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MARSHALL ISLANDS DOSE ASSESSMENT AND RADIOLOGICAL PROGRAM

BIKINI · ENEWETAK · RONGELAP · UTRŌK

Individual Radiation Protection Monitoring in the Marshall Islands: Rongelap Atoll (2002-2004)

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As a hard copy supplement to Marshall Islands Program website (http://eed.llnl.gov/mi/), this document provides an overview of the individual radiological surveillance monitoring program on Rongelap Island (Rongelap Atoll) along with a full disclosure of all verified measurement data (2002-2004)

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Rongelap Whole Body Counting Facility
Rongelap Atoll
Republic of the Marshall Islands

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INTRODUCTION

The United States Department of Energy (U.S. DOE) has recently implemented a series of strategic initiatives to address long-term radiological surveillance needs at former U.S. nuclear test sites in the Marshall Islands. The plan is to engage local atoll communities in developing shared responsibilities for implementing radiation protection monitoring programs for resettled and resettling populations in the northern Marshall Islands. Using the pooled resources of the U.S. DOE and local atoll governments, individual radiological surveillance programs have been developed in whole body counting and plutonium urinalysis in order to accurately assess radiation doses resulting from the inhalation and/or ingestion of residual fallout radionuclides in the environment.

Permanent whole body counting facilities have been established at three separate locations in the Marshall Islands including Rongelap Atoll (Figure 1). These facilities are operated and maintained by Marshallese technicians with scientists from the Lawrence Livermore National Laboratory (LLNL) providing on-going technical support services. Bioassay samples are collected under controlled conditions and analyzed for plutonium isotopes at the Center for Accelerator Mass Spectrometry at LLNL using state-of-the art measurement technologies. We also conduct an on-going environmental monitoring and characterization program at selected sites in the northern Marshall Islands. The aim of the environmental program is to determine the level and distribution of important fallout radionuclides in soil, water and local foods with a view towards providing more accurate and updated dose assessments, incorporating knowledge of the unique behaviors and exposure pathways of fallout radionuclides in coral atoll ecosystems. These scientific studies have also been essential in helping guide the development of remedial options used in support of island resettlement.

Together, the individual and environmental radiological surveillance programs are helping meet the informational needs of the U.S. DOE and the Republic of the Marshall Islands. Our updated environmental assessments provide a strong scientific basis for predicting future change in exposure conditions especially in relation to changes in life-style, diet and/or land-use patterns. This information has important implications in addressing questions about existing (and future) radiological conditions on the islands, in determining the cost and predicting the effectiveness of potential control measures, and

Figure 1. Whole body counting system on Rongelap Island with a plastic calibration phantom sitting in the chair.

in general policy support considerations. Perhaps most importantly, the recently established individual radiological surveillance programs provide affected atoll communities with an unprecedented level of radiation protection monitoring where, for the first time, local resources are being made available to monitor resettled and resettling populations on a continuous basis.

As a hard copy supplement to Marshall Islands Program website (http://eed.llnl.gov/mi/), this document provides an overview of the individual radiation protection monitoring program established for resettlement workers living on Rongelap Island along with a full disclosure of all verified measurement data (2002-2004). Readers are advised that an additional feature of the associated web site is a provision where users are able calculate and track doses delivered to volunteers (de-identified information only) participating the Marshall Islands Radiological Surveillance Monitoring Program.

BRIEF HISTORY OF NUCLEAR TESTING IN THE MARSHALL ISLANDS

Immediately after WWII, the United States created a Joint Task Force to develop a nuclear weapons testing program. Planners examined a number of possible locations in the Atlantic Ocean, the Caribbean, and the Central Pacific but decided that coral atolls in the northern Marshall Islands offered the best advantages of stable weather conditions, fewest inhabitants to relocate and isolation with hundreds of miles of open-ocean to the west where trade winds were likely to disperse radioactive fallout. During the period between 1945 and 1958, a total of 67 nuclear tests were conducted on Bikini and Enewetak Atolls and adjacent regions within the Republic of the Marshall Islands. The most significant contaminating event was the Castle Bravo test conducted on March 1, 1954 (Figure 2). Bravo was an experimental thermonuclear device with an estimated explosive yield of 15 MT (USDOE, 2000), and led to widespread fallout contamination over inhabited islands of Rongelap and Utrōk Atolls, as well as other atolls to the east of Bikini. Today, the United States Department of Energy (U.S. DOE) through the Office of Health Studies continues to provide environmental monitoring, healthcare and medical services on the affected atolls.

Key directives of the Marshall Islands Dose Assessment and Radioecology Program conducted at the Lawrence Livermore National Laboratory are (1) to provide technical support services and oversight in establishing radiological surveillance monitoring programs for resettled and resettling populations in the northern Marshall Islands; (2) to develop comprehensive assessments of current (and potential changing) radiological conditions on the islands; and (3) provide recommendations for remediation of contaminated sites and verify the effects of any actions taken

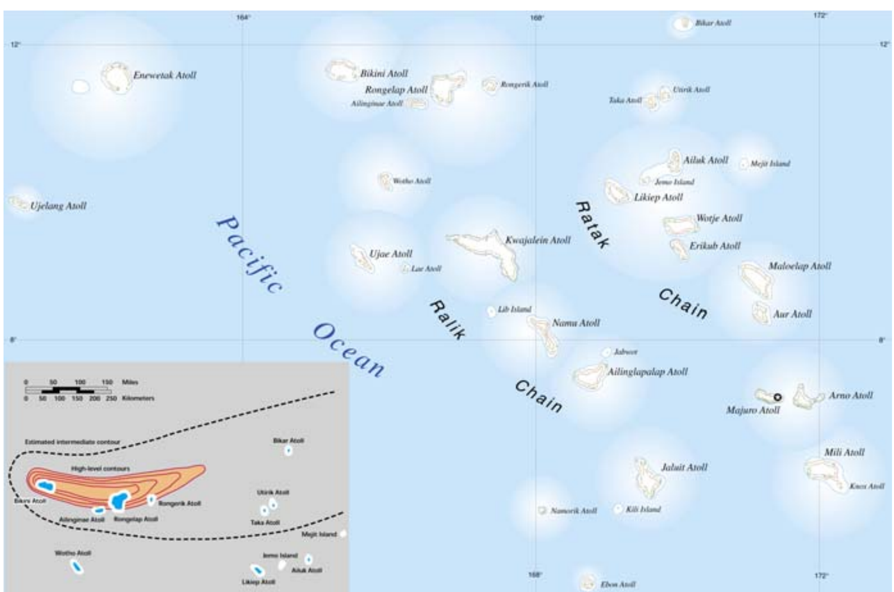
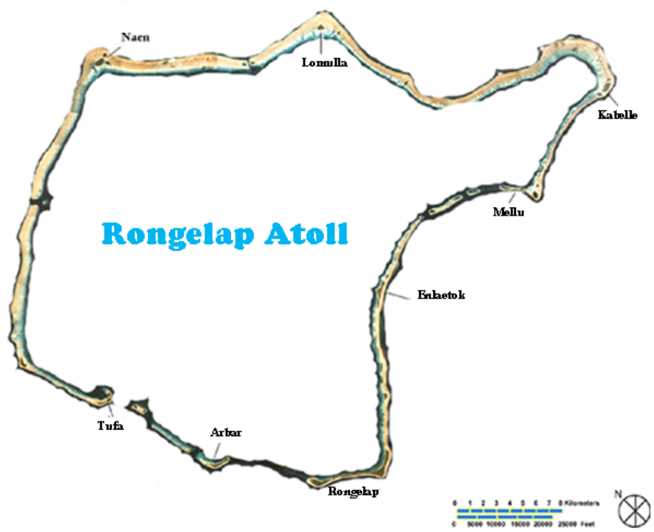


Figure 2. Map of the Republic of Marshall Islands showing the fallout pattern from the Bravo nuclear test conducted on March 1 of 1954.

RONGELAP ATOLL

People & Events | Resettlement of Rongelap Atoll



People and Events on Rongelap Atoll

On March 1, 1954 the United States conducted a nuclear test on Bikini Atoll in the northern Marshall Islands code named Bravo that led to widespread fallout contamination over inhabited islands of Rongelap, Ailingnae and Utrōk Atolls. Prior to Bravo, little consideration was given to the potential health and ecological impacts of fallout contamination beyond the immediate vicinity of the test sites. A total of 64 people living on Rongelap Atoll (including those people on Ailingnae Atoll) received significant exposure to radioactive fallout and had to be evacuated to Kwajalein Atoll for medical treatment. The Rongelap community spent the next 3 years living on Ejit Island (Majuro Atoll) before returning home to Rongelap in June 1957. However, growing concerns about possible long-term health effects associated with exposure to residual fallout contamination on the island prompted residents to relocate again to a new temporary home on Mejatto Island in 1985 (Kwajalein Atoll). The people of Rongelap are still resident on Mejatto today although parts of the community have split off to live on Ebeye Island (Kwajalein Atoll) and Majuro Atoll.

The Rongelap community has always expressed a strong desire to return to their ancestral homeland. Through the Rongelap Resettlement Act, the U.S. Congress approved and continued a 1996 resettlement agreement between the United States and the Rongelap Atoll Local Government, and extended distribution authority for ten years to advance resettlement. As a part of the 1996 resettlement agreement, a Phase I resettlement program was initiated in 1998. The U.S. Department of Energy, the Rongelap Atoll Local Government and the Republic of the Marshall Islands have since signed a Memorandum of Understanding (MOU, 1999) outlining shared provisions in support of resettlement. Under this agreement, scientists from the Lawrence Livermore National Laboratory were tasked with developing individual radiation protection monitoring programs for resettlement workers and to verify the effects of the remediation program.

Resettlement of Rongelap Atoll

Phase I resettlement of Rongelap Island is nearing completion. Rongelap Island now boasts a host of modern-day facilities including electrical power, a freshwater supply, a modern field station, a new runway, a whole-body counting facility and an adjoining health physics laboratory, and a large concrete pier.

The remedial actions adopted under the Rongelap Resettlement Program are based on recommendations provided by scientists from the Lawrence Livermore National Laboratory. The remediation technique being employed is referred to as the *combined option* and involves replacing contaminated surface soil in the community area, where people spend most of their time, with a layer of clean crushed coral fill (Figure 3 & 4) and addition of potassium chloride fertilizer to the surrounding agricultural fields. Limited soil removal and addition of coral fill reduces external exposure to gamma/beta radiation as well as inhalation exposure to resuspended radioactive contaminants in the air that people breathe. The addition of potassium fertilizer to the agricultural areas partially blocks cesium-137 uptake into plants, especially into the fruits of the major subsistence crops such as coconut. It is expected that addition of potassium fertilizer on Rongelap Island will reduce the ingestion dose from ^{137}Cs to less 20-30% of the pretreatment level and, at the same time, help support plant growth and increase the productivity of plants (see related information under Bikini Atoll).

After living in exile for nearly 2 decades, the prospect that the people of Rongelap will soon return to their ancestral homeland is an important milestone in the history of the Marshall Islands Program. Moreover, the Rongelap resettlement program is among the first in which a local government has engaged the U.S. Department of Energy to develop shared provisions to monitor the return of the population.

Figure 3. Satellite image of Rongelap Island showing (insert) the location of the community center where surface soil was removed and replaced with clean crushed coral fill (approximately 11.4 ha or 36.1 acres). The initial phase of this work was completed in March 2001. A detailed *in-situ* gamma monitoring survey of the entire area was conducted in May 2001. The results of this study show that the combination of limited soil removal and addition of crushed coral fill was very effective in reducing the external exposure rates. The clean surface layer of coral also has the added benefit of reducing potential exposures from inhalation and ingestion of plutonium and/or other long-lived radionuclides present in the soil (Hamilton *et al.*, 2001).

Figure 4. View of the village area on Rongelap Island after the addition of crushed coral fill and showing view with the restored church in the background.

WHOLE BODY COUNTING

What is Whole Body Counting? | What Will the Whole Body Counting Show? | Estimating Doses from Cesium-137 Based on Whole Body Counting | Doses to Rongelap Resettlement Workers from Internally Deposited Cesium-137

What is Whole Body Counting?

The whole body counting systems installed in the Marshall Islands contain large volume sodium iodide radiation detectors that measure gamma rays coming from radionuclides deposited in the body. The detector systems are modeled after the 'Masse-Bolton Chair' design (Figure 3) and can be used to detect high-energy gamma-emitting radionuclides from the decay of cesium-137, cobalt-60 and potassium-40 in most of the body and all of the internal organs. Using established protocols the whole body counting measurement data are converted into an annual effective dose using specially designed computer software (Canberra, 1998a; 1998b).

There are currently three operational whole body counting facilities in the Republic of the Marshall Islands including Rongelap Island. The whole body counting systems are calibrated using a mixed-gamma point source. The point source calibration procedure was developed by cross-reference to a Bottle Man-akin Absorption (BOMAB) phantom (or human surrogate) calibration source containing a standard mix of gamma-emitting radionuclides traceable to the U.S. National Institute of Standards and Technology (NIST).

Wherever possible, the whole body counting program in the Marshall Islands is conducted using the same quality requirements as established under the U.S. Department of Energy Laboratory Accreditation Program (DOELAP) for internal dosimetry. Background and other quality control check counts are performed on a daily basis to ensure that the measurement system conforms to all applicable quality requirements. Also, each whole body counting facility participates in external performance testing exercises with the Hazards Control Department at the Lawrence Livermore National Laboratory using '5 bottle phantoms' prepared under contract by the Oak Ridge National Laboratory. These performance test samples are distributed around each of the facilities including a *mirror* whole body counting system located at Livermore. The performance of the facilities is then evaluated by comparing results with those obtained by the Hazards Control Department at the Lawrence Livermore National Laboratory–a DOELAP accredited facility–and with the reference values supplied by the

Oak Ridge National Laboratory. Under this quality assurance program, the data returned by these remote facilities in the Marshall Islands has consistently exceeded ANSI 13.30 criteria for measurement accuracy and precision.

