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Individual Radiation Protection Monitoring in the Marshall Islands: Utrōk Atoll (2010–2012)

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Utrōk Whole Body Counting Facility
Majuro Atoll
Republic of the Marshall Islands

As a hard copy supplement to the Marshall Islands Program website (https://marshallislands.llnl.gov), this document provides an overview of the individual radiological surveillance monitoring program established in support of residents of Utrōk Atoll and nonresident citizens of the Utrōk Atoll population group, along with full disclosure of verified measurement data (2010–2012). The Utrōk Atoll Whole Body Counting Facility has been temporarily stationed on Majuro Atoll and, in cooperation with the Utrōk Atoll Local Government, serves as a national radiological facility open to the general public.

November 2014

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INTRODUCTION

The United States Department of Energy has implemented a series of strategic initiatives to address long-term radiological surveillance needs at former U.S. nuclear test sites in the northern Marshall Islands. The plan is to engage local atoll communities in developing shared levels of responsibility for implementing radiation surveillance monitoring programs for resettled and resettling populations in the northern Marshall Islands. Using the pooled resources of the United States Department of Energy and local atoll governments, individual radiological surveillance programs have been developed in whole-body counting and plutonium urinalysis. These programs are used to accurately track and assess doses delivered to Marshall Islanders from exposure to residual fallout contamination in the environment. The key fallout radionuclides of radiological concern include fission products such as cesium-137 and strontium-90, and long-lived alpha emitting radionuclides such as plutonium-239, plutonium-240 and americium-241.

Permanent whole-body counting facilities have been established at Enewetak, Majuro and Rongelap Atolls. The Majuro facility was developed as a temporary site for housing the Utrōk Atoll whole-body counting system and serves as a national facility open to the general public. All the whole-body counting facilities in the Marshall Islands are operated and maintained by Marshallese technicians with scientists from the Lawrence Livermore National Laboratory providing on-going technical support services. The concentration of cesium-137 in soils from the northern Marshall Islands is significantly elevated over that expected from global fallout deposition. Local inhabitants may be exposed to cesium-137 in their diets from consumption of locally grown foods. Whole-body counting provides a direct measure of internally deposited cesium-137 inside peoples' bodies, and is a very reliable method for assessing the internal dose contribution from ingestion of cesium-137.

We have also developed a state-of-the-art measurement technology in support of the Marshall Islands Plutonium Urinalysis Bioassay Program. Bioassay samples are collected by locally trained technicians under controlled conditions, and returned to the United States for analysis of plutonium isotopes by accelerator mass spectrometry. High-quality bioassay measurements based on accelerator mass spectrometry are providing more reliable and accurate baseline measurements, and could potentially be used to track and reassess intakes of plutonium associated with past events.

Site specific environmental surveys are also conducted to determine the fate and transport of fallout radionuclides in the environment or simply to verify the effects of cleanup programs. The general aim of the on-going environmental studies is to provide understanding of the long-term behavior of key radionuclides in the environment. These data and information will ultimately be used to develop more reliable predictive dose assessments for resettlement taking into account future change in radiological conditions. This information is essential in helping determine the most appropriate measures for cleanup and in assessing the impacts of changes in life-style, diet and land-use on radionuclide uptake and dose.

Together, the individual and environmental radiological surveillance programs in the Marshall Islands are helping meet the informational needs of the United States Department of Energy and the Republic of the Marshall Islands. Our mission is to provide high quality measurement data and reliable dose assessments, and to build a strong technical and scientific foundation to

help sustain resettlement of affected atolls. Perhaps most importantly, the recently established individual radiological surveillance programs provide atoll population groups with an unprecedented level of radiation protection monitoring where, for the first time, local resources are being made available to actively monitor resettled and resettling populations on a more permanent basis.

As a hard copy supplement to the Marshall Islands Program website (https://marshallislands.llnl.gov/), this document provides an overview of the individual radiological surveillance monitoring program established in support of residents of Utrōk Atoll and nonresident citizens of the Utrōk Atoll population group, along with full disclosure of verified measurement data (2010–2012).). Users of the website are able to obtain access to individual, de-identified measurement and dosimetric data from the whole-body counting and plutonium urinalysis bioassay programs. In addition, a new interactive website application was developed during the reporting period to allow users to calculate their own hypothetical ingestion dose (Ingestion Dose Calculator) from cesium-137 based on the consumption of different types of locally grown foods.

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 Marshall Islands offered the best advantages of stable weather conditions, fewest inhabitants to relocate and isolation with hundreds of kilometers 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 in the vicinity of Bikini and Enewetak Atolls in the northern Marshall Islands (Fig. 1). The most significant contaminating event was the CASTLE Bravo test conducted on March 1, 1954. Bravo was an experimental thermonuclear device with an estimated explosive yield of 15 Mt (DOE, 2000) that led to widespread fallout contamination over inhabited islands on Rongelap and Utrōk Atolls as well as other atolls to the east of Bikini. Today, the United States Department of Energy through the Office of Health and Safety continue to provide environmental monitoring, healthcare and medical services in the Marshall Islands.

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 assess potential changing) radiological conditions on the islands; and (3) provide recommendations for remediation of contaminated sites and verify the effects of actions taken.

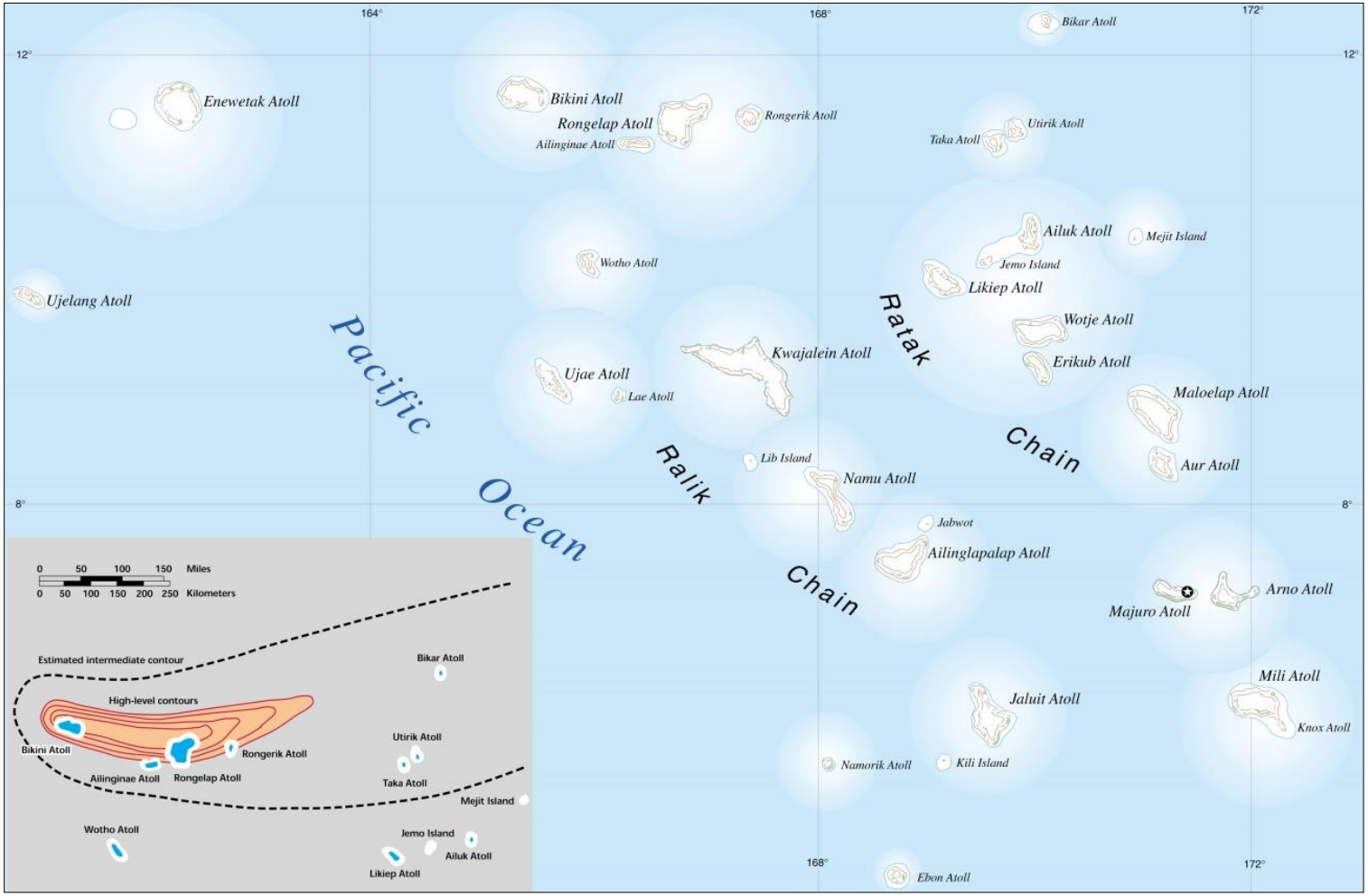
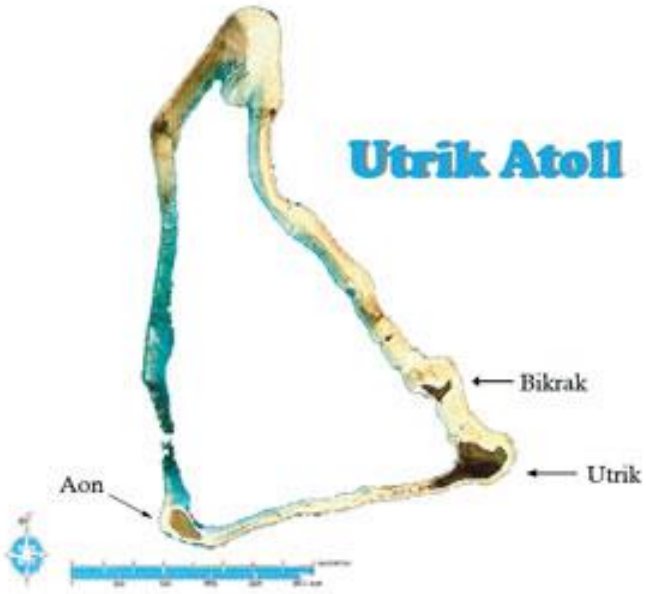


Fig. 1. Map of the Republic of Marshall Islands showing the fallout pattern from the CASTLE Bravo thermonuclear test conduct on 1 March of 1954.

UTRŌK ATOLL

People & Events | Historical Data



People and Events on Utrōk Atoll

Utrōk Atoll is located about 500 kilometers east of Bikini Atoll. The atoll experienced elevated levels of radioactive fallout deposition from atmospheric nuclear weapons tests conducted in the northern Marshall Islands during the 1950s. The most significant contaminating event impacting Utrōk Atoll was the CASTLE Bravo test conducted at Bikini Atoll on March 1, 1954. The 167 residents (including 8 *in utero*) living on Utrōk Atoll at the time of the blast received significant external and internal exposures to *fresh* fallout contamination and were evacuated to Kwajalein Atoll. They returned to Utrōk Atoll about 3 months later. Today, the people of Utrōk Atoll and their leadership continue to seek assurances from the United States Government that the atoll is safe for habitation.

The United States Department of Energy originally assigned responsibility for the internal dosimetry program on Utrōk Atoll to the Brookhaven National Laboratory. Through the 1990s scientists from Brookhaven conducted periodic whole-body counting missions to the Marshall Islands to determine the body burdens of gamma-emitting fallout radionuclides such as cesium-137 and cobolt-60 in Marshallese people from Bikini, Enewetak, Rongelap and Utrōk Atolls (Sun *et al.*, 1992; 1995; 1997a). More recently, the United States Department of Energy has

developed a series of initiatives to address long-term radiological monitoring needs in the Marshall Islands. Under a working agreement between the Utrōk Atoll Local Government, the Republic of the Marshall Islands and the United States Department of Energy (MOU, 2002), a permanent whole-body counting system was established on Majuro Island (Majuro Atoll) during May 2003. This facility is maintained and operated by Marshallese technicians with Livermore scientists providing general program oversight, training and data reporting (Fig. 2). It is expected that people living on Utrōk Atoll will be able to receive whole-body counts on visits to Majuro until such time that the local government is able to build the necessary infrastructure to house a permanent whole-body counting facility on Utrōk Atoll. Under an informal agreement with the Utrōk Atoll Local Government, the Majuro facility also serves the general public with emphasis on developing baseline data on the general Marshallese population with special emphasis given to those people living or working on nuclear affected islands/atolls in the northern Marshall Islands.

Fig. 2. Whole-body counting technicians responsible for daily operations in the Utrōk Atoll Whole Body Counting Facility located on Majuro Atoll [from left to right, Mr. J. Henson, Ms. Lolieta Chee (seated), and Mr. M. Mettao].

Historical Data

Today, exposure to residual fallout contamination on Utrōk Atoll represents only a small fraction of the dose that people receive from natural background radiation in the Marshall Islands. The nuclear test-related dose delivered to inhabitants living on Utrōk Atoll from residual fallout contamination in the environment is dominated by internal (ingestion) exposure to cesium-137 (and to a lesser extent, strontium-90) contained in locally grown food crop products such as coconut, breadfruit and *Pandanus*. According to Robison *et al.*, (1999), the estimated population average maximum annual effective dose on Utrōk Atoll, based on a mixed diet containing imported foods, is less than 0.04 mSv per year and has no consequence on the health of the population. Moreover, the predictive dose assessments based on environmental data and dietary models developed by scientists from the Lawrence Livermore National Laboratory appear to be in excellent agreement with measurements based on whole-body counting (Robison and Sun, 1997).

