dietary intakes and are reasonably appropriate to the proposed resettlement of Rongelap: a 1978 survey of the Ujelang community by Micronesian Legal Services Corporation (Robison et al., 1980, 1992, 1993) and a 1970s survey of the dietary habits of the northern Marshallese by Naidu et al. (1980). A thorough assessment of the strengths and weaknesses of both surveys is needed to interpret any calculations of radiological exposure based on their data; such an assessment is provided below.

UJELANG DIET MODEL

The Ujelang diet model is based on a survey of the Ujelang community in 1978 by the Micronesian Legal Services Corporation (MLSC) staff with the aid of a Marshall Islands school teacher on Ujelang (Robison et al., 1992, 1980). Although the survey had weaknesses, it was in many ways superior to national diet surveys in the United States (Human Nutrition Information Service, 1988; Public Health Service, 1979; Science and Education Administration, 1980). In particular, these surveys suffer from poor participation rates, non-optimal statistical selection procedures, lack of timeliness, or inherent limitation of the methods (Guenther and Tippett, 1993). The diet surveys of the Rongelap and related populations provide critical data for the evaluation of projected doses because of the importance of the ingestion pathway for exposure to radionuclides. In view of the need for precise dose calculations to examine the conditions set forth in the MOU, the requirements for an acceptable diet survey far exceed those for usual surveys.

The positive aspects of the Ujelang diet survey include the following:

- The sampling plan was reasonable. It was based on an enumeration of all members of the population. Subjects were grouped by age and sex, and an attempt was made to interview at least 20% of the subjects in each category.
- The purpose of the study was carefully explained to all subjects. An official (a magistrate) emphasized the importance of giving an accurate recall that neither ignored some foods because they were "unimportant" nor overestimated intake of others to please the interviewer.
- Trained interviewers conducted all the interviews, so data collection was standardized and fairly uniform.
- The survey instrument was detailed and so should have helped subjects to remember details about their food intake. An attempt was made to help subjects in estimating serving sizes by making comparisons to a 12-oz. can. Subjects were asked to estimate intakes for days, weeks, and months.
- The survey team identified the situation in which local foods were most apt to be consumed (i.e., famine) and asked detailed questions on both that situation and the typical situation.

The MLSC diet survey in Ujelang also had shortcomings, as presented below, and its deficiencies must be recognized when using the data generated, especially because extrapolations from diet have such a critical effect on estimated doses of ingested radionuclides. Each deficiency must be considered in relation to different contexts of Marshallese life, but the first four presented potentially have the most important impacts from the point of view of data application.

- Although the magistrate emphasized the importance of giving an accurate recall of foods eaten, the climate of the survey was politically charged. Pritchard, who conducted the survey for the MLSC, told the community that "an earlier survey had reported what seemed to be an unrealistically high consumption rate for local foods, particularly coconuts, and if these reports were utilized in assessing the risk, there was almost no likelihood that people would be able to live on Enjebi in the foreseeable future" (Pritchard, 1979:2-3). Because the exiled Enewetok people would, at that point, have done virtually anything to ensure they would be returned to Enewetok Atoll (Carucci, 1992), presenting the request for dietary information in this way almost certainly affected how people responded to the survey, particularly residents whose lands were mainly in the northern (Enjebi) half of Enewetok Atoll.

- Lack of information on subjects' living situations, especially during famine periods, limits the interpretation of data from this survey. All Ujelang residents over 1 year of age are known to have consumed large quantities of arrowroot, out of necessity, during a famine period in 1978 (the year before the survey). But Ujelang people are extremely mobile. Some of those reporting no arrowroot consumption might not have lived on Ujelang at the time of the famine. The researchers did not keep track of residents' histories, so the causes of discrepancies are not immediately apparent. As noted in the study by Naidu et al. (1980), type A communities (outer islands, where residents depend on imports, not local food) have substantially different patterns of food use from other communities. During the 1978 food shortage, over a dozen Ujelang residents tended tapped coconut trees. General coconut consumption, particularly of coconut liquid and sprouted coconuts, increases when men make copra. During famines, coconut is included in dishes not described in the survey (pikukuk, mokkir, and aojek). That these are Ujelang foods with distinctive names, perhaps not known to the Marshallese translator, contributed to their not being reported in the survey.
- The reported low energy intake (1392 kcal/d) of the Marshallese when eating an "indigenous" diet is surprising and probably unrealistic (Robison et al., 1992). This estimate is less than the average recommended energy intake for 25-to 50-y-old men but not women, 1,800 and 1380 kcal/d, respectively (Food and Nutrition Board, 1989). These recommended intakes constitute a general guideline, but their applicability to Ujelang residents is not known. The food intake of subjects consuming the indigenous diet of 1,392 kcal/d was reported to be only 40% of their typical intake, 3490 kcal/d (Robison et al., 1992). That inverts the probable energy requirements of adults. Island residents would expend more energy in collecting and preparing indigenous foods than in preparing imported, often pre-packaged imported items. A deficit in energy balance of the type indicated by the data would have caused the men to lose about 4 lb of weight per week. There are no reports of such rapid weight loss during the famine period.
- Another major limitation of this survey was the failure to distinguish food events systematically. The researchers did ask about times of famine, as well as everyday consumption when imported foods were available, but they failed to differentiate between food intake at feasts and on weekends, as opposed to weekday consumption. Feasts, particularly first-birthday celebrations, occur frequently, and food intake increases at these times. Food intake also increases substantially during the 4-month period during which local people celebrate Christmas (October-January), Enewetok liberation day, and Easter. As throughout Micronesia and Polynesia, food intake is generally greater on weekends than on weekdays (Pelletier, 1987). Food intake also varies with occupation. The intake of particular foods increase greatly during copra production, and on extended fishing and gathering expeditions. In this survey, subjects might have reported typical intakes on weekdays, weekends, feast days, or hypothetical "average" days. It is likely that Ujelang residents varied in their interpretation of a "typical" day. Subjects might or might not have included in their estimates special labor conditions, weekdays and weekends, feast days, and the lengthy celebration of Christmas.

- The age stratifications by 5-y increments are compromised by the fact that "people on Ujelang [are] unsure of their own and their children's ages and all these figures should probably be read ± 1 or 2 [years]" (Pritchard, 1979a). Parental estimates of "ages" are again inexact and probably should be ± 5 [years]" (Pritchard, 1979a). Thus, the balance of subjects in each category might be skewed from the 20% representation claimed in the report.
- Interviewers were trained to perform dietary interviews, but they were not experienced nutritionists or dietitians, nor were they familiar with Ujelang foods. Even the local "Marshallese" school teacher was an "in-married" man from Pingelap Atoll who spoke an acceptable variant of the local dialect. In addition, the survey instrument was administered differently over time. Some foods were added as the interviewers became aware of them (Pritchard, 1979a:15); others were measured more accurately as the survey progressed (Pritchard, 1979a:4). During the first 2 d, questions were translated, often with extensive explanation, and the answers were translated back for transcription to the survey form. After the first two days, the Marshallese assistant, who was unfamiliar with the Ujelang dialect of Marshallese, simply stated the question in Marshallese and translated only answers or requests for further explanation to the interviewer (Pritchard 1979a: 2). Thus, many linguistic and nonverbal responses went untranslated after day two.
- The survey instrument was based on a general knowledge of Marshall Islands foods, but it failed to exhibit a specific knowledge of the food items on Ujelang Atoll. Neither the names of the foods nor their modes of preparation were accounted for by the survey team. Researchers "added the term *mado* to our survey the second day, [but] there may be some underreporting since the word used on Ujelang is *Kiraj*" (Pritchard, 1979a: 15). At times, the survey team's lack of knowledge of local methods of preparing indigenous foods caused them to overlook numerous variables that directly affect food consumption and composition. For example, pork is most often prepared by boiling, but the interviewers stated that pork was baked or reheated in a frying pan (Pritchard, 1979a:16). Similar problems arose in relation to coconuts, which at that time were considered the most critical local food in relation to radioisotope uptake (Pritchard, 1979b). In spite of a commendable attempt to corroborate the general levels of coconut consumption (Pritchard, 1979b), confusion persists in relation to the stages of coconut, the physical characteristics of coconut at different stages, and how each coconut stage is related to patterns of food preparation and consumption (Pritchard, 1979b:13, 17). Some of the food designations, such as "Marshallese cake," and questions used in the survey were probably confusing to the interviewees. Marshallese cake has multiple forms. Although one type includes substantial quantities of coconut, another is made without shredded coconut. Mokkir, a Ujelang creation, consists of cake broken into bite-sized bits and mixed with warm coconut cream. This common feast food was not mentioned among the list of local consumables. To some extent, the interviewers tried to compensate for these survey limitations by asking people to estimate the amounts of coconut cream added to food in general for a set period (Pritchard, 1979b); people who did not prepare the food would have difficulty in answering this question.
- Although a familiar vessel (a 12-oz cola can) was displayed to help people to estimate

quantities of ingested items, no attempt was made to demonstrate how much food or drink could be contained in it.

- The survey population was small. Unintentional collusion due to the interview situations might have skewed some results. For example, in one situation, both subject A and her daughter, subject B, reported exactly the same intakes of foods (W.L.Robison, personal communication, 1993). Their responses are suspect (although not impossible) because in 1978 subject A was a large, mature woman and subject B was slight. Extraneous values might also have skewed the results of this small survey. For example, subject C, the younger sister of subject B, in 1978 shared the same cookhouse. She estimated that she consumed 180 g of baked bread per day; that is 2 times the next highest woman's estimate in the community and over 8 times the quantity being consumed by subject B. Another example of questionable data concerns subject X, who claimed that she consumed 63 g of arrowroot per day as part of her normal diet, not in famine conditions. That is 3 times the next highest woman's estimate in a field of 38 in which 32 women claimed that they consumed no arrowroot. A translation problem probably caused subject X to make her estimate. Whatever the cause, the estimate skewed the data on arrowroot consumption.
- As is typical of diet surveys, this one made great demands on subjects' memories and abilities to quantify food intakes. It is doubtful that subjects were able to remember all the foods that they consumed or to estimate serving sizes accurately. In recent surveys in the United States and Northern Ireland, average subjects reported energy intakes 18-19% below maintenance intakes (Mertz, 1992; Lichtman et al., 1992; Livingstone et al., 1990). However, the extent of underestimation varies among subjects. Lichtman et al. (1992) reported that a group of obese subjects underreported their energy intake by 47±16%. Robison et al. (1992 and 1980) noted that the estimated food intake was about 20% greater for women than men. Other investigators have noted that more accurate dietary information was obtained from women than men (Rider et al., 1984; Yuhas et al., 1989). That might reflect greater attention to food by women. In the Marshall Islands, food preparation depends on the occasion, but maturing girls and young women do most of the regular cooking. Generally, people remember foods consumed as major components of meals more accurately than foods and beverages consumed as "accessory" foods (Greger and Etnyre, 1978; Mullen et al., 1984). Food events are highly variable in the Marshall Islands, and a great deal is consumed ad hoc as people move around the village accepting invitations to eat at relatives' houses or as they work in the bush. Moreover, it is rude to eat elsewhere and not bring food home to share. Therefore, when interviews were conducted in household settings, the intake of "snack" foods and beverages might well have been underestimated. It is particularly difficult for subjects to report past behaviors accurately (Bradburn et al., 1987; Dwyer et al., 1987); the most recent famine experiences were slightly more than a year before the time of the survey, and the lower food intakes and increased variability in the "famine" statistics might be explained in part by the time lapse.
- There might be at least three other sources of error in extrapolation from the 1978 survey of the Ujelang diet to the 1990s Rongelap diet. First, the diet observations were made

when the Ujelang council members were absent from the island. If their diet differed from the noncouncil population and if the council members should be considered part of the target population, then the sampling was biased. Second, extrapolating from Ujelang to Rongelap assumes similar ecological situations and dietary habits. Third, the use of a 1978 diet survey to estimate food consumption in the 1990s assumes that dietary practices have not changed substantially. The presence and practical consequences of these potential sources of error are unknown.

The Ujelang diet model represents the best data on which to base estimates of a Rongelap diet. Although it has several limitations, it is as good as many major diet studies in the United States (Human Nutrition Information Services, 1988; Public Health Service, 1979; Science and Education Administration, 1980). Even with its drawbacks, it was the logical and appropriate choice for Robison et al. (1992) to use to estimate exposure to isotopes in ingested food and beverages. However, the provisional character of this diet model necessitates a recognition that absolute answers on the average intake and on measures of variability are unlikely. Thus, the committee feels that an additional way to use the Ujelang diet model is in preparation of scenarios that allow for variations in energy intake, food selection (e.g., imports vs. local foods and such activities as coconut-gathering), and effects of potential remediation activities (such as application of KCl fertilizer to soil). Table 3-1 gives several potential scenarios; more could be devised to reflect the concerns and life style of the members of the Rongelap community.

BNL DIET MODEL FOR THE NORTHERN MARSHALL ISLANDS

This diet model that has been applied to people of the northern Marshall Islands, was developed by Naidu et al. (1980) of BNL based on intermittent observations by a survey team and qualitative data collected in a formal survey. The survey team lived in local communities for brief periods and reported the food-preparation techniques and food patterns of the islanders. Systematic records of food intake were not made by the survey team. Thus, their report —with those of Murai et al. (1958), Pollock (1970), Carucci (1980), and Maifeld (1982) and the historical accounts mentioned earlier —contribute to a comprehensive set of qualitative descriptions of the dietary habits of the residents of the Marshall Islands. However, the qualitative data collected by the BNL team are not useful for making quantitative estimates of intake of specific nutrients or even foods.

The following points are important for the interpretation and use of the BNL data:

- Like the Ujelang survey data, the BNL study is dated (data were collected before 1980). Food habits have changed dramatically throughout the Pacific as residents have become more integrated into the world economy (Bindon and Baker, 1985; Pelletier, 1987; McGarvey, 1991; Taylor et al., 1991). Local people are probably substantially less dependent on indigenous foods, particularly foods that require extensive preparation, than they were at the time of this survey.

TABLE 3-1. Potential Dietary Scenarios Considering Variations in Energy Intake, Food Choices, and Remediation with KCl

	Ujelang local & imported diet[a] (A)	Ujelang local-only diet[a] (B)	Local-only diet[b] (C)	Coconut-collector's diet[c] (D)	Local-only from northern islets[d] (E)	Local-only with KCl applied[e] (F)
Energy intake						
kcal/d	3,208	1,392	3,208	2,018	3,208	3,208
137 Cs intake[f]						
Bq/d	31	78	180	152	291-1084	32
Food intake (g/d)						
Total	3,490	1,541	3,270	2,517	3,270	3,270
Fish	42	90	208	180	208	208
Seafood	27	118	272	118	272	272
Meat	26	50	116	50	116	116
Eggs	18	149	59[g]	59[g]	59[g]	59[g]
Pandanus	9	32	75	32	75	75
Breadfruit	27	93	215	93	215	215
Coconut	202	415	957	1,690	957	957
Marsh cake	12	---	---	---	---	---
Fruits	7	14	32	14	32	32
Squash	1	3	6	3	6	6
Arrowroot	4	47	109	47	109	109
Beverages	947	530	1,222	230	1,222	1,222
Imported foods	2,168	---	---	---	---	---

[a]Robison et al., 1992; 1993, Tables 5 and 6.

[b]Local diet adjusted to provide the same energy as Ujelang local and imported diet (Column B x 2.305).

[c]Energy intake of Ujelang local diet increased by changing intake of fish (two-fold), coconut juice (five-fold), drinking coconut meat (five-fold), sprouted coconut (five-fold), consumption of turtle eggs (- 90 g), and beverages (-300 g) to make diet quantities logical.

[d]Local diet in Column C but with pandanus, coconut, and arrowroot collected in northern islets of Rongelap and Rongerik Atolls. Kohn (1989) estimated whole-body doses 2-9 times greater than on Rongelap Island.

[e]Local diet in Column C with assumed 90% loss of cesium-137 in coconut breadfruit and pandanus because of KCl fertilization (Robison et al., 1993).

[f]Cesium-137 intake adjusted to 1995 concentration.

[g]Estimate of turtle-egg consumption in latest Ujelang diet (Column B) is unrealistic; egg intake reduced to 9 g/d.

- The BNL study shows no evidence of a sampling plan. The number of subjects interviewed and the demographic situation of each subject were not defined in the major report of data.

  The survey team did not seem to appreciate the principles for estimating average diets. They suggested that it would be impossible for an outside observer to choose a "typical family" to monitor for dietary observation, although the "typical maximum" or "typical minimum" diet would stand out (Naidu et al., 1980). Once a sample population was defined, normative values could be easily derived. Without a demographic profile, it is impossible to define the "meaning" of the BNL data or to subdivide the data and derive separate profiles with sensitivity to sex, age, residence, day-to-day occupation, and seasonal or weekly variations.
- The survey instrument was poorly designed to elicit quantitative information. For instance, Question 28 asked "How many pumpkins do you cook for your family during a typical year?" and Question 37 asked "How many times do you make a meal of pig during the typical month or year?" (Naidu et al., 1980). Such questions did not elicit quantitative information, e.g., on the sizes of pumpkins or pigs or on the sizes of typical servings for males and females or adults and children. The questions also made unrealistic demands on the subjects' memories; estimating consumption of an item for a typical month or year is very difficult (Dwyer et al., 1987), especially when variations of residence, activity, and season are likely. The interviewers had no systematic mechanism to allow respondents to standardize quantities. Moreover, adults made the estimates of consumption for children —a likely source of reduced variability in sampling.
- The amount of food *prepared* was measured in the BNL study, not food *intake*. It is difficult to estimate the percentage of prepared food actually consumed by humans. Refrigeration at the time of the survey was available only in urban areas. The leftovers were probably fed to pigs, chickens, and dogs. No estimates of wastes have been made, so conversion of prepared food to consumed food is very questionable. Cycles of feast and famine have immediate effects on waste and food conservation. The difference in sampling e.g., assessment of prepared food versus consumed food —accounts for a lower estimate of coconut intake and hence of ingested isotopes in the Ujelang diet model than in the BNL diet model. It is also logical that the Ujelang diet data (based on food consumption) correlate more closely with measured isotope body burden than BNL data (based on food preparation with no correction for waste).
- The most useful information from the BNL survey is derived from the discussion of seasonal variability of food intake. Unfortunately, the survey provides no information on differences in food intake based on age, sex, residence history, occupational pursuit, weekday versus weekend, ordinary day versus feast, etc.
- The delineation of diet patterns on the basis of three hypothetical community types provided by the Naidu et al. study is potentially useful, but the basis of the classification and the actual communities that were surveyed were never made apparent (Naidu et al., 1980). The

creation of hypothetical Communities A, B, and C by the authors in an attempt to be objective ultimately compromised the scientific utility of the research, in that the maintenance of community and respondent anonymity means that the data could not be reanalyzed. Although the contrast between Community A and Community C represents the logical extremes in the Marshall Islands, Community B is anomalous. It was not described adequately to make the data useful. Generally, a dense population is subject to heavy fishing pressure and reduced fishing success. Nonetheless, Community B is defined as "overpopulated" with low availability of local food and yet with "excellent fishing"; about 33% of its diet comes from fish. It is extremely unlikely that residents of the "overpopulated" areas of the Marshall Islands (Uliga, Majuro; and Ebeye, Kwajalein) have access to enough fish to make up 33% of their diet. To make the data usable, terms like "overpopulation" need to be quantified, the communities need to be identified, and for purposes of Rongelap resettlement the living circumstances in the research communities need to be compared with the expected situation on Rongelap Atoll.

- The BNL survey data have other serious anomalies that are unexplainable without further information. For example, a reasonable hypothesis (on the basis of information from other diet surveys) would be that consumption of coconut in general and coconut cream in particular would decline as a community became more urban. Indeed, in Community A (with a low population density), about 10,000 g of grated coconut for cream (milk) per person was produced per person each year; and in Community B (high density but fish plentiful), grated coconut production used for cream dropped to 2,500 g/y —a reasonable expectation. In Community C, however, with high population density and low availability of local produce, grated coconut for cream production was estimated to be 45,000 g/y. This is highly unlikely: coconuts are virtually unavailable in either Ebeye or Uliga, and when available they are expensive. Such anomalies decrease confidence in the BNL diet survey.

The dietary data generated by the BNL diet survey are not quantitative and therefore are of only supplementary value in estimating dietary intake of the Marshallese.

EXTRAPOLATIONS FROM DIET MODELS

The lack of a comprehensive DOE research plan to relate the BNL and LLNL research endeavors formally has produced mixed results. The Ujelang diet model and the LLNL environmental information can be combined to yield whole-body burdens of cesium-137 that are generally consistent with the BNL measured values. However, some features of the diet model are clearly unrealistic. There are many dietary components in the model, and single confirmation solely by BNL measured values cannot be taken as confirmation that the *details* of the dietary model are correct. In particular, there is little evidence that the relative importance of some local foods in the diet is being accurately assessed.

Diet information now being obtained might help to reduce the uncertainties, but historically BNL' s reliance on LLNL diet information from the Ujelang diet survey to calculate potential plutonium intake through food has been a risky strategy (Sun et al. 1992b, 1993). Potentials for soil contamination during outdoor food preparation were recognized as early as 1985 (Lessard et al., 1985, as quoted in Sun et al., 1992a), but LLNL measurements were based on collected foods, rather than prepared foods. Indeed, radioactive assessments of foods prepared under local conditions are lacking. Although improvements in the urine-collection protocol appear to have answered questions about increased plutonium in BNL' s urine-bioassay measurements, absolute assurances about plutonium intake from food (Conard 1992:53) cannot be answered, given our current lack of knowledge about Marshallese food-preparation techniques.