Local Marshallese technicians are responsible for all daily operations within the facilities including scheduling of personal counts, performing systems performance checks, data reduction, and reporting to program volunteers (Figure 5). The technicians receive an initial six weeks of intensive training at the Lawrence Livermore National Laboratory and are employed to run the facilities for up to 40 hours per week. Scientists from the Lawrence Livermore National Laboratory provide on-going technical support services, advanced training in whole body counting and basic health physics, and perform a more detailed data quality assurance appraisal before the data are released in reports or posted to the world-wide web.

Figure 5. Whole body counting technician, Mr. Ericson Arelong, working in the Rongelap Whole Body Counting Facility.

What Will the Whole Body Counting Show?

The main pathway for exposure to residual fallout contamination in the northern Marshall Islands is through ingestion of cesium-137 contained in locally grown foods such as coconut, *Pandanus* fruit and breadfruit. The strategic objective of the whole body counting program in the Marshall Islands is to offer island residents an unprecedented level of radiation protection monitoring until it is clearly demonstrated that radiation surveillance measures can be relaxed. The value of this type of radiation protection monitoring program lies in the fact that whole body count data provides a direct measure of the full range of radionuclide uptakes into the local population. Information about potential *high-end* health risks and seasonal fluctuations in the body burden of cesium-137 within exposed Marshallese can be assessed from measurement data rather than relying on a range of assumptions from different dietary scenarios.

In combination with environmental monitoring data, residents who receive a whole body count showing the presence of cesium-137 can now make an informed decision about their eating habits or life-style based on what is considered a “safe” or acceptable health risk. The Republic of the Marshall Islands Nuclear Claims Tribunal has adopted a standard for cleanup of radioactively contaminated sites of 0.15 millisievert (mSv) per year (or 15 mrem per year) [EDE, Effective Dose Equivalent] using a lifetime cancer risk criterion recommended by the U.S. Environmental Protection Agency (EPA). As displaced communities return to their ancestral homelands, the Marshall Islands Whole Body Counting Program will allow the U.S. Department of Energy to monitor the return of the people and help ensure that the radiation related health risks remain at or below these established standards.

Estimating Doses from Cesium-137 Based Whole Body Counting

People living in the Marshall Islands may be exposed to cesium-137 contained in their diets from eating locally grown food crop products such as coconut. Whole body counting provides a direct measure of the amount of cesium-137 inside the body of people. The biokinetic behavior of cesium-137 inside the human body is well known and allows information from the whole body counter to be converted to a radiation dose. The radiation dose is what is used to quantify the potential human health risk associated with radiation exposure. The dosimetric data displayed in graphics presented in this report and the associated web site are based on the calendar year committed effective dose equivalent (CEDE) from intakes of radionuclides in the year of measurement projected over 70 years [Appendix 3, see under Daniels *et al.*, (2006)]. Dose equivalent is given in units of rem, the conventional units used by federal and state agencies in the United States. The SI unit of dose equivalent is the joule per kilogram or sievert (Sv). Doses from exposure to environmental radioactivity (natural or manmade) are normally expressed as 1/1000th of the base unit, i.e., in millirem (mrem) or millisievert (mSv). 1 mSv is equal to 100 mrem.

INFORMATION NOTE

We have recently updated our methodologies for computing doses from the whole body counting and plutonium urinalysis programs (refer to the Technical Basis Document, Daniels et al., 2006). This new methodology uses a 50 y dose commitment and complies more fully with ICRP methodology. The algorithms developed to allow users to compute doses directly from the measurement data made available on the web site are also consistent with this new methodology.

Doses to Rongelap Resettlement Workers from Internally Deposited Cesium-137

The individual (de-identified) measurement data developed under the whole body counting program on Rongelap Island are tabulated in Appendix I, TABLE 1.

The frequency distribution of the committed effective dose equivalent received by resettlement workers and other visitors to Rongelap Island (1999-2004) from exposure to dietary cesium-137, annualized to the year of measurement, is shown in Figure 6.

The majority of resettlement workers and visitors to Rongelap Island received internal doses from intakes of cesium-137 of less than 1 mrem per year. The average committed effective dose equivalent for each year of measurement was 0.6±0.7 mrem in 1999 (N = 41), 0.5±0.6 mrem in 2000 (N = 66), 0.3±0.5 mrem in 2001 (N= 102), 0.3±0.5 mrem in 2002 (N=104), 0.3±0.7 mrem in 2003 (N=26), and 1.9±1.8 mrem in 2004 (N=36). The corresponding maximal individual committed effective dose equivalent for each year of measurement was 3.4 mrem, 3.4 mrem, 2.4 mrem, 2.3 mrem and 8.1 mrem, respectively.

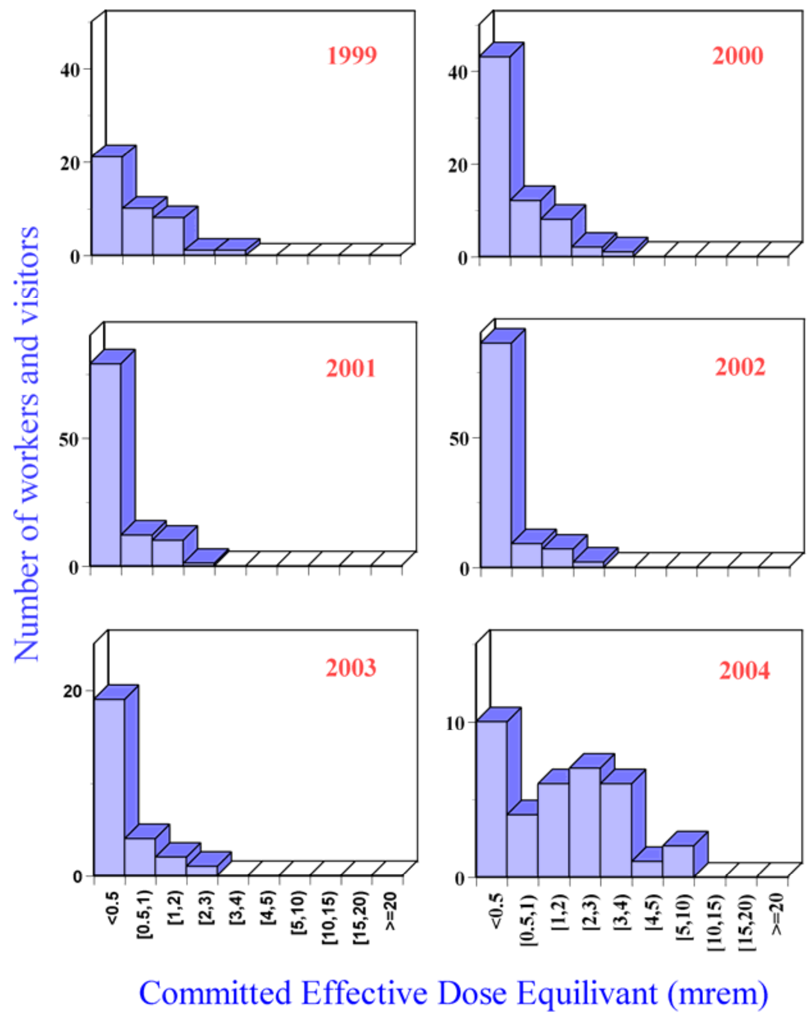
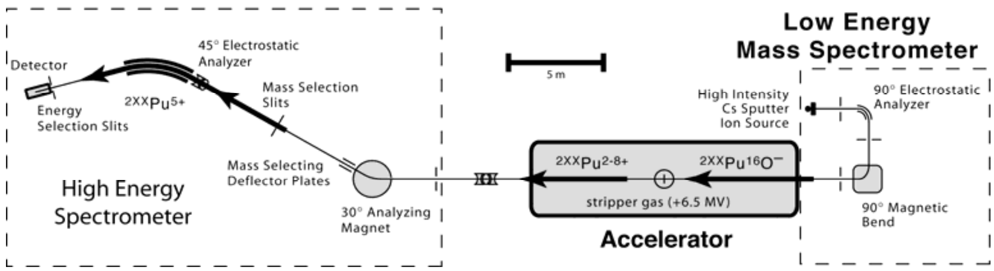


Figure 6. Frequency distribution of the committed effective dose equivalent received by Rongelap resettlement workers from internally deposited cesium-137 annualized to the year of measurement (1999-2004). Summary graphics for each measurement year are based on the committed dose received over 70 year; refer supporting documentation (Daniels *et al.*, 2006, Appendix 3).

The committed effective dose equivalent for internally deposited cesium-137 in resettlement workers and other visitors to Rongelap can be compared with natural background doses of 140 mrem per year in the Marshall Islands and about 300 mrem per year in the United States. Rongelap resettlement workers are also receiving doses from ingestion of cesium-137 that are significantly below the annual dose criteria of 100 mrem per year, excluding medical irradiation, imposed in 10CRF Part 20 (NRC, 1994) for protection of the public. Consequently, the whole body counting program on Rongelap appears to demonstrate that resettlement workers are not being exposed to significantly elevated levels of cesium-137in their diets. However, permanent residents living on Rongelap Atoll are more likely to adopt a traditional lifestyle and consume larger quantities of locally grown foods. Accordingly, we recommend that similar action be taken in developing a whole body counting program to monitor the return of the resettled population.

PLUTONIUM URINALYSIS (BIOASSAY) MONITORING

What is Plutonium Urinalysis | Routes of Exposure | Purpose of Plutonium Urinalysis Monitoring | Methods of Detection | Methods Validation | Plutonium Urinalysis Monitoring on Rongelap | Plans for the Future



Schematic diagram of the systems configuration for measuring plutonium isotopes based on Accelerator Mass Spectrometry (AMS). AMS is about 200 to 400 times more sensitive than standard techniques commonly employed in routine internal dosimetry programs, and far exceeds the standard requirements established under the latest United States Department of Energy regulation 10CFR 835 for in vitro bioassay monitoring of alpha-emitting radionuclides such as plutonium-239.

What is Plutonium Urinalysis Monitoring?

Plutonium urinalysis is a very sensitive *in-vitro* bioassay measurement technique used to determine the amount of plutonium in human urine as a means of estimating the systemic burden (or total amount of plutonium) in the human body. Plutonium urinalysis tests are performed by collecting urine from individuals over a 24-hour period. The test turns a urine sample into a powder which scientists analyze by counting the number of plutonium atoms contained in the sample. Under the Marshall Islands Radiological Surveillance Program, we have developed a new state-of-the-art technology for measuring the amount of plutonium in urine based on Accelerator Mass Spectrometry.

Everybody has a small amount of plutonium in their bodies. Plutonium occurs in nature at very low concentrations but human exposure to plutonium increased dramatically through the 1950s as a result of global fallout from atmospheric nuclear weapons testing. Marshall Islanders are potentially exposed to higher levels of contamination in the environment as a result of close-in and regional fallout deposition.

Routes of Exposure

Plutonium is an important radioactive element produced in nuclear explosions. Plutonium emits alpha particles (or alpha-rays). Alpha-particles have a short range in tissue (about ~40 μm) and cannot be measured by detectors external to the body. However, as heavy slow moving charged particles they have a high relative effectiveness to disrupt or cause harm to the content of biological cells. As a consequence, *in-vitro* bioassay tests have been developed to test for the presence of systemic plutonium in the human body based on measured urinary excretion patterns and modeled metabolic behaviors of the absorbed isotopes.

The main pathway for exposure to plutonium in humans is inhalation of contaminated dust particles in the air that people breathe. Inhaled or ingested plutonium may eventually end up in various organs–especially the lung, liver and bone–resulting in continuous exposure of these tissues to alpha particle radiation. Plutonium remains in the body for a long time but the systemic uptake of plutonium for people living in the northern Marshall Islands is still expected to be very low (Robison *et al.*, 1980; 1982; 1997).

Inhalation exposure can be estimated from the product of the soil concentration, resuspension enhancement factors and inhalation dose conversion factors for radionuclides of interest. These estimates show that the projected dose contribution from exposure to plutonium in the Marshall Islands is less that 5% of the total lifetime dose from exposure to residual fallout contamination in the environment (Robison *et al.*, 1980; 1982; 1997). However, plutonium is a major concern to people living in the northern Marshall Island because of its long half-life and persistence in the environment. Radioactive debris deposited in lagoon sediments of coral atolls formed a reservoir and source term for remobilization and transfer of plutonium through the marine food chain and potentially to man. Also, elevated levels of plutonium in the terrestrial environment from close-in fallout deposition represent potential long-term inhalation and/or ingestion hazards. Early characterization of the terrestrial environment also revealed the presence of hotspots containing milligram-sized pieces of plutonium metal that clearly required some form of remediation (DOE, 1982). Consequently, dose assessments and atoll rehabilitation programs in the Marshall Islands have historically given special consideration to monitoring plutonium uptake in resettled and resettling populations.

What is the Purpose of Plutonium Urinalysis Monitoring in the Marshall Islands?