Justification for establishing a permanent whole-body counting system on Majuro Atoll for use by the Utrōk community comes from renewed concerns about *high-end* doses to maximal exposed individuals living on the atoll, and that the associated health risk may exceed current guidelines adopted by the Marshall Islands Nuclear Claims Tribunal for cleanup of radioactively contaminated sites. Such *high-end* individual doses in the Utrōk population have not been clearly demonstrated but the potential does exist for members of the resident population to binge on a local foods only diet or eat more foods containing higher than average radionuclide concentrations, *e.g.*, coconut crab. Justification for intervention could then be made on the presumption that *high-end* doses are reasonably achievable and that the risk from radiation exposure could be reduced by means of effective and meaningful remedial actions.

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 Delivered to the Residents of Utrōk Atoll and Nonresident Citizens of the Utrōk Atoll Population Group | Summary

What is Whole-Body Counting?

The whole-body counting systems installed in the Marshall Islands contain large volume radiation detectors made of sodium iodide, and are designed to measure gamma-rays coming from radionuclides deposited in the human body. The detector systems are modeled after the ‘Masse-Bolton Chair’ design (Fig. 3) and can be used to detect high-energy, gamma-emitting radionuclides such as cesium-137 and cobalt-60 in most of the body and all of the internal organs. Using established procedures, the whole-body counting measurement data are converted into an annual effective dose using specially designed computer software (Canberra, 1998a; 1998b) and a dose report immediately issued to program volunteers.

Daily check counts of the whole-body counting system are performed using a mixed-gamma point source method. The check count quality assurance procedure was developed by cross-reference to a Bottle Manikin Absorption (BOMAB) phantom (or human surrogate) calibration source containing a standard mix of gamma-emitting radionuclides traceable to the United

States National Institute of Standards and Technology (NIST). Local Marshallese technicians are responsible for all daily operations within the facilities including scheduling of personal counts, performing systems performance checks, and for reporting of data to program volunteers. The technicians receive an initial period of training at the Lawrence Livermore National Laboratory. 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 any data are released in reports or posted to the Marshall Islands website.

Wherever possible, the whole-body counting program in the Marshall Islands is conducted using the same quality control requirements as established under the United States Department of Energy Laboratory Accreditation Program (DOELAP) for internal dosimetry. A systems background and other quality control counts are performed daily to ensure that the measurement systems conform to all applicable quality requirements. Also, the whole-body counting facilities participate in performance testing under the umbrella of the Intercomparison Studies Program (ISP) at the Oak Ridge National Laboratory. These performance test samples are distributed around to each of the facilities in the Marshall Islands after an initial count using the *mirror* whole-body counting training facility located at Livermore under the Marshall Islands Program.

The performance of each facility 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 reference values supplied by the Oak Ridge National Laboratory. Based on our external quality assurance program, the Marshall Island Program whole-body counting facilities consistently conform to ANSI Standard N13.30-1996 (ANSI/HPS N13.30-1996, 1996) performance criteria for measurement bias and precision (Kehl *et al.*, 2007; 2010; 2014).

What Will 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 (Robison *et al.*, 1997a; 1997b; Robison and Hamilton, 2010). The strategic objective of the Marshall Islands Whole Body Counting Program is to offer island residents an unprecedented level of radiation protection monitoring until such time that it is clearly demonstrated that radiation surveillance measures can be relaxed. The value of whole body count radiation protection monitoring resides in the fact that the data provides a direct measure of radionuclide uptake by local populations. Information about potential *high-end* health risks and seasonal fluctuations in the body burden of cesium-137 within various Marshallese cohort population groups can be assessed from repeated 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

Fig. 3. A *Masse-Bolton* whole-body counter detector system and BOMAB calibration phantom on Majuro Atoll.

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 United States Environmental Protection Agency (EPA). As displaced communities return to their ancestral homelands, the Marshall Islands Whole Body Counting Program will allow the United States Department of Energy to closely monitor resettled and resettling atoll populations, and provide assurances that radiation related health risks remain at or below established standards.

Estimating Doses from Cesium-137 Based on 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 peoples' bodies. 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 health risks associated with radiation exposure. The Marshall Islands dose reporting and data graphics on the Marshall Islands website (https://marshallislands.llnl.gov/) are based on the calendar year committed effective dose equivalent (CEDE) from intakes of cesium-137 in the year of measurement projected over 50 years (Daniels *et al.*, 2007). Dose equivalents are given in units of joule per kilogram or sievert (Sv). The conventional unit for dose equivalents used by federal and state agencies in the United States is the rem. Doses from exposure to environmental radioactivity (natural or nuclear test-related) are normally expressed as 1/1000th of the base unit, i.e., in millisievert (mSv) or millirem (mrem). 1 mSv is equal to 100 mrem.

Information Note: The methodologies for computing doses from the whole-body counting and plutonium urinalysis programs have been outlined in a Technical Basis Document (refer to Daniels *et al.*, 2007). The same calculation algorithms are being used by the Individual Monitoring WBC Report application on the Marshall Islands website. This methodology uses a 50-y dose commitment and complies more fully with the International Commission on Radiological Protection (ICRP) methodology compared with the algorithms previously used for dose reporting.

Performance Evaluation of the Whole Body Counting Program

Whole-body counting facilities in the Marshall Islands as well as a *mirror* facility maintained at the Lawrence Livermore National Laboratory participate in bi-annual performance evaluation exercises conducted under the umbrella of the Intercomparison Studies Program (ISP) at the Oak Ridge National Laboratory. The ISP was specifically designed to help support whole-body counting facilities comply with quality requirements established under the United States Department of Energy Laboratory Accreditation Program (DOELAP). In this way, the Marshall Islands Radiological Surveillance Program has established quality assurance measures that are consistent with standard requirements used to monitor Department of Energy workers in the United States.

The performance evaluation samples for whole-body count measurements are prepared in a mock-up geometry that simulates a human body torso, and usually contains a mix of barium-133 (^{133}Ba), cobalt-60 (^{60}Co), cesium-137 (^{137}Cs) and yttrium-88 (^{88}Y) isotopes at nominal concentrations of $\leq$ 500 nCi (or 18.5 kBq) contained in a '5-bottle phantom'. The ISP at Oak Ridge use stock isotope solutions indirectly traceable to the National Institute of Standards and Technology (NIST). Details concerning the NIST stock solutions and ISP spikes used in the preparation of the whole-body count performance evaluation samples can be found elsewhere (ISP Report, 2010; 2011; 2012). For practical purposes we have limited performance evaluation testing of the Marshall Island whole-body counting facilities to detection and measurement of cesium-137.

For testing purposes, the relative bias (%, B_{ri}) for the ith measurement conducted in a facility shows how close the measured activity (A_i) is to the actual spike value (A_{ai}), and is defined as;

$$B_{ri} = {(A_i - A_{ai})}/{A_{ai}} \times 100$$

The relative bias (%, B_r) for any whole body count facility is calculated as the average of the individual relative biases B_{ri}, and is defined as;

$$B_r = \sum_{i=1}^{n} \frac{B_{ri}}{N}$$

where N is the number of test measurements performed within each facility. The acceptance criteria for the relative measurement bias statistic based on the ANSI 13.30-1996 standard for radiobioassay service laboratory quality control, performance testing, and accreditation in the United States is -25% to +50%.

The estimated, mean relative bias statistic for the Utrōk (Majuro), Enewetak, Rongelap, and LLNL facilities for 5-bottle ORNL performance evaluation exercises conducted between 2010 and 2012 were 21.7%, 20.7%, 20.0%, and 31.8%, respectively. This compares with ANSI Standard N13.30-1996 acceptance criteria for radiobioassay service laboratory quality control, performance testing and accreditation, in the United States, of -25% to +50%. The results for each performance evaluation exercise conducted between 2010 and 2012 are shown graphically (Fig. 4) with the acceptance criteria represented by Upper (UCL) and Lower (LCL) Control Limits.

The relative precision (%, S_B) of the measurements performed across each whole-body count facility is the relative dispersion of the values of B*ri* from their mean B*r*, and is defined as;

$$S_B = \sqrt{\frac{\sum_{i=1}^{N} (Bri - Br)^2}{(N-1)}}$$

The acceptance criteria for the relative measurement precision statistic (S_B) based on ANSI Standard N13.30-1996 is less than or equal to 40%. The estimated, mean relative precision statistic for the Utrōk (Majuro), Enewetak, Rongelap, and LLNL facilities based on performance evaluation exercises conducted between 2010 and 2012 were 14.8%, 6.5%, 5.8%, and 7.4%, respectively.

The combined mean relative bias and relative precision statistic across the three remote Marshall Islands whole-body counting facilities were 20.8% and 9.0%, respectively. Consequently, whole-body count facilities in the Marshall Islands have consistently passed ANSI Standard N13.30-1996 performance criteria for relative measurement bias and precision during the reporting period (also see Kehl *et al.*, 2007; 2010; 2014).

ANSI Standard N13.30-1996 has been revised and now uses a combined standard error of 25% (combined bias and precision) (ANSI/HPS N13.13-2011, 2011). It is not clear when this new standard will be fully implemented under the Department of Energy Laboratory Accreditation Program. However, steps have already been taken to reduce bias and improve precision to help ensure that the Marshall Islands Whole Body Counting Program can continue to meet all applicable quality requirements.

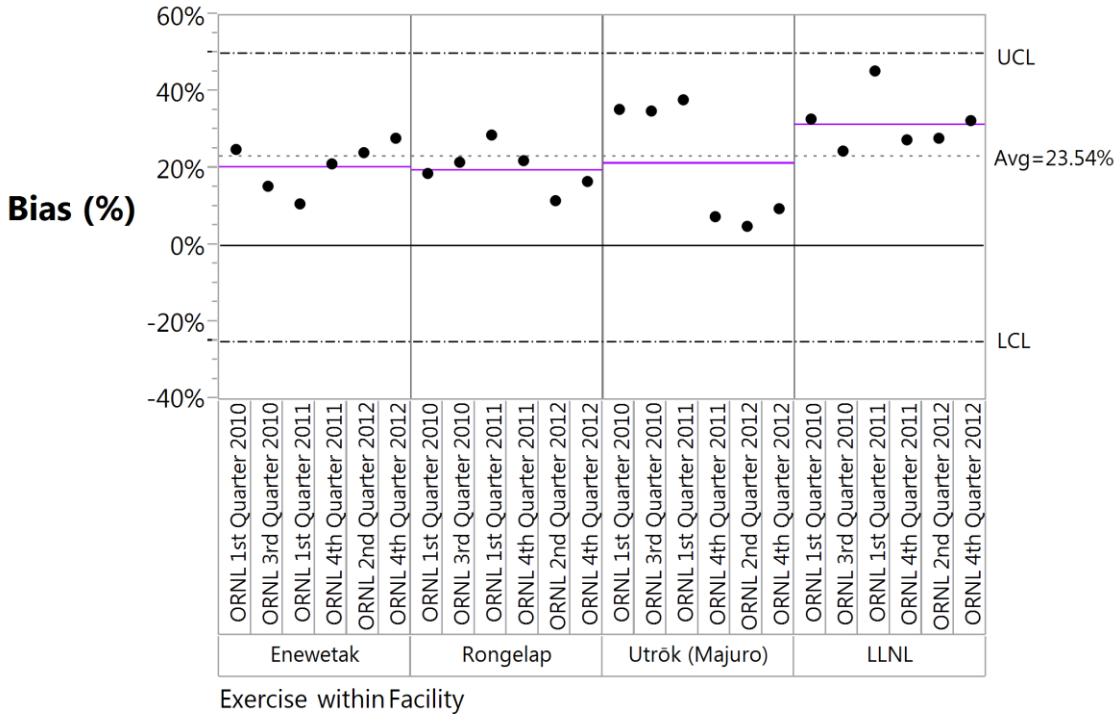


Fig. 4. Repeatability and Reproducibility (R&R) variability/gauge plot showing results of whole-body count analyses of 5-bottle performance evaluation test samples distributed under the Intercomparison Studies Program (ISP) at the Oak Ridge National Laboratory (ORNL) (2010-2012).

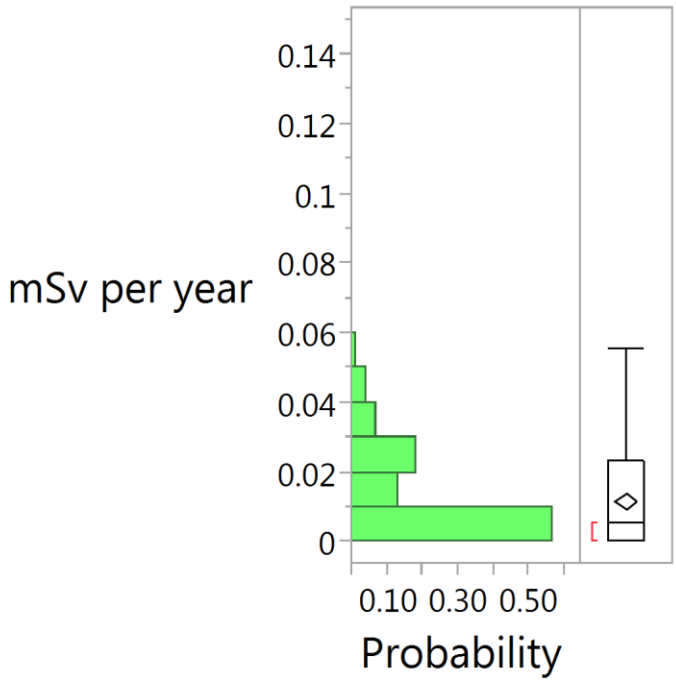
Doses Delivered to the residents on Utrōk Atoll and Nonresident Citizens of the Utrōk Atoll Population Group

The individual measurement and dosimetric data for the Marshall Islands Whole Body Counting Program (2010-2012) are available on the Marshall Islands Program website, https://marshallislands.llnl.gov/.