The unanswered dietary questions include these: How accurately does the Ujelang diet survey predict the pattern of food consumption on Rongelap? How have northern Marshall Islands consumption patterns systematically changed since 1978? How have outer-island food-preparation techniques altered the ingestion of cesium and plutonium? Robison et al. (1992) recognize the existence of problems in knowledge of the Ujelang diet. The Committee hopes that a few of these problems will be solved through a more systematic assessment of Marshall Islands diets.

RECOMMENDATIONS

We recommend that a comprehensive research plan be developed to integrate the BNL and LLNL research endeavors. Historically, the dietary and dosimetric data have not reached their optimal use, because well-defined research objectives and program review have been lacking. A comprehensive research plan could have brought the individual laboratory efforts together toward a common goal with greater effect than that achieved separately. The laboratories should make ample use of experts in nutrition, diet, dosimetry and in the cultural characteristics of the local people in developing their comprehensive research plan.

The following suggestions might help in the interpretation of the total data set but will not alter the Committee's basic conclusions.

- Individual dietary differences are not well described in the current diet models. Individuals differ in both total amount of food consumed and choice of items in the diet. The cesium intake of each person in the Ujelang survey should be calculated individually from food intake and reported in terms of grams per day and picocuries per day. This is under way at LLNL. Separate values (means plus or minus standard derivation) for food and isotope intakes for each age and sex groups should also be calculated.
- Measurement of food prepared and food left at the end of meals before animals are fed would yield information on waste. If such measurements were made in 10 households under a variety of circumstances —e.g., feast versus everyday and weekend versus weekday —it would be possible to estimate waste and apply this correction factor to the BNL diet model. These estimates could not be statistically validated, but they would provide a way to establish closer correlations between the BNL diet model and the Ujelang diet model. Considering the other limitations of the BNL diet model, however, such corrections may not be considered worth the effort.

- It is not realistic to expect the Marshallese to return to a totally indigenous diet. Active adults need more than 1,392 kcal/d (1,541 g/d) —the estimated average energy intake of adults subsisting on a totally indigenous diet on Ujelang —but are unlikely to consume 6,000 g/d, the approximate amount consumed by people with the highest consumption in the Ujelang survey (Robison et al., 1993:37). Therefore, estimating dietary intakes for a 100% indigenous food diet is probably not useful. The best way to estimate maximum intake of indigenous food is debatable, but it might be possible to survey food intake on Ujae or Lae Atoll. Residents of these outer atolls in the central western Marshall Islands use more indigenous foods than those of Rongelap Atoll because their financial resources are smaller.
- The study by Calf (J. Calf, personal communication, 1993) will update information on dietary intake of the Marshallese from before 1980 to 1993. It should provide important information on infant feeding practices and might help to identify food intakes of children, young single males and females, nursing women, adult males, nonnursing females, and the elderly. Such data will yield estimates of variance in food intake for each group. More important, this survey was designed to provide realistic estimates of energy intakes for subjects of different ages and should accomplish that goal. However, the survey conducted by Calf consisting of 1-d diet recalls of all residents on Mejatto during May 1993 will not provide data on seasonal variation. A study being conducted by Burton and Nero of the University of California, Irvine (Burton, personal communication, 1993), although not quantitative, will be a useful source of supplementary data on shifts in food intake due to seasonal variations, feasts, and special activities, such as intensive food-gathering or copra production. This information will be helpful in formulating potential diet scenarios involving indigenous foods and people with varied activities.
- An accounting of all shipping records for imported foods arriving in Mejatto would provide a cross-check of data collected in the Ujelang and Calf diet surveys and provide another means of assessing the relative uses of imported foods. This accounting should include all government subsidies (U.S. Department of Agriculture: school lunch and supplemental food supplies that are part of nuclear-related compensations) and all purchased foods. Some sort of food-supplement program or agricultural program will be essential if energy intakes are to be maintained after resettlement of Rongelap.
- Data on the radiation content of selected *prepared* indigenous foods would aid in the interpretation of current data on the radiation content of *raw* food products. The result would reassure northern Marshall Islands residents about one of the possible ingestion pathways of plutonium and strengthen the case for multiple uses of the Ujelang diet model.

If residents of Rongelap agree on a reasonable goal for indigenous-food intake, the Ujelang diet model will be sufficient for scenario-based calculations of dose.

4.

Measurements on Humans

The measurement of the kind, quantity, location, and retention of radionuclides in the body (often called bioassay) is accomplished either by direct means or by indirect means. With direct, or in vivo, bioassay, a radiation detector (or system of detectors) outside the body is used as a whole-body or partial-body counter to identify and estimate the body burden or organ burdens of radionuclides. This method can be used for radionuclides that emit radiation that is sufficiently penetrating to be detected outside the body, such as penetrating gamma rays associated with cesium-137, potassium-40 and cobalt-60. Indirect, or in vitro, methods involve the collection and analysis of samples that are excreted, secreted, or removed from the body (such as urine, feces, breath, hair, and perspiration) and infer the body burden or organ burdens through use of a metabolic model. In vitro methods, commonly urinalysis, must be used for radionuclides whose emissions cannot be readily detected outside the body, such as plutonium and strontium.

Bioassay measurements have both historical and prospective relevance to the Marshall Islands situation. Historical measurements provide information on the uptake of radionuclides from past habitation on the islands, provide data on the metabolic behavior of the relevant radionuclides in these populations, and provide a basis for testing models that are used to estimate intake and radionuclide burdens from environmental data. A contemporary bioassay program would establish preresettlement baselines on the people expecting to return to Rongelap. A bioassay program for the Rongelap people after resettlement will provide a means for tracking dose from future radionuclide intake.

Bioassay measurements on Rongelap residents have been performed by BNL personnel as part of a medical examination program after the nuclear-test series in the Pacific (Lessard et al., 1984; Miltenberger et al., 1980; Sun et al., 1992b). Whole-body counting, with emphasis on cesium-137, has been conducted since 1958. From the studies conducted by BNL during the Rongelap resettlement from 1957 to 1985 the whole-body measurements were instrumental in providing information on the build-up of radionuclide burdens. For the first few years after resettlement the body-burdens of cesium-137 and strontium-90 increased, reached an equilibrium with the environment, and then began a gradual decline. The body-burdens of cesium-137 were found to reach their peak in 1965 at about 23% of the maximum permissible lifetime values for world populations (Conard, 1992). In the early 1980s, BNL began investigating urine-bioassay methods suitable for detecting plutonium-239 and 240 in the Marshallese. Early attempts using a Photon Electron Rejection Alpha Particle Liquid Scintillation (PERALS) technique were unsuccessful owing to high readings contributed from naturally occurring concentrations of polonium-210. These findings prompted the development of the fission-track analysis (FTA) method to obtain better sensitivity by removing the polonium interference. Unfortunately the early PERALS and FTA results, which were released without adequate QA, may have contributed to the people of Rongelap deciding to leave their homeland for Mejatto in 1985 (Sun et al., 1992c).

WHOLE-BODY COUNTING

Review of Activities

Detailed information on the whole-body counting (WBC) system, its use, and the associated quality-assurance (QA) program was given to all members of the committee in a notebook entitled *Operating and QA Procedures Documents for the Radiological Dose Assessment Project*. In addition, the current Marshall Island Radiological Safety Program at BNL was reviewed by several members of this committee during a site visit on May 28, 1992. That visit provided the opportunity to review much of this material and to see an operating WBC system similar to the two currently used on the ship, Offshore Venture, during sampling trips to the Marshall Islands.

The committee was also provided copies of a report dated April 23, 1990, prepared by an independent BNL scientific review committee. The report was attached to a letter dated May 2, 1990, from Roscoe L. Hall, chairman of the review committee, to Walter Kato, chairman of the BNL Department of Nuclear Energy. The review committee reported that "the whole-body counting procedures used for estimating total body burdens of cesium-137, potassium-40 and cobalt-60 were within acceptable guidelines of technical excellence and conformed to recognized standards set for making accurate measurements of these radionuclides *in vivo*."

Recent bioassay missions to the Marshall Islands were conducted during July 1989, February 1991, and June 1992. The general approach during those missions was to measure baseline cesium-137 body burdens in populations from Enewetok, Rongelap, and Utirik Atolls. Table 4-1 shows the numbers of persons (volunteers) that were counted who were residents, or former residents, of those locations during the 1989 and 1991 missions and the population average dose rates from ingested cesium-137 based on those measurements; the uncertainties in doses shown as 1 standard deviation (L. C. Sun, Personal communication, 1994) Each person was counted for 15 min. Because two different chair-oriented counting systems were used, part of the QA program involved recounts of some persons in the same chair and cross-counts of some persons in both chairs. There was no statistically significant difference between original counts and recounts at the 97% confidence level or between original counts and cross-counts at the 99% confidence level; hence, the precision obtained in these measurements was judged to be high.

On the basis of information provided on the counting and standardizing procedures and on the QA program, the committee believes that the program is technically sound and capable of producing consistent, reproducible, and high-quality WBC measurements of Marshall Island residents. Two aspects of dose-assessment strategy that will need to be addressed are who should be counted and how often counts should be made. The MOU for the Rongelap Resettlement Project bears directly on those aspects. A primary condition for determination to initiate resettlement is (Article II, Section 2) "that the calculated maximum whole-body radiation dose equivalent to the maximally exposed resident shall not exceed 100 millirem (mrem)/year above natural background, based upon a local food only diet." Also, the MOU states (Article II, Section 11) that "the parties ... recognize the need for continual radiological monitoring both of returned citizens and of the Rongelap Atoll environment upon resettlement." As will be seen later, cesium-137 will continue to be the major contributor to dose; therefore WBC should be the primary means of providing continued radiological monitoring.

Table 4-1. Numbers of Persons Residents and Former Residents of Several Locations Who Volunteered for Whole-Body Counting and the Population Averages of Cesium-137 Annual Dose Rates Determined[a]

	Number Persons Counted		Cesium-137 Population Average Annual Dose Rate[b]	
	1989	1991	1989	1991
Enewetok	216	311	11 ± 3 (1.1 ±0.3)	22 ± 4 (2.2 ± 0.4)
Rongelap (Mejatto)	258	427	3 ± 2 (0.3 ± 0.2)	2 ± 2 (0.2±0.2)
Utirik	414	272	39 ± 2 (3.9± 0.2)	35 ± 3 (3.5 ± 0.3)
Others	28	41		
	—	—		
Totals	916	1,051		

[a] Data presented in an unpublished Brookhaven National Laboratory internal report (Sun et al., 1992c); based on measured WBC distribution medians from cesium-137.
[b] Dose rates expressed in units of µSv/y (mrem/y); uncertainties are 1 standard deviation.

The emphasis of the BNL program has been on population-related values. However, with the emphasis given the maximally exposed resident in the MOU, changes in the future direction of the WBC program might be required. It appears that the BNL program, has so far emphasized how many people to count, rather than whom to count and how often to count them. There has been no plan to follow a defined group of individuals with prescribed characteristics of age distribution, life style, or diet; instead, only volunteers have been counted. Because the makeup of the volunteer group has been different in each sampling trip, it is difficult to interpret increases or decreases in average cesium-137 body burdens measured in the sampled population from one sampling trip to another and it's particularly difficult to obtain and maintain individual records that will be needed to evaluate future trends.

The BNL staff has considered an effort to locate records for persons who have undergone multiple whole-body counts. Although this effort might provide some additional information, the long time between counts is a critical shortcoming. All WBC is now currently done on the ship Offshore Venture and can be done only when the ship is available for BNL use. Other organizations, such as LLNL, use the ship, and seasonal weather conditions also affect the schedule. According to BNL personnel, plans call for one sampling trip per year and half the planned survey done each year, for instance, Rongelap and Utirik is sampled one year and

Enewetok and Bikini (Kili) the next year. On this schedule, the Rongelap people will be counted every 2 y; this is an inappropriate schedule for trying to follow possible intakes of cesium-137 which has an effective biological half-time of about 100 d.

Recommendations

The Committee offers the following recommendations for the WBC program:

- Until experience dictates otherwise, the program should ensure that every member of the resettled population receives a whole-body count annually. This will aid in providing assurance that the conditions of the MOU are being met by determining actual body burdens and thereby providing the data necessary to evaluate the dose to the maximally exposed resident.
- Adopt the approach of following a defined Rongelap subpopulation during different seasons to obtain a better temporal definition of cesium-137 uptake and loss before and after resettlement.
- Summarize the data on persons who have participated in the historical WBC program over the long term. This will aid in identifying a core study group for the future. It would also provide insight into the initial rapid increase observed in cesium-137 body burdens in the "average adult" from 11 nCi in 1957 to 730 nCi in 1958 and the increase from 170 to 280 nCi during 1979-1982.
- Develop the facilities or logistical capability for regular, more frequent counting of the study group. There are two possible approaches. One would be to use another ship that could be dedicated most of the time to WBC activities; this option might not be feasible, because of the substantial costs involved. Another approach is to establish facilities at selected locations so that WBC instrumentation could be quickly installed, used, and moved to the next location; this option seems possible on the basis of experience in maintaining WBC facilities in remote areas (Hanson, 1982; Hanson et al., 1964), although some logistical aspects would have to be addressed, including staffing, electrical power, water, air conditioning; and continued participation of the study group. Centralized, land-based WBC facilities on three atolls in the Marshall Islands (or however many locations are deemed necessary for the DOE mission) would have several advantages over the current ship-based practice: weather conditions would be less constraining, more adults would be available without the 24-h confinement to the ship now required, sampling could include more frequent recounts of people (as recommended above); and greater mobility and flexibility of WBC capability could be integrated with dietary and life style phenomena to provide measurements at critical times indicated by that information.
- Give greater representation to adolescent females in the WBC program. In 1983 dose rates calculated for cesium-137 in young females (59 mrem/y) were nearly twice those calculated for adult males and females (32 mrem/y). Adolescent females had cesium-137 body

burdens exceeding those of both adult males and adult females during the measurement years 1981-1984 and 1989.

URINALYSIS FOR PLUTONIUM

According to the dosimetry estimates made by Robison et al. (1993), the primary contributors to the annual effective radiation dose for persons on Rongelap Island would be the external dose from cesium-137 in the soil and the internal dose from cesium-137 in food. Together, those two sources account for about 95% of the annual radiation dose. The inhalation and ingestion of plutonium-239 and plutonium-240 account for about 1% of the calculated annual effective dose, as does the inhalation and ingestion of americium-241.

Although plutonium-239 and plutonium-240 are expected to be minor contributors to the annual effective radiation dose, plutonium is a concern of the Rongelap people and soil concentration limits are included in the MOU. A logical follow-up to assure the limits are not exceeded is to determine the extent to which plutonium-239 and plutonium-240 have been deposited in the bodies of Rongelap residents after resettlement and verify that plutonium-239 and plutonium-240 are in fact minor contributors to dose.

As discussed above, WBC is a useful tool for measuring internal burdens of radionuclides that emit radiations, x-and γ-rays, that can escape from the body and be measured by external detectors. However, WBC is not useful for measuring low-level internal deposition of alpha-emitting radionuclides such as plutonium-239 and plutonium-240 because of the very short range of the emitted alpha radiation (about 40 μm in unit-density tissue). Therefore, an in vitro bioassay test, such as urinalysis, is generally used to detect and estimate the magnitude of internal deposition of plutonium and other alpha-emitting radionuclides. The usefulness of urinalysis for assessing possible uptakes of plutonium after resettlement depends on the expected magnitude of internal deposition, the fraction of the internal burden excreted per day, the sensitivity of the analytical radiochemical method used, and other factors.

Urinary excretion of plutonium by resettled Rongelap persons will consist of a baseline long-term excretion from any residual systemic burdens acquired from previous exposure, a baseline component consisting of prompt and long-term excretion from the general worldwide environmental contamination, and the potential prompt-excretion component (plus, eventually, the long-term excretion) from any intake associated with resettlement. Pertinent questions regarding long term follow-up of a population that has potential for ingestion of plutonium then are these: What is the expected baseline excretion for these people? What new contribution is likely to be expected from local sources, and can it be detected in the presence of the preexisting component? What excretion corresponds to a "significant" increment of intake, and can it be detected in the presence of the pre-existing component?

Sensitivity Requirements

When absorbed from the gastrointestinal tract after ingestion or from the respiratory tract after inhalation, plutonium enters the blood and is deposited primarily in the liver and skeleton where it is retained for biological half-lives of 20 and 50 y, respectively. A small fraction (about 1%) of the amount that enters the blood is excreted in the urine during the first day after absorption. Later urinary excretion of plutonium from this absorption decreases rapidly because of the prolonged retention of plutonium in the liver and skeleton, eventually approaching excretion of about 2 x 10^{-5} of the systemic burden per day. Knowledge of these rates is important when interpreting the analytical results for plutonium in urine.

Because of worldwide fallout of plutonium due to atmospheric testing of nuclear weapons, it is likely that residents of the northern hemisphere have sufficient systemic burdens of plutonium to produce daily urinary plutonium excretion rates of around 2-4 μBq (54-108 aCi; aCi = attocurie = 10^{-15} Ci) (Boecker et al., 1991). The urinary excretion of plutonium by Marshall Islands residents has been measured recently with a very sensitive fission-track analytical technique that is claimed to detect plutonium-239 concentrations as low as 2 μBq (54 aCi) per 24-h urine sample (Sun et al., 1992b; Sun, private communication, BNL briefing, 1992). In their estimates, Sun et al. assume an excretion of 1-2 μBq (27-54 aCi) per 24-h urine sample from adults as a result of global weapons fallout. Of the 67 Rongelap urine samples assayed in 1989, 16 were above 2 μBq (54 aCi) for a 24-h sample; the highest was 6 μBq (162 aCi). Values of this magnitude are the background levels against which the results of future urinalysis must be distinguished to follow any possible future uptakes of plutonium after resettlement.

After resettlement, exposures might occur as a result of ingestion of plutonium in food or soil or inhalation of plutonium resuspended into air from the soil. Such exposures would be expected to be primarily low-level, chronic exposures. Two approaches can be considered for analysis of plutonium in Rongelap residents exposed under these conditions: the very sensitive fission-track process now being used by BNL staff and the much less sensitive alpha spectrometric process currently used to detect and assess possible occupational exposures to plutonium.

Considerable day-to-day fluctuations occur in urinary excretion of plutonium and these fluctuations in the background excretion rates can interfere with the detection of a very small increases in the level in plutonium due to chronic intakes after resettlement. For purposes of discussion, assume that urinary excretion must increase by 4 μBq (108 aCi) for it to be detected above the existing background excretion level. With the long-term urinary excretion factor of 2 x 10^{-5} of the systemic burden per day, such an excretion would correspond to a systemic plutonium burden of about 0.2 Bq (5.4 pCi). With an approximate dose-conversion factor of 27 μSv of annual effective dose from 1 Bq of systemically deposited plutonium (0.1 mrem/pCi), a systemic burden of 0.2 Bq (5.4 pCi) would result in an annual effective dose of 5 μSv (0.5 mrem). Those conditions suggest that the fission-track analytical process could be used for long-term urinalysis to follow the possible systemic deposition of plutonium from low-level chronic exposures that would contribute a small fraction to the total dose likely from radionuclide contamination.

If the fission-track analytical method is used for that purpose, it is important to understand possible problems with its use. It is still a new method with which little operational experience is available as described later. The method is extremely sensitive, and fluctuations in the observed daily excretion rate can be quite large for a variety of reasons including temporarily larger excretions from very recent intakes. These fluctuations could be misleading in interpretation.

As an alternate approach, one might consider the use of the alpha-spectrometry method.

However, the detection sensitivity is about 1/40 that of the fission-track method, and the minimum detectable systemic burden would be about 7 Bq (189 pCi). Such an internal burden of plutonium would result in an annual effective dose of about 0.2 mSv (20 mrem), or 1/5 the annual limit specified in the MOU. This method, therefore, is insufficiently sensitive and does not provide a useful alternative to the more sensitive fission-track analytical process.

Review of Activities

A program of urinalysis of the Marshallese, in addition to the WBC program, is being conducted by BNL. In this committee's review of BNL activities, it observed problems in the methods, partly because of the attocurie-level sensitivity they are attempting to achieve (Moorthy et al., 1992). Because the rate of excretion of systemic plutonium is so small, the procedure for its analysis must have high sensitivity. The BNL procedure, which is based on fission-track counting, consists of many steps and is very time-consuming. To avoid contamination by uranium, whose 235 isotope produces fission-tracks that would be interpreted as being caused by plutonium, elaborate reagent-purification and container-cleaning procedures are necessary. Separation and purification of plutonium are accomplished by anion exchange. Because of great changes in volumes and concentrations of the solutions, two anion-exchange steps are used, the second with distilled acids and carefully washed containers to exclude uranium. The purified plutonium fractions are mounted on quartz slides that have been exhaustively washed, and they are sent to a reactor for neutron irradiation, after which the number of fission tracks on each slide is carefully determined. The results are used to calculate the amount of plutonium-239 present. The sensitivity of the method is estimated to be around 2 mBq (54 aCi).