Plutonium urinalysis is a measurement technique that ultimately provides information to individuals on the amount of plutonium they have in their bodies. Although plutonium is expected to be a minor contributor to the total manmade dose, it is a concern to people living in the northern Marshall Islands who are potentially exposed to elevated levels of plutonium in the environment from close-in or regional fallout deposition. Consequently, the United States Department of Energy has agreed to monitor resettlement workers and perform a limited number of urinalysis tests on island residents using advanced measurement technologies available at the Lawrence Livermore National Laboratory. The measurement technique currently employed at the Lawrence Livermore National Laboratory is based on Accelerator Mass Spectrometry. AMS is about 200 to 400 times more sensitive than monitoring techniques commonly employed in internal dosimetry monitoring programs in the United States, and far exceeds the standard requirements established under the latest Department of Energy regulation 10CFR 835 for *in vitro* bioassay monitoring of alpha-emitting radionuclides such as plutonium-239.

The Marshall Islands Plutonium Urinalysis Monitoring Program was implemented under the following action criteria:-

1) To provide more reliable and accurate data to assess *baseline* and potentially significant incremental uptakes of plutonium within resettled and/or resettling populations in the Marshall Islands.

2) To monitor plutonium exposure in critical populations groups such as field workers engaged in soil remediation or agriculture.

3) To determine occupational and/or public exposures to plutonium in the Marshall Islands and confirm they are below levels that will impact human health.

4) To participate in analytical proficiency testing programs to ensure that the accuracy and reliability of our measurement data meets all applicable quality requirements, and that all procedures are carefully documented.

5) To document and test the reliability of using environmental data to assess human exposure (and uptake) of plutonium in a coral atoll ecosystem.

Methods of Detection of Plutonium in Urine

Researchers from the Brookhaven National Laboratory (BNL) were the first to use whole body counting and plutonium urinalysis techniques to assess intakes of internally deposited radionuclides in Marshallese populations (Sun *et al.*, 1992; 1995; 1997a; 1997b; 1997c; Conard 1982; Lessard *et al.*, 1984; Miltenberger *et al.*, 1981; Greenhouse *et al.*, 1980). Classical methods for evaluating intakes of plutonium in bioassay samples include alpha-spectrometry and fission-track analysis. Alpha spectrometry cannot distinguish between plutonium-239 and plutonium-240, and results are normally reported for the sum of the two isotopes. Moreover, alpha spectrometry lacks the necessary detection sensitivity to accurately assess systemic plutonium uptake and dose in the Marshall Islands (Hamilton *et al.*, 2004). Fission Track Analysis is limited to the quantification of plutonium-239 but with a reported detection limit (MDA, Minimum Detection Amount) of around 1 to 3 microBecquerel (μBq) of plutonium-239 offers greatly improved potential for assessing likely uptakes associated with low-level chronic exposure to plutonium in the environment.

Under the Marshall Islands Plutonium Urinalysis Program, urine samples were initially sent to the University of Utah for analysis of plutonium using fission track analysis. Fission is a process where heavy nuclei such as plutonium and uranium break up into two large fragments. Fission may occur spontaneously or be induced by collisions with neutrons. During fission track analysis samples are exposed to a source of neutrons in a reactor in contact with a quartz or plastic slide. Any resulting fission fragments leave behind tracks on the slide that can be counted under an optical microscope to determine the amount of plutonium present. Historically, fission track analysis has been plagued with a number of deficiencies including the use of less than reliable and tedious preparative methods, low chemical yields, contamination issues and inaccurate quantification. The University of Utah and the Brookhaven National Laboratory improved on the fission track process methodology, and adopted a more rigorous approach to data reduction and quality assurance in support of urinalysis testing programs in the Marshall Islands.

More recently, scientists from the Lawrence Livermore National Laboratory have developed a low-level detection technique for determination of plutonium isotopes in bioassay samples based Accelerator Mass Spectrometry (Brown *et al.*, 2004; Hamilton *et al.*, 2006). The technique has vastly improved the quality and reliability of assessments of urinary excretion of plutonium by Marshall Islanders and avoids many of the disadvantages of using conventional atom counting techniques or other competing new technologies.

INFORMATION NOTE

There are two main long-lived plutonium isotopes contained in nuclear debris from weapons testing isotopes–namely plutonium-239 (^{239}Pu) and plutonium-240 (^{240}Pu). The isotopic composition of plutonium (i.e., the relative amounts of ^{239}Pu and ^{240}Pu) may vary significantly depending on the source of plutonium. For example, the ^{240}Pu/^{239}Pu content of nuclear fallout from high–yield atmospheric nuclear tests in the Marshall Islands produced ^{240}Pu/^{239}Pu atom ratio signatures of ~0.3-0.35 compared with that present in integrated global fallout deposition (~0.18) or unfissioned nuclear fuel (~0.05). Consequently, it may be possible to use urinalysis testing and plutonium isotope measurements as an investigative tool to assess source specific exposures to Bravo as well as other nuclear test events.

Method Validation

Method <u>validation</u> is the process used to monitor and document the quality of the measurement data. Methods validation testing under the Marshall Islands Plutonium Urinalysis Program has included the labs participation in an interlaboratory exercise organized by the U.S. National Institute of Standards and Technology (NIST). The results of this exercise clearly demonstrate that Accelerator Mass Spectrometry is well suited for detection of μBq concentrations of plutonium-239 and plutonium-240 in urine (Figure 7) (Marchetti *et al.*, 2002). An independent report on the results of this intercomparison exercise was recently published in the open scientific literature (McCurdy *et al.*, 2005).

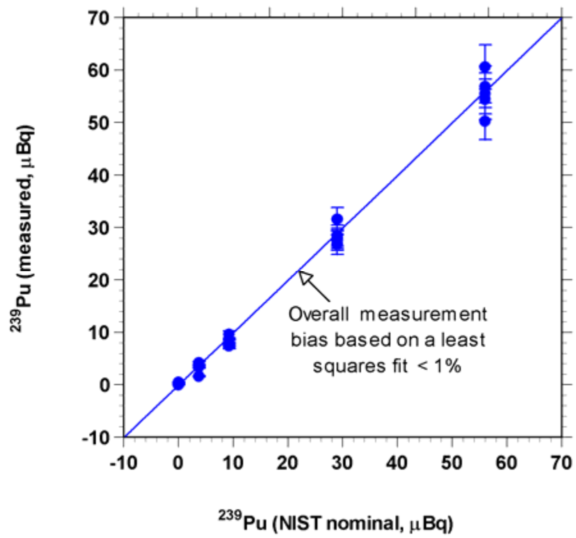


Figure 7. Results of a NIST interlaboratory exercise on determination of plutonium-239 in synthetic urine in the microBecquerel (μBq) range.

We also continue to test the performance of the technique by analyzing externally-prepared quality control natural urine samples artificially spiked with known amounts of plutonium. The quality control samples are prepared under contract with the Oak Ridge National Laboratory and analyzed along with routine bioassay samples collected from the Marshall Islands. The activity concentration of plutonium-239 in the quality control samples is kept below 200 μBq in order to avoid possible cross-contamination problems, and the plutonium-240/plutonium-239 atom ratio approximates that observed in integrated worldwide fallout deposition, i.e., ~0.2. The results of the quality control analyses are sent to Oak Ridge National Laboratory researchers for review who, in return, prepare a data quality assurance report. All quality control data must pass ANSI 13.30 performance criteria for accuracy and precision before acceptance of any routine bioassay measurement data. The average combined measurement bias and precision based on spiked quality samples analyzed through March 2004 were -1.2% and ±5.1% for plutonium-239, and +6.1% and ±10.3% for plutonium-240, respectively. The results of the plutonium-239 measurements are shown in Figure 8. Based on the results from these performance tests we consider that the methodologies employed under the Marshall Islands Urinalysis Program to represent the current state-of-the-art in the field.

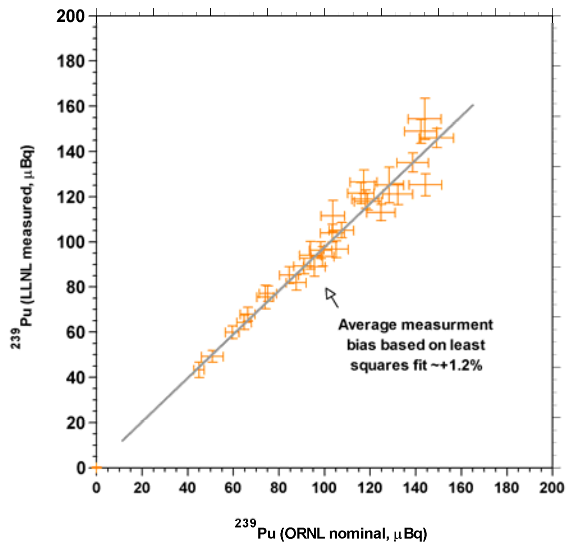


Figure 8. Results of plutonium-239 measurements in externally-prepared natural matrix spiked quality control samples.

Plutonium Urinalysis Monitoring on Rongelap

The Individual (de-identified) measurement data developed under the Marshall Islands Plutonium Urinalysis Monitoring Program on Rongelap Island are tabulated in Appendix I, TABLE 2.

The bioassay sampling program was designed to monitor the systemic uptake of plutonium into resettlement workers who were either actively involved in soil remediation or lived on Rongelap Island for extended periods as part of Phase I resettlement support operations. The geometric mean in the urinary excretion of plutonium-239 from resettlement workers stationed at Rongelap during the period between 1999 and 2003 was ~0.2 µBq per 24-hour void (N = 171). This compares with a mean of -0.01 µBq of plutonium-239 measured in a comparable set of field blanks (N = 21, excluding one outlier) prepared and analyzed over the same period. A more detailed statistical analysis of these data will be given elsewhere (Bogen *et al*., 2006).

Urinary excretion of plutonium from Marshallese populations will consist of a long-term <u>baseline</u> component from residual systemic burdens acquired from all previous exposures plus any prompt (new) contributions (and eventual long-term excretion) resulting from recently acquired systemic burdens of plutonium. It is estimated that residents of the Northern Hemisphere have acquired sufficiently high systemic burdens of plutonium from exposure to global fallout contamination to produce urinary excretion rates of plutonium of around 2-4 μBq per 24-h void (Boecker *et al.*, 1991). Based on fission track analysis of urine samples collected by scientists from Brookhaven National Laboratory, the systematic deposition of plutonium from exposure to global fallout contamination in the Marshall Islands is estimated to produce background urinary excretion rates of plutonium of around 1-2 μBq per 24-h void (National Research Council, 2004) or about an order of magnitude higher than levels observed in our studies. Consequently, we believe that higher quality bioassay data based on Accelerator Mass Spectrometry will provide a more accurate basis for assessing small incremental uptakes of plutonium in the resettled population on Rongelap. Similarly, the sensitivity of the method is such that we may be able to track long-term changes in the availability and transfer of plutonium through the marine and/or terrestrial pathways to man.

The vast majority of the bioassay samples collected from Rongelap resettlement workers contained less than the critical level of plutonium to provide measurements with an acceptable level of precision and accuracy. Nonetheless, we can say that the systemic burden of plutonium in Rongelap resettlement workers is generally very low and well within the background range expected for people living elsewhere in the Northern Hemisphere. This would normally negate the necessity to assign doses to the individual measurements. However, for completeness, we attempt to assign a dose to all our measurement data using default assumptions (refer associated Technical Basis Document, Daniels *et al.*, 2006).

The range of estimates for the committed effective dose equivalent from systemic burdens of plutonium measured in resettlement workers temporarily housed on Rongelap for measurement years between 1999 and 2003 are shown in Figure 9. The committed dose shown in summary graphics on this web page is the dose received over 70 years from the year of measurement; refer supporting documentation (Daniels, *et al.*, 2006, Appendix 3). Please note that the annualized dose criteria developed for remediation of radioactively contaminated sites (NCRP, 2004) is usually based on estimates of the total effective dose equivalent (TEDE) over 50 years and consists of the sum of the committed dose due to intakes of radionuclides during the measurement year (of which, plutonium is just one potential component) and the deep dose equivalent from external exposures in that year.

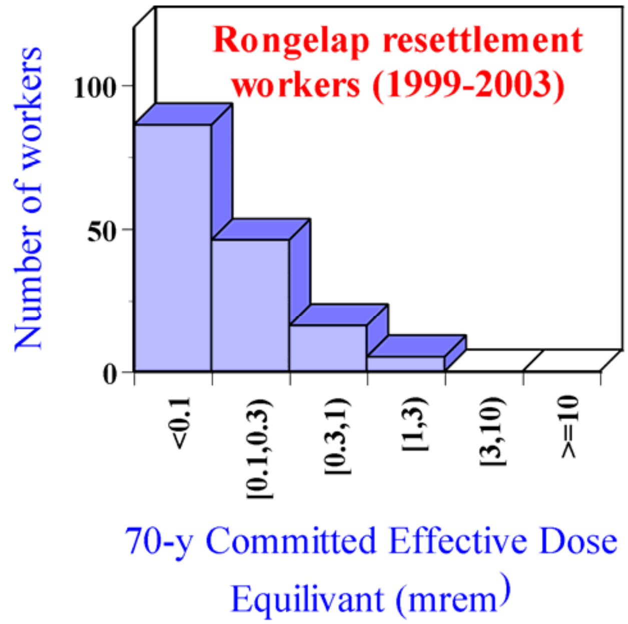


Figure 9. Frequency distribution of the committed effective dose equivalent from measured urinary excretion of plutonium by Rongelap resettlement workers during the year of measurement (1998 thru. 2003). Summary graphics are based on the committed dose received over 70 years from the year of measurement; refer supporting documentation (Daniels *et al.*, 2006, Appendix 3).