These data and information are not to be used in scientific reports without permission.

Dose distribution plots of the committed effective dose equivalent for internally deposited cesium-137 for Utrōk Atoll residents and nonresident citizens of the Utrōk Atoll population group are shown in Fig. 5a and Fig. 5b, respectively. These data can be compared with the dose distribution for the general Marshallese population as shown in Fig 6. The general Marshallese population has been divided into two subgroups. The first subgroup includes permanent and temporary residents of the northern atolls (Fig. 6A.) while the second contains volunteers from the southern atolls (Fig. 6B). In general, the whole-body count data for various population group cohorts in the Marshall Islands are highly skewed and contain disproportionate numbers of non-detects. A more detailed statistical analysis of these data will be published elsewhere using censored data techniques.

The estimated, population average, effective dose (mean value) from internally deposited cesium-137 for Utrōk Atoll residents during 2010-2012 is 0.011 mSv per year [CI (mean value) = 0.010-0.0138; N=175]. This compares with the reported population average effective dose for

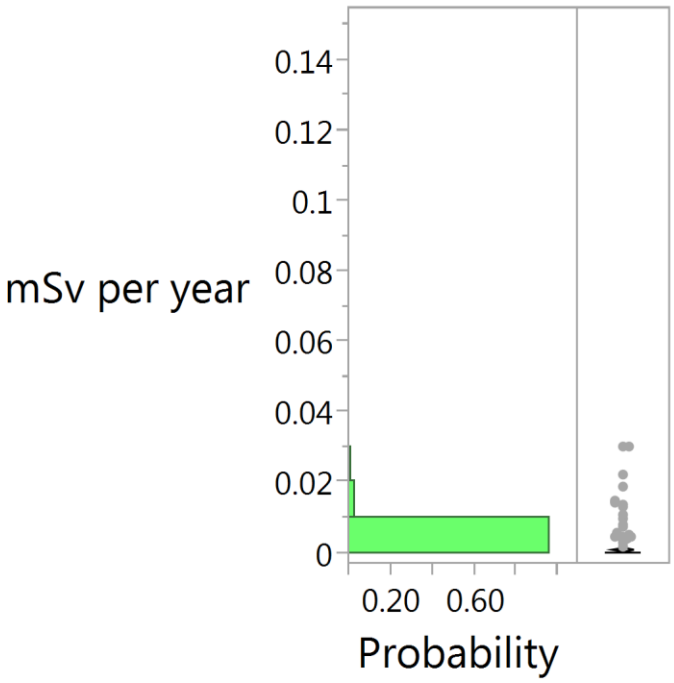


[Basic Statistics: Mean = 0.012; Median = 0.014; Std. Err. Mean = 0.0011; 95% CI (mean value) = 0.010-0.014; N = 175]

Fig. 5a. Distribution/Box plot of the committed effective dose equivalent (mSv per year) from cesium-137 (2010-2102) delivered to Utrōk Atoll residents.

Utrōk residents during 2007-2009 of 0.020 mSv per year [CI (mean value) = 0.017-0.022; N = 287] (Hamilton *et al.*, 2014). The maximum annual effective dose delivered to a resident of Utrōk Atoll during 2010-2012 is 0.055 mSv (or 5.5 mrem).

The estimated, population average, effective dose from internally deposited cesium-137 for nonresident citizens of Utrōk Atoll for 2010-2012 is 0.001 mSv per year [CI (mean value) = 0.0005-0.0015; N=225]. The nonresident comparison group data was compiled from volunteers identifying as citizens of the Utrōk Atoll population group who were living away from their home atoll during the measurement year that they were counted for internally deposited cesium-137. The range of radiation doses delivered to Utrōk Atoll residents from internally deposited cesium-137 is generally considered to be low, and reasonably well constrained with few high-end outliers (Fig. 5a). The reported doses also fall below the Republic of the Marshall Islands dose criterion for cleanup of radioactively contaminated sites of 0.15 mSv per year. However, these data do show that people who live or work at Utrōk are more likely to acquire measurable quantities of cesium-137 in their bodies compared with those people living on the southern atolls. For example, excluding volunteers who had inhabited other atolls in the northern Marshall Islands, about 53% of the Utrōk Atoll residents counted during 2010-2102 had detectable levels of cesium-137 in their bodies. This compares with about 7% of volunteers in the nonresident comparison group.



[Basic Statistics: Mean = 0.0010; Median = 0.0000; Std. Err. Mean = 0.0003; 95% CI (mean value) = 0.0005-0.0015; N = 225]

Fig. 5b. Distribution/Box plot of the committed effective dose equivalent (mSv per year) from cesium-137 (2010-2012) delivered to the nonresident citizens of the Utrōk Atoll population group.

The estimated, population average, effective dose from internally deposited cesium-137 delivered to the general Marshall Islands population (including non-national visitors) ranged from 0.0003 mSv per year for inhabitants living on the southern atolls to 0.036 mSv per year for inhabitants of the northern atolls. The northern atoll cohort excluded permanent residents and citizen volunteers of Enewetak, Rongelap and Utrōk Atolls.

The highest estimated dose rates detected in the Marshall Islands from internally deposited cesium-137 during 2010-2012 were almost exclusively associated with a small number of Bikini Project Department (BPD) and International Outreach Services Inc. (IOS)/U.S. Department of Energy (DOE) personnel stationed on Bikini Island (seen as graphical outliers in the box plot shown in Fig. 6B). The estimated, average effective dose for the Bikini cohort alone for this period is 0.19 mSv per year (range = 0-0.47 mSv per year; N = 17).

People from Mejit Atoll are also consistently acquiring measureable quantities of cesium-137 in their bodies. For 2010-2012, the average, effective dose contribution from internally deposited cesium-137 delivered to Mejit residents is 0.036 mSv per year (range = 0-0.096 mSv per year, N=57). With the exception of those volunteer working on Bikini Island, the Mejit Atoll volunteer cohort also contained the highest percentage of volunteers (about 91 percent) of any resident cohort population group in the Marshall Islands with a measureable dose contribution from internally deposited cesium-137.

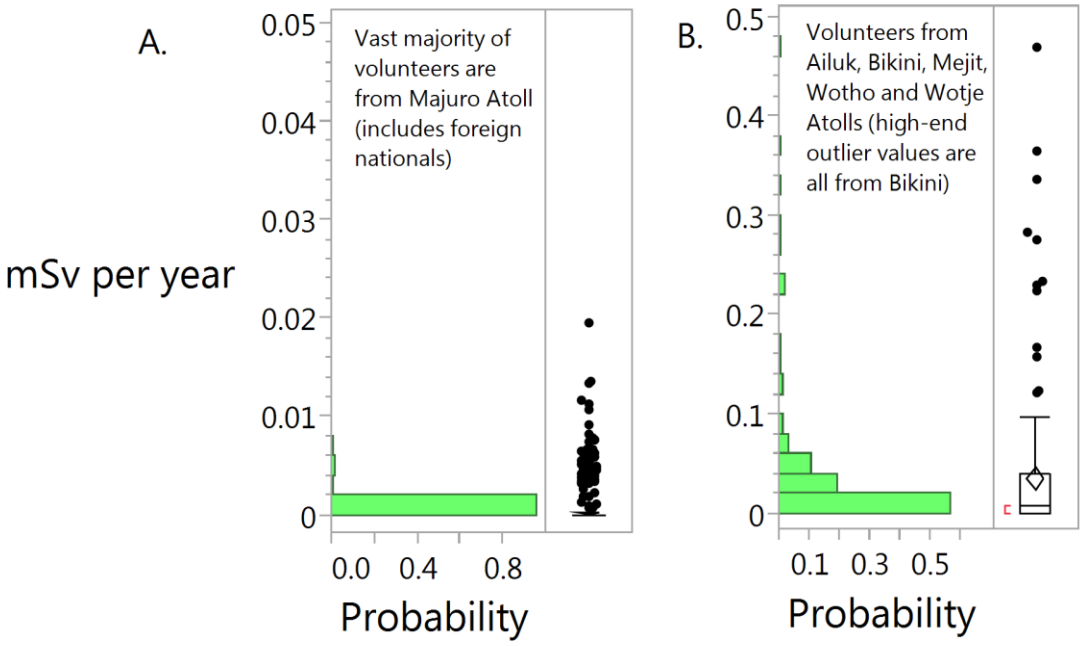


Fig. 6. Distribution/Box plot of the committed effective dose equivalent (mSv per year) from cesium-137 (2010-2012) delivered to the general population of the Marshall Islands.

A. Inhabitants of Majuro and other southern atolls. Basic Statistics: Mean = 0.0003; Median = 0.0000; Std. Err. Mean = 0.00003; 95% CI (Mean value) = 0.0002-0.0003; N = 1451.

B. Inhabitants of the northern atolls excluding permanent residents and citizens of Enewetak, Rongelap and Utrōk Atolls. Basic Statistics: Mean = 0.036; Median = 0.006 Std. Err. Mean = 0.006; 95% CI (Mean value) = 0.024-0.047; N = 150.

For the purposes of developing these summary graphics and statistics, a whole-body count showing a non-detect for internally deposited cesium-137 is assigned a radiation dose equal to zero. The critical level (L_c) for detection of cesium-137 using whole-body counting in the Marshall Islands is around ~0.05 kBq. This equates to an integral annual dose detection limit of about 0.002 mSv (0.2 mrem) for an adult male or an annual effective dose detection limit of 0.0025 mSv (or 0.25 mrem). Consequently, any minor dose contribution that is overlooked (<0.0025 mSv per year) could be accounted for by reporting doses as values of equal to or less than 0.0025 mSv per year for non-detects. Similarly, the reported summary statistics could be adjusted to reflect average measures and ranges of not less than the detection limit, i.e., 0.025 mSv per year.

Summary

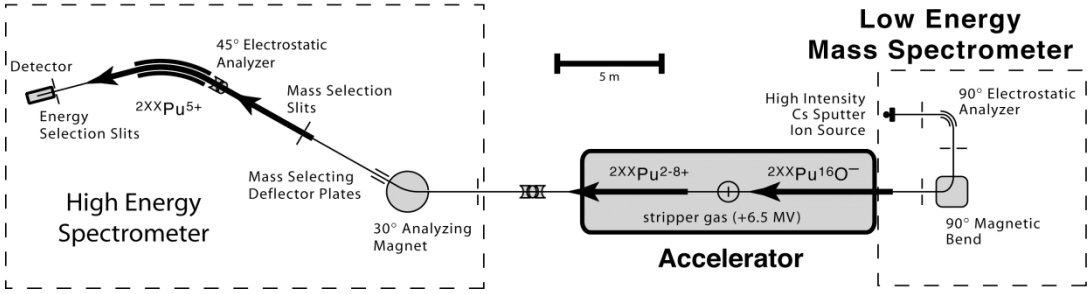
The estimated effective dose from internally deposited cesium-137 developed for the Utrōk Atoll population group can be compared with the natural background dose in the Marshall Islands and the United States of 1.9 mSv and 3.1 mSv per year, respectively. Dose estimated based on internally deposited cesium-137 for all program volunteers independent of where they live were

also well below the annual dose criteria of 1.0 mSv per year, excluding medical irradiation, imposed in 10 CFR Part 20 for protection of the public (NRC, 1994).

The Republic of the Marshall Islands Nuclear Claims Tribunal has adopted a standard for cleanup of radioactively contaminated sites in the Marshall Islands of 0.15 mSv (15 mrem) per year. Under present day living conditions in the Marshall Islands, cesium-137 ingestion dominates the nuclear tested-related dose from exposure to residual fallout contamination in the environment. Data derived from the Marshall Islands Whole Body Counting Program are therefore likely to provide a good measure of the total risk posed by exposure to residual fallout contamination in the environment. In this instance, the results from the whole-body counting program on Majuro Atoll demonstrate that residents living on Utrōk Atoll are not exposed to significantly elevated levels of cesium-137 in their diets. It is, however, recommended that the monitoring program be continued. This should be done to provide an accurate assessment of doses across different age groups, gender and food intake groups, and to identify potential individuals at higher risk from radiation exposure. The continuing monitoring program will also allow doses to be tracked and assessed on other northern atolls, and provide a measure of future change in radiological conditions based on land-use, population dynamics, and the export of foods across atoll boundaries. To this end, there does appear to be some evidence suggesting that individuals living on Majuro Atoll may acquire a measureable quantity of cesium-137 in their bodies from importing tree food crop products from the northern atolls.

PLUTONIUM URINALYSIS (BIOASSAY) MONITORING

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



A schematic diagram of the systems configuration for analysis of plutonium isotopes in bioassay samples using 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 workers who routinely handle 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 bioassay samples from individuals over a 24-hour period. 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. The test turns a urine sample into a powder which scientists analyze by counting the number of plutonium atoms contained in the sample.

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 exposure to close-in and regional fallout contamination.

Routes of Human 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, alpha-particles have a high relative effectiveness to disrupt or cause harm to biological cells. As a consequence, *in-vitro* bioassay tests have been developed to test for the presence of systemic plutonium inside the human body based on measured urinary excretion patterns and modeled metabolic behaviors of the absorbed radionuclides.

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 also remains in the body for a long time but the systemic uptake of plutonium in people living in the northern Marshall Islands is still expected to be very low (Robison *et al.*, 1980; 1982; 1997a; 1997b).

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 than 5% of the total lifetime dose from exposure to residual fallout contamination in the environment. However, plutonium is a major concern to people living in the northern Marshall Islands because of its long half-life and persistence in the environment. Moreover, radioactive debris deposited in lagoon sediments of coral atolls formed a reservoir and potential long-term source for remobilization and transfer of plutonium through the marine food chain and potentially to humans. Elevated levels of plutonium in the terrestrial environment represent potential inhalation and/or ingestion hazards. Early characterization of the terrestrial environment has also revealed the presence of hotspots containing milligram-sized pieces of plutonium metal that 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 the uptake of plutonium in resettled and resettling populations (Sun *et al.*, 1995; 1997b).