As anticipated, the complex nature of the plutonium analysis resulted in the development of an extensive radioanalytic procedure. During the review of the procedure supplied to committee members as a BNL internal report there were a number of questions raised. The documented BNL procedures given the committee contained errors that could lead to improper chemical operations that could invalidate the final results, and it did not, in some steps, describe what is actually done. For example, in two cases there was confusion between nitrate and nitrite ions, one being specified when the other is required. Sodium nitrite is used to convert all plutonium to the tetravalent state so that it will sorb on an anion-exchange column; if sodium nitrate were used instead, some of the plutonium would not be converted and would pass through the anion-exchange column unsorbed, leading to a low value for the final plutonium content. Plutonium is also subject to hydrolysis that forms colloidal species that tend to sorb onto container walls, but there are ways to prevent this, such as keeping solution pH low and using Teflon containers. At one point, the BNL procedure called for dilution with water, which can cause localized areas of high pH that can lead to hydrolysis; dilute acid should be used for this dilution. Containers are said to be exhaustively washed to remove uranium contamination, but they are not specified as made of Teflon. The need to exclude uranium is indeed important, but equally so is the need to avoid plutonium loss by sorption. These possibly contradictory requirements might require a compromise, but at least the factors influencing the choice of an optimum container should be addressed.

The conditions leading to plutonium retention by the container are not limited to hydrolysis. Evaporating a plutonium solution —even in concentrated acid —to total dryness can cause the residue to become overheated and bake onto the container bottom; complete redissolution is then difficult. Despite that problem, the BNL procedure provided in an internal report called for evaporation to dryness. Another question that needs further verification is whether the higher content of plutonium-240 in fallout than in weapons-grade plutonium, has been taken into account in the calculations. Although there have been informal assurances that this correction has been made, the matter needs further documentation.

The BNL recipe for synthetic urine provided to the Committee includes creatine instead of creatinine, even though the latter is the normal component of urine. In conversations with BNL staff, it was indicated that they were currently using neither. The omission is important because creatinine, a potential complexing agent, could have a significant effect on the behavior of plutonium. When the committee discussed the shortcomings cited above with BNL personnel, they stated that they were not adhering strictly to the procedure provided, that the procedure was being updated, and that the committee's concerns were unwarranted. The new procedure was under development and was expected to be implemented in June 1993. In February 1994, the committee was provided a preliminary draft of an updated version of the chemical procedures (Kaplan, personal communication, 1994). The "marked-up" draft procedures suggest that many of the points raised in the critique of the original procedures have been recognized. Whether application of the new procedures is eminent is, however, unknown. It is important that the new procedures be properly reviewed and documented prior to their being implemented in the routine laboratory setting. The primary recommendation of the committee is that, in an analytic procedure as complex as that used in the analysis of trace quantities of plutonium in urine, there must be careful oversight, review, and testing to assure optimum precision and accuracy of the assay. Efforts should also be intensified to develop alternative techniques, such as mass spectroscopy, that may have the necessary sensitivity, but a higher degree of accuracy and precision.

The QA program, under which the plutonium analyses were conducted by BNL personnel consisted almost entirely of the use of in-house-prepared blind samples in synthetic urine. This program needs improvement. As part of this program, sample exchange was instituted with the University of Utah (Singh, personal communication, 1993), but apparently only two samples have been run by both laboratories to date. The results on the two samples were encouraging: the two laboratories' values agreed to within 25% in both cases, with one laboratory reporting a higher value for one sample and the other a higher value for the other sample. Nevertheless, two samples constitute far too small a population from which to draw a meaningful conclusion. More exchange samples were not run, because of lack of adequate funding at that time, but it was stated that an additional four exchange samples are planned. Results of these exchanges, if they have taken place, have not been available to this committee. In any case, additional sample exchanges are necessary before the validity of the BNL procedure can be properly assessed. The University of Utah is a good choice for this sample exchange, because its procedure is substantially different from the BNL procedure, specifically in the use of a front-end precipitation with rhodizonic acid for preliminary separation of plutonium, the use of hydrochloric acid rather than nitric acid solutions in the anion-exchange steps, and the use of polycarbonate rather than quartz slides to mount the samples for neutron-irradiation. The claimed sensitivity of the Utah procedure is about 1.5 μBq (40 aCi).

Conclusions and Recommendations

For measurement of plutonium in urine, to ensure that plutonium remains a negligible contribution to dose, an extremely sensitive method will be required to detect likely intakes. The fission-track method currently being used (and apparently undergoing further refinement) appears to have sufficient sensitivity to provide the needed assurances, but its accuracy and precision is presently unproven. Careful attention is needed to ensure that problems inherent in the chemical-separation procedures and in the urine-collection protocol are resolved and understood. The committee feels that an active program of interlaboratory comparison should be undertaken to document the accuracy and precision of the techniques being implemented for routine plutonium analysis. In addition, problems encountered in interpreting measurements of plutonium in urine need to be carefully documented and understood before any program is initiated for routine monitoring of plutonium intake.

5.

DOSIMETRY AND ITS APPLICATION

As stated earlier, radiation dose attributable to fallout contamination of Rongelap Atoll results from external exposure from gamma-emitting radionuclides distributed through the environment and from internal exposure due to the intake of radionuclides through inhalation, ingestion, and absorption through the skin. Owing to the natural processes of weathering and the decay of many elements with short half-lives only five of the radionuclides originally deposited on Rongelap as a consequence of the BRAVO test are still present in sufficient quantities to contribute significantly to the estimated dose to individuals who may return to live on Rongelap (Kercher and Robison, 1993). These are: cesium-137, strontium-90, plutonium-239, plutonium-240, and americium-241. Of these radionuclides, cesium-137 accounts for more than 90% of the projected radiation dose.

Potential radiation doses from exposure to external radiation can be predicted directly from measurements of the radiation field. Prediction of radiation doses from internal sources is more complicated. When radioactive material is taken in by inhalation or ingestion or is presented to the skin, a fraction is absorbed and reaches the blood stream. The absorbed material is then distributed to various organs and tissues. The radioactivity is eventually removed from the fluids, organs, and tissues by radioactive decay and by biological processes. The fraction absorbed, the distribution after absorption, and the rates and pathways of radionuclide metabolism are determined by the elements and chemical forms.

In doses calculated prospectively, intake of each radionuclide is estimated as the product of its concentration in air, food, water, or other medium and the quantity of such medium taken into the body through breathing, ingestion, or skin absorption. The absorption (uptake), distribution, and retention of a radionuclide is estimated from biokinetic models of the element in humans. Radiation dose rates to various organs and tissues are then calculated from the characteristics of the radiation and physical dosimetric models of the transport and absorption of the radiation in the human body. Cumulative (time-integrated) doses can be calculated from the expected residence time of the radionuclide in the body.

After a single intake, the quantities of radioactivity in individual organs (organ burdens) and the whole body (body burden), and hence the associated radiation dose rates, rapidly reach a maximum and then decrease because of radioactive decay and biological elimination. In the case of continuous, chronic exposure, organ and body burdens continue to build up until a maximum is reached at which the increase is balanced by the loss. The burdens (and associated doses) then follow the concentrations in the relevant environmental media. The time to reach this maximum varies with the radionuclide and its chemical form. The maximum occurs earlier for radionuclides with short effective half-lives (as determined by radioactive decay and biological retention time). It occurs later for radionuclides with long effective half-lives. For example, cesium-137 has an effective half-life of about 100 d in the adult human; under constant (or slowly decreasing) continuous chronic intake, the maximum dose rate can be expected to occur within about 2 years. In contrast, a portion of the plutonium in the human body has an effective half-life of around 50 y, and under continuous chronic intake, the body burden (and associated dose rates) would be expected to increase throughout the lifetime of a person.

For the purposes of radiation protection, radiation dose is expressed in terms of *equivalent dose*, which, for a given type of radiation, is the product of the energy deposited (absorbed dose) and the effectiveness of the type of radiation (radiation weighting factor). Doses resulting from nonuniform spatial distribution in the body, as occurs with the selective deposition of radionuclides in various organs or tissues, can be expressed in terms of *effective dose*, a summation of organ doses in a manner calculated to be biologically equivalent to the dose from a uniform whole-body exposure. Effective dose is calculated by multiplying the individual tissue equivalent doses by specific tissue weighting factors and summing the weighted tissue doses.

Once radionuclides enter a person's body, the person is "committed" to the dose resulting from the radioactive decay of the radionuclides for as long as they remain in the body. For assessing radionuclide intakes by members of the public, the International Commission on Radiological Protection (ICRP) Report 56 (ICRP, 1989) recommends calculating committed doses from the time of intake to age 70. In contemporary terminology, the dose commitments from an intake are expressed in terms of the *committed equivalent dose* to organs and tissues and *committed effective dose* to the whole body. For the purposes of dose limitation, the committed dose (for 50 y in adults and to age 70 for children) from the annual intake of radionuclides is considered part of that year's radiation dose (ICRP, 1991a).

In the international system (SI) of units, equivalent dose, effective dose, committed equivalent dose, and committed effective dose are expressed in sieverts (Sv). Before adoption of SI units, the unit of dose in the traditional system was the rem (1 rem = 0.01 Sv).

Reconstruction of past radiation doses and prediction of future doses also involves knowledge, or prediction, of the time-dependent nature of the exposure pattern. In circumstances where no continuous individual record of external exposure or radionuclide intake is available, the exposure pattern must be modeled. A frequently used approach to estimating exposure is to develop scenarios for different exposure patterns, which in turn might include different estimates of intake. The scenarios might be for a "reasonable" exposure, a "maximum" exposure, or any other desired situation. Although it is difficult to verify any individual scenario, reasonable boundary conditions for exposure can be established if several are developed.

DOSIMETRY APPROACHES

External Dose

The dose rate from external radiation is readily measurable. Instruments can identify the type, energy, and intensity of radiation. From these measurements, the radiation doses to tissues and organs can be calculated. Alternatively, dose rates can be calculated from the measured or projected concentrations of radionuclides in air or soil. Dose-rate coefficients for these quantities are cited in *Federal Guidance Report* 12 (EPA, 1993), but age-specific coefficients are not given.

Internal Dose

As noted earlier, environmental data, physiological-anatomical data, and element-specific biokinetic computer models can be used to estimate body burden and radiation dose at any time after an intake. These element-specific models are used to estimate tissue burdens and associated dose rates after ingestion and (when combined with a respiratory tract dosimetry model) inhalation of radionuclides. The biokinetic models can also be coupled to intake through the skin to estimate organ burdens and dose rates.

Many models have been developed to estimate the metabolism of elements. The most generally applicable for dosimetry are those developed by the ICRP. The ICRP biokinetic models have evolved from the simple retention models of ICRP-2 (ICRP, 1959) through the more complex retention models in ICRP-30 (ICRP, 1982, 1988) and to models that include age-specific absorption and organ transfer coefficients, as exemplified in ICRP-56 (ICRP, 1989).

Intake by Inhalation and Ingestion

The intake from inhaled radionuclides can be estimated from measurements of body burdens or from projections of radionuclide concentrations in air. Measurements of intake or projections based on radionuclide concentrations in the air, water, and soil are used as the basis for calculating radiation dose from ingested radionuclides. For convenience, ICRP has published the results of biokinetic models, for "reference" persons, for radionuclide uptake and retention by the various tissues, factors relating organ burdens to dose rates in various target tissues, and dose coefficients for converting inhalation and ingestion intakes to committed doses in ICRP-30 (ICRP, 1982, 1988). Age-specific biokinetic and dosimetric models were developed later. Calculations for selected radionuclides were performed and inhalation and ingestion dose coefficients (committed dose per unit intake) for generic persons age 3 mo, 1 y, 5 y, 10 y, and 15 y old and adults were published in ICRP-56 (ICRP, 1989). The dose coefficients, although developed for generic models, provide a consistent set of calculations and are recommended for comparison purposes. Estimates of the radiation dose to the uterus and the embryo or fetus from intake of radionuclides for new exposures and for pre-existing conditions have been published as NUREG/CR-5631 (Sikov et al., 1992; Sikov and Hui, 1993)

Intake through the skin

Intake through the skin can be either through the intact skin or through wounds. Of particular interest in the Marshall Islands resettlement is the potential for uptake from contaminated soil. Uptake through intact skin can be estimated from skin contamination (expected to be a function of skin surface area and skin adherence of contaminants) and uptake fractions (EPA, 1989). For chronic exposure to contaminated soil, skin contamination for an individual of age p can be estimated from

$$S_c = C_s \times S_a \times A_p \ , \qquad (8)$$

where S_c is total-body skin contamination in Bq, C_s is concentration in soil in Bq/kg, S_a is skin adherence of soil in kg/m^2 and A_p is age-specific skin area in m^2. Daily uptake, D_u, in the equilibrium, chronic-exposure situation can then be estimated from

$$D_u[Bq/d] = S_c[Bq] \times U_f[d^{-1}] \ , \qquad (9)$$

where U_f is the daily uptake fraction and S_c is defined in E_q. 8 above. In the case of resettlement of Rongelap, the soil contaminant of interest is plutonium. Studies of plutonium absorption through the skin have usually used plutonium as the nitrate in acid solution. Reported uptake fractions through the skin in humans range from 0.0002%/h (4.8×10^{-5}/d) for plutonium nitrate in 0.4 M HNO_3 (Langham, 1964; Khodyreve, 1966) to 0.01%/h (2.4×10^{-3}/d) for plutonium in 9% HCl (ICRP, 1986).

Oakley and Thompson (1956), e.g. as cited in Langham (1964, pp. 565-582), reported that uptake of plutonium nitrate from wounds in animals was 3 times that through intact skin. Overall systemic absorption was less than 1% of the amount applied. In the environmental-contamination scenario, the quantity of soil in wounds would be substantially less than the quantity adhering to the overall skin, so uptake from wounds should not add substantially to the uptake from skin contamination.

Uptake of plutonium from abrasion-type wounds should be negligible. Plutonium, particularly plutonium oxide, is trapped in the tissue exudate and immobilized in the eschar. The plutonium will be eliminated when the eschar detaches and drops off (Langham, 1964; Langham et al. 1962).

APPRAISAL OF CURRENT DOE ASSESSMENTS

In estimating doses and potential risks to the people of the Marshall Islands, metabolic and dosimetric models have been used to calculate contributions from external sources and from inhalation and ingestion of radionuclides. LLNL personnel have used some of the most current biokinetic models when estimating metabolism and dosimetry for inhaled or ingested radionuclides. The most recent re-evaluation of the potential dose (Robison et al., 1993) uses ICRP-30 (ICRP, 1982, 1988), ICRP-56 (ICRP, 1989), and, for some cases, ICRP-61 (ICRP, 1991b). Complete anatomical and biokinetic factors were not examined, but two indicators —body weight and the biological half-life of cesium-137 —do not suggest any serious problems with application of the ICRP models for external and internal dosimetry for the Marshall Islands population.

- *Body weight*. Robison et al. (1993) provide data on the weights of males and females from four atolls, including Rongelap. Average values are comparable to those for the reference 70-kg male and 58-kg female given in ICRP-23 (ICRP, 1975).

- *Biological half-life*. Robison et al., (1993) quote BNL data on cesium-137 biological half-life in Marshallese (23 males and 21 females). The half-life for males (median, 115 d; mean, 119 d) is not greatly different from the 110 d given for the long-lived component in ICRP-56 (ICRP, 1989). A shorter half-life is reported for females (83 d); this is consistent with the discussion of cesium-137 retention in females given in ICRP-56.

The nuclides of primary importance have been cesium-137, strontium-90, plutonium-239, plutonium-240 and americium-241 (Robison et al., 1982, 1993; Kohn, 1989; Robison and Phillips, 1989). Those references and other documents by LLNL personnel have reported estimated doses received by Marshall Islands people for many years. Except where otherwise noted, the following discussion addresses the 1993 LLNL dose assessment for Rongelap Island (Robison et al., 1993).

External Dose

Estimates of external dose rate have been consistent when repeated measurements have been made (Kohn, 1989, Table 5.1). Gamma-ray exposure rates as a function of location were estimated from an aerial survey made in 1978 and from indoor and outdoor gamma spectroscopy conducted in 1988. The major current contributors to external gamma dose were identified as cesium-137 (more than 99%) and cobalt-60 and corresponding radioactive-decay corrections were applied. The annual dose equivalent to the typical resident of the island was estimated with a scenario involving occupancy-time weighting factors for four indoor and outdoor locations of different radiation levels. A conversion factor of 0.0075 sievert/roentgen (Sv/R) was used to convert measured exposure in air to dose equivalent to the testes. Doses were decay-corrected for the projected resettlement date of 1995, and annual doses and accumulated doses were calculated for each of the next 70 y. The maximum external gamma-ray dose rate was projected to be 0.11 mSv/y (11 mrem/y) in 1995; this will decrease as cesium-137 continues to decay and to migrate in the environment.

The source of data is appropriate, and the aerial-survey and ground-based results are consistent with each other when decay-corrected to a common date. The occupancy scenario for Rongelap Island appears reasonable; however, because of the different dose rates on the island, the dose will be lower if less time is spent in the island's interior. The exposure rate from fallout is higher on most other islands of Rongelap Atoll than on Rongelap Island itself (Kohn, 1989), so estimates for external gamma-ray dose for the maximally exposed resident should include consideration of time spent on other islands. For the purposes of projecting the post-resettlement dose, it would have been more appropriate and more consistent to convert measured values to effective dose, using factors such as presented in ICRP-51 (ICRP, 1987), rather than dose to the testes. However, the conversion factors would not be greatly different from the value used, and the results would not be significantly different. On the basis of the data presented, the decay-corrected external gamma dose of 0.11 mSv/y for 1995 appears reasonable. The projected doses for future decades are probably overestimated, inasmuch as the corrections were based only on physical half-life of the radionuclides with no consideration of the effective environmental half-life.

The LLNL report points out that the external beta dose would be a shallow dose only and that the beta contribution would add only slightly to the gamma shallow dose. It concludes, considering the relatively low risk-based weighting factor for the skin, that the beta contribution to the total effective dose would be extremely small. This appears to be a reasonable conclusion.

Intake and Internal Dose

Inhalation

Potential inhalation exposure due to resuspension of radionuclide-bearing soil was assessed. Airborne radionuclide concentrations were projected for Rongelap from measured concentrations in Rongelap soil and enhancement factors developed in the resuspension experiments conducted on other Marshall Islands atolls. Because the average concentrations of transuranic radionuclides in surface soils over the entire island were observed to be roughly twice those in the vicinity of the village and housing area, location was an important variable in projecting airborne concentration and inhalation intake. Inhalation intake for the typical Rongelap resident was projected with a scenario involving time weighting for four activity-location combinations.

Average plutonium and americium concentrations reported for Rongelap surface soil and the projected average annual intake of these radionuclides are presented in Table 5-1 for the reference year 1995. Concentrations of cesium-137 and strontium-90 in the soil were also measured but these radionuclides were not included in the inhalation dose assessment; the product of the soil concentration and the inhalation dose factors for the various radionuclides indicates that the relative dose contributions of these two will be orders of magnitude less than the dose contributions from plutonium and americium.

ICRP dose methods and models were used to convert inhalation intake to dose. Projected intakes of plutonium and americium were presented as fractions of the intake limit corresponding to 1 mSv/y (numerically equivalent to the committed effective dose in millisieverts/year —see Table 5-1).

From the information provided, the resuspension experiments appear to be reasonable and add an important dimension to the dose assessment. The algorithm for computing intake accounts for the important factors. The occupancy scenario is difficult to evaluate, but there are no obvious problems. The breathing rates and the distribution between resting and active are similar to, but not identical with, the values for the ICRP reference adult male. The committed effective doses are on the order of a scale of microsieverts/year; annual doses will initially be much lower and will slowly approach this value.

There were no age-dependent calculations. Although the use of reference-man breathing patterns should give a conservative estimate of nonadult intake —the ICRP inhalation model is the same (ICRP, 1989) —an age-dependent scaling of breathing rates would have given a better approximation. Comparison of the 70-y effective doses calculated for children for plutonium and americium with those for adults in ICRP-56 suggests that the dose rates for americium might go down by a factor of about 2, but those for plutonium might go up by a factor of 3. Uncertainties in inhalation deposition and dose by nuclide were not calculated.

Table 5-1 Surface-Soil Radioactivity, Projected Inhalation Intakes and Projected Inhalation Dose of Selected Radionuclidesa

	Plutonium	Americium
Soil concentration	Bq/g (pCi/g)	Bq/g (pCi/g)
Village mean	0.063 (1.7)	0.046 (1.2)
Island mean	0.13 (3.5)	0.097 (2.6)
Average individual inhalation intake		
	Bq/y (pCi/y)	Bq/y (pCi/y)
	0.044 (1.2)	0.023 (0.62)
Average individual committed effective dose		
	mSv/y (mrem/y)	mSv/y (mrem/y)
	0.0027 (0.27)	0.0016 (0.16)

[a] Adapted from Robison et al. (1993), projected to 1995.

Ingestion

Local sources of ingested radionuclides considered in the LLNL assessment include soil (incidental ingestion), drinking water (from rainfall and groundwater), and diet (marine and terrestrial foods). The radionuclides of potential importance, because of their presence in the environment are cesium-137, strontium-90, plutonium-239, plutonium-240, and americium-241. The relative contributions to projected radionuclide intake from local sources are summarized in Table 5-2 for two LLNL scenarios: A, imported-foods-available, and B, imported-foods-unavailable.

