RONGELAP RESETTLEMENT PROJECT

Summary Report of First Phase:

Determining Compliance with Agreed Limits

for Total Annual Dose-rate on Rongelap Island and

Actinide Contamination of Soils on

Rongelap Island and Neighbouring Islands

by

Scientific Management Team

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Executive Summary

Herein are described the results of a comprehensive radiological survey of Rongelap Island to determine its compliance with agreed limits on annual dose-rate to residents subsisting on a "local food only" diet, and total actinides in soil, under the terms of the Memorandum of Understanding reached between the Departments of Interior, and Energy of the United States of America, the Republic of the Marshall Islands and the Local Government of the Rongelap Atoll and signed on 21 February 1992. The present report is a non technical summary based upon six detailed appendices carrying the results of the survey.

Summary and Recommendations

Given the terms and conditions of the MoU we find the two specified compliance limits are out of compliance on Rongelap Island and the neighbouring islands but that they could be met, under the terms of the MoU, by appropriate remedial action.
We recommend that:

- urgent consideration should be given, in close consultation with the Rongelap community and their representatives, to agreeing measures to reduce the level of Caesium in the local food diet and to providing, through other measures, support to eliminate the need to gather food from the more contaminated regions in the atoll.

- In the light of information being gathered on the micro-distribution of actinides in soil and on the degree to which children ingest soil, consideration should be given, again in close consultation with the Rongelap community, to the desirability of measures to reduce the availability of actinides for incorporation into the body

- in all above considerations careful attention should be paid to the need to ensure that the Rongelap community is comfortable with the radiological status of their islands as a future home for them and their children in perpetuity. The need to offset the loss of well-being incurred by past uncertainties concerning the safety of their homelands should be given a high priority when exploring with the Rongelap community solutions to redress the radiological status of their islands .

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1. Introduction

1.1 Scope and Purpose of the present report

This report is intended to be a non technical summary of the objectives, methodologies, results and implications of the first phase of the Rongelap Resettlement Project. It is backed by six technical appendices describing in detail the methods employed and the results obtained.

1.2 Historical perspective

On 21 February 1992 a Memorandum of Understanding was reached between the Republic of the Marshall Islands Government, the Rongelap Atoll Local Government, the US Department of Energy (Office of Environment, Safety and Health) and the US Department of the Interior (Office of Territorial and International Affairs). The agreement enacted two radiological limits which must be in compliance before resettlement of Rongelap should take place. These are:

- An annual dose, over and above that from natural background radiation, of 100mrem assuming that the diet consists of only locally produced foods, and
- A surface concentration of Plutonium and other transuranic elements of 0.2uCi/m^2 which was translated by the DoE to 17pCi/g averaged over the top five centimetres of the soil.

The purpose of the first phase of the Rongelap Resettlement Project is to determine whether either of the limits will be exceeded on Rongelap Island and the neighbouring southern islands in the Rongelap Atoll.

1.3 Summary of the strategy employed

1.3.1 *Criteria for compliance*

The above limits are framed in the MoU in deterministic terms, i.e. that no one will exceed the 100 mrem compliance limit and that at no point on the island will the 17pCi/g compliance limit for actinides in the top 5 cm of soil be exceeded. In the case of both limits determinism is inappropriate since there are no circumstances in which exceedence could be excluded entirely. In practice there will be a distribution of doses and activity concentrations within the population from which either a probability that an individual or location will exceed the limit, or a proportion of the population or locations exceeding the limit, can be derived.

In order to overcome this difficulty we propose to re-define the criteria for exceedence of the limits in probabilistic terms as follows:

- The limit will be deemed exceeded if 1% or more of the population or locations exceed the compliance limits, or an individual or location has a 1% or more chance of exceeding the compliance limits.

The 100mrem limit is taken to include all sources of exposure other than natural background radiation, i.e. external radiation, from nuclides in the terrestrial environment and internal radiation derived from locally produced foods. In practice the dominant contributor to both will be Caesium-137 retained in the soil and transferred to the food chain. Other nuclides, e.g. ^{241}Am and ^{60}Co contribute to external exposure and ^{90}Sr contributes to internal exposure. In the following dose rates from ^{137}Cs have been calculated and the additional contribution from other sources estimated.