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

Plutonium urinalysis is a measurement technique that ultimately provides information on the amount of plutonium people have in their bodies. Although plutonium is expected to be a minor contributor to the total nuclear test-related dose, it is a concern to people living in the northern Marshall Islands because of its long half-life ($T_{1/2}$ = 24,000 years) and proportionally higher levels of plutonium found in close-in or regional fallout contamination. 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. Accelerator mass spectrometry is about 200 to 400 times more sensitive than monitoring techniques commonly employed in occupational internal dosimetry monitoring programs within 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 plutonium-239.

The Marshall Islands Plutonium Urinalysis Monitoring Program was implemented under the following action plan.

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 population groups such as workers involved in soil remediation or agriculture.
3. To demonstrate and document that occupational and/or public exposures to plutonium in the Marshall Islands are below levels that will have an impact on human health.
4. To ensure that our plutonium bioassay data meet all applicable quality requirements through the use of standardized procedures and performance testing.
5. To document and test the reliability of using environmental data to assess human exposure (and uptake) to plutonium in coral atoll ecosystems, and predict future change.

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; Conard, 1992; 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 plutonium exposure in the Marshall Islands (Hamilton *et al.*, 2007a). Fission Track Analysis (FTA) is limited to the quantification of plutonium-239 but with a reported detection limit (MDA, Minimum Detectable Amount) of around 1 to 3 microBecquerel (μBq) of plutonium-239 that offers a greatly improved potential over alpha-spectrometry for assessing low-level chronic exposures to plutonium in the environment.

Under the Lawrence Livermore National Laboratory Marshall Islands Plutonium Urinalysis Program, bioassay 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 while in contact with a quartz or plastic slide. Any resulting fission fragments will 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.

Over the past decade, scientists from the Lawrence Livermore National Laboratory have developed a state-of-the-art technology for measurement of plutonium isotopes in bioassay samples based on accelerator mass spectrometry (Brown *et al.*, 2004; Hamilton *et al.*, 2007a).

The technique has vastly improved the quality and reliability of assessments of urinary excretion of plutonium from Marshall Islanders, and avoids many of the disadvantages of using conventional atom counting techniques, fission track analysis or other competing new technologies.

Information Note: *There are two main isotopes of plutonium in the environment–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 ~0.35 compared with that present in integrated global fallout deposition (~0.18) or unfissioned nuclear fuel (~0.05). Consequently, it may be possible to use bioassay testing and plutonium isotopic measurements as an investigative tool to assess historical and/or contemporary source/event specific exposures.*

Method Validation

Method validation is the process used to monitor and document the quality of the measurements. Methods validation testing under the Marshall Islands Urinalysis Monitoring Program has included participation in an independent interlaboratory exercise organized by the United States National Institute of Standards and Technology (NIST). The results of this exercise clearly demonstrate that accelerator mass spectrometry is well suited for detection of microBecquerel (μBq) concentrations of plutonium-239 and plutonium-240 in bioassay samples (Fig. 7) (Marchetti *et al.*, 2002). An independent report has since been published (McCurdy *et al.*, 2005) providing a level of validation for use of this technology under the Marshall Islands Program.

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. These quality control performance test samples are prepared under contract with the Intercomparison Studies Program (ISP) at the Oak Ridge National Laboratory (ORNL), and are 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. The plutonium-240/plutonium-239 atom ratio in test samples approximates that observed in integrated worldwide fallout deposition, i.e., ~0.2. Results of these quality control sample analyses are sent to Oak Ridge National Laboratory researchers for review and, in return, they prepare a data quality assurance report. All quality control data must pass ANSI Standard N13.30-1996 performance criteria for accuracy and precision before acceptance of any routine bioassay measurement data. The combined average, measurement bias and precision for measurement of plutonium-239 between 2010 and 2012 based on analysis of spiked performance test samples prepared by Oak Ridge National Laboratory and analyzed by accelerator mass spectrometry (2010-2012) were −2.1% and ±5.1% (N = 13) (Fig. 8). The methodologies employed under the Marshall Islands Urinalysis Monitoring Program are considered representative of the state-of-the-art in routine internal dosimetry monitoring of plutonium for the general public.

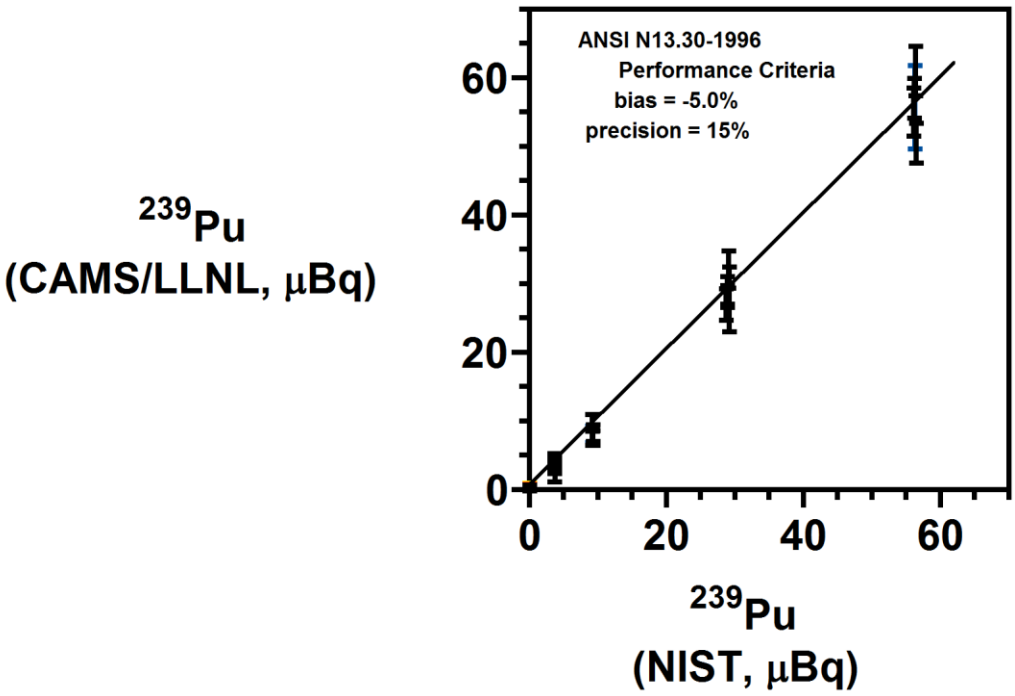


Fig. 7. Results of an interlaboratory exercise conducted by the National Institute of Standards and Technology (NIST) on determination of plutonium-239 in synthetic urine in the microBecquerel (μBq) range.

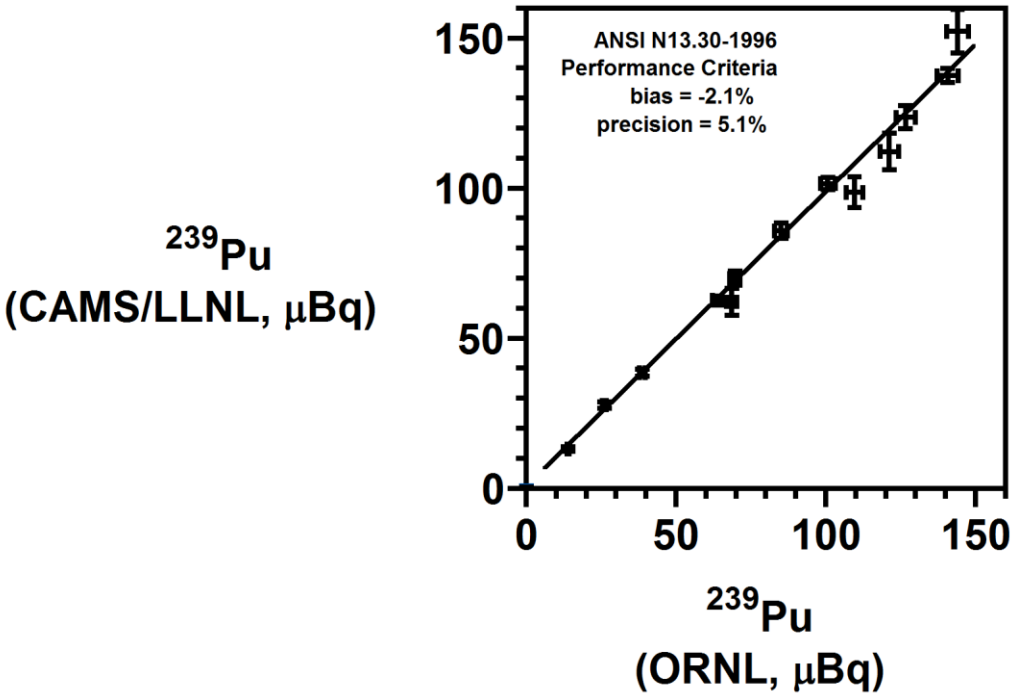


Fig. 8. Analyses of externally prepared natural matrix spiked performance evaluation test samples (2010-2102) prepared under the auspices of the Intercomparison Studies Program (ISP) at the Oak Ridge National Laboratory (ORNL).

Plutonium Urinalysis Monitoring on Utrōk Atoll

All individual measurement and radiometric data developed under the Marshall Islands Plutonium Urinalysis Monitoring Program are available on the Marshall Islands website, https://marshallislands.llnl.gov/.

A bioassay monitoring program to assess urinary excretion rates of plutonium from Utrōk Atoll residents was initiated during 2006 (Hamilton *et al.*, 2007b). The monitoring program was formally established under a working agreement between the United States Department of Energy, the Utrōk Atoll Local Government and the Republic of the Marshall Islands (MOU, 2002). The aim of the program is to develop statistically meaningful, high quality data on urinary excretion of plutonium similar to baseline studies conducted on Enewetak Atoll.

Predictive dose assessments based on environmental data indicate that the 50-y committed effective dose from plutonium on Utrōk Atoll will be around 0.12 mSv (12 mrem) (Robison *et al.*, 1999) but these estimates have never been substantiated by individual bioassay testing due largely to technical shortfall in measuring low levels of plutonium in bioassay samples. Moreover, historical measurements of plutonium urinary excretion in the Marshall Islands (including measurements for people living on Utrōk Atoll) have generally proven to be unreliable for estimating the low doses from plutonium exposures typically encountered in the Marshall Islands.

In general, urinary excretion of plutonium from Marshallese populations will consist of a long-term baseline 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 reported that people living in 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 to 4 μBq per 24-h void (Boecker *et al.*, 1991). Based on fission track analysis, scientists from Brookhaven National Laboratory estimated that exposure to worldwide fallout contamination in Marshall Islands will produce background urinary excretion rates of plutonium of 1 to 2 μBq per 24-h void (NRC, 1994). Both measures are an order of magnitude higher than contemporary measurements of urinary excretion of plutonium from Marshallese populations based on accelerator mass spectrometry (Hamilton *et al.*, 2007b; 2014).

The combined, weighted average urinary excretion of plutonium-239 from Utrōk Atoll residents measured through 2006 and 2007-2009 is 0.18 μBq per 24-h void [95% CI (mean value) = 0.12-0.24; N=60] (recalculated from Hamilton *et al.*, 2014). This compares with an error-weighted average of −0.02 μBq of plutonium-239 [95% CI (mean value) = -0.7-0.03; N=26) measured in a compatible set of field blanks over the same time period.

All the measurement data developed for the Utrōk Atoll population group were well below the occupational action level established under the latest Department of Energy regulation 10 CFR 835 in the United States for *in vitro* bioassay monitoring of plutonium-239. Moreover, the individual bioassay samples contained levels of plutonium-239 that were not significantly different to the critical level of measurement (L_c ~0.25 μBq) needed to accurately determine if plutonium was actually present in the sample or not. Excluding outliers, the analyses of

plutonium-240 in bioassay for the Utrōk Atoll population group through 2006 returned a combined mean null value of <0.03 μBq of plutonium-240 per 24-h void, and was indistinguishable to the concentration of plutionium-239 measured in field blanks (Hamilton *et al.*, 2007b). Subsequently, plutonium-240 measurements were not included in the analytical scheme or reporting for 2007-2009. Similarly, plutonium-240 was not included in the analytical scheme or reporting for 2010-2012. Also, the algorithm on the Marshall Islands website was also modified to compute the dose contribution from plutonium-239 alone as the actual analyte of interest being measured. As such, the reported 50-y committed dose equivalent calculations contained in this report do not give any consideration to the presence of plutonium-240. For clarity, this omission effectively underestimates the reported dose contribution from plutonium by an average of 40% but could range between 15 to 65% percent.

The Marshall Islands Program bioassay database for Utrōk Atoll was expanded during 2010-2012 to include analyses of plutonium-239 in bioassay samples collected from 24 Utrōk Atoll residents and nonresidents along with associated measurements on 62 field blanks. The current synopsis on urinary excretion of plutonium from the Utrōk population group is based on the combined data for all years (Fig. 9).

The plutonium-239 content of bioassay samples collected from the Utrōk Atoll resident and nonresident volunteer cohorts is clearly distinguishable (p values = <0.0001 to 0.0005) to that measured in field blanks. The urinary excretion of plutonium-239 from the resident volunteer cohort ranged between −0.20 and 1.07 μBq per 24-h void with an error-weighted average of 0.18 μBq per 24-h void [95% CI (mean value) = 0.12-0.22; N=70]. The range and error-weighted average urinary excretion rate of plutonium-239 from the nonresident volunteer cohort is −0.15-1.75 μBq per 24-h void, and 0.09 μBq per 24-h void [95% CI (mean value) = 0.12-0.22; N=70], respectively. By comparison, the pooled field blanks contained a weighted average plutonium-239 content of −0.020 μBq [95% CI (mean value) = -0.05-0.01; N=87; outlier excluded]. Using nonparametric comparisons, there appears to be no statistically significance difference in the urinary excretion of plutonium-239 between the resident versus non-resident volunteer cohorts.