Plans for the Future

Some of the early urinary excretion data for plutonium in the Marshall Islands is of questionable quality because of the poor quantification sensitivity of the methods employed and/or general lack of adequate quality control. Consequently, we plan to collect additional bioassay samples from Rongelap Island to establish a baseline for those people resettling the island. After resettlement, any increase in the systemic burden of plutonium will result from very low-level chronic intakes of plutonium in food and/or soil or from inhalation of plutonium resuspended in the air. High quality baseline urinary excretion data will be required to provide a measure against which all future urinalysis tests on this population can be compared. Such provisions should help provide assurances to the resettled population that we will be able to adequately monitor the return of the population and assess any changes in the systemic uptake of plutonium associated with resettlement. Similarly, high quality baseline data for Rongelap as well as for other resettled population groups, e.g., Utrōk Atoll population group, will provide value in helping confirm that the levels of plutonium in people living in the Marshall Islands are consistently low and well within the range expected from exposure to global fallout contamination, Additionally, by establishing an updated and well documented baseline for urinary excretion of plutonium, we will be better able to track and monitor potential long-term changes in exposure conditions on the atoll, especially in relation to the remobilization and transfer of plutonium through the aquatic food chain or from changes in land use patterns.

MEASUREMENT DATA FROM THE INDIVIDUAL RADIOLOGICAL SURVEILLANCE PROGRAM

Introduction | Individual Measurement Database

Introduction

The individual (de-identified) measurement database developed in support of the Rongelap Resettlement Program is accessible over the world-wide web (Figure 10, http://eed.llnl.gov/mi/);

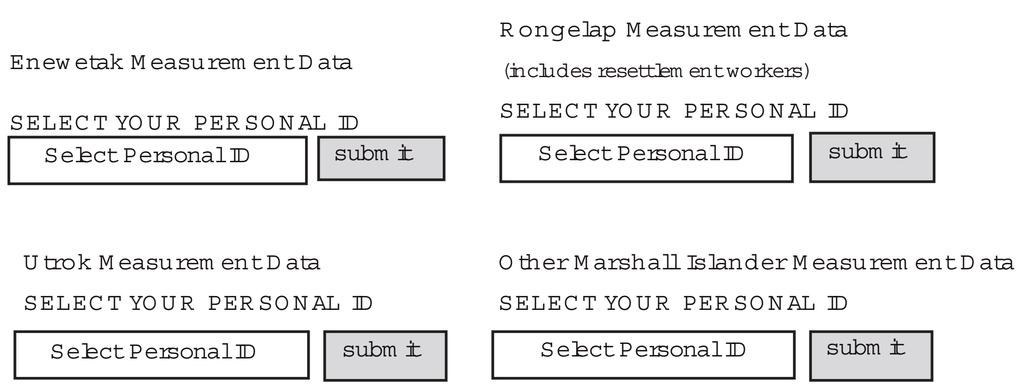


Figure 10. Layout of the menu to access measurement data from our whole body counting and plutonium urinalysis programs over the world-wide web (http://eed.llnl.gov/mi/).

Whole-body counting provides a direct measure of the total amount of cesium-137 present in the human body at the time of measurement. The amount of cesium-137 detected is usually reported in activity units of kilo-Becequerel (kBq), where 1 kBq equals 1000 Bq and 1 Bq = 1 nuclear transformation per second (t s^{-1}). The detection of plutonium-239 (^{239}Pu) and plutonium-240 (^{240}Pu) in bioassay (urine) samples indicates the presence of internally deposited (systemic) plutonium in the body. At Livermore, these measurements are performed using a state-of-the-art technology based on Accelerator Mass Spectrometry (AMS) (Brown *et al.*, 2004; Hamilton *et al.*, 2004; 2006). Under the Marshall Islands Plutonium Urinalysis Program, the urinary excretion of plutonium from program volunteers is usually described in activity units, expressed as micro-Becquerel (μBq) of $^{239+240}Pu$ (the sum of the ^{239}Pu and ^{240}Pu activity) excreted (lost) per day (d^{-1}); where 1 μBq d^{-1} = 10^{-6} Bq d^{-1} and 1 Bq = 1 t s^{-1}.

Individual Measurement Database

The website provides electronic access to verified whole body counting and plutonium urinalysis data developed under the Marshall Islands Radiological Surveillance Program at the Lawrence Livermore National Laboratory (1999-present). Please note that measurement data developed for Rongelap resettlement workers and other visitors to the island incorporates counts from all three of our whole body counting facilities and may include people from other affiliations with the exception of permanent residents from Enewetak and Utrōk Atolls.

DOSIMETRIC DATA AND METHODOLOGY

Introduction | Dose Methodology

Introduction

The individual (de-identified) dosimetric database developed in support of the Rongelap Atoll Resettlement Program is accessible over the world-wide web (Figure 11, http://eed.llnl.gov/mi/);

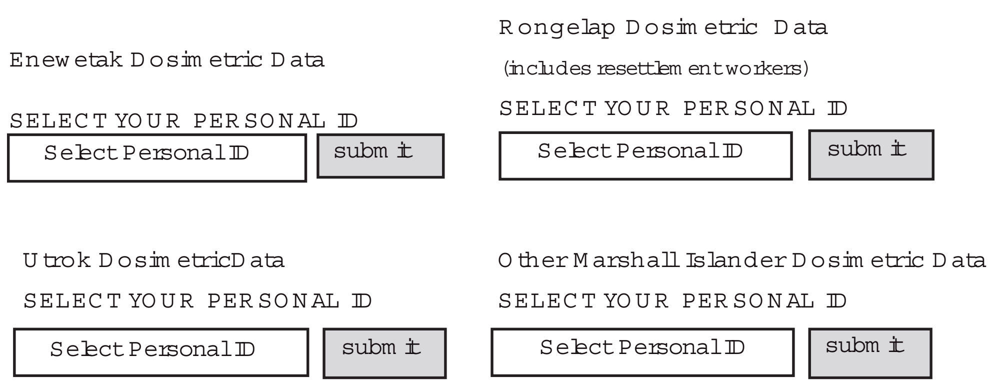


Figure 11. Layout of the menu to access dosimetric data from our whole body counting and plutonium urinalysis programs over the world-wide web (http://eed.llnl.gov/mi/).

In general, nuclear transformations emit energy and/or particles in the form of gamma rays, beta particles and alpha particles. Tissues in the human body may adsorb these emissions with the potential for any deposited energy to cause damage and disrupt biological function of cells. The general term used to quantify the extent of any health risk from radiation exposure is referred to as the dose. The equivalent dose is defined by the average absorbed dose in an organ or tissue weighed by the average quality factor for the type and energy of the radiation causing the dose. The effective dose equivalent (as applied to the whole body) is the sum of the average dose equivalent for each tissue weighted by tissue weighing factors. The SI unit of effective dose equivalent is the joule per kilogram (J kg^{-1}), named the sievert (Sv). The conventional unit often used by federal and state agencies in the United States is called a rem; 1 rem = 0.01 Sv.

Based on measurements of the internally deposited cesium-137 and/or the urinary excretion of plutonium, an estimate can be derived for either or both radionuclides of the annual number of nuclear transformations (t y^{-1}) that occurred in the body during the measurement year. For both radionuclides, this result is the time integral of activity in the body of an individual normalized over a one-year measurement period. In addition to nuclear transformations occurring during the year of measurement, additional transformations may occur in the future due to the presence of residual activity in the body at the end of the measurement year. The number of transformations derived from the residual radioactivity is usually evaluated up to 50 y in the future (a conservative maximum as defined by the United States (U.S.) Environmental Protection Agency (EPA) for members of the public) resulting in a committed dose. Accordingly, these future transformations will commit additional dose to the individual according to the biological half-life of the radioactive element of concern. For this reason, it is considered appropriate and conforming with the national and international recommendations of the United States Environment Protection Agency (U.S. EPA) and the International Commission on Radiological Protection (ICRP) that this additional dose commitment be assigned to the year of measurement. Consequently, dose reports issued under the Marshall Islands Radiological Surveillance Program are based on the Committed Effective Dose Equivalent (CEDE).

Dosimetric Methodology

The calendar year dose represents the sum of radionuclide-specific, age-dependent, committed effective dose equivalent for each monitored radionuclide. The total calendar years dose is calculated over a calendar year but only applies to the sum of the committed dose from cesium-137 and the 50-y integrated dose from plutonium (based on a time integral of any whole body counting and any available plutonium bioassay measurements performed during that year). When only one radionuclide is measured, the total dose assigned in a year and the CEDE for a specific radionuclide are identical. When more than one radionuclide is measured, the total annual 'calendar year' dose is the sum on the CEDE for each measured radionuclide. The calendar year dose estimates based on whole body counting and plutonium bioassay are conservative in nature, especially in relation to plutonium, and is only be comparable to the internal dose component of the EDE standard of 15 mrem per year as adopted by the Marshall Islands Nuclear Claims Tribunal for cleanup and rehabilitation of radioactively contaminated sites (to view the full report on the dose methodology, see Daniels *et al.*, 2006).

PROVIDING FOLLOWUP ON RESULTS

All volunteers participating in the Marshall Islands Individual Radiological Surveillance Program are issued preliminary copy of their dose report immediately after they receive a whole body count. Scientists from the Lawrence Livermore National Laboratory verify the measurement data and, if required, a revised dose report is generated and returned to the individuals concerned. Annualized doses of 10 mrem or above evoke a pre-determined action or investigation. These actions may include follow-up verification measurements, a dietary evaluation and/or a work history review. Below this level, default assumptions for assigning doses (refer Daniels *et al.*, 2006) are assumed to be valid and no further action is taken. Data may be withheld from the website while these investigations are on-going. Our action level is one-tenth of the investigation level used throughout the U.S. Department of Energy and is well below the 15 mrem per year standard adopted by the Republic of the Marshall Islands Nuclear Claims Tribunal for cleanup of radioactively contaminated sites. In addition, at the end of each calendar year, all program volunteers receive a final written report containing an estimate of their "*calendar year* dose" based on available data for the measurement year.

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GLOSSARY OF TERMS

Absorbed Dose

The absorbed dose is the energy deposited in an organ or tissue per unit mass of irradiated material. The common unit for absorbed dose is the rad, which is equivalent to 100 egs per gram of material. The international scientific community has adopted the use of different terms. The SI unit of absorbed dose is the joule per kilogram (J kg^{-1}) and its special name is the gray (Gy). One Gy is the same as 100 rad.

Activity

Activity is the rate of transformation or decay of a radioactive material. The SI unit of activity is the reciprocal second (s^{-1}) and its special name is the Becquerel. Federal and state agencies in the United States use conventional units where activity is given in curies (Ci); 1 Ci = 3.7 x 10^{10} Bq.

Alpha Particles

Alpha particles are one of the primary types of radiation associated with radioactivity and exist as energetic nuclei of helium atoms, consisting of two protons and two neutrons. Alpha rays are heavy, slow moving, charged particles that travel only one or two inches in air, and can be stopped by a piece of paper or the outer dead layer of human skin.

Background Radiation

The average person in the United States receives about 3.6 mSv (360 mrem) of ionizing radiation every year. About 3.0 mSv (300 mrem) per year comes from natural background radiation including cosmic radiation, radiation emitted by naturally occurring radionuclides in air, water, soil and rock, and radiation emitted by natural radionuclides deposited in tissues of organs; and about (0.6 mSv) 60 mrem from man-made sources such as exposures to diagnostic X-rays and consumer products (e.g., from smoking tobacco). The general worldwide contribution from radioactive fallout contamination is <0.3% of the average total annual dose. Exposures to natural background radiation vary depending on the geographic area, diet and other factors such as the composition of materials used in the construction of homes. The natural background radiation dose in the Marshall Islands is around 1.4 mSv (140 mrem) per year and is significantly less than what most people receive around the world.

Baseline

We have all been exposed to some level of worldwide fallout contamination. In the United States, the general population receives up to 0.015 mSv (1.5 mrem) or about 0.3% of the average total annual dose from exposure to worldwide fallout contamination from atmospheric nuclear weapons testing and about 0.005 (0.5 mrem) or about 0.1% of the average total annual dose from operations related nuclear power generation. Similarly, people living in the Marshall Islands will have very small quantities of internally deposited fallout radionuclides such as cesium-137, strontium-90 and plutonium in their bodies from worldwide contamination of food, air, water and soil. Assessments of possible increases in radiation exposure from elevated levels of fallout contamination in the northern Marshall Islands can only be made on the basis of comparisons with residual systematic burdens of radionuclides acquired from previous exposures to global fallout contamination. Under the Marshall Islands Radiological Surveillance Program, efforts are being made to improve on the reliability of measurements of background urinary excretion rates of plutonium from Marshallese populations against which the results of future bioassay measurements can be compared to accurately assess the impacts of resettlement on radiation exposure and dose.

Becquerel (Bq)

A Becquerel (abbreviated as Bq) is the International System (SI) unit for activity of radioactive material. One Bq of radioactive material is that amount of material in which one atom is transformed or undergoes 1 disintegration every second. Whole body counting and plutonium bioassay measurements are usually reported in activity units of kBq (kiloBecquerel) (1000 x 1 Bq) and μBq (microBecquerel) (1×10^{-6} x 1 Bq), respectively.

Biokinetic

The word ‘biokinetic’ is used here to describe the adsorption (uptake), distribution and retention of elements in humans.

Calibration

Calibration is the process of adjusting or determining the response or reading of an instrument to a standard.