1.3.2 *Determining compliance*

Natural background radiation is low in coral atolls due to the lack of minerals in the terrestrial environment. Never-the-less, direct measurement of external exposure with, for example, a proportional counter, would entail subtracting a component for natural background. Direct measurement of ^{137}Cs allows the direct determination of exposure from fallout.

The following integrated strategy has been adopted:

- 63 *in situ* measurements of the gamma spectrum one metre above the ground and at 200m intervals over Rongelap Island have been made with a germanium detector and count rates for Caesium-137 and Cobalt-60 determined from the spectra.
- Four grid squares were selected, two in the vicinity of the main settlement (where soil disturbance was likely) and two remote from it, and within each 25 further measurements were made.
- Determinations of the distribution of ^{137}Cs with depth in the soil have been made at 12 of the 63 locations measured.
- ^{137}Cs, ^{60}Co, ^{241}Am and Pu-239/240 have been determined from a composite of three 15 by 15 by 5 cm deep samples taken within 15 m of each *in situ* measurement.
- ^{137}Cs has been measured in samples of foodstuffs at a relatively small number of locations primarily to confirm the much more comprehensive measurements of food samples by DoE. Intercomparisons have justified the use of those data.
- Maps of ^{137}Cs count rates ($S_{(x)}$) and total actinide concentrations in soil have been prepared by interpolation from the sample points.
- By application of the "radii of utilisation" maps of Cs count rate in soil averaged over radii of 200, 500 and 1000 m ($T_{R(x)}$) have been derived.
- ^{137}Cs count rates have been converted, with the help of the soil profile data to ^{137}Cs concentrations in soil and compared with the soil determinations.
- Soil: plant transfer factors have been derived from measured concentrations in vegetation and from soil concentrations and supplemented by earlier data collected by the DoE and the distribution of values computed.

архивных материалов ПО «Маяк» производится сбор информации по индивидуальному контролю персонала ПО «Маяк» и методикам проведения измерений. Производится оценка качества измерений и их сравнение с современными методами контроля.

Составляется отчет.

Содержание отчета:

Описание методик индивидуального контроля персонала, применявшихся на ПО «Маяк» с 1948 г. Сравнение применявшихся методов с современными. Оценка неопределенностей данных контроля, полученных различными методами.

<u>3.2. Задача 2.</u>

В ходе работы будут проанализированы существующие на ПО «Маяк», в ГГП Гидроспецгеология и др. информационные базы данных. На основании их сравнения будет выбрана и доработана структура базы данных, наиболее подходящая для хранения данных по индивидуальному контролю.

Составляется отчет.

Содержание отчета:

Описание существующих баз данных, их анализ. Описание структуры базы данных по индивидуальному контролю персонала.

<u>3.3. Задача 3.</u>

Будет проведен статистический анализ и обобщение данных индивидуального контроля персонала ПО «Маяк» по периодам контроля, месту работы и применяемым методам; рассмотрены возможные методы верификации данных в зависимости от условий работы и периода контроля.

Составляется отчет.

Содержание отчета:

Представляются результаты статистической обработки данных индивидуального контроля персонала ПО «Маяк». Выбирается метод моделирования для верификации данных.

<u>3.3. Задача 4.</u>

Будет проведено гидрографическое и гидрологическое описание реки Теча. Описание будет сделано по состоянию на конец 40-х - начало 50-х годов, то есть для периода времени, когда в реку Теча поступали жидкие радиоактивные отходы ПО «Маяк».

Составляется отчет.

Содержание отчета:

Гидрографическое и гидрологическое описание реки Теча, анализ данных о параметрах пойменных почв и донных отложений.

<u>4. Ожидаемые результаты.</u>

Выполненные работы позволят:

- подойти к созданию баз данных по индивидуальному контролю для различных групп и категорий персонала ПО «Маяк»;
- оценить неопределенности существующих данных;
- выбрать методы верификации данных индивидуального контроля, полученных в

2. Methodology

2.1 Measurements of external exposure (see Appendix 1)

Hyperpure germanium detectors manufactured by Canberra Industries were used for all spectrometric measurements both *in situ* and in samples taken of soils and vegetation for laboratory analysis .