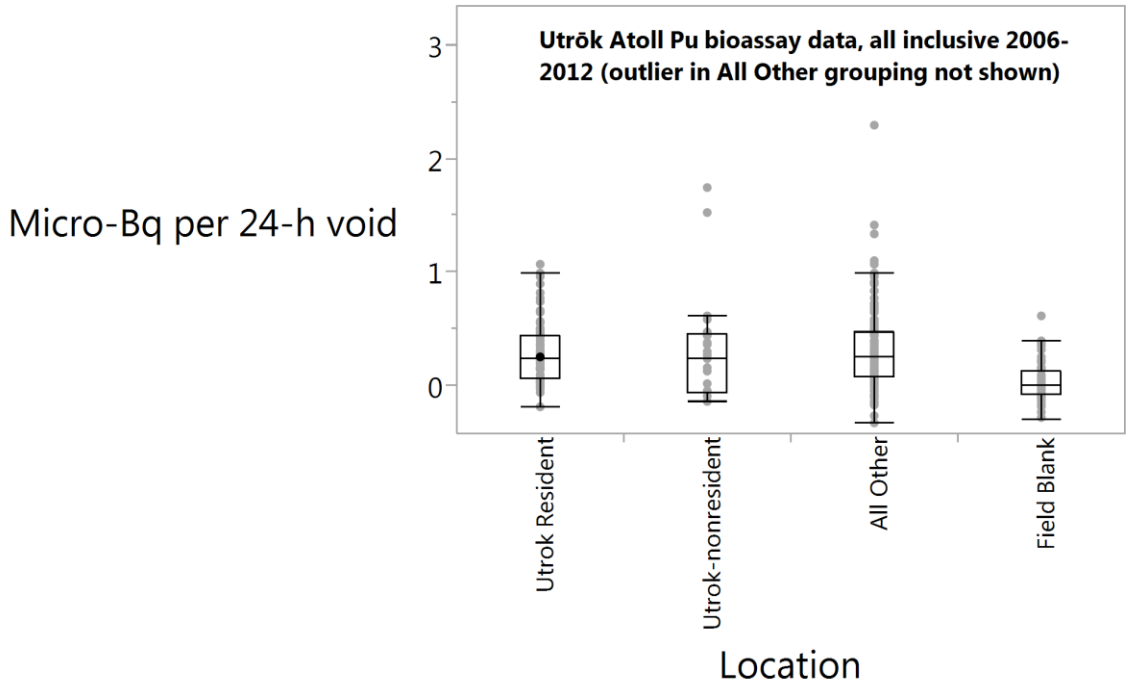


Fig. 9. Distribution plot of ^{239}Pu (μBq per 24-h void) measured in bioassay samples collected between 2006 and 2012.

Utrōk Resident = resident of Utrōk Atoll (2006-2012, inclusive).

Utrōk nonresident = nonresident citizen of the Utrōk Atoll population group (2006-2012, inclusive).

All Other = updated bioassay data for 2010-2012 (includes bioassay data for Enewetak residents and nonresidents, Rongelap Atoll residents and nonresidents, and other volunteers from the general Marshall Islands population).

Field Blank = process sample bottle blank samples collected in the Marshall Islands, and handled and processed in exactly the same manner as the human urine bioassay samples.

Similarly, the urinary excretion rate of plutonium-239 from all other volunteers collected during 2010-2012 ranged between –0.33 and 8.5 μBq of plutonium-239 per 24-h void with an error-weighted average of 0.17 μBq per 24-h void [95% CI (mean value) = 0.13-0.21; N=197; including data for an unverified outlier]. At the same time, all the individual bioassay measurement data contain relatively large uncertainties (Table A2) and fall close to the reported critical level (L_c) of measurement. A more detailed statistical analysis of the plutonium bioassay data will be published elsewhere**.**

Based on the weighted average urinary excretion of plutonium-239, the computed population average, 50-y committed effective dose equivalent delivered to Utrōk Atoll residents and non-residents during 2006-2012 from internally deposited plutonium-239 is estimated to be around 21 μSv (2.1 mrem) and 11 μSv (1.1 mrem), respectively. The maximum 50-y committed

effective dose equivalent delivered to Utrōk Atoll resident or nonresidents from internally deposited plutonium during 2006-2012 is 210 μSv (21 mrem). It should be noted that the annualized dose criteria developed for remediation of radioactively contaminated sites (NCRP, 2004) in the United States is usually based on estimates of the total effective dose equivalent (TEDE) over 50 years. The TEDE consists of the sum of the committed dose due to intakes of fallout radionuclides (of which, plutonium-239 is just one potential isotope) and the deep dose equivalent from external exposures experienced during the measurement year.

Plans for the Future

Prior to establishing the existing sample collection and measurement protocols at the Lawrence Livermore National Laboratory, much of the early urinary excretion (bioassay) data for plutonium in the Marshall Islands was of questionable quality. This largely resulted from poor quantification sensitivity of the detection methods employed and/or from the general lack of quality control in sample collection and measurement. In addition to expanding the plutonium bioassay database for Utrōk Atoll resident and nonresident cohorts, we plan to develop high-quality baseline data for other atoll population groups and control populations including plutonium excretion data for those individuals who plan to resettle Rongelap Island.

Such provisions should help provide assurances to resettled and resettling populations concerned about long-term exposure to residual fallout contamination in the Marshall Islands. Additionally, by establishing a well-documented baseline for urinary excretion of plutonium from Marshall Island populations, we will be better able to track and monitor potential changes in exposure conditions on the atolls. This is especially true of conditions that may affect the remobilization and transfer of plutonium through the aquatic food chain or from potential increases in inhalation exposure associated with resettlement of islands or atolls, remediation activities, commercial development and/or changing land-use patterns. Repeated measures of individuals (especially for the investigatory individuals) will also enhance the ability to subtract previous year doses and provide a more accurate determination of Effective Dose Equivalent.

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MEASUREMENT DATA FROM THE INDIVIDUAL RADIOLOGICAL SURVEILLANCE MONITORING PROGRAM

Introduction | Individual Measurement Database

Introduction

The individual (de-identified) measurement data for program volunteers are accessible on the Marshall Islands website (https://marshallislands.lln.gov/) using menu driven routines (Fig. 10).

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-Becquerel (kBq), where 1 kBq equals 1000 Bq and 1 Bq = 1 nuclear transformation per second (t s^{-1}). The detection of plutonium-239 and plutonium-240 in bioassay (urine) samples indicates the presence of internally deposited (systemic) plutonium in the human body. At Livermore, plutonium bioassay measurements are performed using a state-of-the-art technology based on accelerator mass spectrometry (Brown *et al.*, 2004; Hamilton *et al.*, 2007a). 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 plutonium-239 and, if detectable, plutonium-240 excreted (lost) per day (d^{-1}); where 1 μBq d^{-1} = 10^{-6} Bq d^{-1} and 1 Bq = 1 t s^{-1}.

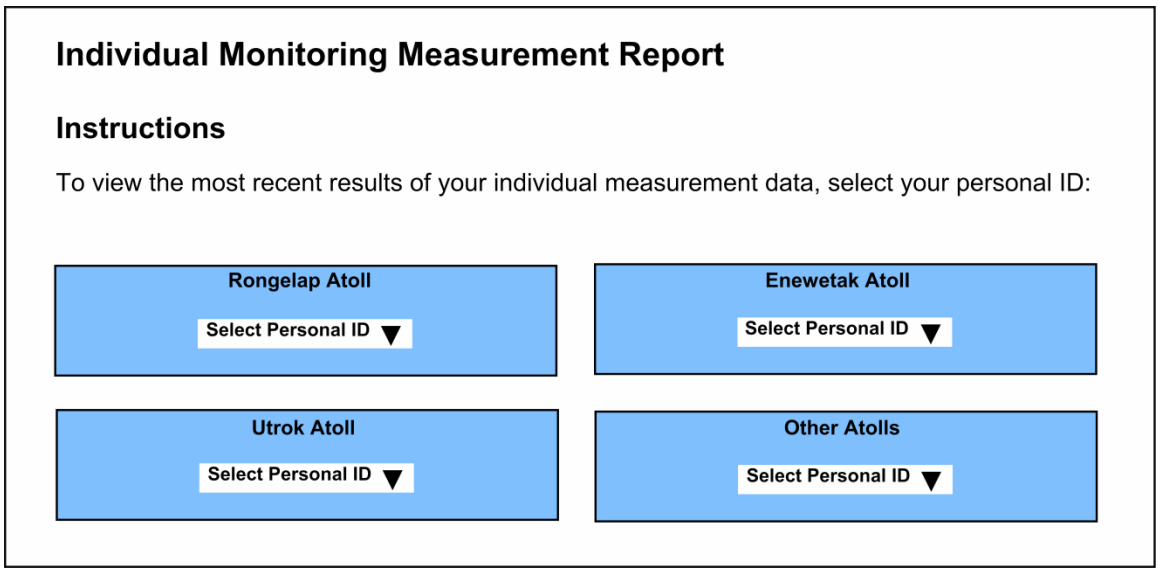

Fig. 10. Layout of the menu structure used to access individual measurement data from the Marshall Islands website, https://marshallislands.llnl.gov/.

Individual Measurement Database

The Marshall Islands website provides electronic access to all whole-body counting and plutonium urinalysis data developed under the Marshall Islands Individual Radiological Surveillance Program (1999–present). Please note that measurement data developed for Utrōk Atoll residents are generally given a UU prefix identification number whereas inhabitants living on other atolls (with exception of those people living on Enewetak and Rongelap Atolls) are given an MI prefix identification number.

DOSIMETRIC DATA AND METHODOLOGY

Introduction | Dose Methodology

Introduction

The individual (de-identified) dose reports for all program volunteers participating in the Marshall Islands Individual Radiological Surveillance Monitoring Program are accessible on the Marshall Islands website (https://marshallislands.llnl.gov/) using menu driven routines (Fig. 11).

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 absorb 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 International System (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 years in the future [a conservative maximum as defined by the United States 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 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), often abbreviated in this report as the annual effective dose.

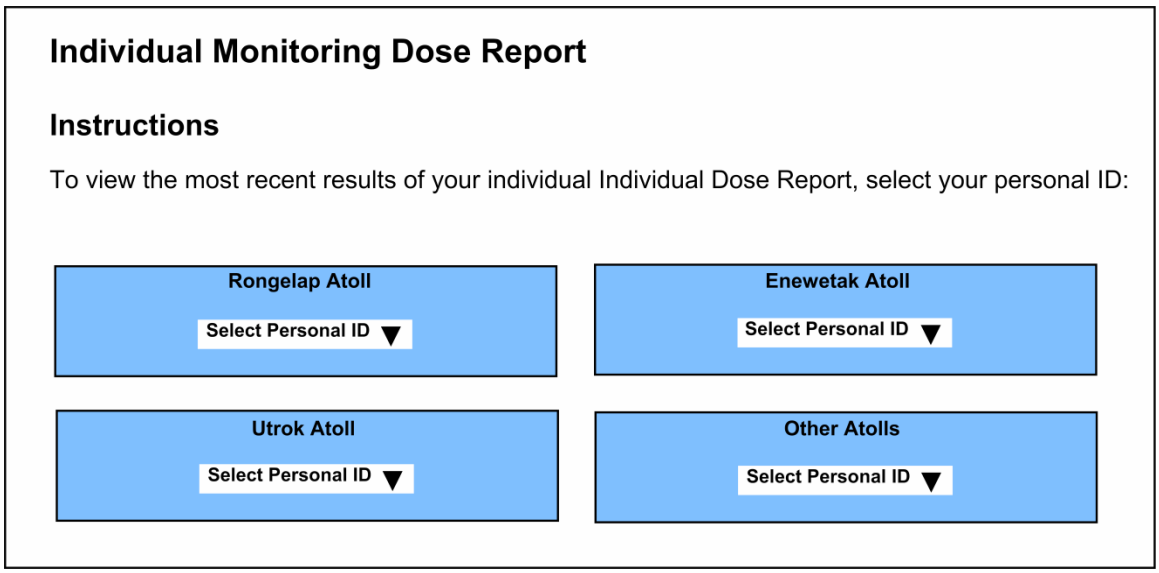

Fig. 11. Layout of the menu structure used to access individual dosimetric data from the Marshall Islands website, https://marshallislands.llnl.gov/.

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 year 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 committed dose contributions from plutonium, and exclude dose contributions from external radiation exposure and from other internally deposited radionuclides such as the other isotopes of plutonium, and strontium-90 (after Daniels *et al.*, 2007).

For comparison, the Marshall Islands Nuclear Claims Tribunal has established a standard of 0.15 mSv (15 mrem) per year (EDE) for cleanup and rehabilitation of radioactively contaminated sites in the northern Marshall Islands.

PROVIDING FOLLOW-UP ON RESULTS

All volunteers participating in the Marshall Islands Radiological Surveillance Program are issued a preliminary copy of their dose report immediately after receiving a whole-body count. Scientists from the Lawrence Livermore National Laboratory verify the measurement data and, if required, issue a revised measurement dose report. Statistically significant individual whole-body counter or plutonium bioassay measurement data that yield computed doses of 0.1 mSv (10 mrem) or higher will normally evoke some type of pre-determined action or investigation (refer to the discussion outline below). These actions will nearly always lead to follow-up

verification measurements but may also include a dietary evaluation and/or a work history review. Below dose levels of 0.1 mSv, default assumptions for assigning doses (Daniels *et al.*, 2007) are assumed to be valid and no further action is taken. Data may be withheld from the website and/or hard copy reports while any investigations are on-going. The Lawrence Livermore National Laboratory Marshall Islands Program action level (0.1 mSv) is one-tenth of the investigation level used for occupational workers throughout the United States Department of Energy and two-thirds of the United States Environmental Protection Agency guideline for cleanup of radioactively contaminated sites (0.15 mSv). In addition, at the end of each calendar year, all program volunteers receive a formal written report containing an estimate of their '*calendar year* dose' based on all available verified data for that year. Program volunteers are also invited to discuss their concerns with local technicians and/or to contact Terry Hamilton at Lawrence Livermore National Laboratory for more information.