The assessment assumed an average soil ingestion of 100 mg/d. For the models used, soil makes a small contribution to the intake of cesium-137 and strontium-90 but it is the major contributor of transuranics in Scenario A and an important contributor in Scenario B. Thus, a dose from ingestion of transuranics is sensitive to the assumptions about the quantity of soil intake. The assessment used the average island-soil radioactivity values, and the doses are higher than would be estimated with the lower village-vicinity values.

Table 5-2. Local Source Contributions to Intake by Ingestion of Various Radionuclides

		Contributions			
Component	mass intake, g/d	^{137}Cs	^{90}Sr	$^{239,240}Pu$	^{241}Am
Scenario A-imported foods available:					
Soil	0.1	0.2%	3.6%	72.3%	81.1%
Water[a]	977	0.05%	3.6%	1.0%	0.5%
Local food	375	>99%	92.8%	26.7%	18.4%
Intake, Bq/d	—	31	0.47	0.018	0.012
Scenario B-imported foods unavailable:					
Soil	0.1	0.07%	1.1%	35.0%	54.0%
Water[b]	530	0.01%	1.0%	0.4%	0.3%
Local food	1,011	99.9%	97.9%	64.6%	45.7%
Intake, Bq/d	—	78	1.5	0.037	0.018

[a] Including rainwater, well water, and drinking water in coffee or tea and malolo.
[b] Including rainwater and well water.

The LLNL assessment assumes that the drinking-water source is rainwater 60% of the time and groundwater 40% of the time. The diet model for Scenario A uses 947 g for the total daily intake of rainwater, well water, and water used to brew coffee or tea and B. Thus, the dose from ingestion of transuranics is sensitive to the assumptions about the reconstitute dried drinks (malolo). The quantity of water specified for Scenario B is only 530 g with the absence of coffee or tea and malolo. These quantities are less than the daily water reguirements given for the ICRP-23 reference persons (ICRP, 1975), fluid water values of 1,700 g/day for the male and 1,200 for the female. The quantity of water specified in these scenarios therefore seems low. For the water-consumption quantities used, the radionuclide intakes are probably overestimated —groundwater (with higher radionuclide concentrations than rainwater) is used only in conditions of extreme drought, but the assessment assumed relatively high groundwater use of 40%. However, neither the daily quantity nor the percentage of groundwater is critical, in that it appears that drinking water would contribute only a few percent, at most, of the projected radionuclide intake.

The remainder of the diet constitutes the major source of the projected fission-product intake and contributes a large fraction of the projected transuranic intake. Average radionuclide concentrations for the various food items vary over a range of 10^5; consequently, the composition of the diet model is critical to the dose assessment. Diet models were reviewed in previous sections of this report; this section addresses primarily the dose-estimation method and doses estimated with the LLNL diet model.

In the LLNL assessment, the scenario-based radionuclide intakes were converted to doses with the methods and models of ICRP-30, -48, -56, and-61 (ICRP, 1979, 1986, 1989, 1991b). One special consideration was the use of gastrointestinal-to-blood transfer factors (f_1 values) of 10^{-4} for plutonium ingested in soil and the ICRP value of 10^{-3} for plutonium in other media. Intakes of these radionuclides were presented as fractions of the intake limit corresponding to 1 mSv/y (in effect, the committed effective dose in millisieverts/year). Ingestion intakes and the associated committed effective doses projected for the initial year are summarized by radionuclide for the two scenarios in Table 5-3.

The LLNL assessment did not make age-specific dose estimates. However, doses from ingestion of the major contributor, cesium-137, are fairly constant with age from 1 y through adult life (see, for example, ICRP-56, 1989). Also, Robison and Phillips (1989) calculated doses from continuous intake, beginning at various ages, of cesium-137 and strontium-90 from an intake source decaying with a 30-y half-life. These calculations indicated that, although maximum dose rates occurred when intake began at an earlier age,[4] estimated *integral* effective doses for adults due to intake of cesium-137 and strontium-90 can be used as conservative estimates for intake beginning at earlier ages.

In summary, estimates of radionuclide ingestion were based on a substantial database. All the credible routes of ingestion appear to have been considered. The estimate of the soil-ingestion route would be improved by stronger data on quantities of soil ingested, particularly as a function of age. The estimation of ingestion due to water is not clear, particularly in Scenario B; however, drinking water does not appear to be a major dose contributor. The diet model plays an important role and has been discussed in an earlier section. The conversion of intake to dose uses accepted ICRP models and methods. The assessment was limited to a reference adult; however, evidence was given to support the position that this provides a conservative assessment for the broader population. A possible exception, not thoroughly

[4] The maximum dose rate for cesium-137 was calculated to occur when intake begins at age 4 months and to have a value about twice that for intake beginning as an adult. For strontium-90 the maximum rate occurred when intake began about age 13; this value was slightly greater than for intake beginning as an adult.

covered, is the question of intake of transuranics through the ingestion of soil by various age groups.

Table 5-3. Summary of Annual Whole-Body Doses Attributable to Local Fallout Projected for 1995 †

Route	Scenario A. Imported Food Available			Scenario B. Imported Food Unavailable		
Radionuclide	Intake Bq/y	Dose* mSv/y	% of Total Dose	Intake Bq/y	Dose* mSv/y	% of Total Dose
Ingestion						
^{137}Cs	11,000.	0.16	56	28,000	0.40	73
^{90}Sr	170.	0.0057	2	550	0.018	3
$^{239,240}pu$	6.6	0.0033	1	14	0.008	2
^{241}Am	4.4	0.0029	1	6.6	0.0044	1
Subtotal		0.17	60		0.43	79
Inhalation						
$^{239,240}Pu$	0.044	0.0027	1	0.044	0.0027	< 1
^{241}Am	0.023	0.0016	< 1	0.023	0.0016	< 1
Subtotal		0.0043	2		0.0043	1
Intake Subtotal	—	0.18	62	—	0.43	80
External	—	0.11	38	—	0.11	20
Total		0.29	100		0.54	100
-		(29 mrem/y)			(54 mrem/y)	

† Data derived from Robison et al., 1993.
* Dose = Effective dose (external) and committed effective dose (intake).

The dietary scenarios developed in Table 3-1 can be used to estimate the effects of changing dietary assumptions on dose calculations. In Table 5-4, the dose contribution of all components of the diet other than those from cesium-137 have been held constant. For a first approximation, the dose associated with cesium-137 (projected for 1995) has been calculated on the basis of the estimated daily cesium-137 intake for the various dietary scenarios.

Table 5-4. Calculated Average Annual Whole-Body Dose to Rongelap Residents Associated with Potential Dietary Scenarios Considering Variations in Energy Intake, Food Choices, and Remediation with KCl (Projected for 1995)

	Ujelang local & imported diet	Ujelang local only	Local only[1]	Coconut collector's diet[2]	Local only from northern islets[3]	Local only KCl applied[4]
	(A)	(B)	(C)	(D)	(E)	(F)
^{137}Cs intake,						
kBq\y	11	28	66	56	106-396	12
^{137}Cs Dose,						
mSv/y	0.16	0.40	0.92	0.78	1.50-5.57	0.17
Other sources,[5]						
mSv/y	0.13	0.14	0.14	0.14	0.14	0.14
Total local source dose:						
mSv/y	0.29	0.54	1.06	0.92	1.64-5.71	0.31
mrem/y	29	54	106	92	164-571	31

* Robison et al., 1992; 1993, Tables 5 and 6.

[1] Ujelang local-food-only diet adjusted by the committee to provide energy equal to the Ujelang local-and-imported-food diet (Column B × 2.305) to bring caloric intake to a sustainable level.

[2] Energy intake of Ujelang local diet increased by increasing intake of fish (two-fold), coconut juice (five-fold), drinking coconut meat (five-fold), sprouted coconut (five-fold), consumption of turtle eggs reduced (90g) and of water reduced (300g) to make diet quantities logical.

[3] Local diet in Column C but with pandanus, coconut, and arrowroot collected in northern islets of Rongelap and Rongerik Atolls. Kohn (1989) estimated whole body doses 2-to 9-fold greater than on Rongelap Island.

[4] Local diet in Column C with an assumed 90% loss of cesium-137 in coconut breadfruit and pandanus because of KCl fertilization (Robison et al., 1993).

[5] All internal and external sources of radiation other than those due to cesium-137.

Comparison of the results of the dietary scenarios listed in Table 5-4 shows the impact of dietary assumptions. Although the average annual dose calculated in columns A and B is less than 1 mSv (100 mrem), the average annual doses calculated in columns C and D are around 1 mSv, indicating that a sizable fraction of the population will exceed the 100-mrem limit of the MOU if these diet scenarios are valid. In the scenario presented in column E, the average annual dose exceeds 1 mSv (100 mrem).

The effect of mitigation can be seen in column F; all assumptions are identical with those of column C, but KCl is applied to reduce cesium-137 uptake in food plants. In this case, the calculated annual dose is similar to that calculated if the local-food diet is supplemented with imported foods. Obviously, there is benefit to mitigation with KCl, and various exposure scenarios can be used to investigate potential effects of other actions that might be taken.

Intake through skin

The effect of skin contamination with plutonium has not been addressed in the published LLNL reports. Application of the previously cited absorption factors from the literature would project substantial intake of plutonium from Rongelap soil. Such projections applied to Rongelap, however, would be expected to produce an overestimate, because the plutonium in that soil is of a fired-oxide form that is substantially less soluble than the nitrate forms used in most of the experiments in the literature. This is supported by the history of low excretion of plutonium measured in persons who resided on Rongelap 1957 to 1985. However, because of the uncertainties in the projections, assessments should be performed on the potential intake of plutonium through the skin.

6.

UNCERTAINTY AND VARIABILITY IN DOSE PROJECTION

Two approaches can be used to define maximally exposed persons in risk assessments: the probabilistic approach and the scenario approach. The probabilistic approach specifies frequency distributions for quantities that are relevant to dose or risk and then uses Monte Carlo simulation to estimate the population distribution of dose or risk. This approach uses statistical distributions to define a maximally exposed person. In the Rongelap assessment, the distribution of doses to individuals is estimated from distributions of diet, biological half-life, and radionuclide concentrations. The average dose to the maximally exposed person is estimated as some high percentile (e.g., the 99th percentile) of the individual dose distribution. It is not possible to work back from the dose received by the maximally exposed person and determine the characteristics of that person. The uncertainty in the dose is a consequence of the variability in radionuclide concentrations in the environment and uncertainties in the dosimetry models and coefficients.

LLNL PROBABILISTIC APPROACH

The LLNL model extends the standard probabilistic approach by dividing the uncertainty in the dose into the variability among persons and the uncertainty in the dose to a specific individual (Robison et al, 1993; Bogen and Spear, 1987). The variability among persons depends on individual diet (intake of radionuclides), the biological half-life of cesium-137, and the fraction of ingested cesium stored in the long-lived body compartment of different persons. The uncertainty in a person's estimated dose depends on variability in radionuclide concentrations in the environment and uncertainty in the dose model used and its coefficients (Fig. 10).

Two sources of data contribute to the LLNL dose assessment: characteristics of people and characteristics of the environment. The sample size used to estimate environmental characteristics is much larger than the sample size available to estimate the characteristics of the people (see Table 2-3). According to the current assessment of sources of variation in the dose assessment, the interindividual components of variation are much larger than the random environmental variation (Robison et al, 1993). The large among-individual variance and small sample sizes for individual characteristics limit the usefulness of the individual variability. Estimating the entire distribution of individual doses is mathematically sophisticated, but it depends on particular assumptions:

- The native diet of the people returning to Rongelap has exactly the same mean and variance as were observed in the sample of 34 people on Ujelang, and the biological turnover time of cesium-137 has exactly the same mean and variance as were observed in the sample of 23 Marshallese. This assumption involves two sub-assumptions:

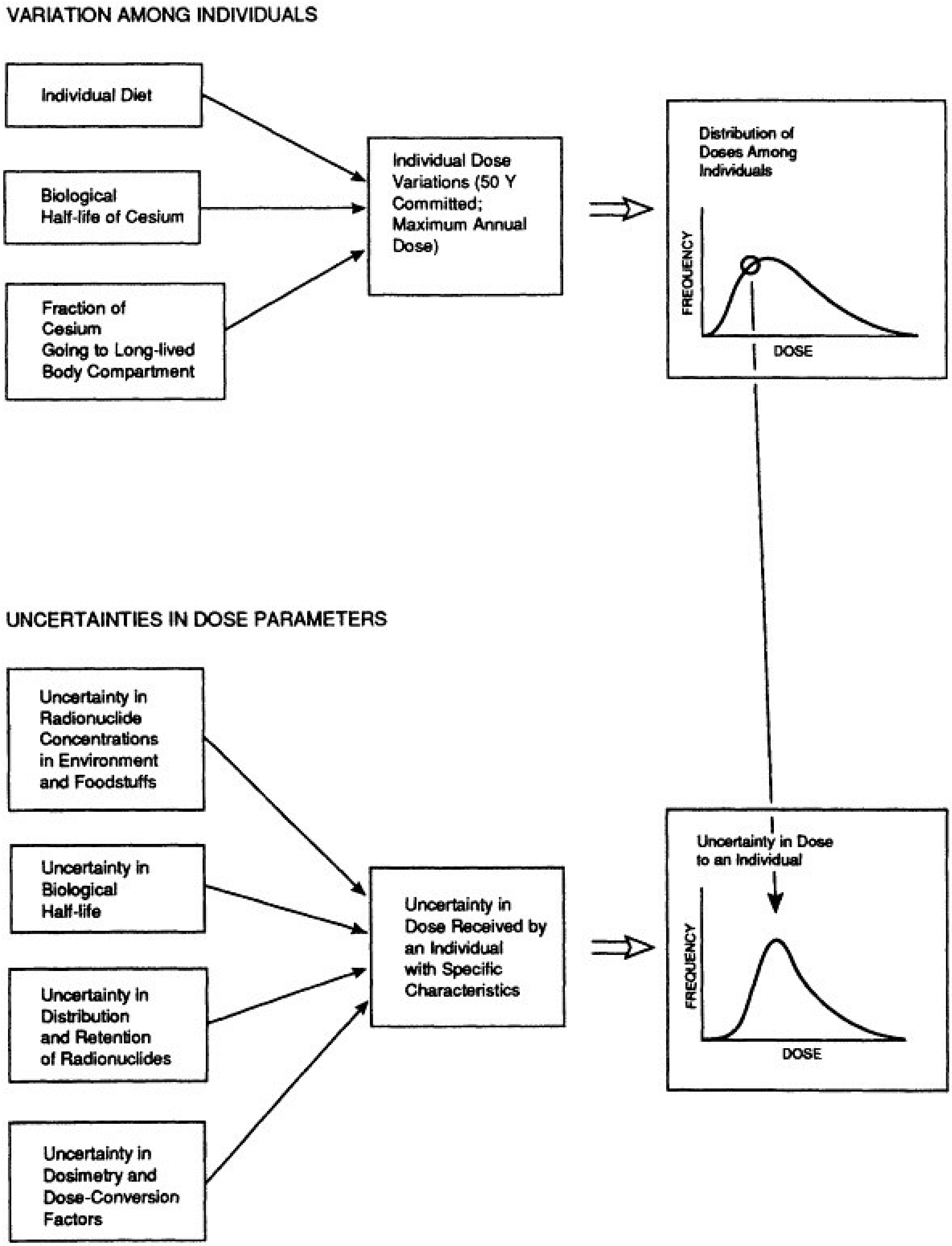


Figure 10. Contributions to the uncertainties in individual doses from variations among individuals and from uncertainties in dose parameters.

There are no systematic differences between the people in the diet or biological-turnover studies and the Rongelap people.

The means and variances observed in the samples are exactly the same as the true mean and variance in the population. Sample means and variances usually differ from the true population values because of random sampling from a variable population. Small samples, such as for the diet and biological-turnover data, are usually highly variable. The Monte Carlo simulation ignores the sampling variation and uses the sample estimates of mean and variance as the parameters of the true distribution.

The variance in daily cesium-137 intake among persons is highly influenced by the extreme values in the distribution of daily cesium-137 intake. In the Ujelang diet survey, the diets that have the highest daily cesium-137 intake were those whose daily intake was poorly estimated. The precision of the estimate of total cesium-137 intake, for a given diet, depends on the precision of the measurements of cesium-137 concentration in each foodstuff. The standard error of the total cesium-137 intake, given some fixed diet, can be expressed as

$$s_{total} = \sqrt{\sum_i W_i^2 s_i^2}\ , \qquad (10)$$

where W, is the intake of item i, s_i is the standard error of cesium-137 concentration in item i, and S_{total} is the standard error of the total cesium-137 intake. Foodstuffs that are large components in the diet (i.e. have large W_i) have the largest influence on the precision of the total cesium-137 intake. If the cesium-137 concentration in those foodstuffs is poorly estimated, then the total cesium-137 intake from that diet will be poorly estimated.

Large values of cesium-137 intake are poorly estimated, but the average cesium-137 intake is relatively precisely estimated, see for example, Table 6-1. Female number 17 in the Ujelang diet survey has the highest dietary intake of cesium-137, but the approximated standard error for her intake is extremely high, 75 Bq/day, because she consumes a lot of chicken and papaya. Mean specific activities for both papaya and chicken parts are poorly estimated because the sample sizes are small. The next largest cesium-137 intake is relatively well estimated (standard error = 4.2 Bq/day, Table 6-1) because the local food components of her diet are primarily coconuts and breadfruit. The standard error of the third largest intake is relatively large because that diet includes a lot of papaya and pork. In contrast, the cesium-137 intake from the average imported-foods available diet is relatively well estimated (Table 6-1).

- Dietary intake and biological half-life of cesium are independent. That would not be true if people with high dietary intake tended to have higher cesium biological half-lives. Body weight is correlated with high dietary intake and might be correlated with biological half-life in adults (Miltenberger et al., 1981; Leggett 1986). If body weight is positively correlated with both dietary intake and cesium biological half-life, then intake and half-life will be positively correlated, violating the assumption of independence.

Table 6-1. Estimated daily intakes and approximate standard errors for the imported-foods-available diet and the three women in the Ujelang diet study with the largest estimated cesium-137 intake

Diet	Estimated Cs intake	Approximate standard error*
Imported-foods	31 Bq/d	2.9 Bq/d
Of Female #17	173 Bq/d	74. Bq/d
Of Female #15	103 Bq/d	4.2 Bq/d
Of Female #16	60 Bq/d	12. Bq/d

* These standard errors are approximate. They are calculated from the Ujelang diet survey raw data and data in Robison et al, 1993, tables 20 and B-1. The calculations are underestimates of the true standard error because they assume random sampling of foodstuffs, independent estimates of cesium-137 concentrations in all foodstuffs, and no sampling error in certain foodstuffs (e.g. most seafood).

- Lognormal distributions are appropriate to describe the distribution of body weights, dietary intakes, and biological half-lives for cesium in the Rongelap population. Special concern should be given to whether the upper tail of the lognormal distribution appropriately matches extreme values in the Rongelap population. The LLNL dose assessment does test whether the data fit lognormal distributions (Robison et al., 1993). None of the tests rejects the hypothesis that the distributions are lognormal, but failing to reject does not prove that the distributions are lognormal, especially in the tails. The tests of normality or lognormality have low power, especially when the sample sizes are small (Shapiro et al., 1968). In other words, data might appear to be lognormal even if the true distribution is not lognormal. Inspection of the probability plots given in Robison et al., (1993) suggests that lognormal distributions might not be appropriate to represent the extreme tails of the true distributions. In general, the largest and smallest data points deviate the most from the predicted quantiles for lognormal distributions (e.g., see Figs. 6, 8, 10, and 11 of Robison et al., 1993). To some extent, that is expected because the variance of extreme values is larger than the variance of the median. It is not clear whether the extreme values are more deviant than would be expected.

  The issue of the appropriate distribution to use in the Monte Carlo simulation is important because some sort of distributional assumption must be made to extrapolate to extreme percentiles. The sample sizes for the diet and biological half-life samples are too small to use nonparametric estimates of the extreme percentiles. The 99 percentile cannot be estimated unless there are more than 50 observations, and it is not reliably estimated unless the sample is considerably larger.
- There is no measurement error included in any of the variance estimates. The Monte-Carlo uncertainty analysis uses the between-individual variances in dietary intake, biological turnover, and other quantities to calculate the distribution of annual doses to individuals. The Monte-Carlo analysis assumes that the observed between-individual variances estimate the true

variance among individuals. Under some simplifying assumptions, the observed variance among individuals (σ_o^2) is the sum of the true inter-individual variance (σ_i^2) and the measurement variance (σ_e^2) (Searle et al., 1992). That is,

$$\sigma_o^2 = \sigma_i^2 + \sigma_e^2 \ . \qquad (11)$$

Hence, the observed variance estimates the true between-individual only when there is no measurement error. However, there is some measurement error associated with all data. Table 6-1 shows some of the estimated measurement errors for dietary intake. There is also a measurement variance associated with estimates of biological half-life, but we have not estimated it. If estimates of measurement error are available, e.g. from repeated sampling of individuals, then σ_i^2 can be estimated separately from σ_e^2. The effects of measurement error in dietary surveys on the distribution of usual dietary intake and some approaches to correct for it are explored by Nusser et al. (1990).

Those assumptions have different effects on the distribution of doses to individuals. Accounting for sampling variation (the first sub-assumption) increases the variance in the dose distribution and so increases the probability of a large dose to an individual. The effect of correlated dietary intake and biological half-lives depends on the sign of the correlation. If they are positively correlated, the probability of extreme doses is higher; if they are negatively correlated, the probability is lower. The effect of mis-specifying the tails of some distribution depends on whether the tails of the true distribution are more or less extreme than those of a lognormal distribution. If they are more extreme, the probability of an extreme dose will be higher. Accounting for measurement error decreases the among-individual variance, which decreases the probability of an extreme dose to an individual.