All *in situ* measurements were made and interpreted according to the method of Beck (1972)[1] and the detectors calibrated by standard procedures.

In situ measurements were made at 63 locations on a 200m grid over the island (see figure 2.1) and at 100 locations within four 200m grid squares at 40m spacing. These values were used to construct maps of count rate, $S_{(x)}$, by interpolation between points on the grid matrix and maps of count rate averaged over various radii, $T_{R(x)}$

Count rate in the photopeak is dependent on the vertical profile of activity in the soil due to scattering of photons from deeply buried activity. Soil profiles to a depth of 30 cm (6 increments by 5 cm depth each) were taken in order to correct for this effect.

Three soil samples were taken within 15 m of the sites of each *in situ* measurement and dried and counted under standardised conditions in the laboratory.

^{60}Co and ^{241}Am also make a contribution to external dose and measurements of the count rates in the ^{60}Co and ^{241}Am photopeaks were also made .

Conversion factors for corrected count rate to exposure rate were taken from Beck (1972) and for exposure rate to dose rate from ICRP Publication 51.

2.2 Measurement of internal exposure

Levels of caesium contamination of vegetation depend on the soil concentration of Cs.. The ratio soil:plant for ^{137}Cs has been determined for a number of local food types, the most important of which is the coconut. Although there is considerable variability from sample to sample a value of 0.2 for both the liquid and solid components of the drinking coconut is representative with 50% of all samples within a factor two above and below. The data acquired in this study have been supplemented by earlier data collected on Rongelap by DoE.

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1 Beck, H. L., DeCampo and Gogolak 1972 In situ Ge(Li) and NaI(Tl) Gamma-ray Spectrometry. HASL-258 Health and Safety Laboratory, US Atomic Energy Commission

The dietary survey yielded a distribution of energy intakes for the Mejatto population which was corrected as described in the section on the Dietary Survey to reduce the overdispersion due to the use of single 24 hour recall data set. Body mass and height data were recorded in the dietary survey. Basal metabolic rates were estimated from the relationship of Schofield et al..[2]

2.3 Diet survey (see Appendix 2)

For more than 100 years, the Marshallese diet has consisted of a mixture of imported and local foods. From the periods of the occupations by Germany in the mid-1800s, the Japanese, and finally the Americans, the Marshallese people have subsisted on varying types and quantities of imported food as an adjunct to their abundant but monotonous marine-based diet. As atoll dwellers [and not agriculturists] the Marshallese and other people living in Pacific atolls have the most restricted diet of all oceanic peoples.

A local food only diet cannot be measured directly since there appears to be no population in the Marshall Islands which subsists for prolonged periods of time on a diet consisting of entirely local food items with no consumption of imported foods. Even if one were to conduct a dietary survey on more traditional islands, the problem would remain how to substitute imported food items, such as instant noodles or rice, with local food items.

The dietary survey was designed to satisfy two requirements of the dose calculation, namely to provide a distribution of energy intakes and to indicate the nature of the local food in the current diet on Mejatto.

A 24-hour recall survey was chosen to give an estimate of the mean intake of nutrients and energy. Given the small size of the Mejatto population and the desirability of including everyone in the survey, a single 24-hour recall was collected from all Mejatto residents. Heights and weights of the population were taken as an external validity check of the mean energy intakes. A repeat survey of women 18 years and older was conducted.

Training was given to twelve volunteers of the Mejatto community during a five day workshop in Majuro. The training program ensured that the interviewers understood the objectives of the dietary survey; had a rounding in basic nutrition relevant to the Marshall Islands' food culture; developed skills in interviewing techniques; were able to use common food utensils and food models to elicit amounts of food eaten by interviewees; were able to fill-in the dietary questionnaire; and understood the importance of the dietary survey in relation to the Rongelap Resettlement Project as a whole.

Dietary data were collected from 319 residents, with a repeat 24 hour recall of 48 women 18 years and over, several days after the first recall. The survey was planned so that interviews were spread evenly over the different days of the week, and so that interviewers

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[2] Schofield, W. N., Schofield, C. and James, W. P. T. Basal metabolic rate - review and prediction, together with an anotated bibliography of source material. Human Nutrition: Clinical Nutrition 39C(Suppl 1) 1 - 96 (1985)

carried out their interviews in at least two households each day, and attempted to interview a mixture of men, women and children each day. The age and sex distribution of those interviewed is shown in table 2.1.