Due to the very conservative nature of our dose methodology and preference not to trivialize doses no matter what the level, we anticipate that the default assumptions for calculating committed doses from low-level plutonium bioassay measurements will occasionally yield values that exceed the 0.1 mSv investigation level. In some cases, doses in excess of 0.1 mSv will not necessarily evoke a follow-up response. The reasoning for this is that the low-level plutonium bioassay measurements usually contain a relatively large uncertainty where the confidence level (nominally tested at 3 $\times$ measurement MDA) spans the investigation action level. As such, dose estimates are computed for all the measurement data but the scope of any follow-up action may be limited to those sample analyses that are clearly distinguishable from the measurement MDA or upon receiving specific requests from concerned individuals. All data are reported but may be revised depending on findings of any follow up actions. In this case a revised Individual Dose Reports may also be issued.

EXTERNAL DOSE CALCULATOR

This website application functions using a combination of Goggle Maps API code, PHP, JavaScript, and HTML. On opening, a map of Rongelap Island is displayed with data markers (Fig. 12). Drop-down list boxes include links to other locations in the northern Marshall Islands wherever data are available. The data markers represents points contained in a database of static dose rate measurements of *in-situ* gamma exposure rates to cesium-137. These data were collected using Model 935 and Model 940 Surveillance and Measurement (SAM) *in-situ* gamma spectrometers supplied by Berkeley Nucleonics Inc. (BNC) with no other corrections applied. Each data point in the database is also linked to the geographical position, the date of measurement and a site designator. Site designator descriptions (*e.g.*, island interior, house, beach, etc.) are color coded and displayed to the right of the map with a notes field describing how to select a region of interest and compute out an external dose rate. The dose rate is displayed in a table format in units of milliSievert (mSv) and millirem (mrem). In general, external gamma exposure to residual cesium-137 in the environment contributes about 10-15% of the total nuclear test-related dose in the Marshall Islands.

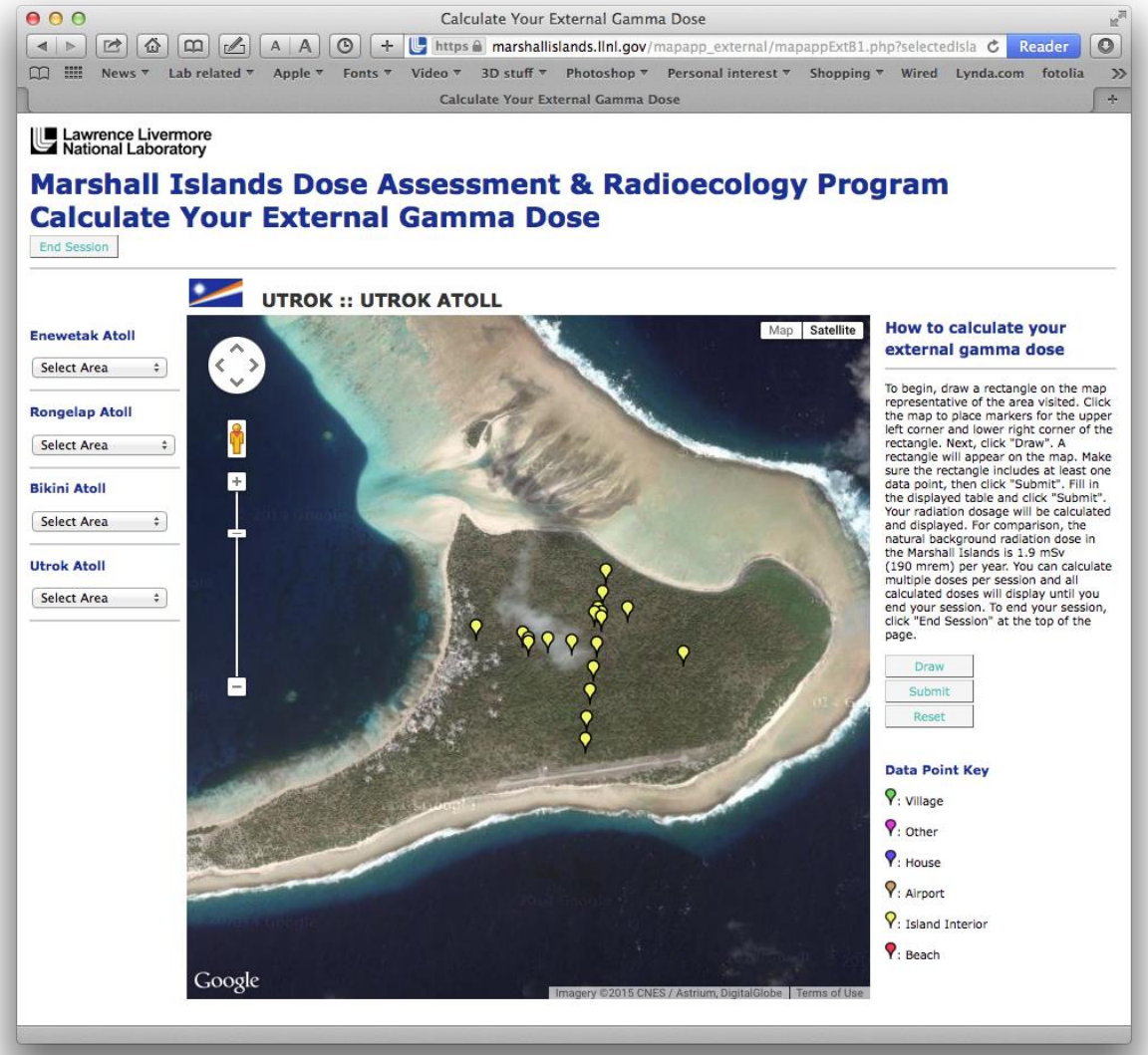

Fig. 12. An example External Dose Calculator website page featuring Utrōk Island, Utrōk Atoll.

INGESTION DOSE CALCULATOR (NEW)

The Lawrence Livermore National Laboratory has developed a series of interactive internet applications to provide the public with an open access platform to learn more about radiological conditions in the Marshall Islands. The ingestion dose calculator application described here is one such feature whereby users can calculate hypothetical ingestion doses from cesium-137 based on interactive user input matched to environmental data on the activity concentration of cesium-137 contained in food plants such as coconut, breadfruit, *Pandanus,* and arrowroot. Users are asked to enter a date, an island and atoll location, a plant food type, and a daily intake amount (highlighted by the number of portions eaten per day in estimated gram equivalents). The application computes the user daily dose and the user equivalent annualized dose, and then compares the results with default settings based on a dietary model developed for the Marshall Islands from independent dietary surveys. Environmental data are decay

corrected to the date entered by the user using an effective half-life of cesium-137 of 8.5 years (after Robison, *et al.*, 2003).

The website application functions using a combination of Google Maps API code, PHP, JavaScript, and HTML. On entering the site, a map of Rongelap Island is displayed along with a drop-down menu linking to maps of islands and atolls in the northern Marshall Islands (Fig 13). The data collection and mapping feature is limited to the four main nuclear affected atolls of Bikini, Enewetak, Rongelap and Utrōk (also known in the literature as the 'four affected atolls'). Data markers on the map represent site locations in the database containing available measurement data on the activity concentration of cesium-137 in food plants. Each data marker contains information such as the GPS site coordinates, the measured activity concentration of cesium-137 in Bq g^{-1} (wet wt.), the date the item was collected, the island designator, and a category descriptor on the type of plant food or fruit, *e.g.*, drinking coconut meat, drinking coconut juice, copra meat, copra juice, *Pandanus* fruit (*Pandanus* spp.), breadfruit (*Actocarpus* spp.) or Polynesian arrowroot (*Tacca leontopetaloides*). Users may select a specific location on an island, a whole island or multiple islands on an atoll by drawing a rectangle on a map containing at least one measurement data point. Once users are satisfied with their selection, selecting 'submit' opens an input table.

The input table allows the user to enter a date, and the number of hypothetical daily servings of food consumed for each food group or type. For the purposes of this website application, we have loosely followed what constitutes a standard serving using guidance developed by the U.S. Department of Agriculture (USDA) under the Food Guide Pyramid, and by the Nutrition Facts label under the regulation of the U.S. Food and Drug Administration. For milk type products such as drinking coconut and copra juice, we designate a standard serving as 1 cup or 226 g. For all other food plant products, we consider a standard serving as a ½ cup or 113 g. The website also uses a series of default settings to compute an annual effective dose (milliSievert, mSv per year) for the food plants selected using a standard model diet consumption table. The standard model diet used in the current version of this website application is based on living patterns where imported foods are available or the IA (imported foods available) model diet as described by Robison *et al.*, 1997a.

After entering the relevant information and selecting the 'submit' button, the website application runs a cesium-137 dose algorithm as described below.

$$\text{Effective Dose } (\mu Sv) = \Sigma\,[C \times \exp(-\lambda_{eff} t)] \times (CA \times DCF) \text{ (Single Intake)}$$

where,

C = Activity concentration of cesium-137 in the food group (Bq g^{-1}).

CA = Consumption amount (g)

DCF = Committed Dose Equivalent per unit intake (Sv Bq^{-1}) (ICRP, 1993).

t = Number of days between sample collection and consumption.

λ_{eff} = Effective half-life decay constant for cesium-137 in vegetation (λ_{eff} = 0.000223) (after Robison *et al.*, 1997a).

n = Number of individual food types consumed.

For user annualized and model diet dose calculations, the consumption amount is replaced with the daily intake rate (g d^{-1}) multiplied by 365 (days in a year) to give the annual effective dose (mSv y^{-1}). To enable users to select multiple areas on multiple islands and atolls, the application assigns each user a random session identification number upon opening the website. Each calculated dose is stored until the user ends the session or leaves the website, at which point the user's session identification number and information are deleted.

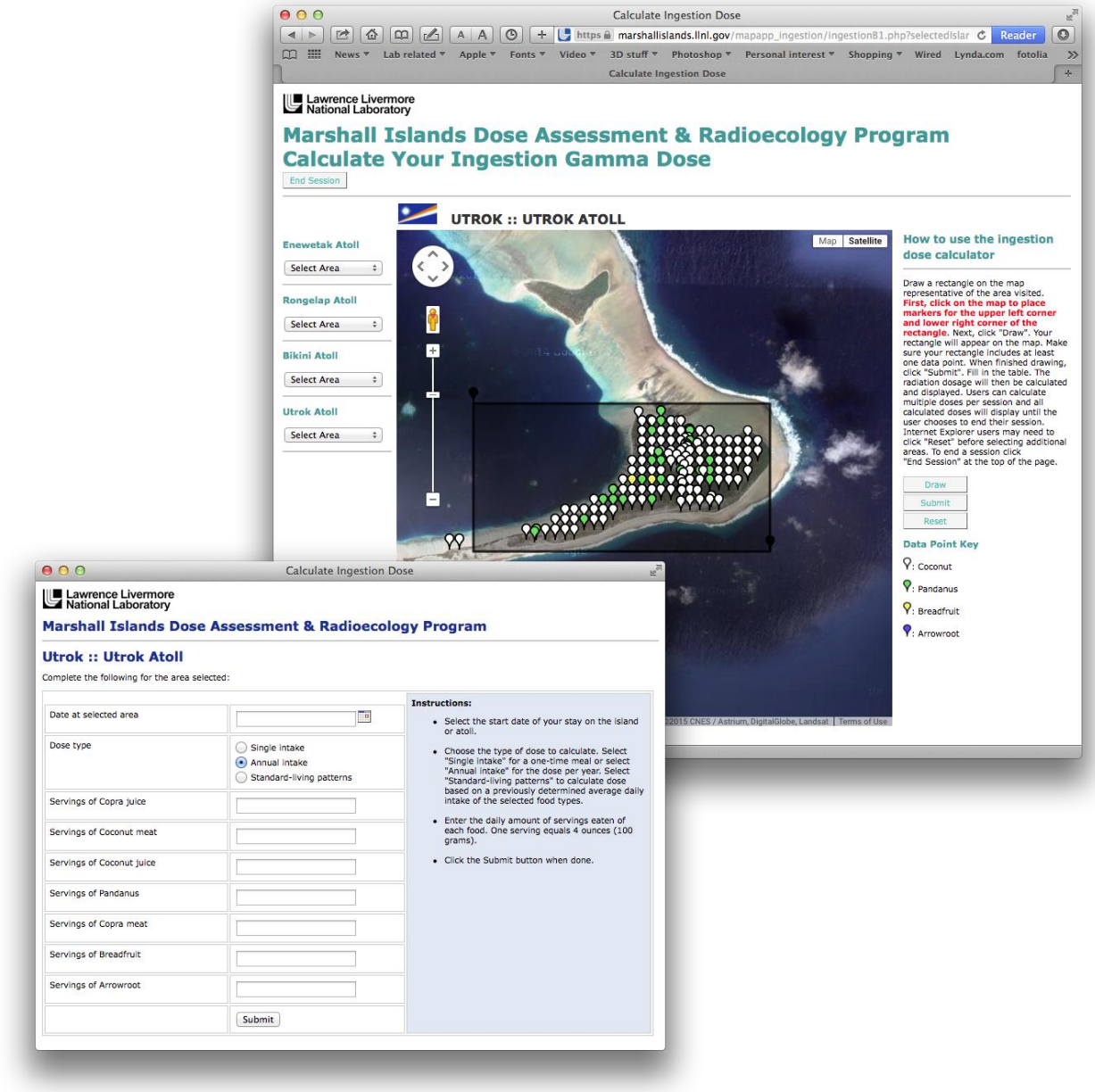

Fig. 13. An example Ingestion Dose Calculator website page featuring Utrōk Island, Utrōk Atoll.