The net effect of the assumptions and small sample sizes defining the characteristics of individuals is that the true distribution of doses to the Rongelap population upon resettlement might differ from the calculated distribution (Robison et al., 1993, Fig. 18). The difficulty stems from uncertainties in characterizing the variability among individuals. Using scenarios for estimating exposure and estimating the distribution of doses for specific scenarios avoids the problem of estimating the variability among individuals.

SCENARIO APPROACH

In the scenario approach, one can easily define characteristics of a maximally exposed person. For the Rongelap assessment, scenarios can be used that specify the sex, weight, and diet for any individual situation. The scenario could also include the life style, biological half-life of cesium, and fraction of cesium going to the long-lived body compartment. A scenario for the "critical group" that defines the maximally exposed person might specify the sex, weight, and diet of that group. Alternative scenarios should explore the impact of food consumption (kilograms/day), effects of binges (e.g., consuming a large number of coconut crabs in a short period), effects of different lifestyles (e.g., primarily harvesting and eating coconuts or primarily fishing), and the impact of KCl applied to the soil as a fertilizer. The average dose and its uncertainty are computed for that combination of characteristics.

The uncertainty in the average doses from the various scenarios might include one or all of the relevant sources of variability in the input data: daily variation in diet, variation in radionuclide concentration in the foodstuffs, or biological half-lives, and uncertainties in the dosimetry models and coefficients. Individual variability in biological half-lives can be dealt with in one of three ways: adding a specification of biological half-life to the description of the scenario, fixing the cesium biological half-life at 110 d (the ICRP average adult value), or incorporating variability in the biological half-life in the uncertainty in the dose. If the latter approach is taken the database on biological half-lives in the Rongelap (or Marshallese) population must be expanded.

The scenario approach to risk assessment is often used. Because the risk is computed for a person with specific characteristics, it is possible to identify the characteristics associated with high dose and decide whether any person is likely to possess those characteristics.

CONCLUSIONS

- The reliability of the probabilistic approach for estimating uncertainty in the dose to returning Rongelap people is limited by the sparseness of information on variability among individuals.
- A scenario approach might be more effective because it can identify events that contribute to high doses. A suite of relevant scenarios should be developed in collaboration with the Marshallese.

7.

DOSE LIMITS AND THEIR APPLICATIONS

This committee was charged to review and comment on the applicability of the ICRP recommendations on annual dose limits for general populations as they pertain to anticipated dose commitments after resettlement in contaminated areas of the Marshall Islands.

The question of applicability is somewhat academic, inasmuch as radiological criteria for the decision on resettlement have been agreed on and are presented in the MOU (Article V, paragraph 1). These criteria are that no person resettling on the southern islands of Rongelap Atoll and subsisting on a local-food-only diet would receive a calculated annual effective radiation dose exceeding 100 mrem above natural background or would be incidentally exposed to concentrations of transuranics in the soil in excess of the prescribed action level of 17 pCi/g. It should be noted that the committee had serious reservations regarding the MOU provision relating to a dose limit, or action level, based on the *maximally exposed individual*. Radiation standards and the techniques used in radiation dosimetry do not lend themselves to the determination of dose to the maximally exposed individual. This is particularly true for a population of limited size where the statistical power for determining doses at the extremes of the dose distributions is limited. The committee was informed by DOE representatives, however, that this limit was to be used only as a guideline for resettlement decisions and that, as an internationally negotiated parameter, we were to consider it as a fixed parameter.

The action level of 17 pCi/g for plutonium soil concentrations is based on a U. S. Environmental Protection Agency action level of 0.2 $\mu Ci/m^2$ for public protection from accidental contamination of the environment. The EPA action level was developed for application to recent contamination, thus all of the radioactive contamination was considered to be concentrated within the top 1 cm of the soil. With this approach, soil concentrations less then the action level would warrant no further action. The MOU action limit of 17 pCi/g was derived by DOE from this 0.2 $\mu Ci/m^2$ EPA guideline using a soil density of 1.2 g/cm^3 appropriate to Rongelap and assuming that the radioactivity was in the top 1 cm of soil. Because the contamination on Rongelap took place nearly 40 years ago the initial concentration of radionuclides has leached into the soil column and no longer resides on the surface. In addition the vegetation cycle has produced approximately 1 cm of fresh organic material over the last three decades. Taking these considerations into account, the MOU considers the potential for subsequent radionuclide migration in the soil by providing provisions for averaging of the 17 pCi/g radionuclide concentration over the top 5 cm of soil.

The annual dose limit recommended for members of the public by ICRP is not intended to be directly applicable to decisions on when to return to an area that has been evacuated because of radiological concerns raised by potential or actual radiation contamination. In the latter circumstances, ICRP recommends that the decision to return to a previously evacuated area is justified when being back is more beneficial to the people involved than remaining away. The assessment of which is more beneficial must take into account all the factors that influence health and well-being. A population might expect to achieve the greatest net benefit by appropriate allocation of whatever resources it has available to it within the context of all the factors that affect its health and well-being. It follows that in any specific situation brought about by intervention, a decision by a displaced population needs to be made on the basis of factors that have the greatest influence on them. There is no reason to expect that the magnitude of any particular factor (for example, residual contamination) on which a decision to return is based will be the same from case to case. Each population's situation will involve different tradeoffs.

ICRP recognizes that numerical criteria —action levels —are often helpful in making decisions; in this instance, such criteria have been defined in the MOU. Implicit in the wording of the MOU is that the parties to it believed that a net benefit would accrue to the displaced population when there could be assurance that, on their return to Rongelap, the maximum annual dose received by any person and the concentration of transuranics everywhere in soil had naturally decreased or had been reduced to stated action levels. With those conditions met, resettlement would be justified.

The MOU is not clear on how the specified numerical dose and concentration criteria are to be applied, i.e., how does one define the maximally exposed person? For the individual dose, the general approach in intervention is to apply the criteria to the group involved as a whole, if it is small and is reasonably homogeneous, or to a definable subset of the group whose circumstances and habits are reasonably similar and typical of individuals who could be regarded as those maximally exposed. The latter is the concept of the "critical group." Various combinations of habits and environmental factors are usually examined in deciding the characteristics of the individuals in the critical group. For the returning Rongelap community, such a subset could be a group that has a particular diet, some defined fraction of which is locally grown food. For applying the criterion on soil concentration, another subset of the population could be a group of children whose time is spent playing in particular areas and whose daily soil ingestion could be defined. Such definition of the group of maximally exposed children provides the basis for interpreting the numerical criterion for the concentration of transuranics in soil. The area and depth of soil over which the concentration of transuranics should be averaged can be determined by considering the habits and, in effect, sampling such a group of children.

Those are examples of the scenario approach discussed in the section on diet models. The alternative is to take the statistical or probabilistic approach and assess the probability that a given fraction of the population might receive a maximum annual dose above a given value. The probability that a given concentration in soil, when averaged over a given area, will be exceeded can also be estimated.

8.

RECOMMENDATIONS FOR REMEDIAL ACTION

The committee has concluded from its study of available information (Chapters 2-6) that the annual-dose criterion might not be met for every individual. However, the annual-dose criterion may be considered as an arbitrary action level that does not present an absolute barrier to resettlement. Remedial actions should not be judged solely on the basis of a need to meet an action level, but as a means to increase the physical and psychological well-being of the Rongelap people if they decide to resettle.

Knowledge of the chemistry of cesium and plutonium and an understanding of tropical ecosystems can be used to devise a set of potential remedial actions. The following constitute means of remedial actions —not meant to be all-inclusive —that could substantially reduce the amount of radiation received by people living on Rongelap.

1. The first generally accepted remedial action, implied in the MOU, and recommended by this committee is that the local-food-only diet is limited to food gathered on the southern islands of Rongelap Atoll. The potential consequences of not following this recommendation and of consuming food collected on the northern islets of Rongelap or Rongerik Atoll are summarized in column E of Table 5-4. Exposure to cesium-137 could be increased by a factor of 8-32 if all pandanus, coconut, and breadfruit were collected on the northern islets. A major consequence of restricted access to the northern parts of these atolls will be to limit available food resources.
2. People living on Rongelap will receive most of their exposure to cesium-137 from surface soil, either through direct irradiation of the body (external dose) or through ingestion of plants that have extracted cesium-137 from the soil during growth (internal dose). It is recommended that the returning population restrict the quantities of some local foods in their diet. The effectiveness of this act is obvious in the dose projections of Table 5-4. Exposure to cesium-137 may be reduced by a factor of greater than 5 when imported foods are substituted for some local foods (i.e., diet A versus diet C in Table 5-4). A modest supplementary food program would help the returning Rongelap people to obtain the necessary quantities of imported food.
3. Actions that reduce the direct exposure from subsurface cesium-137 or reduce the uptake of cesium-137 from the soil by local foodstuffs are also likely to reduce the maximum annual dose. One such action is to remove the upper layer of surface soil from the village and on each houseplot (Robison et al., 1993). Another is to add a layer of crushed coral around the houses and to common areas of congregation throughout the village. Both these actions are recommended as they could be accomplished as housing is rebuilt on Rongelap Island before resettlement with little impact on resettlement activities.

4. The committee also recommends the application of KCl as fertilizer and for remediation in agricultural areas. The application of KCl would reduce the uptake of cesium-137 by coconut, breadfruit, and pandanus fruit. Robison and Stone (1992) have demonstrated the effectiveness of KCl in reducing cesium-137 in coconuts grown on Bikini and in increasing plant growth in the relatively potassium-deficient tropical soils of the northern Marshall Islands. Potassium chloride is a common fertilizer used in the United States with no known detrimental health effects when used in the concentrations commonly applied as a commercial fertilizer. This form of remediation requires only modest effort and has no reported detrimental effects for humans or other parts of the ecosystem.
5. The removal of the top 30-40 cm of soil from the island is another potential remedial action. However, this approach is *not* recommended; it has had substantial effects on life style and on the environment of Enewetok Atoll. Given the fragile ecology of these coral islands the regeneration of topsoil removed in such an extreme procedure may require decades, or even centuries. Such an extreme measure should be one of last resort; on the basis of the projected doses achievable with more moderate means of remediation, it appears unnecessary.

Continuation of remedial actions 1, 2, and 4 might be relaxed if monitoring indicates that whole-body burdens are lower than estimated.

9.

RECOMMENDATIONS FOR POST-RESETTLEMENT MONITORING

RADIATION DOSIMETRY

To ensure the continued well-being of the people of Rongelap and to ensure that the conditions of the MOU are being met, continuing post-resettlement radiation surveillance will be necessary. For the purposes of this discussion, we estimate that about 400 persons will elect to return to Rongelap. We suggest that this population initially be under rather tight surveillance, which can be relaxed as experience dictates.

It is suggested that the following activities be initiated before and continued after resettlement:

1. Each person should receive a whole-body count (WBC) before resettlement and a whole-body count annually thereafter with the counting activity to be conducted during one of four such activities each year.
2. A cohort of 80 persons stratified by age and sex drawn from the estimated 400 who may choose to resettle will be monitored for whole-body radionuclide burdens at each of the four WBC counting periods. This will provide cohort data on potential seasonal variations in the radionuclide intake. Persons found at an annual count to have unusually high body burdens should be immediately recounted to determine whether errors in counting had occurred; if not, they should be added to the group sampled quarterly until the cause(s) of their high body burdens is identified. Dietary intake should be assessed each time whole-body counting is conducted; this is best done with a carefully planned food-frequency questionnaire. The committee recommends that this dietary survey, including the questionnaire, be developed in consultation with well qualified experts in nutrition and diet, and with knowledge of the local culture.
3. A baseline urine sample should be obtained before resettlement and stored under ideal conditions for radioassay in case it becomes necessary. A limited number of samples, chosen at random, should be analyzed to test that plutonium levels remain at, or below, the levels of sensitivity of current analytic methods (50-80 aCi). Effort should be expanded to develop more sensitive analytic techniques, including a study of the emerging technology of mass spectroscopy, to enable more reliable and accurate monitoring of low levels of plutonium in the future.
4. An effort should be initiated to establish a central repository for both individual dosimetry records and biological samples as references for future individual medical concerns.

If the monitoring measurements indicate that the terms of the MOU are being adequately met and if remedial activities are then relaxed, surveillance should continue. If after several years of further surveillance it is clear, even with such relaxation of remedial measures, that the terms of the MOU are being met, the surveillance procedures can be further relaxed.

MEDICAL CONSIDERATIONS

On the basis of current radiation dose estimates, there is no expectation that any medical illness due to exposure to ionizing radiation will occur in any members of the resettlement population of the island of Rongelap from either intake of native foods or environmental contact. Unrelated and perceived medical problems will occur, however, so basic medical-care and medical-surveillance programs should be developed that are closely integrated with continuing biodosimetry programs. The basic program should be conducted by the indigenous inhabitants of the island and should be designed to meet the challenges of the serious medical problems of a changing society in an isolated geographical environment. It is anticipated that the major medical concerns of the future will be high incidences of obesity, diabetes, and hypertension, most cases of which are related to increased acceptance of "westernized" diets with high sodium and fat content in association with a relatively sedentary life style.

The specific problems that must be addressed for those returning to the island of Rongelap require a reasonable and continuing medical program, which should consist of the following:

1. Regular medical surveillance.
2. Management of acute and chronic medical problems.
3. Capability to investigate changes in dietary patterns that might be related to diabetes, hypertension, obesity, vitamin deficiency, malnutrition, and related disorders.
4. Maintenance of individual medical records.
5. Ability to collect and prepare biological samples for medical laboratories and radioassay.
6. Staff and facilities for performing basic laboratory tests, including blood counts, urinalysis, and stool examination.
7. Central medical communication and evacuation programs.

To implement the medical program noted above, we offer the following recommendations:

1. *Facilities*. At a minimum, a centrally located government-operated health clinic should be established. It should contain adequate space and provisions for medical examination of adults and children, medical first aid, a basic medical laboratory, an office for administrative personnel and the maintenance of medical records, and equipment for telecommunication with a reliable source of medical consultation. The medical facility might also be an excellent location for whole-body counting and the maintenance of individual dosimetry records.
2. *Personnel*. At a minimum, one paramedical person (nurse, nurse practitioner, or physician assistant) with some training in nutrition and radiation effects should operate the medical aspects of the medical program. It would be advisable to have that person be a member of the resettlement population. Training of such a person should commence well in advance of resettlement. He or she should be capable of conducting medical interviews and physical examinations, maintaining medical records, performing basic laboratory examinations, administering first aid, operating channels to communicate with physician consultants, and preparing and storing or shipping biological samples for bioassay. It is conceivable that the same person might be trained to conduct and record the results of whole-body counting.
3. *Medical Surveillance*. The resettlement population should be encouraged to have regular medical interviews, physical examinations, and laboratory studies at intervals at least once every 2 years. The results of such examinations should be recorded in individual health records and be reviewed by a physician at least once a year. Morbidity and mortality statistics for the entire resettlement population also should be reviewed at least once a year by a qualified physician or epidemiologist. It is essential that a physician or other qualified person be available for consultation to determine whether a specific medical problem is radiation-related.

REFERENCES

Amerson, A. B., Jr. 1969. Ornithology of the Marshall and Gilbert Islands. Atoll Research Bulletin 127. Washington, D.C.: Smithsonian Institution.

Bair, W. J., J. W. Healy, and B. W. Wachholz. 1982. The meaning of radiation for those atolls in the northern part of the Marshall Islands that were surveyed in 1978. DOE/NBM —1052. Washington, D.C.: United States Department of Energy.

Bendure, G., and N. Friary. 1992. Micronesia-A Travel Survival Kit. Berkeley, Calif.: Lonely Planet Publications.

Bindon, J. R. and P. T. Baker. 1985. Modernization, migration, and obesity among Samoan adults. Ann. Hum. Biol. 12: 67-76.

Boecker, B. B., R. Hall, K. Inn, J. Lawrence, P. Ziemer, G. Eisle, B. Wachholtz, and W. Bunn, Jr. 1991. Current status of bioassay procedures to detect and quantify previous exposures to radiative materials. Health Phys. 60: 45-100.

Bogen, K. T., and R. C. Spear. 1987. Integrating uncertainty and interindividual variability in environmental risk assessment. Risk nal. 7:427-436.

Bradburn, N. M., L. J. Rips, and S. K. Sheyell. 1987. Answering autobiographical questions: the impact of memory and inference on surveys. Science 236: 157-161.

Burrough, P. A. 1991. Sampling designs for quantifying map unit composition. Pp. 89-125 in M. J. Mausbach, and L. P. Wilding, eds. Spatial Variabilities of Soil and Landforms. Soil Science Society of America Special Publication 28. Madison, WI: Soil Science Society of America.

Carucci, L. M. 1980. The Renewal of Life: A Ritual Encounter in the Marshall Islands. Ph.D. dissertation. University of Chicago: Department of Anthropology.

Carucci, L. M. 1988. Small fish in a big sea. Pp. 33-42 in J. Gledhill, B. Bender, and M. T. Larsen, eds. State and Society: The Emergence and Development of Social Hierarchy and Political Centralization. London: Unwin Hyman.

Carucci, L. M. 1992. We planted mama on Jeptan: constructing continuities and situating identities on Enewetak Atoll. Pp. 191-199 in Donald H. Rubinstein, ed. Pacific History. Mangilao, Guam: University of Guam Press and Micronesian Area Research Center.

Conard, R. A. 1992. Fallout: The experiences of a medical team in the care of a Marshallese population accidentally exposed to fallout radiation. BNL-46444. Upton, New York: Brookhaven National Laboratory.

Cressie, N. 1991. Geostatistical analysis of spatial data. Pp. 87-108 in Spatial Statistics and Digital Image Analysis. Washington, D.C.: National Academy of Sciences.

Dwyer, J. T., E. A. Kral, and K. A. Coleman. 1987. The problem of memory in nutritional epidemiology research. J. Am. Dictet. Assoc. 87: 1509-1512.

Environmental Protection Agency. 1989. Risk Assessment Guidance for Superfund. Vol. 1. Human Health Evaluation Manual, Part A. EPA/540/1-89/002. Washington, D.C.: Environmental Protection Agency.

Finsch, O. 1893. Ethnologische Erfahrungen und Belegstücke aus der Sudsee, (English Translation 1031). Available at the Hamilton Library, Honolulu, HI.

Food and Nutrition Board. 1989. Recommended Dietary Allowances. Washington, D.C.: National Academy of Sciences.

Fosberg, F. R., and D. Carroll. 1965. Terrestrial Sediments and Soils of the Northern Marshall Islands. Atoll Research Bulletin 113. Pacific Science Board, National Academy of Sciences. Washington, D.C: National Academy of Sciences.

Gilbert, R. O. 1987. Statistical Methods for Environmental Pollution Monitoring. New York: Van Nostrand Reinhold.

Greger, J. L., and G. M. Etnyre. 1978. Validity of 24-hour dietary recalls by adolescent females. Am. J. Pub. Health 68: 70-72.

Griffith, R. 1994. IAEA reference Asian man program. Health Phys. 66: 110.

Gunther, P. M., and K. S. Tippett, Eds. 1993. Evaluation of Nonresponse in the Nationwide Food Consumption Survey, 1987-88. Washington: U.S. Department of Agriculture, Human Nutrition Information Service. Nationwide Food Consumption Survey 1987-88, NFCS Rep. No. 87-M-2, 76pp.

Gurland, J., and R. C. Tripathi. 1971. A simple approximation for unbiased estimation of the standard deviation. Amer. Stat. 25: 30-32.

Hahn, G. J., and W. Q. Meeker. 1991. Statistical Intervals: A Guide for Practitioners. New York: Wiley Interscience.

Hanson, W.C. 1982. ^{137}Cs concentrations in northern Alaskan eskimos: effect of ecological, cultural, and political factors. Health Phys. 42: 433-447.

Hanson, W. C., H. E. Palmer, and B. I. Griffin. 1964. Radioactivity in northern Alaska Eskimos and their foods, Summer 1962. Health Phys. 10: 421-429.

Hezel, F. X. 1983. The First Taint of Civilization: a History of the Caroline and Marshall Islands in Pre-colonial Days, 1521-1885. Honolulu: University of Hawaii Press.

Human Nutrition Information Service. 1988. CSFII Nationwide Food Consumption Survey. Continuing Survey of Food Intakes by Individuals. Women 19-50 Years and Their Children 1-5 years, 4 Days. Report 86-3. Hyattsville, Md.: U.S. Department of Agriculture.

International Commission on Radiological Protection. 1959. Report of Committee 2 on Permissible Dose for Internal Radiation. ICRP Publication 2. New York, NY:Pergamon Press.

International Commission on Radiological Protection. 1975. Report of the Task Group on Reference Man. ICRP Publication 23. New York, NY: Pergamon Press.

International Commission on Radiological Protection. 1982. Reports of Committee 2 on limits for intakes of radionuclides by workers . ICRP Publication 30 (Parts 1-3 including supplements) in 7 volumes. New York, NY: Pergamon Press.

International Commission on Radiological Protection. 1986. The metabolism of plutonium and related elements. ICRP Publication 48. Ann. ICRP Vol. 16, Nos. 2 and 3.