Committed Dose Equivalent

Committed dose equivalent is the time integral of the dose-equivalent rate in a particular tissue that will be received by an individual following an intake of radioactive material into the body by inhalation, ingestion or dermal absorption. For adults the committed dose is usually the dose received over 50 years. For children, the committed dose is usually calculated from the age of intake to age 70 years. For these age groups the term ‘integrated dose equivalent’ is used.

Committed Effective Dose Equivalent (CEDE)

The committed effective dose equivalent is the committed dose equivalents to various tissues or organ in the body each multiplied by an appropriate tissue-weighing factor and then summed. The conventional unit for committed effective dose equivalence (CEDE) used by federal and state agencies within the United States is the rem. The international scientific (SI) unit of committed effective dose equivalent is called a sievert (Sv). One Sv is the same as 100 rem.

Critical Level (L_C)

The critical level is the amount of a count or final measurement of a quantity of an analyte at or above which a decision is made that the analyte is definitely present ($L_C \approx$ MDA/2).

Default Assumptions (used in assignment of dose)

The largest dose contributions attributable to exposure to residual nuclear fallout contamination in the Marshall Islands result from either internal exposure from intakes of radionuclides through ingestion, inhalation and/or absorption through the skin or external exposure from radionuclides distributed in the soil. External exposure rates can be measured directly using instrument surveys of the radiation field. The assignment of dose to internally deposited radionuclides is much more complicated. Biokinetic and dosimetric models developed by the International Commission on Radiological Protection (ICRP) are used to convert whole body burdens (from whole body counting or from *in vitro* bioassay tests such as urinalysis) into dose. In the case of a chronic exposure, organ and body burdens continue to build up over time until a steady state is reached where losses due to decay and excretion are balanced by intake and absorption. Cesium-137 has an effective half-life in an adult of about 110 days, and under chronic exposure conditions reaches a maximal dose contribution after about 2 years. By contrast, plutonium absorbed from the gastrointestinal or respiratory tract enters the blood stream and deposits in liver and bone with an effective half-life of 20 to 50 years. Only a small fraction of plutonium entering the blood stream is excreted in urine with the long-term excretion rate approaching 2×10^{-5} of the systemic body burden per day. Knowledge of excretion rates and time of exposure are important when interpreting urinalysis data. A more detailed discussion of the dose calculation methodology is given elsewhere (see under Daniels *et al.*, 2006).

Direct bioassay

The measurements of radioactive material in the human body utilizing instrumentation that detects radiation emitted from radioactive material in the body (synonymous with *in vivo* measurements).

Dose Assessment

The scientific process used to determine radiation dose and uncertainty in the dose.

Dose Equivalent

The dose equivalent is the adsorbed dose at a point in tissue multiplied by a biological effectiveness factor or quality factor for the particular types of radiation to cause biological damage. The conventional unit of dose equivalents used by federal and state agencies in the United States is the rem. A dose of 100 rem to an adult normally produces some clinical signs of radiation sickness and requires hospitalization. The international scientific unit for dose equivalent is the joule per kilogram (J kg^{-1}) and is called the sievert (Sv). One Sv is the same as 100 rem.

Effective Dose Equivalent

The effective dose equivalent for the whole body is the sum of dose-equivalents for various organs in the body weighted to account for different sensitivities of the organs to radiation. It includes the dose from radiation sources internal and/or external to the body. The effective dose equivalent is usually expressed in units of millirem (mrem). The international scientific unit for dose equivalent is the joule per kilogram (J kg^{-1}) and is called the sievert (Sv). One Sv is the same as 100 rem.

External Dose or Exposure

That portion of the dose equivalent received from radiation sources outside the human body.

Fission Track Analysis

During neutron irradiation heavy nuclei such as uranium and plutonium undergo nuclear fission with release of large fission fragments. This property has led to the development of a number of measurement techniques such as delayed neutron activation analysis and fission track analysis. Fission track analysis is a measurement technique commonly employed in plutonium urinalysis (bioassay) monitoring programs. Urine samples are chemically treated to remove plutonium. The plutonium is then mounted in contact with a special plastic or quartz slide known as solid-state nuclear track detector (SSNTD). The slide along with the sample is then irradiated in a reactor where neutron-induced fission of plutonium-239 (or uranium-235) causes emission of energetic fission fragments. Some of the fragments penetrate into the SSNTD damaging the integrity of the material before coming to rest. The SSNTD is separated from the sample and chemically etched to expose the damaged areas (known as fission tracks) on the detector surface. The fission tracks are then counted under an optical microscope. The amount of plutonium (and/or uranium) present in the sample is a function of the total number of tracks and the neutron flux.

Gamma-rays

Gamma-rays are electromagnetic waves produced by spontaneous decay of radioactive elements during de-excitation of an atomic nucleus. Sunlight also consists of electromagnetic waves but gamma-rays have a shorter wavelength and much higher energy. High-energy gamma-rays such as those produced by decay of cesium-137 may penetrate deeply into the body and affect cells. Gamma-rays from a cobalt-60 source are often used for cancer radiotherapy.

High-End Health Risk

High-end health risk is used here under the context that it refers to the maximally exposed individuals in a population.

In Vito

In vitro measurements are synonymous with indirect bioassay techniques, such as plutonium urinalysis.

In Vivo

In vivo measurements are synonymous with bioassay techniques, such as whole body counting.

Indirect bioassay

In direct bioassay are measurements used to determine the presence of and/or the amount of a radioactive material in the excreta, urine or in other biological materials removed from the body (synonymous with *in vitro* measurements).

Individual

An individual is any human being.

Internal Dose or Exposure

The internal dose is that portion of the dose equivalent received from radiation sources inside the human body.

Isotope

Atoms with the same number of protons but different numbers of neutrons are called isotopes of that element. We identify different isotopes by appending the total number of nucleons (the total number of proton plus neutrons in the nucleus of an atom) to the name of the element, e.g., cesium-137. Isotopes are usually written in an abbreviated form using the chemical symbol of the element. Two examples include ^{137}Cs for cesium-137 and ^{239}Pu for plutonium-239.

Minimum Detectable Amount (MDA)

The minimum detectable amount (MDA) is the smallest activity or mass of an analyte in a sample or person that can be detected with an acceptable level of uncertainty.

Quality Assurance

All those planned and systematic actions necessary to provide adequate confidence that an analysis, measurement or surveillance program will perform satisfactorily.

Quality Control

Quality Control is defined as those actions taken to control the attributes of a analytical process, system or facility according to predetermined quality requirements.

Radiation Dose (or mrem)

A generic term to describe the amount of radiation a person receives. Dose is measured in units of thousands of a roentegen equivalent man (rem) (called the millirem). The conventional unit used by federal and state agencies in the United States is the millirem (mrem). Dose is a general term used to assist in the management of exposure to radiation. The common international scientific (SI) unit for dose is the millisievert (mSv). One mSv is the same as 100 mrem.

Radioactivity

A natural and spontaneous process by which unstable atoms of an element emit energy and/or particles from their nuclei and, thus change (or decay) to atoms of a different element or a different state of the same element.

Radiological Monitoring

Radiological monitoring is the process of measuring radiation levels or individual doses, and the use of the results to assess radiological hazards or potential and actual doses resulting from exposures to ionizing radiation.

Remediation

Remediation is the actions taken to reduce risks to human health or the environment posed by the presence of radioactive or hazardous materials.

Risk

The probability of harm from the presence of radionuclides or hazardous materials taking into account (1) the probability of occurrences or events that could lead to an exposure, (2) probability that individual or populations would be exposed to radioactive or hazardous materials and the magnitude of such exposures, and (3) the probability that an exposure would produce a response.

Validation

Validation refers to the process of defining the method capability and determining whether it can be properly applied as intended.

Whole Body

For the purposes of external exposure includes the head, trunk, the arms above and including the elbow, and legs above and including the knee.

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Appendix I

Individual Radiological Surveillance Monitoring Data Based on Whole Body Counting and Plutonium Urinalysis (2002-2004)

RONGELAP RESETTLEMENT WORKERS

Table 1. Whole body count data for resettlement workers on Rongelap Island (2002-2004).

Personal ID #	Age Type	Gender	Collection Date	^{137}Cs (kBq) Value	MDA
RR00007	Adult	Male	2002-03-18	0.00 ± 0.00	0.08
RR00007	Adult	Male	2002-05-23	0.10 ± 0.02	0.12
RR00007	Adult	Male	2002-07-26	0.00 ± 0.00	0.08
RR00007	Adult	Male	2002-10-08	0.00 ± 0.00	0.08
RR00009	Adult	Male	2003-11-04	0.00 ± 0.00	0.11
RR00012	Adult	Male	2002-03-14	0.00 ± 0.00	0.08
RR00012	Adult	Male	2002-05-23	0.00 ± 0.00	0.08
RR00012	Adult	Male	2002-06-29	0.06 ± 0.02	0.12
RR00026	Adult	Male	2002-03-13	0.13 ± 0.02	0.12
RR00026	Adult	Male	2002-06-17	0.14 ± 0.02	0.13
RR00026	Adult	Male	2004-03-22	0.52 ± 0.05	0.21
RR00026	Adult	Male	2004-05-12	0.61 ± 0.05	0.20
RR00029	Adult	Male	2002-03-09	0.34 ± 0.02	0.13
RR00029	Adult	Male	2002-05-18	0.50 ± 0.03	0.13
RR00029	Adult	Male	2002-06-27	0.40 ± 0.02	0.13
RR00029	Adult	Male	2002-07-24	0.39 ± 0.02	0.13
RR00029	Adult	Male	2002-08-03	0.45 ± 0.02	0.13
RR00029	Adult	Male	2002-09-13	0.44 ± 0.02	0.12
RR00029	Adult	Male	2002-10-17	0.29 ± 0.02	0.11
RR00029	Adult	Male	2002-11-17	0.32 ± 0.02	0.13
RR00029	Adult	Male	2004-03-22	0.76 ± 0.05	0.19
RR00029	Adult	Male	2004-04-06	0.81 ± 0.05	0.20
RR00029	Adult	Male	2004-05-12	0.63 ± 0.05	0.20
RR00029	Adult	Male	2004-09-22	0.47 ± 0.04	0.18
RR00030	Adult	Male	2002-03-17	0.22 ± 0.02	0.12
RR00030	Adult	Male	2002-07-26	0.15 ± 0.02	0.12
RR00030	Adult	Male	2002-10-17	0.10 ± 0.02	0.11
RR00030	Adult	Male	2004-03-14	0.79 ± 0.05	0.18
RR00030	Adult	Male	2004-05-15	0.75 ± 0.05	0.20
RR00030	Adult	Male	2004-08-27	0.61 ± 0.05	0.20
RR00030	Adult	Male	2004-11-29	0.62 ± 0.05	0.19
RR00030	Adult	Male	2004-12-30	0.47 ± 0.08	0.34
RR00032	Adult	Male	2002-03-18	0.08 ± 0.02	0.10
RR00032	Adult	Male	2002-06-03	0.00 ± 0.00	0.08
RR00032	Adult	Male	2002-10-18	0.00 ± 0.00	0.08
RR00034	Adult	Male	2002-02-03	0.12 ± 0.02	0.11
RR00034	Adult	Male	2002-03-09	0.00 ± 0.00	0.08
RR00034	Adult	Male	2003-11-05	0.00 ± 0.00	0.11
RR00038	Adult	Male	2002-05-30	0.00 ± 0.00	0.08
RR00038	Adult	Male	2002-06-29	0.00 ± 0.00	0.08
RR00038	Adult	Male	2002-11-09	0.05 ± 0.02	0.13
RR00038	Adult	Male	2004-04-06	0.00 ± 0.00	0.07
RR00038	Adult	Male	2004-05-13	0.00 ± 0.00	0.07
RR00051	Adult	Male	2003-11-27	0.25 ± 0.02	0.18
RR00051	Adult	Male	2004-02-27	0.09 ± 0.03	0.15
RR00054	Adult	Male	2002-05-20	0.14 ± 0.02	0.13

Table 1. Continued.