Table 2.1 Description of population and measurements obtained

Age-sex grouping	Weight data	Height data	Diet data	Repeat diet data
Males				
< 5 yrs	20	14	30	-
5 - 9 yrs	28	28	33	-
10 - 17 yrs	36	35	42	-
18 - 60 yrs	51	51	62	-
>60 yrs	3	3	6	-
Females				
< 5 yrs	17	12	26	-
5 - 9 yrs	26	26	30	-
10 - 17 yrs	22	22	26	-
18 - 60 yrs	48	54	54	42
>60 yrs	8	10	10	6

The data from the survey were analyzed using the Nutritionist IV version 2.0 database. For nutrient information on local foods such as coconuts, the 1983 South Pacific Commission tables were used.

The data for mean energy intake (EI) as well as consumption of protein, carbohydrates and fat are commensurate with reference data (ICRP Publication 23). The average protein intakes of men and women are higher than the US Recommended Dietary Intakes whereas the energy intakes are slightly lower. Intake rates for males are higher than for females.

Table 2.2 provides an analysis of the observed energy intake rates in comparison with the estimated basal metabolic rate. The observed mean energy intake for men and women of 1.6 times the estimated mean basal metabolic requirement (BMR_{est}) is consistent with sedentary-light activity. The distribution is over-disperse with a small number of individuals reporting energy intakes below their estimated basal metabolic rate, whereas the maximum reported energy intake would be equivalent to unrealistically high physical activity levels.

Since annual mean values for energy intake are needed for the dose assessment, the variation in intake is described by a lognormal distribution of the ratio of EI/BMR_{est} whereby the standard deviations of the natural logarithm of the mean m is adjusted such that the

1st percentile of the distribution is equivalent with a ratio of $EI/BMR_{est} = 1$. Since very heavy physical activity is associated with an average daily energy intake of 2.3 EI/BMR_{est} for males and 2.0 for females, the 99th percentile reflects reasonable upper limits of EI/BMR_{est}.

Table 2.2 Energy Intake (EI) compared to the estimated basal metabolic rate (BMRest)[3]

Parameter	**Boys 10-17 yrs (N=35)**	**Girls 10-17 yrs (N=22)**	**Men 18+yrs (N=53)**	**Women 18+yrs (N=41)**
observed data:				
EI/BMR_{est}, avg	1.6	1.7	1.7	1.4
EI/BMR_{est}, min	0.46	0.69	0.59	0.72
EI/BMR_{est}, max	2.4	2.5	3.5	2.3
m (EI/BMR_{est})	0.41	0.51	0.45	0.33
s (EI/BMR_{est})	0.33	0.32	0.39	0.28
adjusted data:				
m (EI/BMR_{est})	0.41	0.51	0.45	0.33
s (EI/BMR_{est})	0.18	0.22	0.19	0.14
EI/BMR_{est}, 01-percentile	1.0	1.0	1.0	1.0
EI/BMR_{est}, 50-percentile	1.5	1.7	1.6	1.4
EI/BMR_{est}, 95-percentile	2.1	2.6	2.3	1.8
EI/BMR_{est}, 99-percentile	2.3	2.8	2.4	1.9

A local food only diet was derived using the following principles:

- Energy intake derived from measured energy intakes of the Mejatto community.
- Items available on Rongelap and providing a good balance of nutrients.
- The selection of food items not be biased by availability or non-availability of radionuclide data on the food item.
- Diet determined in consultation with local community.

With the endorsement by the Rongelap communities, the following diets were selected:

(#1) "Mejatto observed"

The current level of local food items as observed in the Mejatto survey (about 18% of total energy intake)

[3] BMR estimated based on equations by Schoffield et al. (see footnote 2)

(#2) "Mejatto scaled"
Imported food items are replaced by local food items on a calorie-by-calorie basis in the same proportions as these local food items were consumed in the mean on Mejatto during the survey.

(#3) "Mejatto scaled with rice"
same as #2 but accounting for the same mean rice consumption as observed on Mejatto (between 25% and 30% of total energy intake).