International Commission on Radiological Protection. 1987. Data for use in protection against external radiation. ICRP Publication 51. Ann. ICRP Vol. 17, Nos. 2 and 3.

International Commission on Radiological Protection. 1988. Limits for intakes of radionuclides by workers: an addendum. ICRP Publication 30. Part 4. Ann. ICRP Vol. 19.

International Commission on Radiological Protection. 1989. Age-dependent doses to members of the public from intake of radionuclides, Part 1. ICRP Publication 56. Ann. NCRP Vol. 20, No. 2.

International Commission on Radiological Protection. 1991a. Recommendations of the International Commission on Radiological Protection. ICRP Publication 60. Ann. ICRP Vol. 21, Nos. 1 and 3.

International Commission on Radiological Protection. 1991b. Annual limits on intake of radionuclides by workers based on the 1990 recommendations. ICRP Publication 61. Ann. ICRP Vol. 21, No. 4.

Kercher, J. R., and W. L. Robison. 1993. Uncertainties in predicted radionuclide body burdens and doses from discrete stochastic source terms. Health Phys. 65:47-68.

Khodyreve, M. A. 1966. Absorption of ^{239}Pu through the skins of animals and its distribution in the organism. Pp. 99-105, in Distribution and Biological Effects of Radioactive Isotopes. AEC-tr-6944 (rev.). Moscow: Atomizdat.

Kohn, H. I. 1989. Rongelap reassessment project report, Corrected Edition, March 1, 1989. Report to the President and Congress of the United States Pursuant to the Compact of free Association of 1985. Rongelap Reassessment Project, 1203 Shattuck Avenue, Berkeley, CA.

Kotzebue, O von. 1821. A Voyage of Discovery into the South Sea and Baring's Straits, for the Purpose of Exploring a North-East Passage, Vol. II. London: Longman, Hurst, Rees, Orme, and Brown.
Kotzebue, O yon. 1830. A New Voyage Round the World in the Years 1823, 24, 25, 26, Vol. I. London: Henry Colburn & Richard Bentley.
Kramer, A., and H. Nevermann. 1938. Ralik-Ratak (Marshall-Inseln), Hamburg: Friederichsen, DeGrye [translation is located in Human Relations Area Files, New Haven, Connecticut].
Langham, W. H. 1964. Physiological properties if plutonium and assessment of body burden in man. In Assessment of Radioactivity in Man. Vienna: International Atomic Energy Agency.
Langham, W. H., J. N. P. Lawrence, J. McClelland, and L. H. Hempelman. 1962. The Los Alamos Scientific Laboratory's experience with plutonium in man. Health Phys. 8: 753-760.
Lawrence, J. F. 1943. Food Supply in the Marshall Islands. Thesis, Yale University.
Leggett, R. W. 1986. Predicting the retention of Cs in individuals. Health Phys. 50: 747-759.
Leggett, R. W., and K. F. Eckerman. 1987. A method for estimating the systemic burden of Pu from urinalysis. Health Phys. 52: 337-346.
Lessard, E. T., R. P. Miltenberger, S. H. Cohn, S. V. Musolino, and R. A. Conrad. 1984. Protracted exposure to fallout: the Rongelap and Utirik experience. Health Phys. 46: 511-527.
Lessard, E. T., R. P. Miltenberger, R. A. Conrad, S. V. Musolino, J. Naidu, A. Moorthy, and C. Schopfer. 1985. Thyroid Absorbed Dose for People at Rongelap, Utirik, and Sifo on March 1, 1954. Report BNL-51882, Upton, NY: Brookhaven National Laboratory.
Lichtman, S. W., K. Pisarska, E. R. Berman, M. Pestone, H. Dowling, E. Offenbacher, H. Weisel, S. Heshka, D. E. Matthews, and S. B. Heymsfield. 1992. Discrepancy between self-reported and actual caloric intake and exercise in obese subjects. N. Engl. J. Med. 327: 1893-1898.
Livingstone, M. B. E., A. M. Prentice, J. J. Strain, W. A. Coward, A. E. Black, M. E. Barker, P. G. McKenna, and R. G. Whitehead. 1990. Accuracy of weighed dietary records in studies of diet and health. Br. Med. J. 300: 708-712.
Maifeld, M. H. 1982. The Study of the Foodways of the Enewetak-Ujelang People of the Marshall Islands with a Nutrient Comparison of Their Foods in 1877 and 1977. Thesis, School of Industrial Technology and Home Economics, Program in Food and Nutrition, University of Northern Colorado, Greeley.
Maramba, M. G. 1960. The Economics of Food and Nutrition in the U. S. Trust Territory of the Pacific Islands. South Pacific Commission Technical Information Circular 39. Noumea, New Caledonia: South Pacific Commission.
Mason, L. E. 1947. The Economic Organization of the Marshall Islanders. Honolulu: U.S. Commercial Company.
Mason, L. E. 1967. The Laura Report. Honolulu: University of Hawaii.
McGarvey S. T. 1991. Obesity in Samoans and a perspective on its etiology in Polynesians. Am. J. Clin. Nutr. 53: 1586s-1594s.
Mertz, W. 1992. Food intake measurements: is there a "gold standard?" J. Am. Dietet. Assoc. 92: 1463-1465.
Miltenberger, R. P., N. A. Greenhouse, and E. T. Lessard. 1980. Whole body counting results from 1974 to 1979 for Bikini Island residents. Health Phys. 39: 395-407.
Miltenberger, R. P., E. T. Lessard, and N. A. Greenhouse. 1981. ^{60}Co and ^{137}Cs long-term biological removal rate constants for the Marshallese population. Health Phys. 40: 615-623.
Moorthy, A. R., C. J. Schopfer and D. H. Henze. 1992. Fission Track Analytical Method for Assaying ^{239}Pu in Urine: Operating Procedures Manual. In Operating and QA Procedures Documents for the Radiological Dose Assessment Project, Upton, NY: Brookhaven National Laboratory Internal Report, February 12.
Moss, W. D., E. E. Campbell, H. F. Schults, and G. L. Tietjen. 1969. A study of the variations found in plutonium urinary data. Health Phys. 17: 571-578.
Mount, M. E., S. Kehl, and W. L. Robison. Undated. Analytical Quality Control Program. Livermore, CA: Lawrence Livermore National Laboratory internal report.

Mullen, B. J., N. J. Krantzler, L. E. Grivetti, H. G. Schulte, and H. L. Meiselman. 1984. Validity of a food frequency questionnaire for the determination of individual food intake. Am. J. Clin. Nutr. 39: 136-143.

Murai, M., F. Pen, and C. D. Miller. 1958. Some Tropical South Pacific Island Foods. Honolulu: University of Hawaii Press.

Murdock, G. P. 1943. Cross Cultural Survey, Institute of Human Relations, Yale University. Strategic Bulletins of Oceania 5. Food and Water Supply in the Marshall Islands. Washington D.C.: Ethnographic Board, Smithsonian Institution.

Naidu, J. R., N. A. Greenhouse, G. Knight, and E. C. Craighead. 1980. Marshall Islands: A Study of Diet and Living Patterns. BNL 51313. Upton, NY: Brookhaven National Laboratory.

Nusser, S. M., A. L. Carriquiry, H. H. Jensen, and W. A. Fuller. 1990. A transformation approach to estimating usual intake distributions. Pp. 120-132 in J. R. Schwenke, ed. Proceedings of the Kansas State University Conference on Applied Statistics in Agriculture. Manhattan, KS: Kansas State University, Department of Statistics.

Owen, D. B., and T. A. Hua. 1977. Tables of confidence limits on the tail area of the normal distribution. Commun. in Stat. Simul. Compu. (B) 6: 285-311.

Paulding, H. 1831. Journal of a cruise of the voyage of the USS Schooner Dolphin among the islands of the Pacific Ocean. New York, NY: C and H Carvill; also available on microfilm, American Culture Series, Ann Arbor, Michigan: University Microfilms.

Pelletier, D. L. 1987. The relationship of energy intake and expenditure to body fitness in western Samoan men. Ecol. Food Nutr. 19: 185-199.

Pollock, N. J. 1970. Breadfruit and Breadwinning on Namu Atoll, Marshall Islands. Ph.D. Dissertation, University of Hawaii.

Pritchard, M. 1979a. Office memorandum to Ted Mitchell and Bill Robison regarding the report and field notes on Ujelang food survey. April 22-May 9. Unpublished. Available at the Micronesian Legal Services Corporation, Majuro, Republic of the Marshall Islands.

Pritchard, M. 1979b. Office memorandum to Bill Robison and Ted Mitchell regarding the Ujelang diet survey, May 23. Unpublished. Available at the Micronesian Legal Services Corporation, Majuro, Republic of the Marshall Islands.

Public Health Service. 1979. Dietary Intake Science Data, United States 1971-74. DHEW (PHS) 79-1221. Hyattsville, Md.: Department of Health, Education, and Welfare.

Rider, A. A., B. M. Calkins, R. S. Arthur, and P. P. Nair. 1984. Diet, nutrition, intake, and metabolism in populations at high and low risk for colon cancer. Am. J. Clin. Nutr. 40: 906-913.

RMI Ministry of Health Services. 1991. The Republic of the Marshall Islands National Nutrition Survey Technical Report. Majuro: Republic of the Marshall Islands.

Robison, W. L., and W. A. Phillips. 1989. Estimates of the Radiological Dose from Ingestion of ^{137}Cs and ^{80}Sr to Infants, Children, and Adults in the Marshall Islands. Livermore, Calif.: Lawrence Livermore National Laboratory UCRL-53917 Distribution Category VC-702.

Robison, W. L., and E. L. Stone. 1992. The effect of potassium on the uptake of ^{137}Cs in food crops grown in coral soils: coconut at Bikini Atoll. Health Phys. 62: 496-511.

Robison, W. L., W. A. Phillips, M, E. Mount, B. R. Clegg, and C. L. Conrado. 1980. Reassessment of the Potential Radiological Doses for Residents Resettling Enewetok Atoll. Livermore, Calif.: Lawrence Livermore National Laboratory, UCRL-53066.

Robinson, W. L., V. E. Noshkin, W. A. Phillips, and R. J. Eagle. 1981. The Northern Marshall Islands Radiological Survey: Radionuclide Concentrations in Fish and Clams and Estimated Doses via the Marine Pathway. Livermore, Calif.: Lawrence Livermore National Laboratory, August, UCRL-52853, Part 3.

Robison, W. L., M. E. Mount, W. A. Phillips, C. L. Conrado, M. L. Stuart, and A. C. Stoker. 1982. The Northern Marshall Islands Radiological Survey: Terrestrial Food Chain and Total Doses. Livermore, Calif.: Lawrence Livermore National Laboratory, UCRL-52853, Part 4.

Robison, W. L., C. L. Conrado, and K. T. Bogen. 1992. An Updated Dose Assessment for Rongelap Island. Livermore, Calif.: Lawrence Livermore National Laboratory, Environmental Sciences Division, internal report and appendices.

Robison, W. L., C. L. Conrado, and K. T. Bogen. 1993. An updated dose assessment for Rongelap Island. Livermore, Calif.: Lawrence Livermore National Laboratory, Environmental Sciences Division report UCRL-LR-107036 Rev. 1.

Science and Education Administration. 1980. Nationwide Food Consumption 1980 Survey 1977-78. Preliminary Report 2. Food and Nutrient Intakes of Individuals in 1 Day in the United States, Spring 1977. Hyattsville, Md.: U.S. Department of Agriculture.

Searle, S. R., G. Casella, and C. E. McCulloch. 1992. Variance Components . New York: Wiley.

Shapiro, S. S., Wilk, M. B., and Chen, H. J. 1968. A comparative study of various tests for normality. J. Am. Stat. Assoc. 63: 1343-1372.

Sikov, M. R., R. J. Traub, T. E. Hui, H. K. Meznarich, and K. D. Thrall. 1992. Contribution of maternal radionuclide burdens to prenatal doses. Richland, Wa.: NUREG/CR-5631. PNL-7445) Rev. 1.

Sikov, M. R., and T. E. Hui. 1993. Contribution of maternal radionuclide burdens to prenatal doses. Richland, Wa.: NUREG/CR-5631. (PNL-7445) Rev. 1, Addendum 1.

Simon, S. L., A. M. Barron, J. C. Graham, and S. Duffy. 1993. An overview of the Marshall Islands nationwide radiological study. Pp. 21-41 in R. L. Kathren, D. H. Denham, and K. Salmon eds. Proceedings of the Twenty-Sixth Midyear Topical Meeting of the Health Physics Society. Richland, Wash.: Richland Chapter-Health Physics Society.

Snefft, A. 1903. Die Marshall-Insulaner: Rechtsverhaltnisse von Eingeborenen Volker. Pp. 425-455 in S. M. Steinmetz, ed. Africa und Ozeanien. Berlin (Translation No. 1037).

Stoline, M. R. 1991. An examination of the lognormal and Box and Cox family of transformations in fitting environmental data. EnvironMetrics 2:85-106.

Sun, L. C., C. B. Meinhold, and D. Phillips. 1992a. An Estimation of the Plutonium Gastrointestinal Absorption Constant for the Marshallese Based on Urine Samples and Environmental Data. Upton, LI.: Brookhaven National Laboratory, (unpublished report).

Sun, L. C., C. B. Meinhold, A. Moorthy, E. Kaplan, and J. Baum. 1992b. Radiological dose assessment in the Northern Marshall Islands. Paper presented at IRPA-8 Conference, Montreal, and at Meeting of NRC Committee on Radiological Safety in the Marshall Islands, March 16-18, 1992, Washington D.C. (unpublished report).

Sun, L. C., C. B. Meinhold, A. R. Moorthy, J. Clinton, E. Kaplan, and J. W. Baum. 1992c. Radiological Dose Assessments in the Northern Republic of the Marshall Islands (1987-1991); February 13, 1992, Upton, N.Y.: Brookhaven National Laboratory (unpublished report).

Sun, L. C., J. H. Clinton, J. McDonald, A. R. Moorthy, E. Kaplan, and C. B. Meinhold. 1993. Urine collection protocol in the Republic of the Marshall Islands. Radiation Protection Management 10:64-72.

Taylor, R., B. Jalatudin, S. Levy, B. Montaville, K. Gee, and T. Sladden. 1991. Prevalence of diabetes, hypertension and obesity at different levels of urbanization in Vanuatu. Med. J. Aust. 155: 86-90.

Tobin, J. A. 1952. Ujelang field notes, October 14-19. Typescript. Available at the Government Records Office. Majuro, Republic of the Marshall Islands.

Tobin, J. A. 1953. Kili food consumption record, in the Bikini people, past and present. Typescript. Available at the Government Records Office. Majuro, Republic of the Marshall Islands.

Warrick, A. W., D. E. Meyers, and D. R. Nelson. 1986. Geostatistical methods applied to soil science. Pp. 53 in Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods, Second edition, A. Klute, ed. Agronomy Monograph 9. Madison, WI: American Society of Agronomy.

Wiens, H. J. 1957. Field notes on atolls visited in the Marshalls —1956. Atoll Research Bulletin. No. 54. Pacific Science Board, National Academy of Sciences. Washington, D.C.; Washington D.C. Pp. 1-23.

Wong, K. M., G. S. Brown, and V. E. Noshkin. 1978. A rapid procedure for plutonium separation in large volumes of fresh and saline water by manganese dioxide coprecipitation. J. of Radioanalytical Chem. 42: 7-15.

Wong, K. M., T. A. Jokela, and V. E. Noshkin. 1994. Radiochemical Procedures for Analysis of Pu, Am, Cs, and Sr in Water, Soil, Sediments, and Biota Samples. UCRL-ID-116497. Lawrence Livermore National Laboratory, Livermore, CA. Pp. 1-17.

Yuhas, J. A., J. E. Bolland, and T. W. Bolland. 1989. The impact of training, food type, gender, and container size on the estimation of food portion sizes. J. Am. Dietet. Assoc. 87: 1473-1477.

GLOSSARY

a	prefix meaning 10^{-15} when used as a unit designation, i.e., aCi (atto-Curie)
BNL	Brookhaven National Laboratory
Bq	Unit of activity equal to 1 per second
BRAVO	Code name for the U.S. nuclear test that contaminated the Rongelap Atoll
Ci	Unit of radioactivity equal to 3.7 X 10^{10} disintegrations per second
DOE	U.S. Department of Energy
d	unit of time, day
g	unit of mass, gram
h	unit of time, hour
ICRP	International Commission on Radiation Protection
LLNL	Lawrence Livermore National Laboratory
μ	prefix meaning 10^{-6} when used as a unit designation, i.e., μCi (micro-Curie)
m	prefix meaning 10^{-3} when used as a unit designation, i.e., mCi (milli-Curie)
MOU	Memorandum of understanding between the U.S. and the Republic of the Marshall Islands
n	prefix meaning 10^{-9} when used as a unit designation, i.e., nCi (nano-Curie)
rem	unit of absorbed dose
NRC	National Research Council
RMI	Republic of the Marshall Islands
s	unit of time, second
Sv	unit of absorbed dose (1 Sv = 100 rem)
SI	International system of units and measures
WBC	Whole body count, or whole body counting
y	unit of time, year

APPENDIX

MEMORANDUM OF UNDERSTANDING
by and between
THE REPUBLIC OF THE MARSHALL ISLANDS,THE RONGELAP ATOLL LOCAL GOVERNMENT COUNCIL, THE UNITED STATES DEPARTMENT OF ENERGY OFFICE OF ENVIRONMENT, SAFETY AND HEALTH
and
THE UNITED STATES DEPARTMENT OF INTERIOR, OFFICE OF TERRITORIAL AND INTERNATIONAL AFFAIRS
for the
RONGELAP RESETTLEMENT PROJECT

This MEMEORANDUM OF UNDERSTANDING (hereinafter referred to as "MOU"), is made by and between the REPUBLIC OF THE MARSHALL ISLANDS (hereinafter referred to as "RMI", the RONGELAP ATOLL LOCAL GOVERNMENT COUNCIL (hereinafter referred to as "RALGOV"), the UNITED STATES DEPARTMENT OF ENERGY represented by the Office for Environment, Safety and Health (hereinafter referred to as "DOE/ES&H), and the UNITED STATES DEPARTMENT OF THE INTERIOR (hereinafter referred to as "DOI/OTIA").

WITNESSETH:

WHEREAS, the purpose of this MOU is to implement provisions of Title I, Sections 103(i) and 105(c) of U.S. Public Law 99-239; and

WHEREAS, in furtherance of the foregoing provisions of U.S. Public Law 99-239 and Nitijela Resolution 1986-62, RMI and RALGOV have caused to be prepared the "Rongelap Atoll Resettlement Project Scientific Work Plan:, a copy of which is attached hereto (and hereinafter referred to as the "Rongelap Work Plan"); and

WHEREAS, in furtherance of the foregoing provision of U.S. Public Law 99-239, the U.S. Congress has appropriated funds for the implementation and support of the Rongelap Work Plan pursuant to Public Law 102-154; and

WHEREAS, RMI and RALGOV have agreed to and shall by a future separate agreement establish a Rongelap Resettlement Project (hereinafter referred to as the "Rongelap Resettlement Project") in order to fully implement and assure the day-to-day management of the scientific studies and conduct other resettlement activities; and

WHEREAS, all the parties to this MOU are committed to taking all actions required in order to assure the timely implementation of the Rongelap Work Plan and such future resettlement activities and actions as may subsequently prove necessary such that the resettlement of the people of Rongelap may be secured;

NOW THEREFORE, be it agreed as follows:

ARTICLE I-GENERAL

1. The activities of the Rongelap Atoll Resettlement Project Scientific Work Plan, otherwise referred to herein as the "Rongelap Work Plan", are hereby endorsed by each of the signatory parties as the proper scientific studies that are necessary to characterize the radiological and environmental conditions of the southern islands of Rongelap Atoll, and upon which the determination for resettlement of the southern islands will be made and further that:
2. The signatory parties commit themselves, one to the other and each to all, that upon receipt of funding for the Rongelap Work Plan pursuant to U.S. Congressional appropriation they shall fully cooperate in and support the completion of the Rongelap Work Plan and the studies undertaken pursuant thereto.

ARTICLE II AGREEMENT BY & BETWEEN DOI/OTIA AND DOE/ES&H, RALGOV, AND RMI FOR THE IMPLEMENTATION & CONDUCT OF THE RONGELAP WORK PLAN IN SUPPORT OF THE RESETTLEMENT OF THE PEOPLE OF RONGELAP

The Department of Interior/Office of Territorial and International Affairs, the Department of Energy/Office of Environment, Safety and Health, the Rongelap Atoll Local Government Council on behalf of the People of Rongelap, and the Republic of the Marshall Islands further agree that:

[The initial stage-Determination of readiness for resettlement]

1. The study and ultimate resettlement of Rongelap shall be undertaken in stages, beginning with an initial environmental and radiological assessment of Rongelap Island and those islands comprising the southern one-half of Rongelap Atoll, said area to encompass on the western side of Rongelap Atoll from Bokonlep Island south and on the eastern side from Erebot Island south.