Personal ID #	Age Type	Gender	Collection Date	^{137}Cs (kBq) Value	MDA
RR00054	Adult	Male	2002-06-28	0.15 ± 0.02	0.12
RR00054	Adult	Male	2002-08-22	0.08 ± 0.02	0.11
RR00054	Adult	Male	2002-11-07	0.16 ± 0.02	0.12
RR00057	Adult	Male	2002-03-09	0.00 ± 0.00	0.08
RR00065	Adult	Male	2002-03-13	0.14 ± 0.02	0.12
RR00065	Adult	Male	2002-05-22	0.15 ± 0.02	0.12
RR00065	Adult	Male	2002-06-28	0.12 ± 0.02	0.12
RR00065	Adult	Male	2002-10-12	0.00 ± 0.00	0.08
RR00066	Adult	Male	2002-02-03	0.10 ± 0.02	0.12
RR00066	Adult	Male	2002-03-17	0.06 ± 0.01	0.10
RR00066	Adult	Male	2002-07-28	0.00 ± 0.00	0.08
RR00066	Adult	Male	2002-08-23	0.00 ± 0.00	0.08
RR00066	Adult	Male	2002-10-13	0.00 ± 0.00	0.08
RR00069	Adult	Male	2002-03-16	0.00 ± 0.00	0.08
RR00069	Adult	Male	2002-05-19	0.11 ± 0.02	0.13
RR00069	Adult	Male	2002-07-29	0.00 ± 0.00	0.08
RR00069	Adult	Male	2002-10-13	0.04 ± 0.02	0.11
RR00069	Adult	Male	2002-12-01	0.22 ± 0.02	0.13
RR00071	Adult	Male	2004-09-26	0.28 ± 0.04	0.19
RR00072	Adult	Male	2002-03-08	0.31 ± 0.02	0.12
RR00072	Adult	Male	2002-07-25	0.26 ± 0.02	0.12
RR00072	Adult	Male	2002-11-24	0.31 ± 0.02	0.13
RR00072	Adult	Male	2003-07-21	0.89 ± 0.03	0.18
RR00072	Adult	Male	2004-04-03	0.48 ± 0.05	0.21
RR00072	Adult	Male	2004-08-09	0.52 ± 0.05	0.21
RR00073	Adult	Male	2002-03-17	0.06 ± 0.01	0.11
RR00073	Adult	Male	2002-05-18	0.13 ± 0.02	0.11
RR00073	Adult	Male	2002-07-28	0.00 ± 0.00	0.08
RR00073	Adult	Male	2002-08-31	0.15 ± 0.02	0.13
RR00073	Adult	Male	2002-09-21	0.17 ± 0.02	0.11
RR00073	Adult	Male	2002-10-12	0.07 ± 0.02	0.11
RR00073	Adult	Male	2002-11-14	0.30 ± 0.02	0.12
RR00073	Adult	Male	2004-03-14	0.28 ± 0.04	0.16
RR00073	Adult	Male	2004-04-05	0.35 ± 0.04	0.19
RR00073	Adult	Male	2004-05-15	0.50 ± 0.05	0.21
RR00073	Adult	Male	2004-09-18	0.41 ± 0.04	0.18
RR00076	Adult	Male	2002-03-12	0.11 ± 0.02	0.13
RR00076	Adult	Male	2002-07-25	0.16 ± 0.02	0.12
RR00076	Adult	Male	2002-10-18	0.21 ± 0.02	0.12
RR00076	Adult	Male	2004-03-14	0.13 ± 0.03	0.13
RR00076	Adult	Male	2004-04-03	0.51 ± 0.05	0.21
RR00076	Adult	Male	2004-05-12	0.79 ± 0.05	0.21
RR00076	Adult	Male	2004-06-14	1.00 ± 0.05	0.21
RR00078	Adult	Male	2002-02-03	0.00 ± 0.00	0.08
RR00078	Adult	Male	2002-03-09	0.00 ± 0.00	0.08
RR00078	Adult	Male	2004-09-29	0.00 ± 0.00	0.07

Table 1. Continued.

Personal ID #	Age Type	Gender	Collection Date	^{137}Cs (kBq) Value	MDA
RR00081	Adult	Male	2002-10-21	0.00 ± 0.00	0.08
RR00088	Adult	Male	2004-09-25	0.33 ± 0.05	0.20
RR00089	Adult	Male	2002-11-10	0.00 ± 0.00	0.08
RR00098	Adult	Male	2002-03-08	0.00 ± 0.00	0.08
RR00098	Adult	Male	2002-05-18	0.00 ± 0.00	0.08
RR00098	Adult	Male	2004-06-06	0.00 ± 0.00	0.07
RR00098	Adult	Male	2004-08-17	0.05 ± 0.03	0.12
RR00098	Adult	Male	2004-09-24	0.00 ± 0.00	0.07
RR00111	Adult	Male	2002-03-09	0.16 ± 0.02	0.12
RR00111	Adult	Male	2002-05-22	0.25 ± 0.02	0.12
RR00111	Adult	Male	2002-07-26	0.05 ± 0.02	0.11
RR00111	Adult	Male	2002-08-26	0.07 ± 0.02	0.11
RR00111	Adult	Male	2002-09-21	0.31 ± 0.02	0.13
RR00111	Adult	Male	2002-10-11	0.27 ± 0.02	0.13
RR00111	Adult	Male	2003-05-27	0.45 ± 0.02	0.13
RR00120	Adult	Male	2002-05-18	0.22 ± 0.02	0.12
RR00120	Adult	Male	2002-07-26	0.13 ± 0.02	0.12
RR00121	Adult	Male	2002-09-21	0.06 ± 0.02	0.11
RR00121	Adult	Male	2002-11-15	0.00 ± 0.00	0.08
RR00121	Adult	Male	2003-05-26	0.00 ± 0.00	0.08
RR00122	Adult	Male	2002-03-14	0.06 ± 0.01	0.11
RR00123	Adult	Male	2002-05-22	0.00 ± 0.00	0.08
RR00124	Adult	Male	2002-02-05	0.12 ± 0.02	0.12
RR00124	Adult	Male	2002-03-16	0.00 ± 0.00	0.08
RR00124	Adult	Male	2002-06-13	0.04 ± 0.02	0.10
RR00124	Adult	Male	2002-07-25	0.00 ± 0.00	0.08
RR00124	Adult	Male	2002-10-13	0.00 ± 0.00	0.08
RR00124	Adult	Male	2002-11-10	0.05 ± 0.02	0.12
RR00125	Adult	Male	2002-03-08	0.00 ± 0.00	0.08
RR00125	Adult	Male	2002-05-18	0.06 ± 0.02	0.11
RR00125	Adult	Male	2002-07-26	0.07 ± 0.02	0.13
RR00126	Adult	Male	2002-02-04	0.05 ± 0.01	0.11
RR00126	Adult	Male	2002-06-13	0.00 ± 0.00	0.08
RR00126	Adult	Male	2002-07-25	0.00 ± 0.00	0.08
RR00128	Adult	Male	2003-11-06	0.39 ± 0.03	0.18
RR00128	Adult	Male	2003-12-01	0.39 ± 0.03	0.18
RR00130	Adult	Male	2002-03-18	0.06 ± 0.02	0.12
RR00130	Adult	Male	2002-05-22	0.00 ± 0.00	0.08
RR00130	Adult	Male	2002-07-27	0.05 ± 0.02	0.12
RR00130	Adult	Male	2002-10-13	0.00 ± 0.00	0.08
RR00132	Adult	Male	2002-03-08	0.17 ± 0.02	0.12
RR00132	Adult	Male	2002-05-17	0.09 ± 0.02	0.11
RR00132	Adult	Male	2002-06-29	0.07 ± 0.02	0.11
RR00132	Adult	Male	2002-07-24	0.11 ± 0.02	0.12
RR00132	Adult	Male	2002-08-26	0.00 ± 0.00	0.09
RR00132	Adult	Male	2002-10-23	0.18 ± 0.02	0.12

Table 1. Continued.

Personal ID #	Age Type	Gender	Collection Date	^{137}Cs (kBq) Value	MDA
RR00132	Adult	Male	2004-01-14	0.44 ± 0.04	0.18
RR00132	Adult	Male	2004-04-05	0.53 ± 0.05	0.23
RR00132	Adult	Male	2004-06-05	0.57 ± 0.04	0.18
RR00132	Adult	Male	2004-08-27	0.56 ± 0.05	0.20
RR00136	Adult	Male	2004-05-11	1.38 ± 0.06	0.23
RR00136	Adult	Male	2004-08-31	1.80 ± 0.07	0.23
RR00137	Adult	Male	2002-03-08	0.23 ± 0.02	0.12
RR00137	Adult	Male	2002-05-17	0.64 ± 0.03	0.13
RR00137	Adult	Male	2002-06-27	0.42 ± 0.03	0.13
RR00137	Adult	Male	2002-08-28	0.46 ± 0.02	0.12
RR00137	Adult	Male	2002-09-13	0.66 ± 0.03	0.13
RR00137	Adult	Male	2002-10-17	0.47 ± 0.02	0.13
RR00137	Adult	Male	2002-11-13	0.36 ± 0.02	0.13
RR00141	Adult	Male	2002-03-13	0.00 ± 0.00	0.08
RR00141	Adult	Male	2002-05-18	0.00 ± 0.00	0.08
RR00141	Adult	Male	2002-06-29	0.00 ± 0.00	0.08
RR00141	Adult	Male	2002-07-26	0.05 ± 0.02	0.12
RR00141	Adult	Male	2002-10-12	0.00 ± 0.00	0.08
RR00141	Adult	Male	2002-11-15	0.00 ± 0.00	0.08
RR00142	Adult	Male	2004-09-26	0.19 ± 0.04	0.19
RR00143	Adult	Male	2002-02-04	0.08 ± 0.02	0.11
RR00143	Adult	Male	2002-07-25	0.00 ± 0.00	0.08
RR00144	Adult	Male	2003-11-27	0.53 ± 0.03	0.19
RR00144	Adult	Male	2004-02-27	0.46 ± 0.04	0.19
RR00144	Adult	Male	2004-11-05	0.12 ± 0.04	0.20
RR00145	Adult	Male	2002-03-08	0.00 ± 0.00	0.08
RR00146	Adult	Male	2002-11-10	0.00 ± 0.00	0.08
RR00148	Adult	Male	2003-11-05	0.00 ± 0.00	0.11
RR00149	Adult	Male	2002-03-16	0.00 ± 0.00	0.08
RR00149	Adult	Male	2002-11-10	0.00 ± 0.00	0.08
RR00149	Adult	Male	2003-11-21	0.16 ± 0.02	0.18
RR00150	Adult	Male	2002-03-16	0.00 ± 0.00	0.08
RR00151	Adult	Male	2002-03-30	0.00 ± 0.00	0.08
RR00152	Adult	Male	2002-08-02	0.28 ± 0.02	0.12
RR00153	Adult	Male	2002-10-20	0.08 ± 0.02	0.12
RR00155	Adult	Male	2002-03-17	0.00 ± 0.00	0.08
RR00155	Adult	Male	2002-05-23	0.00 ± 0.00	0.08
RR00155	Adult	Male	2002-08-26	0.00 ± 0.00	0.09
RR00155	Adult	Male	2002-10-18	0.11 ± 0.02	0.12
RR00156	Adult	Male	2002-02-03	0.00 ± 0.00	0.08
RR00156	Adult	Male	2002-03-19	0.00 ± 0.00	0.08
RR00156	Adult	Male	2002-07-27	0.00 ± 0.00	0.08
RR00156	Adult	Male	2002-08-21	0.00 ± 0.00	0.08
RR00156	Adult	Male	2002-10-12	0.05 ± 0.02	0.12
RR00158	Adult	Male	2002-03-13	0.50 ± 0.02	0.13
RR00158	Adult	Male	2002-07-28	0.40 ± 0.02	0.13

Table 1. Continued.

Personal ID #	Age Type	Gender	Collection Date	^{137}Cs (kBq) Value	MDA
RR00158	Adult	Male	2004-05-15	1.25 ± 0.06	0.21
RR00158	Adult	Male	2004-08-09	1.01 ± 0.06	0.23
RR00158	Adult	Male	2004-09-27	0.97 ± 0.05	0.22
RR00159	Adult	Male	2002-03-29	0.16 ± 0.02	0.11
RR00159	Adult	Male	2002-05-27	0.20 ± 0.02	0.13
RR00159	Adult	Male	2002-09-21	0.29 ± 0.02	0.13
RR00159	Adult	Male	2002-10-11	0.28 ± 0.02	0.13
RR00168	Adult	Male	2002-11-24	0.00 ± 0.00	0.08
RR00170	Adult	Male	2002-03-09	0.00 ± 0.00	0.08
RR00170	Adult	Male	2002-05-22	0.00 ± 0.00	0.08
RR00170	Adult	Male	2002-06-03	0.00 ± 0.00	0.08
RR00170	Adult	Male	2002-06-28	0.00 ± 0.00	0.08
RR00174	Adult	Male	2002-03-16	0.06 ± 0.02	0.11
RR00175	Adult	Male	2003-11-06	0.00 ± 0.00	0.11
RR00176	Adult	Male	2002-03-10	0.00 ± 0.00	0.08
RR00176	Adult	Male	2002-07-25	0.00 ± 0.00	0.08
RR00176	Adult	Male	2002-08-04	0.00 ± 0.00	0.08
RR00176	Adult	Male	2002-10-12	0.00 ± 0.00	0.08
RR00177	Adult	Male	2002-03-16	0.00 ± 0.00	0.08
RR00178	Adult	Male	2002-03-15	0.00 ± 0.00	0.08
RR00178	Adult	Male	2002-07-25	0.00 ± 0.00	0.08
RR00180	Adult	Male	2002-05-22	0.07 ± 0.02	0.11
RR00180	Adult	Male	2002-07-26	0.06 ± 0.02	0.12
RR00180	Adult	Male	2003-11-05	0.00 ± 0.00	0.11
RR00182	Adult	Male	2002-10-13	0.00 ± 0.00	0.08
RR00182	Adult	Male	2002-11-30	0.00 ± 0.00	0.08
RR00184	Adult	Male	2002-03-09	0.00 ± 0.00	0.08
RR00185	Adult	Male	2002-03-16	0.00 ± 0.00	0.08
RR00185	Adult	Male	2003-11-28	0.00 ± 0.00	0.11
RR00187	Adult	Male	2002-03-15	0.00 ± 0.00	0.08
RR00187	Adult	Male	2003-05-26	0.76 ± 0.03	0.13
RR00187	Adult	Male	2004-03-14	0.75 ± 0.05	0.21
RR00187	Adult	Male	2004-04-06	0.79 ± 0.05	0.21
RR00187	Adult	Male	2004-06-05	0.83 ± 0.05	0.21
RR00187	Adult	Male	2004-08-28	0.89 ± 0.05	0.20
RR00187	Adult	Male	2004-09-29	0.89 ± 0.05	0.21
RR00187	Adult	Male	2004-12-30	0.78 ± 0.08	0.34
RR00188	Adult	Male	2002-03-16	0.06 ± 0.01	0.08
RR00189	Adult	Male	2002-03-16	0.00 ± 0.00	0.08
RR00189	Adult	Male	2002-10-16	0.00 ± 0.00	0.08
RR00189	Adult	Male	2003-11-05	0.00 ± 0.00	0.11
RR00190	Adult	Male	2002-03-15	0.00 ± 0.00	0.08
RR00190	Adult	Male	2002-07-26	0.00 ± 0.00	0.08
RR00190	Adult	Male	2002-10-17	0.00 ± 0.00	0.08
RR00190	Adult	Male	2003-11-28	0.12 ± 0.02	0.17
RR00191	Adult	Male	2002-03-15	0.00 ± 0.00	0.08

Table 1. Continued.