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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 International System (SI) unit of absorbed dose is the joule per kilogram (J kg^{-1}) and its special name is the gray (Gy). The common unit still used by U.S agencies for absorbed dose is the rad, which is equivalent to 100 ergs per gram of material. One Gy is the same as 100 rad.

Activity

Activity is the rate of transformation or decay of a radioactive material. The International System (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 expressed 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 2 to 5 cm 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 mSv (300 mrem) per year comes from natural background radiation including cosmic radiation and radiation emitted by naturally occurring radionuclides either in the environment (*e.g.*, in air, water, soil and rock) or deposited in tissues inside the body. The other 0.60 mSv (60 mrem) is derived from man-made sources such as exposures to diagnostic X-rays, and consumer products such as smoking tobacco. The general worldwide contribution from radioactive fallout contamination is <0.3% of the average total annual effective 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 1.9 mSv (190 mrem) per year and is significantly less than what most people receive in many other parts of 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) (0.3% of their average total annual effective dose) from exposure to worldwide fallout contamination resulting from atmospheric nuclear weapons testing and about 0.005 mSv (0.5 mrem) (or 0.1% of the average total annual effective dose) from operations related to 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 systemic burdens of radionuclides acquired

from previous exposures. Under the Marshall Islands Radiological Surveillance Program, efforts are being made to improve on the reliability of measurements of systemic plutonium in Marshallese populations using state-of-the-art methodologies in bioassay 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 one disintegration per second. Whole-body counting and plutonium bioassay measurements are usually reported in activity units of kBq (kiloBecquerel) (1000 Bq) and μBq (microBecquerel) (1×10^{-6} Bq), respectively.

Biokinetic

The word 'biokinetic' is used here to describe the absorption (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

The 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 dose equivalents to various tissues or organ in the body each multiplied by an appropriate tissue-weighing factor and then summed. The international scientific (SI) unit of committed effective dose equivalence (CEDE) is the joule per kilogram or sievert (Sv). The conventional unit for committed effective dose equivalent used by Federal and State agencies within the United States is the roentgen equivalent man (rem). One Sv is the same as 100 rem. Chronic doses are usually reported in units of mSv (1/1000th Sv) or mrem (1/1000th rem)

Critical Level

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

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 chronic exposure, organ and body burdens continue to build up over time until a steady state is reached, and 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 employed under the Marshall Islands is given elsewhere (see under Daniels *et al.*, 2007).

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 absorbed 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 International System (SI) unit for dose equivalent is the joule per kilogram ($J\ kg^{-1}$) and is called the sievert (Sv). A 1 Sv dose to an adult will normally produce some clinical signs of radiation sickness, requiring hospitalization.

Federal and state agencies in the United States use conventional units of dose equivalents based on the roentgen equivalent man (rem). One Sv is equal to 100 rem.

Effective Dose (ICRP 60)

The sum of the equivalent dose over specified organs and tissues weighted by the tissue weighing factor (ICRP, 1991). Supersedes the effective dose equivalent in ICRP and NCRP recommendations but is not used in current U.S. regulations.

Effective Dose Equivalent (ICRP 26)

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. Superseded by the effective dose in ICRP and NCRP recommendations but often used in current U.S. regulations. The International System (SI) unit for dose equivalent is the joule per kilogram (J kg^{-1}) and is called the sievert (Sv). Federal and regulatory agencies in the United States usually express effective dose equivalent in roentgen equivalent man (rem). One Sv is equal to 100 rem.

Dose (exposure) Assessment

A quantification of the magnitude, duration and timing of radiation exposures, and the resulting doses from such exposures, based on all possible types of radiological agents involved and their primary pathways and routes of exposure.

Exposure Pathway

The physical route a hazardous substance takes in leading to the exposure of an organism.

External Dose or Exposure to Radiation

That portion of the dose equivalent delivered by ionizing radiation originating from a source outside the body of an organism (*e.g.*, also known as direct radiation).

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 generated and the total irradiation 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.

Half-Life

The Half-Life is time taken for the activity of a radionuclide to halve as a result of radioactive decay. Also used in more general terms to indicate the time taken for the quantity of a specified radionuclide in a specified place to halve as a result of any specified process or processes that follow similar exponential patterns of loss (*e.g.*, biological half-life or effective half-life).

High-End Health Risk

Use of the term 'high-end health risk' usually relates to the maximally exposed individuals in a population.

In-Vitro

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

In-Vivo

In-vivo measurements are synonymous with 'within the living' monitoring techniques, such as whole-body counting.

Indirect bioassay

Measurements 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 or Radiation

That portion of the dose equivalent delivered by ionizing radiation originating from a radiation source inside the body of an organism (*e.g.*, from intakes of radionuclides by ingestion, inhalation or dermal adsorption).

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

Those actions that control the attributes of an analytical process, system or facility according to predetermined quality requirements.

Radiation Dose

A generic term to describe the amount of radiation a person receives. The common International System (SI) unit for dose is the joule per kilogram or sievert (Sv). The preferred unit for radiation dose used by federal and state agencies in the United States is the roentgen equivalent man (rem). Natural background and environmental radiation doses are usually expressed as 1/1000th of the base units as milliSievert (normally abbreviated as mSv) or millirem (normally abbreviated as mrem). One mSv is equal to 100 mrem.

Radiological Monitoring (Monitoring)

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

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.

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.

Total Effective Dose Equivalent (TEDE)

The sum of the deep-dose equivalent (for external exposures) and the committed effective dose equivalent for external from intakes of radionuclides as described by the United States Nuclear Regulatory Commission under 10 CFR Part 20.1003.

Validation

Defining the process of 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 A

Individual Radiological Surveillance Monitoring Data Based on Whole-Body Counting and Plutonium Urinalysis Bioassay

The following tables provide full disclosure of whole-body counting and plutonium bioassay measurement data developed for Utrōk Atoll (2010-2012).

Table A1. Whole-body count data on internally deposited cesium-137 (kBq) developed in support of Utrōk Atoll (2010-2012).

ID#	Age Type	Gender	Count Date	^{137}Cs (kBq)		Method Code	Notes
				Value	MDA		
6415	Adult	Male	30-Apr-2012	0.00	0.10	NaI_WBC	RU, Bik
EN00782	Adult	Male	27-Jul-2012	0.18 ± 0.01	0.13	NaI_WBC	RU, Ene
MI00414	Adult	Female	11-Jul-2011	0.00	0.11	NaI_WBC	RU
MI01085	Adult	Male	1-Aug-2012	0.78 ± 0.08	0.35	NaI_WBC	RU
MI01564	Adult	Male	2-Oct-2012	0.00	0.11	NaI_WBC	RU
MI01742	Adult	Female	1-Jun-2010	0.00	0.11	NaI_WBC	RU
MI01885	Adult	Male	31-Aug-2010	0.00	0.10	NaI_WBC	RU
MI02050	Adult	Male	25-Jun-2012	0.66 ± 0.08	0.37	NaI_WBC	RU
MI02120	Adult	Male	30-Apr-2012	0.00	0.11	NaI_WBC	RU
MI02212	Adult	Female	8-Aug-2011	0.00	0.10	NaI_WBC	RU
MI02212	Adult	Female	23-May-2012	0.07 ± 0.04	0.18	NaI_WBC	RU
MI02213	Adult	Male	8-Aug-2011	0.00	0.10	NaI_WBC	RU
MI02679	Adult	Male	30-Apr-2012	0.00	0.11	NaI_WBC	RU
MI02993	Adult	Male	5-Oct-2012	0.00	0.11	NaI_WBC	RU
MI02997	Adult	Male	22-Oct-2012	0.00	0.11	NaI_WBC	RU
UT00009	Adult	Female	11-Nov-2010	0.17 ± 0.05	0.22	NaI_WBC	RU
UT00036	Adult	Male	13-Sep-2012	0.00	0.11	NaI_WBC	RU
UT00044	Adult	Female	23-Jul-2010	0.74 ± 0.08	0.34	NaI_WBC	RU

ID#	Age Type	Gender	Count Date	^{137}Cs (kBq)		Method Code	Notes
				Value	MDA		
UT00058	Adult	Male	20-Apr-2012	0.50 ± 0.08	0.37	NaI_WBC	RU
UT00059	Adult	Male	28-Mar-2012	0.85 ± 0.08	0.35	NaI_WBC	RU
UT00060	Adult	Male	23-Mar-2010	0.61 ± 0.08	0.35	NaI_WBC	RU
UT00060	Adult	Male	26-Apr-2012	0.59 ± 0.08	0.33	NaI_WBC	RU
UT00062	Adult	Male	20-Apr-2012	0.49 ± 0.07	0.32	NaI_WBC	RU
UT00065	Adult	Female	23-Mar-2010	0.14 ± 0.05	0.21	NaI_WBC	RU
UT00065	Adult	Female	26-Apr-2012	0.35 ± 0.06	0.29	NaI_WBC	RU
UT00066	Adult	Female	26-Apr-2012	0.28 ± 0.07	0.32	NaI_WBC	RU
UT00069	Adult	Male	12-Jan-2010	0.00	0.11	NaI_WBC	RU
UT00076	Adult	Female	28-Jan-2010	0.44 ± 0.07	0.33	NaI_WBC	RU
UT00076	Adult	Female	26-Apr-2012	0.50 ± 0.07	0.33	NaI_WBC	RU
UT00082	Adult	Male	26-May-2010	0.00	0.11	NaI_WBC	RU
UT00082	Adult	Male	20-Dec-2010	0.00	0.11	NaI_WBC	RU
UT00082	Adult	Male	28-Aug-2012	0.00	0.11	NaI_WBC	RU
UT00103	Adult	Female	5-Apr-2012	0.00	0.11	NaI_WBC	RU
UT00114	Adult	Male	7-Jun-2010	0.00	0.10	NaI_WBC	RU
UT00126	Adult	Female	25-Feb-2010	0.47 ± 0.08	0.34	NaI_WBC	RU
UT00128	Adult	Male	13-Apr-2010	0.18 ± 0.06	0.29	NaI_WBC	RU

ID#	Age Type	Gender	Count Date	^{137}Cs (kBq)		Method Code	Notes
				Value	MDA		
UT00128	Adult	Male	26-Aug-2010	0.50 ± 0.08	0.34	NaI_WBC	RU
UT00150	Adult	Male	16-Nov-2010	0.18 ± 0.07	0.32	NaI_WBC	RU
UT00162	Adult	Male	25-Jun-2012	0.47 ± 0.07	0.32	NaI_WBC	RU
UT00172	Adult	Female	4-Jun-2010	0.68 ± 0.09	0.38	NaI_WBC	RU
UT00173	Adult	Female	26-Jul-2010	0.00	0.12	NaI_WBC	RU
UT00189	Adult	Male	5-Nov-2010	0.77 ± 0.08	0.33	NaI_WBC	RU
UT00189	Adult	Male	21-Mar-2012	0.00	0.11	NaI_WBC	RU
UT00193	Adult	Female	11-Nov-2010	0.18 ± 0.05	0.23	NaI_WBC	RU
UT00207	Adult	Female	20-Apr-2012	0.37 ± 0.07	0.31	NaI_WBC	RU
UT00209	Adult	Female	13-Apr-2010	0.00	0.11	NaI_WBC	RU
UT00209	Adult	Female	26-Aug-2010	0.00	0.11	NaI_WBC	RU
UT00212	Adult	Female	27-Aug-2012	0.10 ± 0.04	0.18	NaI_WBC	RU
UT00222	Adult	Female	1-Feb-2010	0.13 ± 0.06	0.25	NaI_WBC	RU
UT00222	Adult	Female	16-Feb-2010	0.00	0.11	NaI_WBC	RU
UT00222	Adult	Female	28-Aug-2012	0.00	0.11	NaI_WBC	RU
UT00223	Adult	Male	28-Aug-2012	0.00	0.11	NaI_WBC	RU
UT00226	Adult	Female	12-Jan-2010	0.19 ± 0.06	0.27	NaI_WBC	RU
UT00241	Adult	Male	7-Sep-2010	0.77 ± 0.08	0.36	NaI_WBC	RU

ID#	Age Type	Gender	Count Date	^{137}Cs (kBq)		Method Code	Notes
				Value	MDA		
UT00242	Adult	Female	22-Jun-2012	0.46 ± 0.07	0.32	NaI_WBC	RU
UT00271	Adult	Male	30-Aug-2012	0.51 ± 0.07	0.33	NaI_WBC	RU
UT00275	Adult	Female	16-Nov-2010	0.41 ± 0.07	0.30	NaI_WBC	RU
UT00285	Adult	Female	19-Mar-2010	0.00	0.10	NaI_WBC	RU
UT00285	Adult	Female	20-Aug-2010	0.12 ± 0.03	0.16	NaI_WBC	RU
UT00285	Adult	Female	11-Nov-2010	0.00	0.11	NaI_WBC	RU
UT00285	Adult	Female	21-Dec-2010	0.04 ± 0.03	0.15	NaI_WBC	RU
UT00290	Adult	Female	22-Jun-2012	0.00	0.12	NaI_WBC	RU
UT00294	Adult	Male	2-Aug-2012	0.00	0.10	NaI_WBC	RU
UT00297	Adult	Female	22-Jul-2010	0.00	0.11	NaI_WBC	RU
UT00298	Adult	Male	22-Jul-2010	0.69 ± 0.08	0.35	NaI_WBC	RU
UT00304	Adult	Female	18-Nov-2010	0.00	0.12	NaI_WBC	RU
UT00316	Adult	Male	16-Jun-2010	0.70 ± 0.09	0.39	NaI_WBC	RU
UT00340	Adult	Female	31-Aug-2012	0.33 ± 0.06	0.28	NaI_WBC	RU
UT00363	Adult	Female	22-Jun-2012	0.17 ± 0.05	0.21	NaI_WBC	RU
UT00366	Teenager	Female	16-Jun-2010	0.00	0.11	NaI_WBC	RU
UT00368	Adult	Male	16-Jun-2010	1.05 ± 0.10	0.42	NaI_WBC	RU
UT00377	Adult	Male	22-Jul-2010	0.27 ± 0.06	0.29	NaI_WBC	RU