2. The primary condition of a determination to initiate resettlement for the area defined in Section 1 of this Article is that the calculated maximum whole-body radiation dose equivalent to the maximally exposed resident shall not exceed 100 millirem (mrem)/year above natural background, based upon a local food only diet, such that if the radiological assessment undertaken in accordance with the Rongelap Work Plan demonstrates that no individual would receive an annual radiation dose equivalent in excess of 100 mrem above natural background, resettlement will ensue. RALGOV may at its discretion give consideration to additional potential measures (i.e., application of fertilizers) to reduce individual and population radiation exposures to the returning population further below the 100 mrem/year limit.
3. The "local food only diet" declaration is meant to constitute a traditional Rongelap community diet consistent of local food taken, grown and/or gathered from the southern islands of Rongelap Atoll and the immediately surrounding waters as defined in Section 1 of this Article. It is agreed that the makeup of a Rongelap "local food only diet," and for comparison purposes a more "realistic diet," shall be more precisely determined and quantified pursuant to the Rongelap Work Plan, in consultation with the Rongelap community. In its determination of what constitutes a "local food only diet," the Rongelap Atoll Local Government Council may at it discretion include imported foods that are staples of the diet, e.g. rice.
4. (a) An additional condition of mitigation is the extent of transuranic contamination, especially plutonium contamination of soil. The parties are agreed that this issue, as well as the possible need for an environmental cleanup program solely for transuranic contamination, requires careful deliberation. To this end, it is agreed that the studies undertaken pursuant to the Rongelap Atoll, utilizing as an action limit the screening level of the U.S. Environmental Protection Agency ("EPA") of 0.2 microcuries per square meter, which has been translated by the DOE/ES&H into an activity concentration of 17 picocuries/gram (pCi/g) of transuranics averaged in the top 5 centimeters (cm) of soil. The action limit has been set at 17 pCi/g of transuranics in soil. Measurement of transuranic contamination in the environment and determination of whether the action limit has been met or exceeded will be made pursuant to an appropriate environmental sampling plan developed by the Rongelap Resettlement Project.

   (b) Should the Rongelap Work Plan investigations determine that no soil concentration of transuranics is in excess of the aforementioned prescribed action limit, then no further consideration for soil clean-up of transuranics is warranted. If, on the other hand, it is determined that soil concentrations exceed the prescribed action limit, then recommendation as to the need for remedial activity and/or clean-up shall be included as part of the report prepared pursuant to the Rongelap Work Plan.

   (c) To the extent that transuranic contamination exists in excess of the prescribed action limit but is limited in nature, controllable, and does not impact designated dwelling, food gathering, food growing, and/or recreational areas, then resettlement may ensue while mitigative measures are considered and/or undertaken.

5. In the event the assessment of Rongelap Atoll conducted pursuant to the Rongelap Work Plan demonstrates that radiological conditions on Bokonlep Island or Erebot Island (and their immediate waters) exceed the herein-defined standards for resettlement, the overall determination to initiate resettlement for the southern islands of Rongelap Atoll shall be made without consideration of, and to the exclusion of, radiological conditions on Bokonlep Island or Erebot Island.

[A determination of non-readiness for resettlement]

6. In the event that the environmental and radiological assessment undertaken pursuant to the Rongelap Work Plan demonstrates that the southern islands of Rongelap Atoll are not ready for resettlement without first undertaking a clean-up and remedial program, the Rongelap Resettlement Project shall immediately prepare a report for presentation to the parties hereto containing recommendation as to clean-up requirements and optional remedial activities designed to make the southern islands of Rongelap Atoll ready for resettlement.

[Need for further surveys]

7. (a) In the event the Rongelap Work Plan report(s) to be prepared by the Rongelap Resettlement Project in accordance with Article III, Section 6(a) of this MOU demonstrate(s), based upon the standards and criteria herein set forth,

(b) It is the intent of the parties to ensure that appropriate environmental and radiological assessments are ultimately conducted of all of the ancestral homeland of the Rongelap people to include the remainder of Rongelap Atoll, Ailinginae Atoll, and Rongerik Atoll. It is understood that these additional studies contemplated by this section are subject to and conditioned upon future U.S. Congressional funding.

(1) that the southern islands of Rongelap Atoll are fully resettleable, the second stage of project study shall be the radiological characterization of the northern islands of Rongelap Atoll; or, alternatively,
(2) that the southern islands of Rongelap Atoll are not fully resettleable without remedial activity and/or clean-up, even after consideration of Section 5 to this Article, then the Rongelap Resettlement Project shall immediately propose for consideration by the parties an extended environmental radiation characterization necessary to support the development of remedial actions and/or clean-up, as prescribed by Section 6 of this Article, environmental radiation characterization in such other areas as Rongerik Atoll and Ailinginae Atoll and further, upon completion of these objectives, the Rongelap Resettlement Project would proceed with the evaluation of the northern islands of Rongelap Atoll as prescribed in subsection 7(a)(1).

[Resettlement]

8. Rongelap community resettlement will ensue if the initial assessment described at Section 1 of this Article establishes that no individual residing on the southern islands of Rongelap Atoll and consuming a local food only diet would receive a calculated dose of 100 mrem/year or more of radiation above natural background in the Marshall Islands.
9. Once a determination of readiness for resettlement by the Rongelap Resettlement Project is made and affirmed by the parties to this MOU, planning for resettlement and implementation thereof shall immediately commence, with the full cooperation of all parties that funding for rehabilitation and resettlement shall be provided by way of separate U.S. Congressional appropriation, the funds to be transferred from the U.S. Government to a Rongelap Resettlement Trust Fund in accordance with the trust agreement between DOI, RMI, and RALGOV requirements imposed by Congress.
10. For purposes of resettlement, "Rongelap community resettlement" refers to the voluntary return to Rongelap Atoll of the Rongelap people now residing on Mejatto Island and such other citizens of the Marshall Islands who by virtue of their land rights in Rongelap Atoll voluntarily wish to be resettled.
11. The parties recognize that health concerns may exist for many members of the Rongelap community by virtue of their prior exposure to radiation. Additionally they recognize the need for continued radiological monitoring both of returned citizens and of the Rongelap Atoll environment upon resettlement. Accordingly, the parties agree to address these problems as part of the resettlement program.
12. The parties also agree that in the event of a determination for resettlement and subsequent resettlement, relevant revisions to recommended individual exposure levels as expressed in International Commission for Radiation Protection ("ICRP") and the National Council on Radiation Protection and Measurements ("NCRP") guidelines will be reviewed to ensure that radiation exposures are maintained at an acceptable level of risk.

[Future]

13. If in the future applicable radiation protection standards (e.g., the NCRP and the ICRP) are significantly reduced to below current recommendations, or post-resettlement whole-body measurements indicate that Rongelap residents are being exposed to radiation levels in excess of the 100 mrem/year limit established by Section 2 of this Article, then the parties agree to reevaluate the individual doses being received by the population or an individual at that time to determine that no individual is being exposed to any undue risk, and take such remedial action as shall at that time be deemed appropriate.

ARTICLE III AGREEMENT BY & BETWEEN THE RONGELAP ATOLL LOCAL GOVERNMENTCOUNCIL (RALGOV) AND THE REPUBLIC OF THE MARSHALL ISLANDS (RMI)

The RALGOV and RMI further agree that:

1. In order to facilitate the implementation of this MOU and the Rongelap Work Plan, RALGOV and RMI shall establish a separate entity, to be known as the Rongelap Resettlement Project, which shall serve as the contracting authority for implementation of this MOU and the Rongelap Work Plan and which shall be governed jointly by one representative of RMI and one representative of RALGOV.
2. The scientific direction and operational management of the Rongelap Resettlement Project shall be delegated by RMI and RALGOV, through the Rongelap Resettlement Project, to a Rongelap Resettlement Project Scientific Management Team (hereinafter the "Scientific Management Team"). In addition to his/her duties and obligations as set forth in Section 3 of this Article, one member of the Scientific Management Team, mutually selected by RMI and RALGOV, shall serve as principal scientific advisor to the Rongelap Resettlement Project.
3. The Scientific Management Team shall be selected by RMI and RALGOV and be comprised of not less than two nor no more than three appropriately qualified scientists. The members of the Scientific Management Team shall be assigned joint responsibility for the scientific direction and operational management of the Rongelap Resettlement Project, notwithstanding that their respective duties and responsibilities under the Rongelap Work Plan may vary. At least one of the scientists shall have demonstrated expertise in environmental and radiological analysis. Upon appointment of the scientists comprising the Scientific Management Team, RMI and RALGOV shall through the Rongelap Resettlement Project provide a service contract for each individual's term of appointment.
4. RMI and RALGOV shall utilize such funding as is made available by the Government of the United States, pursuant to Congressional appropriation, and the assistance of the RMI Nationwide Radiological Study pursuant to Article VI, paragraph 7 of this MOU and Article II, Section l(e) of the Agreement Between the Government of the Untied States and the Government of the Marshall Islands for the Implementation of Section 177 of the Compact of Free Association ("the Section 177 Agreement"), to fulfill the scientific and technical requirements of the Rongelap Work Plan as well as the reporting requirements that are mandated by this MOU.
5. The RALGOV and RMI shall also mutually establish and contract for a Rongelap Resettlement Project Scientific Peer Group (hereinafter the "Scientific Peer Review Group"), to provide scientific peer review of the implementation of the Rongelap Work Plan and other technological aspects of the conduct of the Rongelap Resettlement Project. The Scientific Peer

Review Group shall be available for consultation to the Scientific Management Team as necessary to execute the Rongelap Work Plan. The RALGOV and RMI may upon mutual agreement change membership on the Scientific Peer Review Group as resettlement proceeds, and needs dictate.

6. (a) The RALGOV and RMI shall charge the Scientific Management Team with the responsibility of providing the following reports, in both English and Marshallese, to the Rongelap Resettlement Project established pursuant to Section 1 of this Article:

   (b) Upon conclusion of subsequent stages of the Rongelap Resettlement Project, comprehensive reports shall be prepared pursuant to such requirements and schedules as may subsequently be deemed necessary by RMI and RALGOV.

7. Upon receipt of a Scientific Management Team report pursuant to Section 6 of this Article, the Rongelap Resettlement Project shall provide copies of same to the Scientific Peer Review Group for review, comment and recommendation. Resulting recommendations of the Scientific Peer Review Group shall be formally accepted or rejected by the Rongelap Resettlement Project.

8. RALGOV and RMI shall, through the Rongelap Resettlement Project, forward any report received pursuant to Section 6 of this Article to the parties to this MOU. Reports forwarded to the DOE/ES&H shall be accompanied by any comments and/or recommendations thereon received from the Rongelap Resettlement Project Scientific Peer Review Group.

(1) On or before May 1, 1992, a preliminary report on the readiness of the southern islands of Rongelap Atoll for resettlement in order to permit the parties to decide whether to pursue the study option set forth at Section 7(a)(2) of Article II of this MOU in preference to the option described at Section 7(a)(1).

(2) Upon conclusion of the Rongelap Work Plan, a comprehensive report, in both English and Marshallese, shall be prepared on the radiological conditions on Rongelap Island and the southern islands of Rongelap Atoll, pursuant to such requirements and such schedules as may subsequently be deemed necessary by RMI and RALGOV. Said report shall address each component of the Rongelap Work Plan, any necessary and appropriate recommendations following therefrom, and shall include: a summary of study results; dose to infants and children; dose assuming a "local food only" diet as compared to a "realistic diet" that includes imported foods; and dose due to plutonium.

[Assurance of future funding]

9. RALGOV and RMI hereby commit and pledge to one another that in the event the findings, conclusions and recommendations resulting from the Rongelap Work Plan warrant additional U.S. Congressional funding —for further studies, clean-up and remedial programs,

and/or for resettlement of the Rongelap people —they will diligently and in good faith work together to obtain the additional Congressional appropriations and funding required.

10. RALGOV and RMI agree to do everything within their respective powers to maintain the scientific integrity of the studies and assessments undertaken pursuant to the Rongelap Work Plan, and to report in writing any compromise thereof to the other parties to this MOU.

ARTICLE IV-DEPARTMENT OF ENERGY, OFFICE OF ENVIRONMENT, SAFETY ANDHEALTH (DOE/ES&H)

The DOE/ES&H further agrees that:

1. The DOE/ES&H shall cooperate with and support the Rongelap Resettlement Project, specifically the Rongelap Work Plan, as requested and to the extent feasible, by providing whenever possible during the execution of its routine biannual environmental monitoring missions such logistical and other support as is mutually agreed, that will assist the Rongelap Resettlement Project in transporting necessary personnel and equipment to and from Rongelap Atoll.
2. Subject to modifications as the parties to this MOU might in the future agree, and Congress might subsequently endorse, DOE/ES&H shall continue the conduct of its bioassay and medical missions for the Rongelap people during and after resettlement of Rongelap, pursuant to Section 103 (h)(1) of Public Law 99-239.
3. Copies of reports received pursuant to Article III, paragraph 8 of this MOU shall be transmitted by DOE/ES&H to the NAS Scientific Peer Review Group for review and comment.
4. The DOE/ES&H shall give due consideration to the recommendations of its scientific peer review group (NAS). DOE/ES&H shall also assure all communications and recommendations by the NAS scientific peer review group are forwarded to RALGOV and RMI, for transmittal to the Rongelap Resettlement Project Scientific Peer Review Group.
5. Upon request by the Rongelap Resettlement Project and/or the Rongelap Project Scientific Management Team, DOE/ES&H shall furnish requested data relevant to the successful implementation and completion of the Rongelap Work Plan to the Rongelap Resettlement Project.
6. The DOE/ES&H agrees to conduct its Rongelap Atoll scientific activities and studies in a manner best calculated to complement and support the Rongelap Work Plan and the Rongelap Resettlement Project. To this end, DOE/ES&H shall regularly consult with the Rongelap Resettlement Project, the Rongelap Scientific Management Team, and other appropriate RALGOV and RMI representatives as to planned and ongoing DOE/ES&H or DOE/ES&H-contracted projects and activities related to or otherwise affecting Rongelap.

7. The DOE/ES&H shall provide or make available to RALGOV, RMI, the Rongelap Resettlement Project and/or the Scientific Management Team, without charge, requested declassified information, documents and data in DOE's possession, or under its custody or control, concerning past atmospheric and terrestrial measurements relevant to the resettlement of the Rongelap people. To the extent if any documents of established relevance are found to be classified, DOE/ES&H shall, upon request, immediately initiate a classification/declassification review in order to ensure, to the maximum extent possible, full disclosure of all information relevant and necessary to the Rongelap Resettlement Project and successful completion of the Rongelap Work Plan.

ARTICLE V-RONGELAP ATOLL LOCAL GOVERNMENT COUNCIL (RALGOV)

The RALGOV further agrees that:

1. As set forth inArticle II of this MOU, RALGOV agrees on behalf of the People of Rongelap that if the initial environmental and radiological assessments of the areas described in Section I of Article II establishes that no individual resettling to the southern islands of Rongelap Atoll and subsisting on a local food only diet would receive an annual radiation dose exceeding 100 mrem/year above natural background or would be incidentally exposed to concentrations of transuranics in the soil in excess of the prescribed action limit of 17 pCi/g, Rongelap community resettlement will ensue without consideration for mitigation. However, consideration may be given by RALGOV to additional potential measures (i.e., application of fertilizers) to reduce individual and population radiation exposures to the renaming population further below the 100 rem/year limit.
2. RALGOV shall support the timely completion of the Rongelap Work Plan through:

(a) Making the RALGOV Members available to confer with the Scientific Management Team upon request;
(b) Securing any necessary permissions for access, entrance, and the conduct of the Rongelap Work Plan from individuals that may be required so that the Rongelap Resettlement Project can undertake and complete all project field work;
(c) Serving as a liaison between the Scientific Management Team and the Rongelap community at large;
(d) Providing local personnel and community support as necessary to accomplish the objectives of the Rongelap Work Plan and any forthcoming approved activities related to resettlement.

ARTICLE VI-REPUBLIC OF THE MARSHALL ISLANDS (RMI)

RMI further agrees that:

1. The Rongelap Resettlement Project and Rongelap Work Plan shall be undertaken in conjunction with the RMI Nationwide Radiological Study conducted pursuant to Article II, Section 1(e) of the Section 177 Agreement.
2. RMI shall, upon receipt of funds from the DOI/OTIA pursuant to this MOU, assure the availability of these funds to the Rongelap Resettlement Project within five (5) business days of receipt thereof, pursuant to the terms and conditions to be set forth in a separate agreement to be entered into and by and between the Rongelap Resettlement Project, RMI and RALGOV.
3. RMI assures that it will comply with all applicable U.S. Federal laws, regulations and requirements as they relate to the application, acceptance, use and accounting of funds provided pursuant to this MOU.
4. An SF-270, Request for Advance or Reimbursement, will be submitted by RMI to DOI/OTIA for release or drawdown of funds on a quarterly basis. Said Requests shall be made in consultation with, and pursuant to instructions received from the Rongelap Resettlement Project.
5. An SF-269, Financial Status Report, will be submitted by RMI to DOI/OTIA quarterly.
6. RMI shall provide copies of all Financial Status Reports and Requests for Advances or Reimbursements, and any other reports required pursuant to this MOU, the Rongelap Resettlement Project, which shall in turn make sam available to the parties to this MOU on a quarterly basis.
7. Utilizing the funds made available to the RMI Government pursuant to Article II, Section l(e) of the Section 177 Agreement, the RMI Nationwide Radiological Study shall contribute certain of its services to the Rongelap Reassessment Project.
8. RMI is to assure the clearing and maintenance of the air runway on Rongelap Island during the course of the Rongelap Resettlement Project sufficient to permit air traffic to and from Rongelap Island.

ARTICLE VII-DEPARTMENT OF THE INTERIOR, OFFICE OF TERRITORIAL ANDINTERNATIONAL AFFAIRS (DOI/OTIA)

The DOI/OTIA agrees that:

1. The DOI/OTIA shall transfer to the RMI the appropriate portion of such funds as are appropriated by the United States Congress, pursuant to the FY 1992 Appropriation Act (P.L. 102-154) for the Department of Interior for the purpose of implementing the Rongelap Resettlement Project/Rongelap Work Plan.
2. The appropriate portion of funds specifically appropriated by the U.S. Congress for the purpose of implementing the Rongelap Work Plan shall be transferred to the RMI on a quarterly basis pursuant to, and upon receipt by DOI/OTIA of a quarterly SF-270 Request for Advance or Reimbursement.
3. Copies of all financial status reports submitted to DOI/OTIA, and any other reports required to be submitted to DOI/OTIA by this MOU, shall be provided on a timely basis to all parties to this MOU.

ARTICLE VIII-ADDITIONAL AGREEMENTS

All parties further agree:

1. The Rongelap Resettlement Project shall be initiated on or about March 1, 1992, or as soon as practicable after funding is made available by the United States Government. It is the understanding and intent of the parties to this MOU that the Rongelap Resettlement Project shall conclude its mandate and submit its final report pursuant to the Rongelap Work Plan and this MOU on or before April 1, 1993.
2. This MOU shall remain in effect pending completion of the Rongelap Resettlement Project. This MOU may be amended by the mutual consent of the parties hereto.
3. This MOU shall be governed and interpreted in accordance with applicable laws of the United States and the Republic of the Marshall Islands. In the event of dispute with respect to the interpretation or execution of this MOU, the parties agree to in the first instance seek to resolve such dispute through food faith negotiations by and between themselves. Should such negotiations fail, resolution of the matter in dispute shall be governed by the Conference and Dispute Resolutions provisions of Title Four, Article II, of the Compact of Free Association, although nothing contained therein shall be construed as a bar to direct and immediate participation by RALGOV in any conference or dispute resolution activities thereunder.

4. Program Funding-The details of the levels of support to be furnished between DOE/ES&H and DOI/OTIA with respect to funding will be developed in specific interagency agreements or other agreements, subject to the availability of funds. This MOU shall not be used to obligate or commit funds or as the basis for the transfer of funds. The DOE/ES&H and the DOI/OTIA will provide each other mutual support in budget justification to the Office of Management and Budget and hearings before the Congress with respect to programs on which the organizations collaborate.
5. Management Agreements-This MOU envisages direct communication between DOE/ES&H and officials of other organizations involved in managing the work to be performed. Interagency agreements or project plans will set forth necessary cooperative arrangements or project plans will set forth specific arrangements for program implementation. Such plans set forth necessary cooperative arrangements and procedures for handling decisions required by various Government officials. Specific funding and tasking will be implemented through interagency agreements.
6. Public Information Coordination-Subject to the Freedom of Information Act (5 U.S.C. 552), decisions on disclosure of information to the public regarding projects and programs referenced in this MOU shall be made by DOE/ES&H or DOE/OTIA following consultation with the other parties representatives.
7. Amendment and Termination- This MOU may be amended by written agreement between the parties. This MOU may be terminated by the mutual written agreement of the parties or by any party upon 45 day written notice to the other parties.
8. Effective Date-This MOU shall be effective upon the latter date of signature of the parties. It shall remain in effect for a 5-year term from the effective date.

APPROVED AND SO AGREED:

The original document was signed by representatives of the U.S. Department of Energy, the U.S. Department of the Interior, the Republic of the Marshall Islands, the Mayor of the Rongelap Atoll Local Government Council and Senator Jeton Anjain, Rongelap Atoll Local Government Council.