(#4) "Naidu et al., scaled"
Imported food items are replaced by local food items on a calorie-by-calorie basis in the same mean proportions as these local food items were reported in the Naidu et al. survey.[4]

(#5) "Naidu et al., scaled with rice"
same as #4 but accounting for the same mean rice consumption as observed on Mejatto (between 25% and 30% of total energy intake).

The resulting diet models for cosumption of local foodstuff are shown in Appendix 2d. Table 2.3 provides a nutritional analysis of the selected diets.

In addition, calculations of local food consumption in between the intake observed on Mejatto and a 100% level were requested by the communities. However, the Diet #2 ("Mejatto scaled") was endorsed as the basis for the dose assessment.

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[4] Naidu, J.R., et al. Marshall Islands: A study of diet and living patterns. Brookhaven National Laboratory, Upton, N.Y. July 1980, BNL 51313

Table 2.3 Key data for diet models to be used in Rongelap compliance assessment (data for females >18 yrs;
data for males >18 yrs)

Diet	#1	#2	#3	#4	#5
Parameter	**Mejetto**	**Mejatto scaled w/o rice**	**Mejatto scaled with rice**	**Naidu et al. scaled w/o rice**	**Naidu et al. scaled with rice**
Total Energy Intake	1,900	1,900	1,900	1,900	1,900
(kcal/d)	*2,750*	*2,750*	*2,750*	*2,750*	*2,750*
Energy Intake from	18%	100%	75%	100%	75%
Local Foodstuffs	*17%*	*100%*	*70%*	*100%*	*70%*
(Percent)					
Energy Intake from Rice	25%	0%	25%	0%	25%
(Percent)	*30%*	*0%*	*30%*	*0%*	*30%*
Protein Intake (g/d)	72	82	71	100	87
	110	*130*	*110*	*150*	*120*
Carbohydrate Intake (g/d)	260	140	210	180	240
	360	*130*	*260*	*260*	*360*
Fat Intake (g/d)	67	120	92	80	61
	95	*200*	*130*	*120*	*83*

2.4 Determination of actinides in soil (see Appendix 3)

Concentrations of ^{239}Pu and ^{240}Pu and ^{241}Am were determined in pooled samples (15 by 15 cm by 5 cm deep) taken at three points within 15m of the site of each of the *in situ* spectroscopic measurements on Rongelap Island and from samples taken on neighbouring islands in the southern part of the atoll. Americium concentration was determined by laboratory gamma spectroscopy measurements of the 59.5 keV emission. Plutonium was determined radiochemically using microprecipitation onto a neodymium fluoride substrate followed by alpha counting with passively implanted silicon detectors. This technique was verified by interlaboratory comparisons with laboratories in New Zealand, Germany and the USA.

Interpolation maps similar to those prepared for the ^{137}Cs were prepared for total actinides.

3. Calculation of total dose from ^{137}Cs (see Appendix 4)

This calculation has been carried out in duplicate at two separate locations (Majuro, RMI and Sussex, UK) with entirely independent programming and according to the same protocol as described in detail in Appendix 4 but with some small differences in approach. This was done to ensure that the final result contained no artefacts of programming or misinterpretations of the primary data.

Dose from ^{137}Cs arises from two sources, namely external, from the radionuclide in the soil, and internal, from the nuclide transferred from the soil to the food chain, either directly from the consumption of leaves, vegetables and fruit or indirectly from locally grown animals such as pigs, chickens and coconut crabs. Both components depend upon the concentrations of ^{137}Cs in soil. Soil concentration can be inferred from measurements of the count rate of ^{137}Cs as measured with a high resolution gamma spectrometer *in situ* under standard conditions (height above the ground etc.) when allowance has been made for the burial of the Cs in the soil. Burial has the effect of scattering radiation thus reducing the contribution to count rate in the unattenuated energy band, or photopeak, for the nuclide.