Personal ID #	Age Type	Gender	Collection Date	^{137}Cs (kBq) Value	MDA
RR00191	Adult	Male	2003-11-28	0.00 ± 0.00	0.11
RR00193	Adult	Male	2002-03-14	0.00 ± 0.00	0.08
RR00193	Adult	Male	2002-06-03	0.00 ± 0.00	0.08
RR00193	Adult	Male	2002-07-26	0.00 ± 0.00	0.08
RR00193	Adult	Male	2003-11-06	0.00 ± 0.00	0.11
RR00194	Adult	Male	2002-03-16	0.00 ± 0.00	0.08
RR00195	Adult	Male	2002-03-16	0.07 ± 0.01	0.11
RR00195	Adult	Male	2003-12-30	0.00 ± 0.00	0.11
RR00198	Adult	Male	2002-03-15	0.00 ± 0.00	0.08
RR00198	Adult	Male	2002-05-23	0.00 ± 0.00	0.08
RR00198	Adult	Male	2002-07-28	0.00 ± 0.00	0.09
RR00198	Adult	Male	2002-10-14	0.00 ± 0.00	0.08
RR00198	Adult	Male	2004-03-22	0.42 ± 0.05	0.22
RR00198	Adult	Male	2004-04-06	0.41 ± 0.04	0.19
RR00198	Adult	Male	2004-05-13	0.44 ± 0.05	0.21
RR00199	Adult	Male	2002-05-27	0.08 ± 0.02	0.11
RR00200	Adult	Male	2002-02-03	0.06 ± 0.01	0.11
RR00202	Adult	Male	2003-07-19	0.00 ± 0.00	0.11
RR00202	Adult	Male	2003-09-01	0.09 ± 0.02	0.17
RR00202	Adult	Male	2003-12-08	0.27 ± 0.02	0.18
RR00202	Adult	Male	2004-02-04	0.38 ± 0.03	0.18
RR00202	Adult	Male	2004-02-28	0.77 ± 0.05	0.21
RR00202	Adult	Male	2004-03-14	0.64 ± 0.04	0.18
RR00203	Adult	Male	2002-02-03	0.09 ± 0.02	0.11
RR00203	Adult	Male	2002-03-18	0.00 ± 0.00	0.08
RR00203	Adult	Male	2002-05-22	0.00 ± 0.00	0.08
RR00203	Adult	Male	2003-12-01	0.07 ± 0.02	0.17
RR00204	Adult	Male	2002-02-03	0.29 ± 0.02	0.13
RR00204	Adult	Male	2002-03-13	0.09 ± 0.02	0.11
RR00204	Adult	Male	2002-07-26	0.00 ± 0.00	0.08
RR00204	Adult	Male	2002-10-12	0.00 ± 0.00	0.08
RR00205	Adult	Male	2002-02-03	0.00 ± 0.00	0.08
RR00206	Adult	Male	2002-02-03	0.00 ± 0.00	0.08
RR00206	Adult	Male	2002-03-31	0.00 ± 0.00	0.08
RR00206	Adult	Male	2002-06-09	0.00 ± 0.00	0.08
RR00206	Adult	Male	2002-10-13	0.00 ± 0.00	0.08
RR00207	Adult	Male	2002-02-03	0.00 ± 0.00	0.08
RR00207	Adult	Male	2002-03-15	0.10 ± 0.02	0.11
RR00207	Adult	Male	2002-06-03	0.00 ± 0.00	0.08
RR00207	Adult	Male	2002-07-24	0.26 ± 0.02	0.13
RR00208	Adult	Male	2002-03-09	0.00 ± 0.00	0.08
RR00211	Adult	Male	2002-03-16	0.00 ± 0.00	0.08
RR00211	Adult	Male	2002-07-27	0.00 ± 0.00	0.08
RR00211	Adult	Male	2002-10-21	0.00 ± 0.00	0.08
RR00211	Adult	Male	2002-11-17	0.00 ± 0.00	0.08
RR00212	Adult	Male	2002-03-16	0.00 ± 0.00	0.08

Table 1. Continued.

Personal ID #	Age Type	Gender	Collection Date	^{137}Cs (kBq) Value	MDA
RR00212	Adult	Male	2002-10-14	0.00 ± 0.00	0.08
RR00213	Adult	Male	2002-03-19	0.06 ± 0.02	0.11
RR00213	Adult	Male	2002-05-17	0.28 ± 0.02	0.13
RR00213	Adult	Male	2002-08-23	0.27 ± 0.02	0.12
RR00213	Adult	Male	2002-08-31	0.46 ± 0.02	0.13
RR00213	Adult	Male	2002-09-21	0.65 ± 0.03	0.13
RR00213	Adult	Male	2003-05-24	0.44 ± 0.02	0.13
RR00214	Adult	Male	2002-03-25	0.00 ± 0.00	0.08
RR00214	Adult	Male	2002-05-17	0.08 ± 0.02	0.12
RR00214	Adult	Male	2002-06-17	0.07 ± 0.02	0.11
RR00215	Adult	Male	2002-03-25	0.00 ± 0.00	0.07
RR00215	Adult	Male	2002-05-17	0.05 ± 0.01	0.10
RR00215	Adult	Male	2002-06-17	0.00 ± 0.00	0.08
RR00215	Adult	Male	2002-07-24	0.00 ± 0.00	0.08
RR00219	Adult	Male	2002-06-13	0.00 ± 0.00	0.08
RR00219	Adult	Male	2002-07-26	0.00 ± 0.00	0.08
RR00220	Adult	Male	2002-06-15	0.00 ± 0.00	0.08
RR00220	Adult	Male	2002-07-24	0.00 ± 0.00	0.08
RR00220	Adult	Male	2002-11-07	0.00 ± 0.00	0.08
RR00221	Adult	Male	2002-06-28	0.05 ± 0.02	0.12
RR00221	Adult	Male	2002-11-16	0.00 ± 0.00	0.08
RR00222	Adult	Male	2003-11-28	0.00 ± 0.00	0.11
RR00226	Adult	Male	2004-03-29	0.11 ± 0.03	0.13
RR00228	Adult	Male	2002-10-08	0.00 ± 0.00	0.08
RR00228	Adult	Male	2002-11-07	0.10 ± 0.02	0.13
RR00229	Adult	Male	2002-10-08	0.06 ± 0.02	0.11
RR00230	Adult	Male	2002-10-08	0.00 ± 0.00	0.08
RR00230	Adult	Male	2002-11-02	0.00 ± 0.00	0.08
RR00231	Adult	Male	2002-10-10	0.00 ± 0.00	0.08
RR00232	Adult	Male	2002-10-10	0.00 ± 0.00	0.08
RR00232	Adult	Male	2002-11-17	0.00 ± 0.00	0.08
RR00233	Adult	Male	2002-10-16	0.00 ± 0.00	0.08
RR00234	Adult	Male	2002-11-02	0.00 ± 0.00	0.08
RR00237	Adult	Male	2002-11-10	0.00 ± 0.00	0.08
RR00238	Adult	Female	2002-11-22	0.00 ± 0.00	0.08
RR00239	Adult	Male	2002-12-01	0.23 ± 0.02	0.12
RR00240	Adult	Male	2002-05-30	0.00 ± 0.00	0.08
RR00240	Adult	Male	2004-01-16	0.00 ± 0.00	0.11
RR00241	Adult	Male	2002-05-30	0.00 ± 0.00	0.08
RR00241	Adult	Male	2004-03-30	0.11 ± 0.03	0.14
RR00242	Adult	Male	2002-05-30	0.00 ± 0.00	0.08
RR00243	Adult	Male	2002-06-03	0.00 ± 0.00	0.08
RR00243	Adult	Male	2002-07-24	0.00 ± 0.00	0.08
RR00243	Adult	Male	2002-08-04	0.05 ± 0.02	0.13
RR00243	Adult	Male	2003-05-24	0.12 ± 0.02	0.13
RR00243	Adult	Male	2004-03-22	0.34 ± 0.04	0.20

Table 1. Continued.

Personal ID #	Age Type	Gender	Collection Date	^{137}Cs (kBq) Value	MDA
RR00244	Adult	Male	2002-06-03	0.00 ± 0.00	0.08
RR00245	Adult	Female	2002-09-17	0.00 ± 0.00	0.08
RR00246	Adult	Female	2002-08-02	0.00 ± 0.00	0.08
RR00247	Adult	Female	2002-08-02	0.00 ± 0.00	0.08
RR00248	Adult	Female	2002-08-02	0.00 ± 0.00	0.08
RR00249	Adult	Female	2002-08-02	0.00 ± 0.00	0.08
RR00250	Adult	Male	2002-08-10	0.00 ± 0.00	0.08
RR00252	Adult	Female	2002-08-18	0.00 ± 0.00	0.08
RR00253	Adult	Male	2002-11-03	0.00 ± 0.00	0.08
RR00255	Child	Male	2004-08-12	0.57 ± 0.05	0.20
RR00255	Adult	Male	2004-12-30	0.54 ± 0.08	0.35
RR00256	Adult	Male	2004-03-22	0.62 ± 0.05	0.20
RR00256	Adult	Male	2004-04-03	0.83 ± 0.05	0.22
RR00256	Adult	Male	2004-05-12	0.80 ± 0.05	0.20
RR00256	Adult	Male	2004-06-06	0.82 ± 0.05	0.22
RR00256	Adult	Male	2004-08-17	1.11 ± 0.06	0.23
RR00256	Adult	Male	2004-09-18	0.82 ± 0.05	0.22
RR00256	Adult	Male	2004-11-29	0.84 ± 0.05	0.21
RR00256	Adult	Male	2004-12-30	0.43 ± 0.07	0.32
RR00258	Adult	Male	2003-05-24	0.07 ± 0.02	0.14
RR00258	Adult	Male	2003-12-02	0.95 ± 0.04	0.18
RR00259	Adult	Male	2003-11-21	0.17 ± 0.02	0.18
RR00263	Adult	Male	2003-11-21	0.00 ± 0.00	0.11
RR00267	Adult	Male	2003-12-01	0.00 ± 0.00	0.11
RR00270	Adult	Male	2003-12-30	0.00 ± 0.00	0.11
RR00274	Child	Female	2004-08-12	0.08 ± 0.03	0.12
RR00274	Child	Female	2004-12-30	0.00 ± 0.00	0.11
RR00275	Adult	Female	2004-02-16	0.00 ± 0.00	0.11
RR00275	Adult	Female	2004-08-12	0.22 ± 0.04	0.20
RR00275	Adult	Female	2004-12-30	0.00 ± 0.00	0.11
RR00276	Adult	Male	2004-06-06	0.56 ± 0.05	0.20
RR00276	Adult	Male	2004-08-12	0.93 ± 0.05	0.21
RR00276	Adult	Male	2004-09-28	0.98 ± 0.06	0.25
RR00279	Adult	Male	2004-03-23	0.15 ± 0.03	0.13
RR00280	Adult	Male	2004-03-29	0.71 ± 0.06	0.26
RR00281	Adult	Male	2004-03-30	0.45 ± 0.04	0.19
RR00282	Adult	Male	2004-04-06	0.50	0.21
RR00283	Adult	Male	2004-08-09	0.00 ± 0.00	0.06
RR00283	Adult	Male	2004-08-16	0.00 ± 0.00	0.07
RR00284	Adult	Male	2004-09-17	0.06 ± 0.02	0.11
RR00285	Adult	Male	2004-09-17	0.09 ± 0.03	0.12
RR00288	Adult	Male	2004-06-04	0.16 ± 0.04	0.17
RR00289	Adult	Male	2004-09-18	0.00 ± 0.00	0.07
RR00291	Adult	Male	2004-09-26	0.22 ± 0.05	0.21
RR00291	Adult	Male	2004-11-29	0.41 ± 0.05	0.20
RR00292	Adult	Male	2004-09-26	0.11 ± 0.03	0.16

Table 1. Continued.

Personal ID #	Age Type	Gender	Collection Date	^{137}Cs (kBq) Value	MDA
RR00293	Adult	Male	2004-09-29	0.31 ± 0.04	0.19
RR00310	Adult	Male	2004-08-27	0.00 ± 0.00	0.07
RR00310	Adult	Male	2004-09-28	0.00 ± 0.00	0.07
RR00356	Adult	Male	2004-08-16	0.00 ± 0.00	0.07
RR00561	Adult	Female	2002-08-18	0.00 ± 0.00	0.08

Table 2. Plutonium urinalysis data for resettlement workers on Rongelap Island (CAMS/LLNL, 2002-2004).