PRECIS OF THE EXECUTIVE SUMMARY ILO KAJIN MAJOL**

Committee eo ikijien bobrae naninmij ko rej walok jen baijin in bomb ilo Majol ear ejak jen National Research Council eo nan uwake kajitok eo jen Department eo an Energy ilo U.S. nan lale im ekatak kake jonan joran ko ilo jet ian ene ko ilo Majol, elaptata kon Rongelap. Juon karok ak kwoon eo ear ejak ikotan Kien eo an America im Kien eo an Majol ilo 1992 eo far naetan MOU. Kwoon in ear kalikar jet kajitok ko ikijien an naj jeblak armij im jokwe ion Rongelap. Lemnak in ear ejak jen konan eo ikijien bar kejeblak armij nan ene ko far komakit er jeni ilo ien eo United States ear kokomelmel e kein tarinae ko rekajur jen 1940s nan 1950s. Rat kajitok bwe National Research Council eo en etali ekatak ko an scientist ro iumun tel im lolorjake eo jen U. S. Department eo an Energy nan lale elane ekatak kein remaron kwalok jonan kauatata, ne ewor, nan ro renaj bar rol nan Rongelap im mona wot jen kein ikkan ko ie, im bok jonan baijin nan enbwinier laplok jen 100 mrem iumin juon iio. MOU eo ej bar komeleleik woran in 17 pCi/g jonan baijen in transuranic eo ilo bwidrej (i.e., plutonium im americium), edik jen jonan eo scientist ro rej aikuij bar lomnok kake im, bwelen, bar kareo.

Jonan baijin eo ilo Rongelap itok wot jen kokomelmel ko an U.S. emoj an driklok jen ukok tak in mejatoto im mot lok im baijin iumin iio kein 40. Ilo tore in, baijin ko nan kajojo ro renaj jokwe ion Rongelap naj woran in strontium-90, cesium-137, plutonium-239, plutonium-240, im americium-241. Ibben kein elaplok jen 90% ej cesium-137, strontium-90 ej kwalok 2-5% in baijin ko, im transuranic-nuclides rej kwalok edrik lok jen 5% ilo aer antonelok.

Jeblak im jokwe ilo aelon ko ittu ean ilo Majol ej kwalok elon mokitkit ko rokael ri-scientist ro rej aikuij lomnok kake. Committee in ej tomak ke kate in clap ilo tore in nan kojeblak lok armij rein nan ijoko jikier ej juon ian kotebar ko rellap im Kien eo ej bok kunan ie im lale jeblak lok eo an elon armij to, ro far emakit jen wot kauatata ko ikijien radiation. Jerbal kein ikijien komanmanlok ene ko im kajeblak armij ro nan ijoko jikier e maron jipan armij ro ilo lol in ko jet elanne e bar walok jonan kauatata jen radiation tokelik. Armij in Rongelap far jeblak ilo 1957 im bar emakit ilo 1985, ilo aer tomak ke Rongelap ejjab juon jikin eo emon nan jokwe ie, im DOE ear jab kwalok tool eo kin jonan joran in baijin eo ilo ene ko im mejatoto eo, im jonan eo enaj jelet armij to. Ej juon men eo earuok nan jonwe jonan lap in radiation eo im joran eo emaron jelet armij in Rongelap im bareinwot kwalok aoleb lomnok ko ilo mol bwe ten jab pok ilo aer konono ikijien jabdewot mokitkit ilo aelon ko ittu ean tokelik.

** Committee in ear pikot juon kilin bwe in ukok Executive Summary in nan kajin Majol. Riutiej ro ilo RMI Embassy, Washington, D.C., rar jipanlok im pikot juon ri ukok. Botab, aoleb ri jipan far jerbal ilo mokaj; kin an oktak kajin Majol im kajin belle, im kin an ben elon wawen konono an ri-scientist ro, ebon lukun jejjet aoleb nan ko ilo ukok eo ilal.

Kon maron eo an, DOE ear tel committee in bwe en etale lokan jerbal in ekatak ko an scientist ro nan lale jonan baijin eo ilo Rongelap ilo kakadruiklok, nan etale elane ekatak kein retobar jonan eo ej emon wot. Rar kajitok lok ibben committee in bwe en lukkun lale jet ian unin konono ko, ibben lok jonan eo rar etale jen International Commission ikkijien Radiological Protection (ICRP) nan lale jonan radiation eo bok iumin juon iio im lale ejimwa ke aer antonelok jonan radiation eo renaj bok ilo aer bar jeblak nan ene ko; kwalok jonan emon ak enana ilo wawen ko rej kojerbali nan jonwelok im antonelok baijin ilo anbwinien armij im ilo melan ko; tokjen mona ko kijier im woran eo rej anton jeni; oktak ko ikotan kein ikkan ko jen mona ko buktok jen ijoko jet, im oktakin ikkijien kora ke ak emman ke, iio eo am, ak ta ko eitok limoem kaki; kilen kadriklok am bok radiation jen am emenono ak kilen am mona; im juon men eo enaj to jetnakin nan ejmour.

Nan jibadbad lok eddo in ion, committee in ear wor an maron in kwalok jerbal ko an ri-jerbal ro an DOE rar ekatak kaki im jebole elon jikin ko im ta ko renaj walok jen joran in baijin ko rar ekatak kaki ilo Majol in. Ibben lok wot, ro uwan committee in rar lolok jikin jerbal ko an ri-jerbal ro an DOE nan lale wawen im kilen aer etale joran in baijin ko ilo Majol, rar bareinwot kajitok elon kajitok ko ibben ri-jerbal ro an DOE im ibben scientist ro rej etale wot jonan joran eo ilo Majol, im etal nan Majol bwe ren lukkun lo jonan joran eo im rej ekatak wot kaki ilo Bikini im Rongelap, bareinwot nan aer etale wawen bed ion Mejato im Ebeye, ijoko elon ian ri-Rongelap ro rej jukjuk im amnak ie rainin. Konono ko rar komman ilo National Academy of Science ilo Washington, D.C., im ilo Mejato ibben ri-tel ro jen Rongelap ro im rekonan jeblak nan Rongelap. Committee eo ear tibriki aolepen ekatak ko rar kommani jen juon ekatak eo rej naetan Nationwide Radiological Study im Rongelap Resettlement Project, iumin tel im lolorjake jan Dr. S. L. Simon, juon physicist in ejmour eo im kien eo an Majol ear kojerbale.

Committee in ear watwat e lok aoleb melele ko ikijien wawen jonwelok im antonelok paijin ilo aen ko tu ean ilo Majol im bareinwot jonan eo armij rein renaj bok, ilo aer jeblak nan Rongelap. Ilo elon wawen ko, committee in ear lori uwak ko ibben ri-etale ro, bareinwot kilen im wawen ko rar jab kalikari lok mokta ilo etale kein; ejjab juon iminene eo DOE akin karok bwe en kwalok aolepen lokan jerbal in etale ko an. Jen men eo rar ekatak jene, committee in enaj karok bwe tokalik Department eo an Energy enaj laplok an lale bwe lokan etale ko re kanuij in melele.

Kwoon eo ear komman ikotan Kien eo an America im Kien eo an Majol naetan MOU ear kobaik lok wot juon kotobar eo ein juon nan jone jonan eo elaptata juon armij e maron bok ilo anbwinien ikijien radiation. Jerbal in etale ko ikkijien radiation rar kalikari bwe in kwalok jonan yeolablab juon bwij in armij remaron bok; rejanin alikar ak ejak nan kwalok jonan eo elaptata im kajojo armij renaj bok jeni; ebareinwot lukkun ben nan jonwe kon jonan iet in armij rein nan jonan kajur in baijen kein. Ibben lok wot, armij rein rar maron kar komman mona jen ene ko jet elaplok radiation ko ie, im kajojo armij remaron kar mona jen mona ko elaplok an baijin in bed ie, einwot baru lep. Aoleb lemnak kein rekomman an ben nan antonelok jonan eo elaptatta juon wot armij eo enaj bok ilo juon melan eo. Committee in ear konan bwe MOU eo en kalikar elon lok kein kaminene ko nan bobrae radiation rej buki, botap ejelok an committee in maron nan komman oktak ilo MOU eo; aolepen antone kein raikuij wonmanlok wot jen karok eo tok jen MOU eo. Botap aolep jerbal in etale kein ikijien bobrae radiation rejjab jimwe nan armij ro renaj boki jen jonan lap in baijin eo, committee in ear kwalok wanjonak ko bwe ren maron wonmanlok wot im wor aer menin konono kake abnono in.

JEMLOK KO

Committee in ear komman jemlok kein jen aolepen kakobaba ko rar lemnak kake. Aoleb melele ko reaorektatta rej bed ilal.

1. *Waren kojerbali karok ko jen ICRP ilo aelon in Majol*. Rar kajitok lok ibben committee in bwe en kwalok lemnak eo an ikijien karok ko jen ICRP ilo jeblak im rol eo an armij ro nan Rongelap, im bareinwot ro jet ibelakin Majol. Konke karok ko jen ICRP rar jab kalikari ekkar nan mokitkit rot in, committee eo ear ejak ke ejjab maron lore karok ko jen ICRP. Bareinwot, nan ro renaj jeblak im bed ion Rongelap im ej kalikar jonan baijen eo elaptatta juon armij emaron boki ilo MOU eo, enin unin an kar committee in jab bar lemnak ke enaj jipanlok im tibdriki jonan eo emoj kajetjete. Botap, ekkar eo jen ICRP nan jonwe jonan baijin eo nan aolep armij rar jab komman ikijien ro renaj jeblak nan ene ko emoj aer joran jen baijin in bomb ko, ICRP ear kile bwinbwin in kakilen ko elajrak im kalikar ilo MOU eo einwot juon men eo eaurok nan kenan kake. Menin konono in ej komeleleik lok ilo jebta 7.
2. *Tibdrikin im jonak in melan ko*. Lajrakin jonak ko ilo melan jen bwidrej, kein ikkan ko, dren im mona ko ion Rongelap elap an mulal im tiljok aer jerbale. Aoleb jerbal kein rar kajion im etale jonin lap in cesium eo ilo bwidrej, ma, waini, im bob ko im jonan transuranic eo ilo bwidrej, katak kein ikijien radiation re kijon walok ilo melan kein. Jerbal in kajimwe kein im rar komman jen scientist ro ilo Lawrence Livermore National Laboratory, juon jikin etale an DOE, ear kalikar debdeb in melele ko nan antonelok jonan radiation eo naj bok jen mejatoto eo kab mona ko ilo aer naj rol im bed ilo ene ko.
3. "*Jikindrikdrik ko elap baijen ie*." Jikindrikdrik ko remaron lukuun joran ilo ijoko rejanin kakileni ej juon an ri-Rongelap abnono. Ijowotke, jonen an lon jikin ko rar etale ilo aen eo, committee in ejjab tamak enaj wor jikindrikdrik ko elekun lab baijen ie. Bareinwot, konke enanin jonan wot juon radiation ilo ijoko rar etali jen LLNL, im kin wawen an baijen walok jen bomb eo, committee in ejjab lo unin an ekkol kon jonan labin radiation (plutonium, cesium, im baijen ko jet) ko remaron kwalok bwe en wor "jikindrikdrik ko elap baijen ie." (Committee in ear bok komelele in "jikindrikdrik ko elap baijen ie" einwot juon jikin jonan kajurin radiation eo ej 10 alen laplok jen jikin ko jet emoj aer ekatak kake kio.)
4. *Jonak ko ilo mona ko*. Melele ko bok jen elon jerbal in etale ko kon mona ko, rejjab jejjet ilo aer antonelok jonan eo ri-Rongelap ro re maron bok jen mona. *Bedbed ion melele kein, ijoke committee in ear watwat e lok ke enanin aolepen ro rej mona jen kein ikkan ko, ak mona ko itok jen ni im waini, maronin laplok jen 100-mrem, ak kon lok jen jonan eo emoj aer kajejjet iumin juon iio eo emoj kelajrake ilo MOU eo*. Tokjen aer jab lukun jela kake jonan armij kajojo renaj mona im, kin menin, jonan baijen ie, rej bar komeleleik ilo komelele ko ilal ilo 6 im 7.

5. *Jonak im kakelkel ko ilo armij*. Bwinbwin in juon enbwinin armij ko rej komman ilo Majol jen ri-jerbal ro an DOE ilo Brookhaven National Laboratory (BNL) ej kwalok jonan joran ko ilo enbwinier, bwe ten maron in erre ekkar nan karok eo ilo MOU eo, emenin aikuij bwe ten ekatak kake kajojo armij ilo aer naj jeblak im bwe en jab jemlok jerbal in etale ko nan er mae juon ien etto jen ran ke in. Melan im mejatoto eo ilo Rongelap, strontium-90, plutonium-239, im plutonium-240 rej kotmene ke enaj kwalok jidrikin wot jonan eo boke jen an to an enbwinnim ajorwawa nan baijin in. Jonan drik in baijen en, jejet in jonak jonan plutonium-239 im plutonium-240 jen dren in raut eben aer etali, ne remaron, kon kein komadmodi ko ilo ran kein. Un ko bwe en maron jejjet aer jonwe jonan plutonium eo ilo raut eikiuj bwe en wor konnan kake, komelele ko remonlok, im jerbal im watwat im jemlok ko rememele ilo aer jonwe jonan plutonium armij kajojo remaron buk jeni.
6. *Wawen antonelok jonan baijen ilo armij kajojo im ilo melan ko*. Watwat im jonan eo rijerbal ro an DOE rar antonelok ekkar nan kwon eo weppen jen ro uwan ICRP. Jonan eo itulik in anbwinien juon armij rej antone ear jimwe im jejjet im lukkun melele. Antone ko kon jonan radiation eo ituloa —ro rar buki jen aer emenono, im oronlok, rar jab tobrak konke iio ko kajitok kaki rejako. Ejjab juon men eo elap ilo an jab bo-lel aolepen jerbal in etale kein, konke anton ko nan jonan eo juon ritto ej kani ej laplok jan anton ko ekkar nan ajiri ro kajojo. Ibben lok, jonan kein ri-scientist ro rejanin jela kake elap an driklok jen men ko rejanin kile ikkijien wawen an armij ro mona.
7. *Ekatak ko ri-scientist rejanin melele ikijien jejjet in jonelok im antonelok radiation*. Ruo ian kilen ko emoj komalim nan antonelok dretan eo elaptata ilo an armij ejerwawa. Juon ej kojerbale probablistic eo ej kojerbal lemnak im ukoktak ko jen jidrikin radiological ko kojerbali ilo ekatak kein. Eo juon ej kojerbale scenario, eo ej kwalok kadkadin jet ian ro elap aer ejerwawa, einwot iio, armij rot (kora ak emman), ijo ej bed ie, im kilan an mona. Ekatak ko an LLNL rej kojerbale wot probablistic, botab reban lukkun jimwe im jejjet aer kamoli jerbal ko aer tokwot jen an iet jonan nan aer maron in antonelok jonan radionuclides ko ilo enbwinier. Ilo aer wonmantak kon scenario eo, committee in ear antone ke kajojo ro rej mona jen kein ikkan ko wot maron in bok jaonan in iumin juon iio 92-106 mrem/y, ekkar nan kilen an mona.
8. *Jipan ko re maron kokomanman ejmour nan armij ro renaj jeblak im jokwe ion Rongelap*. Committee in ej tomak ke unleplep nan komanman lok mejatoto eo ej kojerbal kon ko jen potassium, reban jelet ejmour an ro ion Rongelap, ilo mol eo, kon an lon lok menin eddok ko im ewamourmour lok, emaron kokmanmanlok ejmour nan aolep armij ro. Potassium chloride ej juon koon eo ekka aer kojerbale ilo United States im ejjab kauatata nan ejmour ne ej jerbal ilo un in wot. Kein karuo, kareoik lok bwidrej eo ejoran jen ijoko armij re jokwe ie naj ejelok joran nan ejmour an armij. Committee in ear kile ke ilo aer naj jolok bwidrej in ilo ijoko rejoran itulon, ebareinwot juon men eo ejjab emon, ilo an naj kakure kaan ene ko im jan bok juon ien eo eaetok nan an bar kokal bwidrej.

Bedbed ion etale ko an committee in, Table T-1, eo ej tibdriki jonan radiation eo juon armij enaj buki jen an jeblak im jokwe ion Rongelap, kajur in radiation eo, im ia en paijen eo ej walok jen ie. Ijin ej kwalok ajejin jonan baijin eo armij kajojo re maron bok jen ruo ian ekatak ko: mona ko kijed make koba mona ko jen ijoko jet (scenario A) jen Robinson et al. (1993), im mona ko kijed make ekkar nan Robison et al. (1993) botap tokwot jen jonan calorie ko kani ej kwalok ta eo committee in ej kotmene ke ej laplok an jejjet oon ko nan ejmour (jonan oon einwot Scenario A).

Table T-1. Komolele ko Kon Jonan An ri Rongelap Ejerwawa nan Radiation

	Ajej ko nan Jonan eo Kwoj Bok	mSv/y		(mrem/y)	
I.	JONAN RADIATION EBED IE KADREDRE				
	A. Ejerwawa jen ijoko itulik		0.22	(22)	
	B. Radionuclides ko ituloa		2.0	(200)	
	Subtotal		2.22	(222)	
II.	RADIATION IKIJIEN AN KAR AJERER	Scenario A		Scenario C	
	A. Ejerwawa jen ijoko itulik	0.11	(11)	0.11	(11)
	B. Radionuclides ko ituloa				
	1. men ko jej oranlok	0.17	(17)	0.95	(95)
	2. men ko jej emeonon	0.0043	(0.43)	0.0043	(0.43)
	Subtotal	0.29	(29)	1.06	(106)
	TOTAL	2.51	(251)	3.28	(328)

RECOMMENDATIONS

Bedbed ion ekatak ak etake eo an, committee eo ear komane jet karok ko im reikuij in lori.

1. Kin wot jet melele ko rejanin lukun in alikar ilo wawen in elap an kabukbuk, Committee in ear bake jet ian armij ro rej jeblak im jokwe ion Rongelap remaron buk laplok jan 100-mrem radiation, jonan eo emoj karok ilo MOU. Melele in, armij ro renaj jeblak nan Rongelap im bok enanin aoleb men ko kijier jen mona ko im kein ikkan ko ilo ene ko remaron bok jonan, im ej laplok jen 100-mrem elane ejjelok jipan kin potassium chloride im ejjelok jipan kin mona.
2. Elane armij in Rongelap ro renaj wonmanlok wot im lor wawen lajrak in jonan eo emoj jonwe ilo aer jeblak nan Rongelap, committee in emoj an kamelimi ruo wawen nan jiban

ko im rej lajrak ilal.

- Mokaj im kojerbal juon men eo rej naetan potassium chloride einwot kon nan kadrik lok baijin eo ilo mona ko etan cesium in ekka wot an walok ijoko ewor ni im bob ie.
- Ne enaj dedelok jeblak eo, wawen kilen mona eo enaj jimetan in calories (oon) enaj itok jen mona ko ilikin im jimetan jen mona in aelon kein.

Jipan kein re maron bojrak elanne ilo iio ko tokelik ri-scientist ro rej jonelok baijen eo im ej driklok jan jonen rej antonelok kio.

3. Nan kamol nan armij in Rongelap ke jonan ko ak karok ko an MOU eo rar koman einwot committee eo ear komelim kajojo ian armij ro im renaj jeblak renaj aikiuj im kakolkol im lale ne ewor radionuclides im bareinwot lale juon jambol im kobojak bwe ren maron lale jonan plutonium mokta jen aer jeblak im nan bar tok elik. Ilo kobaik lok, jinoin tarrin 80 armij (jen ba elane woran armij eo ej 400) renaj ajej kin armij rot (kora im emman) im jonan in iio ko aer innem kakolkol eman alen ilo iio otemjej.
4. Committee in ear kabilok ilo jemlokin nan maron iion karok ko jen MOU eo, bwe aelon ko itueon ilo Rongelap im Rongerik bwe ren likiti emo ("off limit") ak armij en jab maron in ebbok mona jeni. "Off limit" eo emaron bojrok ne ilo an iio ko jinoin etale ko rej kwalok ke jonan radiation armij ro kajojo rej buki edik jan 100-mrem, jokron ne renaj kar ebbok mona jen ene ko itueon. Ekatak ko kommon ion Rongelap rar letok juon melele eo ejimwe nan antonelok jonan ko rej buki elane renaj jeblak nan Rongelap. Committee in ear kabilok ke juon kate eo ej wonmanlok wot nan kile ene ko ilo ailin in bwe ren maron in kojerbali im ebbok mona jeni ilo ran kane tok iman. Ekatak in ej aikuij bwe en tibrikrik melele ko kon jonan eo remaron boki ne emaron walok jet wot tokjen makitkit kein. Einwot juon jerbal in kate eikiuj in tiljok ilo an wor jet menin in kotobar ko ibben aikuij ko an armij ro ilo bukon ko im karok ko jen ro rejela ekkatak ko ilo mejatoto eo. Ibben lok wot, committee in ear kwalok ke ilo aer lale melan ko nan mona ko jemaron kani bwe en wonmanlok wot bwe ren maron jonwe jonan radiation eo ilo men en eddok im ilo mejatoto eo.
5. Committee en ear kabilok ke eaikuij bwe en wor jikin dakto ak kakolkol ko nan etale wawen ajmour an armij ro rej jeblak. Kakbiloklok in ejjab ekajak lok ibben naninmij in radiation ak bwe en iion menin melele ko ne renaj wor inebata tokjen radiation.
6. Committee in ear kabiloke bwe en bo-lel lok aer karoki kilen ekatak ko kon aoleb mokitkit ko ikijien jonwe jonan radiation ko ikotan BNL im LLNL ko im rar ejak lok mokta. Kilen ekkatak kein raikuij bwe ren komman (karok) ippen Scientific Management Team eo jen Nationwide Radiological Study eo an RMI.