The external component of dose rate depends on the extent to which an individual moves around the island, particularly if the count rate varies markedly from one part of the island to another. A relatively immobile individual will have an exposure rate typical of the locality in which he or she spends most time whereas a mobile individual will approximate to the average exposure rate for the island. This "mobility" factor is allowed for in the "radius of utilisation" and is used in the mapping procedure to convert the $S_{(x)}$ maps to $T_{R(x)}$ maps. Because the construction of the $S_{(x)}$ map involves interpolation between points on the 200m grid, the dispersion of values of $S_{(x)}$ over the island is narrower than that for the original measurements (the interpolation is in effect an averaging process over the order of distance equal to the grid spacing) and averaging over greater distances, to construct $T_{R(x)}$ maps, further narrows the distribution towards the average. Calculation 1 uses the $S_{(x)}$ and $T_{R(x)}$ maps (for R=500) whereas calculation 2 is based upon the measurements without interpolation of averaging.

The internal component depends upon diet and the extent to which it includes contaminated local foods. Caesium transfer is not highly selective and uptake from the soil depends on factors such as the depth distribution of the Caesium in the soil in ways that are not fully understood. The ratio between Caesium in vegetation and soil is termed the soil:plant transfer factor. Calculation 1 uses a single value of 0.2 and applies a sensitivity analysis in order assess the dependence of total dose on this factor which lies in the range 0.1 to 0.4. Calculation 2 uses values for the soil:pant ratios determined in earlier DoE studies. In both cases the soil concentration is the reference for calculating exposure so food gathered in a particular locality will reflect the Caesium activity in the soil at that location.

Both the external and internal dose rates depend on body mass. In the external case dose rate is derived from exposure rate using standard ICRP conversion factors[5]. For internal exposure dose rate will depend upon energy intake, diet, and body mass. A diet survey of the inhabitants of Mejatto was used to assess the contribution of local foods to the present diet and to assess the distribution of energy intakes. The fractions of time spent in different activities was based on previous DoE assumptions.

Dose was calculated according to the protocol given in Appendix 4. There are a number of ways of carrying out this calculation. In selecting the method used we were mindful of the need to use a method that was readily comprehensible as well as reliable. The approach has been to calculate only the contribution from ^{137}Cs, using sensitivity analyses to determine whether or not the calculation is "robust" to reasonable uncertainties or fluctuations in values. Dose rate distributions have been computed for men and women separately and children are dealt with by comparison of energy intakes in relation to body masses. Dose rate distributions are derived using a Monte Carlo technique, drawing at random from the distributions of soil concentration, body mass and energy intake. Reference is then made to the assumed diets, #1 representing the measured Mejatto diet, #2 the "local foods only diet" agreed with the Rongelap community and 3 other derived diets.

4. Results

4.1 Total Annual Dose Rate

Results are calculated as cumulative dose rate distributions for men and women under differing sets of assumptions. For simplicity they are presented herein as tables giving the annual dose rate for various percentiles (from 1 to 99).

The results of calculation 1, based on the interpolation maps for $S_{(x)}$ and a "base value" for the soil:plant ratio of 0.2 are given in tables 4.1 and 4.2 for men and women respectively. Table 4.3 compares the results of using $S_{(x)}$ and $T_{500(x)}$ maps for men eating diet #2. As anticipated the dispersion of the distribution based on $T_{500(x)}$ is narrower due to the greater degree of averaging involved. The results for calculation 2, based on the measured values of ^{137}Cs count rate and discreet estimates of the soil:plant transfer factors for different plants, are given for diet #2 in column 3 of Table 4.4 for men. In this case the distributions are both broader, due to the over-dispersion of the measured values and have a higher mean value due to the use of individual values for the soil:plant ratio which are generally higher than the "base value" of 0.2 used in calculation 1.

[5] ICRP Publication 51 Data For The Use In Protection Against External Radiation Annals of the ICRP, 20 (2) 1989

Table 4.1 Annual dose rates for men over 18 years based on $S_{(x)}$ map and a soil:plant ratio of 0.2 using calculation 1

Percentile	Diet #1	Diet #2	Diet #3	Diet #4	Diet #5
1	16.5	49.5	37.5	82.5	60.5
5	17.5	59.5	44.5	100.5	73.5
25	20.5	72.5	54.5	125.5	91.5
50	22.5	85.5	63.5	148.5	107.5
75	25.5	101.5	74.5	177.5	128.5
95	30.5	130.5	95.5	230.5	165.5
99	34.5	152.5	110.5	271.5	194.5