Personal ID #	Age Type	Gender	Collection Date	^{239}Pu (µBq) (µBq/24 h void)		^{240}Pu (µBq) (µBq/24 h void)	
				Value	MDA	Value	MDA
RR00007	Adult	Male	2003-06-24	0.60 ± 0.36	0.48	0.71 ± 0.77	1.61
RR00007	Adult	Male	2003-11-10	-0.03 ± 0.19	0.53	0.32 ± 0.54	1.55
RR00026	Adult	Male	2002-09-25	0.11 ± 0.21	0.48	0.66 ± 0.71	1.55
RR00026	Adult	Male	2003-07-25	0.34 ± 0.32	0.53	-0.16 ± 0.64	1.55
RR00026	Adult	Male	2003-11-07	-0.05 ± 0.40	0.49	-0.08 ± 1.42	2.61
RR00029	Adult	Male	2003-07-26	0.75 ± 0.40	0.53	-0.16 ± 0.60	1.55
RR00029	Adult	Male	2003-11-06	-0.01 ± 0.20	0.53	-0.16 ± 0.60	1.55
RR00030	Adult	Male	2003-06-24	0.52 ± 0.32	0.48	0.63 ± 0.70	1.61
RR00030	Adult	Male	2003-11-12	0.16 ± 0.24	0.49	-0.08 ± 0.86	2.61
RR00032	Adult	Male	2002-04-30	-0.11 ± 0.25	0.61	0.00 ± 0.82	2.09
RR00032	Adult	Male	2003-06-24	0.55 ± 0.27	0.48	0.00 ± 0.51	1.61
RR00034	Adult	Male	2002-04-10	0.05 ± 0.17	0.61	0.00 ± 0.58	2.09
RR00036	Adult	Male	2003-11-10	-0.03 ± 0.19	0.53	-0.16 ± 0.52	1.55
RR00038	Adult	Male	2003-07-25	-0.05 ± 0.18	0.53	-0.16 ± 0.49	1.55
RR00038	Adult	Male	2003-11-07	0.09 ± 0.23	0.53	-0.16 ± 0.52	1.55
RR00051	Adult	Male	2003-11-13	0.13 ± 0.22	0.49	-0.08 ± 0.75	2.61
RR00054	Adult	Male	2002-04-08	0.25 ± 0.27	0.61	0.00 ± 0.64	2.09
RR00057	Adult	Male	2002-04-09	0.95 ± 0.38	0.61	0.94 ± 0.85	2.09
RR00062	Adult	Male	2003-01-17	0.06 ± 0.17	0.48	0.00 ± 0.59	1.55
RR00066	Adult	Male	2002-07-12	0.15 ± 0.19	0.48	0.00 ± 0.50	1.55
RR00066	Adult	Male	2003-10-21	0.01 ± 0.22	0.53	-0.16 ± 0.69	1.55
RR00069	Adult	Male	2003-07-27	0.27 ± 0.26	0.53	-0.16 ± 0.45	1.55
RR00072	Adult	Male	2003-07-27	0.50 ± 0.33	0.53	-0.16 ± 0.55	1.55
RR00073	Adult	Male	2003-07-25	0.73 ± 0.34	0.53	-0.16 ± 0.46	1.55
RR00073	Adult	Male	2003-11-11	-0.05 ± 0.23	0.49	-0.08 ± 0.83	2.61
RR00088	Adult	Male	2003-07-24	0.13 ± 0.25	0.53	0.81 ± 0.73	1.55
RR00092	Adult	Male	2003-07-24	0.82 ± 0.40	0.53	-0.16 ± 0.56	1.55
RR00095	Adult	Male	2002-04-11	-0.11 ± 0.16	0.61	0.00 ± 0.53	2.09
RR00098	Adult	Male	2003-01-17	0.05 ± 0.16	0.48	0.00 ± 0.55	1.55
RR00111	Adult	Male	2002-01-17	-0.08 ± 0.14	0.48	0.00 ± 0.49	1.55
RR00111	Adult	Male	2003-11-12	-0.05 ± 0.39	0.49	-0.08 ± 1.42	2.61
RR00121	Adult	Male	2002-07-12	0.43 ± 0.27	0.48	0.44 ± 0.52	1.55
RR00122	Adult	Male	2002-04-08	-0.11 ± 0.23	0.61	0.00 ± 0.81	2.09
RR00123	Adult	Male	2003-07-28	0.22 ± 0.30	0.53	-0.16 ± 0.73	1.55
RR00123	Adult	Male	2002-11-10	-0.05 ± 0.38	0.49	-0.08 ± 1.38	2.61
RR00124	Adult	Male	2002-04-30	0.07 ± 0.20	0.61	0.00 ± 0.67	2.09
RR00124	Adult	Male	2003-06-24	0.00 ± 0.18	0.48	0.00 ± 0.60	1.61
RR00124	Adult	Male	2003-11-07	-0.16 ± 0.22	0.53	-0.16 ± 0.64	1.55
RR00125	Adult	Male	2002-04-30	0.56 ± 0.31	0.61	0.00 ± 0.56	2.09
RR00125	Adult	Male	2003-10-21	0.06 ± 0.26	0.53	0.66 ± 0.86	1.55
RR00126	Adult	Male	2002-04-10	0.07 ± 0.19	0.61	0.00 ± 0.68	2.09
RR00128	Adult	Male	2003-11-12	-0.05 ± 0.23	0.49	0.62 ± 0.81	2.61
RR00130	Adult	Male	2002-04-30	0.56 ± 0.34	0.61	0.00 ± 0.64	2.09
RR00130	Adult	Male	2003-01-28	0.25 ± 0.25	0.48	0.00 ± 0.67	1.55
RR00132	Adult	Male	2002-09-25	0.26 ± 0.26	0.48	0.64 ± 0.69	1.55
RR00132	Adult	Male	2003-07-27	1.74 ± 0.62	0.53	1.81 ± 1.16	1.55
RR00132	Adult	Male	2003-11-11	-0.05 ± 0.58	0.49	-0.08 ± 2.04	2.61
RR00136	Adult	Male	2002-04-10	0.39 ± 0.36	0.61	0.00 ± 0.93	2.09
RR00136	Adult	Male	2003-01-28	0.62 ± 0.32	0.48	1.53 ± 0.92	1.55
RR00137	Adult	Male	2003-01-17	0.06 ± 0.16	0.48	0.00 ± 0.56	1.55
RR00141	Adult	Male	2002-04-09	0.42 ± 0.32	0.61	0.00 ± 0.66	2.09
RR00141	Adult	Male	2003-01-28	0.18 ± 0.20	0.48	0.00 ± 0.54	1.55
RR00143	Adult	Male	2002-04-08	0.19 ± 0.30	0.61	0.00 ± 1.02	2.09

Table 2. Continued.

Personal ID #	Age Type	Gender	Collection Date	^{239}Pu (µBq) (µBq/24 h void) Value	MDA	^{240}Pu (µBq) (µBq/24 h void) Value	MDA
RR00143	Adult	Male	2003-10-21	-0.16 ± 0.2	0.53	-0.16 ± 0.54	1.55
RR00146	Adult	Male	2002-07-16	0.45 ± 0.25	0.48	0.00 ± 0.47	1.55
RR00150	Adult	Male	2003-10-21	0.00 ± 0.21	0.53	-0.16 ± 0.63	1.55
RR00152	Adult	Male	2002-07-16	0.18 ± 0.20	0.48	0.00 ± 0.53	1.55
RR00156	Adult	Male	2002-07-12	0.19 ± 0.18	0.48	0.00 ± 0.43	1.55
RR00157	Adult	Male	2002-04-10	0.24 ± 0.26	0.61	0.00 ± 0.71	2.09
RR00162	Adult	Male	2002-07-16	0.25 ± 0.21	0.48	0.00 ± 0.49	1.55
RR00168	Adult	Male	2002-07-16	0.09 ± 0.19	0.48	0.64 ± 0.69	1.55
RR00170	Adult	Male	2002-08-01	0.03 ± 0.14	0.48	0.00 ± 0.49	1.55
RR00174	Adult	Male	2002-04-12	0.90 ± 0.42	0.61	0.59 ± 0.72	2.09
RR00174	Adult	Male	2003-07-01	0.00 ± 0.22	0.48	0.00 ± 0.74	1.61
RR00179	Adult	Male	2002-04-09	0.40 ± 0.31	0.61	0.65 ± 0.88	2.09
RR00180	Adult	Male	2002-04-08	-0.11 ± 0.22	0.61	0.00 ± 0.86	2.09
RR00180	Adult	Male	2003-03-11	0.00 ± 0.30	0.48	0.00 ± 1.12	1.61
RR00185	Adult	Male	2003-03-11	0.00 ± 0.24	0.48	0.00 ± 0.80	1.61
RR00186	Adult	Male	2002-04-09	-0.11 ± 0.21	0.61	0.00 ± 0.73	2.09
RR00187	Adult	Male	2002-08-01	0.33 ± 0.25	0.48	0.00 ± 0.57	1.55
RR00187	Adult	Male	2003-11-06	0.31 ± 0.31	0.53	-0.16 ± 0.61	1.55
RR00189	Adult	Male	2002-08-01	0.17 ± 0.20	0.48	0.00 ± 0.54	1.55
RR00189	Adult	Male	2002-03-11	0.45 ± 0.33	0.48	0.00 ± 0.85	1.61
RR00190	Adult	Male	2003-03-11	0.40 ± 0.30	0.48	0.00 ± 0.79	1.61
RR00191	Adult	Male	2003-10-14	0.15 ± 0.26	0.53	-0.16 ± 0.59	1.55
RR00193	Adult	Male	2003-10-14	0.58 ± 0.36	0.53	-0.16 ± 0.59	1.55
RR00194	Adult	Male	2002-08-01	0.22 ± 0.23	0.48	0.00 ± 0.60	1.55
RR00198	Adult	Male	2003-07-01	0.15 ± 0.18	0.48	0.00 ± 0.56	1.61
RR00198	Adult	Male	2003-11-06	0.01 ± 0.22	0.53	-0.16 ± 0.66	1.55
RR00202	Adult	Male	2002-04-30	0.05 ± 0.18	0.61	0.00 ± 0.64	2.09
RR00202	Adult	Male	2002-07-19	0.96 ± 0.40	0.48	0.55 ± 0.61	1.55
RR00202	Adult	Male	2003-08-09	0.21 ± 0.21	0.16	0.40 ± 0.58	1.42
RR00202	Adult	Male	2003-08-13	0.18 ± 0.19	0.16	-0.13 ± 0.52	1.42
RR00202	Adult	Male	2003-10-14	-0.16 ± 0.19	0.53	-0.16 ± 0.52	1.55
RR00202	Adult	Male	2003-11-06	1.18 ± 0.47	0.53	-0.16 ± 0.60	1.55
RR00203	Adult	Male	2002-07-12	0.18 ± 0.21	0.48	0.00 ± 0.56	1.55
RR00206	Adult	Male	2003-07-28	0.17 ± 0.27	0.53	-0.16 ± 0.64	1.55
RR00206	Adult	Male	2003-11-10	-0.05 ± 0.39	0.49	-0.08 ± 1.43	2.61
RR00207	Adult	Male	2002-09-25	0.05 ± 0.15	0.48	0.00 ± 0.54	1.55
RR00208	Adult	Male	2003-10-14	0.69 ± 0.35	0.53	-0.16 ± 0.50	1.55
RR00211	Adult	Male	2003-07-01	0.25 ± 0.21	0.48	0.00 ± 0.53	1.61
RR00211	Adult	Male	2003-11-10	-0.16 ± 0.19	0.53	-0.16 ± 0.53	1.55
RR00213	Adult	Male	2003-07-24	0.09 ± 0.29	0.53	0.76 ± 0.96	1.55
RR00213	Adult	Male	2003-11-07	0.11 ± 0.30	0.53	-0.16 ± 1.02	1.55
RR00222	Adult	Male	2002-04-11	0.92 ± 0.37	0.61	0.46 ± 0.57	2.09
RR00223	Adult	Male	2002-04-11	0.39 ± 0.36	0.61	0.00 ± 1.05	2.09
RR00224	Adult	Male	2002-04-11	-0.11 ± 0.15	0.61	0.00 ± 0.57	2.09
RR00225	Adult	Male	2002-04-12	0.15 ± 0.27	0.61	0.00 ± 1.02	2.09
RR00226	Adult	Male	2002-04-12	0.05 ± 0.18	0.61	0.59 ± 1.05	2.09
RR00227	Adult	Male	2002-04-12	0.03 ± 0.16	0.61	0.00 ± 0.56	2.09
RR00233	Adult	Male	2003-07-01	0.38 ± 0.24	0.48	0.44 ± 0.54	1.61
RR00237	Adult	Male	2003-03-05	1.90 ± 0.68	0.48	2.49 ± 1.47	1.61
RR00243	Adult	Male	2003-11-07	-0.16 ± 0.25	0.53	-0.16 ± 0.78	1.55
RR00253	Adult	Male	2003-03-05	0.41 ± 0.30	0.48	0.00 ± 0.80	1.61
RR00256	Adult	Male	2003-11-06	0.40 ± 0.31	0.53	-0.16 ± 0.54	1.55
RR00258	Adult	Male	2003-07-24	0.78 ± 0.41	0.53	0.39 ± 0.61	1.55
RR00258	Adult	Male	2003-11-13	0.25 ± 0.32	0.49	-0.08 ± 1.15	2.61

Table 2. Continued.

Personal ID #	Age Type	Gender	Collection Date	^{239}Pu (µBq) (µBq/24 h void)		^{240}Pu (µBq) (µBq/24 h void)	
				Value	MDA	Value	MDA
RR00259	Adult	Male	2003-11-10	-0.05 ± 0.39	0.49	-0.08 ± 1.42	2.61
RR00260	Adult	Male	2003-11-10	-0.05 ± 0.29	0.49	1.80 ± 1.39	2.61
RR00279	Adult	Male	2003-11-13	0.68 ± 0.38	0.49	-0.08 ± 0.77	2.61