Table 4.2 Annual dose rates for women over 18 years based on $S_{(x)}$ map and a soil:plant ratio of 0.2 using calculation 1

Percentile	Diet #1	Diet #2	Diet #3	Diet #4	Diet #5
1	16.5	46.5	37.5	65.5	51.5
5	17.5	54.5	43.5	76.5	60.5
25	20.5	67.5	53.5	95.5	74.5
50	22.5	78.5	61.5	111.5	86.5
75	25.5	91.5	71.5	131.5	102.5
95	29.5	114.5	88.5	165.5	127.5
99	32.5	130.5	100.5	188.5	145.5

Table 4.3 Comparison of annual dose rates for $S_{(x)}$ and $T_{500(x)}$ maps for women and men over 18 years based on a soil:plant ratio of 0.2 using calculation 1

Percentile	Female: $S_{(x)}$	Female $T_{500(x)}$	Male $S_{(x)}$	Male $T_{500(x)}$
1	46.5	54.5	49.5	58.5
5	54.5	62.5	59.5	65.5
25	67.5	74.5	72.5	79.5
50	78.5	82.5	85.5	90.5
75	91.5	91.5	101.5	101.5
95	114.5	107.5	130.5	124.5
99	130.5	123.5	152.5	143.5

Table 4.4 sumarises the annual dose rates for men eating diet #2 at different percentile points on the distribution and compares the results from the two calculations and the effect of choosing different values for the soil:plant ratio. It demonstrates the importance of the internal component of dose, the external component being about 12% of the 50th percentile in the case of men calculated according to the first method and based on $S_{(x)}$ and a soil:plant ratio = 0.2. Thus the effect of choosing the higher value of 0.4 is marked but conversely the

effect of choosing the lower value of 0.1, equivalent to reducing the uptake for Cs, lowers the doses significantly. For a value of soil:plant ratio of 0.3 calculation 1 based on the $S_{(x)}$ map is in good agreement at the 50th percentile with calculation 2..

Table 4.4

percentile	Calc.1: S(x): F=0.2	Calc. 2	Calc.1: S(x): F=0.4	Calc.1: S(x) F=0.1
1	49.5	20	88.5	29.5
5	59.5	40	106.5	34.5
25	73.5	98	136.5	41.5
50	85.5	140	160.5	47.5
75	101.5	200	192.5	55.5
95	130.5	250	250.5	70.5
99	152.5	450	294.5	81.5

The smaller body mass of children potentially exposes them to greater doses than adults. It can be demonstrated that although the dose per unit intake is higher for children than adults by a factor 1.4 to 1.5 for the 6 to 10 year old, the energy intake more than compensates, such that under identical exposure conditions the ^{137}Cs doses to small children are typically 54% of those to adult males and 74% of the adult female values.

External exposure due to ^{60}Co and ^{241}Am will increase the external component by about 1%. ^{90}Sr may add a further 2% to the internal dose but actinides due to their very limited uptake into the plants contribute only a few percent to internal dose. For young children the intake of actinides from direct ingestion of soil has yet to be examined but is unlikely to add much to the dose. It should however be examined as an issue in its own right. The results of Plutonium and other actinide measurements in exhumed former residents of Rongelap indicate that actinides might contribute about 1mrem/yr to dose rate.

4.2 Actinide concentrations in soil

On Rongelap Island 1.1% (2/175) of the measured values for total actinide exceed the compliance limit of 17pCi/g. The interpolation map was not used in the context of compliance since the requirement is ensure that there are no points with measured values above the limit. The map dose however help to locate those regions of the island that have consistently high values. For neighbouring islands measurements indicate 14% (6/43) of measurements fail to comply with the limit.

5. Discussion

5.1 Total annual dose rate

The results indicate that, on the basis of ^{137}Cs exposure alone, between 25 and more than 75% of male members of the Rongelap community would exceed the compliance limit of 100 mrem per year while living an outer island lifestyle and consuming a local food only diet. The internal dose dominates. The additional contributions from ^{60}Co, ^{90}Sr and ^{241}Am and other actinides will be small. It is noted that calculation 2 yields somewhat higher doses and has a wider dispersion of values than calculation 2. This is because of the higher soil:plant ratios used and the fact that the underlying distributions are lognormal.

Estimates of radiation doses made from whole body counting data of former residents of Rongelap Atoll during the years 1958 to 1985 indicate that if the same diet and food collection patterns applied now, as then, with a mixture of local and imported foods, a small fraction of the population would be above the 100mrem/yr compliance limit.

It should be noted that all calculations are based on the local food being gathered from Rongelap Island. The traditional food gathering islands lie in the north of the atoll and are more, and in some cases considerably more, contaminated than Rongelap Island. The effect of gathering food from these islands would be much the same as increasing the value of the soil:plant ratio. We consider it unreasonable to assume that in practice the gathering of food from these islands, particularly in times of water and food shortages, can be effectively prohibited.

As stated earlier, attention has been concentrated on ^{137}Cs because of its dominance and because it is possible to reduce exposures by practical measures. There is, for example, considerable scope for reduction of the internal component by treating growing areas with potash fertilizer as is demonstrated in table 4.4 by the application of a lower soil:plant ratio value. A reduction by a factor four, which can be achieved by this technique, will more than halve the total dose values bringing almost all the population within the 100mrem compliance limit on the basis of a local food only diet. The consumption of imported foods will reduce doses further..

However, we believe more extensive measures than potash fertilisation are called for. The 100mrem (1mSv)/year limit is widely[6] regarded as the limit of acceptability for public exposure to ionising radiation, for practices which give rise to exposures in addition to those arising from natural and medical exposures, although it is generally accepted in radiological circles that the health impact of such exposures is small. Public concern for health detriment, real or imagined, is in itself a health detriment when health is viewed in its widest sense, that is, including loss of well-being as a detriment. Thus, measures that make the exceedence of the compliance limit less likely contribute to minimising this detriment by reducing the concern in the community for their health. In the case of the Rongelap community the most likely contributing factor to increasing dose will be the need to visit the northern islands at times of food and water shortages. Measures to ensure adequate water and food supplies on Rongelap Island, such as ground or ocean water purification and the capability to refrigerate and store protein foods, are examples of measures that contribute in that direction. We

[6] 1mSv/year is the ICRP recommended public dose limit when averaged over a lifetime. It should be noted that implicit in this figure is the assumption that societal benefit is derived from the activities that lead to this exposure. In the case of the exposures from living on Rongelap the exposed community derives no benefits.

recommend that careful consideration is given to this type of mitigation in close consultation with the Rongelap community.

5.2 Actinide contamination of soil

While the failure to comply with the limit on Rongelap Island is marginal it has to be acknowledged that there is more concern worldwide about exposure to actinides than other forms of radioactivity. Given that many of the measured values are close to the limit we believe it worthwhile to consider taking some remedial measures, especially to reduce the possibility of intakes by young children ingesting contaminated soil. Measurements are in progress to determine the micro-distribution of the actinides which will assist in determining the best strategies for remedial action but we have in mind the provision of, for example, radiologically clean coral to provide actinide free surfaces around houses and in community areas. The study of plutonium in bone from exhumed Rongelap residents does not indicate that the actinides are readily transferred to man, even as children.

The compliance limits are clearly exceeded on the neighbouring islands and attention will have to be given to remedial measures appropriate to the use to which these islands will be put.

6.Summary and Recommendations

Given the terms and conditions of the MoU we find the two specified compliance limits are out of compliance on Rongelap Island and the neighbouring islands but that they could be met, under the terms of the MoU, by appropriate remedial action.
We recommend that:

- urgent consideration should be given, in close consultation with the Rongelap community and their representatives, to agreeing measures to reduce the level of Caesium in the local food diet and to providing, through other measures, support to eliminate the need to gather food from the more contaminated regions in the atoll.

- in the light of information being gathered on the micro-distribution of actinides in soil and on the degree to which children ingest soil, consideration should be given, again in close consultation with the Rongelap community, to the desirability of measures to reduce the availability of actinides for incorporation into the body

- in all above considerations careful attention should be paid to the need to ensure that the Rongelap community is comfortable with the radiological status of their islands as a future home for them and their children in perpetuity. The need to offset the loss of well-being incurred by past uncertainties concerning the safety of their homelands should be given a high priority when exploring with the Rongelap community solutions to redress the radiological status of their islands .