ID#	Age Type	Gender	Count Date	^{137}Cs (kBq)		Method Code	Notes
				Value	MDA		
UT00380	Adult	Female	21-Jan-2010	0.00	0.11	NaI_WBC	RU
UT00396	Adult	Male	31-Aug-2012	0.00	0.11	NaI_WBC	RU
UT00406	Adult	Female	11-Nov-2010	0.29 ± 0.07	0.31	NaI_WBC	RU
UT00406	Adult	Female	16-Nov-2010	0.14 ± 0.05	0.23	NaI_WBC	RU
UT00406	Adult	Female	27-Aug-2012	0.46 ± 0.07	0.33	NaI_WBC	RU
UT00407	Adult	Female	3-Nov-2010	0.27 ± 0.06	0.26	NaI_WBC	RU
UT00407	Adult	Female	27-Aug-2012	0.13 ± 0.04	0.20	NaI_WBC	RU
UT00411	Adult	Female	27-Aug-2010	0.16 ± 0.05	0.24	NaI_WBC	RU
UT00411	Adult	Female	22-Jun-2012	0.00	0.11	NaI_WBC	RU
UT00411	Adult	Female	27-Aug-2012	0.00	0.11	NaI_WBC	RU
UT00412	Adult	Male	12-Nov-2010	0.00	0.11	NaI_WBC	RU
UT00417	Adult	Female	17-Aug-2012	0.00	0.10	NaI_WBC	RU
UT00424	Adult	Female	11-Nov-2010	0.28 ± 0.06	0.27	NaI_WBC	RU
UT00424	Adult	Female	21-Dec-2010	0.19 ± 0.06	0.26	NaI_WBC	RU
UT00451	Adult	Female	11-Nov-2010	0.00	0.11	NaI_WBC	RU
UT00451	Adult	Female	21-Dec-2010	0.00	0.10	NaI_WBC	RU
UT00451	Adult	Female	5-Apr-2012	0.00	0.11	NaI_WBC	RU
UT00453	Teenager	Female	16-Jun-2010	0.00	0.10	NaI_WBC	RU

ID#	Age Type	Gender	Count Date	^{137}Cs (kBq)		Method Code	Notes
				Value	MDA		
UT00457	Adult	Male	16-Jun-2010	0.81 ± 0.09	0.37	NaI_WBC	RU
UT00460	Adult	Female	2-Jun-2010	0.29 ± 0.06	0.29	NaI_WBC	RU
UT00466	Adult	Female	21-Jan-2010	0.00	0.11	NaI_WBC	RU
UT00467	Adult	Female	2-Jun-2010	0.00	0.12	NaI_WBC	RU
UT00468	Adult	Female	4-Jun-2010	0.49 ± 0.06	0.28	NaI_WBC	RU
UT00468	Adult	Female	22-Jun-2012	0.54 ± 0.08	0.34	NaI_WBC	RU
UT00469	Adult	Male	16-Jun-2010	1.10 ± 0.08	0.35	NaI_WBC	RU
UT00469	Adult	Male	27-Oct-2010	0.14 ± 0.06	0.28	NaI_WBC	RU
UT00470	Pre-Teen	Male	16-Jun-2010	0.27 ± 0.06	0.29	NaI_WBC	RU
UT00470	Teenager	Male	25-Jun-2012	0.00	0.11	NaI_WBC	RU
UT00471	Teenager	Male	16-Jun-2010	0.37 ± 0.07	0.30	NaI_WBC	RU
UT00472	Adult	Female	23-Jul-2010	0.00	0.11	NaI_WBC	RU
UT00473	Adult	Female	23-Jul-2010	0.09 ± 0.05	0.24	NaI_WBC	RU
UT00473	Adult	Female	28-Mar-2012	0.00	0.11	NaI_WBC	RU
UT00474	Teenager	Female	2-Aug-2010	0.17 ± 0.05	0.25	NaI_WBC	RU
UT00475	Teenager	Female	20-Aug-2010	0.00	0.11	NaI_WBC	RU
UT00476	Teenager	Female	11-Nov-2010	0.09 ± 0.04	0.18	NaI_WBC	RU
UT00477	Adult	Female	11-Nov-2010	0.00	0.11	NaI_WBC	RU

ID#	Age Type	Gender	Count Date	^{137}Cs (kBq)		Method Code	Notes
				Value	MDA		
UT00478	Adult	Male	16-Nov-2010	0.00	0.11	NaI_WBC	RU
UT00478	Adult	Male	28-Aug-2012	0.46 ± 0.07	0.32	NaI_WBC	RU
UT00479	Teenager	Female	18-Nov-2010	0.00	0.11	NaI_WBC	RU
UT00488	Adult	Female	26-Apr-2012	0.00	0.11	NaI_WBC	RU
UT00501	Adult	Male	8-Aug-2012	0.00	0.11	NaI_WBC	RU
UT00515	Adult	Male	22-Jun-2012	0.80 ± 0.08	0.36	NaI_WBC	RU
UT00515	Adult	Male	28-Aug-2012	0.22 ± 0.07	0.32	NaI_WBC	RU
UT00516	Teenager	Male	22-Jun-2012	0.00	0.11	NaI_WBC	RU
UT00517	Teenager	Male	25-Jun-2012	0.37 ± 0.07	0.29	NaI_WBC	RU
UT00521	Adult	Male	22-Aug-2012	0.46 ± 0.07	0.33	NaI_WBC	RU
UT00522	Adult	Female	30-Aug-2012	0.00	0.11	NaI_WBC	RU
UT00672	Adult	Male	28-Mar-2012	0.65 ± 0.08	0.34	NaI_WBC	RU
UT00690	Adult	Female	6-Feb-2012	0.00	0.11	NaI_WBC	UR
EN00212	Adult	Female	16-Sep-2010	0.00	0.06	NaI_WBC	NR, Ene
EN00298	Adult	Female	9-Aug-2010	0.12 ± 0.04	0.18	NaI_WBC	NR, Ene
EN00927	Adult	Male	12-Apr-2010	0.00	0.06	NaI_WBC	NR, Ene
EN00927	Adult	Male	15-Jan-2011	0.63 ± 0.05	0.20	NaI_WBC	NR, Ene
EN00927	Adult	Male	1-Mar-2011	1.15 ± 0.05	0.18	NaI_WBC	NR, Ene

ID#	Age Type	Gender	Count Date	^{137}Cs (kBq)		Method Code	Notes
				Value	MDA		
EN00927	Adult	Male	19-Apr-2011	0.83 ± 0.04	0.17	NaI_WBC	NR, Ene
EN00927	Adult	Male	31-May-2011	0.61 ± 0.05	0.20	NaI_WBC	NR, Ene
EN00927	Adult	Male	22-Feb-2012	0.39 ± 0.02	0.13	NaI_WBC	NR, Ene
EN00927	Adult	Male	19-Mar-2012	0.25 ± 0.01	0.14	NaI_WBC	NR, Ene
EN00927	Adult	Male	9-Jul-2012	0.14 ± 0.01	0.14	NaI_WBC	NR, Ene
EN00927	Adult	Male	25-Sep-2012	0.18 ± 0.01	0.13	NaI_WBC	NR, Ene
EN00927	Adult	Male	18-Oct-2012	0.11 ± 0.01	0.13	NaI_WBC	NR, Ene
EN00927	Adult	Male	10-Dec-2012	0.12 ± 0.01	0.13	NaI_WBC	NR, Ene
MI00093	Adult	Female	24-May-2010	0.00	0.10	NaI_WBC	NR
MI00093	Adult	Female	5-Apr-2012	0.00	0.10	NaI_WBC	NR
MI01103	Adult	Female	28-Dec-2010	0.00	0.10	NaI_WBC	NR
MI01140	Adult	Male	13-Sep-2012	0.00	0.12	NaI_WBC	NR
MI01141	Adult	Female	26-Jul-2012	0.05 ± 0.03	0.15	NaI_WBC	NR
MI01157	Adult	Female	13-Sep-2012	0.00	0.10	NaI_WBC	NR
MI01158	Adult	Male	29-Aug-2012	0.00	0.11	NaI_WBC	NR
MI01192	Adult	Male	8-Mar-2010	0.00	0.10	NaI_WBC	NR
MI01367	Adult	Female	27-Aug-2010	0.00	0.11	NaI_WBC	NR
MI01367	Adult	Female	12-Sep-2012	0.00	0.10	NaI_WBC	NR

ID#	Age Type	Gender	Count Date	^{137}Cs (kBq)		Method Code	Notes
				Value	MDA		
MI01608	Adult	Male	21-Jan-2010	0.00	0.10	NaI_WBC	NR
MI01608	Adult	Male	3-Feb-2012	0.00	0.11	NaI_WBC	NR
MI01649	Adult	Male	24-Feb-2010	0.00	0.11	NaI_WBC	NR
MI01651	Adult	Female	24-Feb-2010	0.00	0.11	NaI_WBC	NR
MI01656	Adult	Male	27-Feb-2010	0.00	0.11	NaI_WBC	NR
MI01725	Adult	Male	17-May-2010	0.00	0.10	NaI_WBC	NR
MI01906	Adult	Male	9-Sep-2010	0.00	0.10	NaI_WBC	NR
MI01915	Adult	Male	18-Sep-2010	0.00	0.10	NaI_WBC	NR
MI01948	Adult	Female	8-Oct-2010	0.00	0.10	NaI_WBC	NR
MI01973	Adult	Female	27-Oct-2010	0.00	0.10	NaI_WBC	NR
MI01982	Child	Male	28-Oct-2010	0.00	0.11	NaI_WBC	NR
MI02000	Adult	Female	22-Nov-2010	0.08 ± 0.04	0.19	NaI_WBC	NR
MI02010	Adult	Female	10-Dec-2010	0.00	0.10	NaI_WBC	NR
MI02025	Adult	Female	27-Dec-2010	0.00	0.10	NaI_WBC	NR
MI02026	Adult	Male	27-Dec-2010	0.00	0.10	NaI_WBC	NR
MI02040	Adult	Female	30-Dec-2010	0.00	0.10	NaI_WBC	NR
MI02101	Teenager	Female	2-Oct-2012	0.00	0.10	NaI_WBC	NR
MI02231	Adult	Male	16-Aug-2012	0.00	0.10	NaI_WBC	NR

ID#	Age Type	Gender	Count Date	^{137}Cs (kBq)		Method Code	Notes
				Value	MDA		
MI02557	Adult	Male	6-Mar-2012	0.00	0.11	NaI_WBC	NR
MI02563	Adult	Male	6-Mar-2012	0.00	0.11	NaI_WBC	NR
MI02569	Adult	Male	8-Mar-2012	0.00	0.11	NaI_WBC	NR
MI02578	Adult	Male	9-Mar-2012	0.00	0.11	NaI_WBC	NR
MI02595	Adult	Male	14-Mar-2012	0.00	0.10	NaI_WBC	NR
MI02602	Adult	Male	14-Mar-2012	0.00	0.11	NaI_WBC	NR
MI02625	Adult	Male	22-Mar-2012	0.00	0.11	NaI_WBC	NR
MI02754	Adult	Male	11-Jun-2012	0.00	0.11	NaI_WBC	NR
MI02754	Adult	Male	20-Sep-2012	0.00	0.10	NaI_WBC	NR
MI02845	Adult	Male	26-Jul-2012	0.08 ± 0.03	0.14	NaI_WBC	NR
MI02958	Adult	Male	11-Sep-2012	0.00	0.10	NaI_WBC	NR
MI02985	Adult	Male	26-Sep-2012	0.09 ± 0.04	0.17	NaI_WBC	NR
UT00015	Adult	Female	8-Jun-2010	0.00	0.10	NaI_WBC	NR
UT00017	Adult	Female	18-May-2010	0.00	0.11	NaI_WBC	NR
UT00017	Adult	Female	17-Aug-2010	0.00	0.11	NaI_WBC	NR
UT00017	Adult	Female	4-Oct-2010	0.00	0.10	NaI_WBC	NR
UT00019	Adult	Female	21-Sep-2010	0.00	0.10	NaI_WBC	NR
UT00021	Adult	Female	6-Jan-2010	0.00	0.10	NaI_WBC	NR

ID#	Age Type	Gender	Count Date	^{137}Cs (kBq)		Method Code	Notes
				Value	MDA		
UT00023	Adult	Male	9-Feb-2012	0.07 ± 0.04	0.16	NaI_WBC	NR
UT00028	Adult	Female	14-Jul-2010	0.00	0.10	NaI_WBC	NR
UT00028	Adult	Female	21-Dec-2010	0.00	0.10	NaI_WBC	NR
UT00035	Adult	Female	6-Feb-2012	0.00	0.11	NaI_WBC	NR
UT00046	Adult	Female	20-Dec-2010	0.00	0.10	NaI_WBC	NR
UT00056	Adult	Female	10-Nov-2010	0.00	0.10	NaI_WBC	NR
UT00056	Adult	Female	3-Feb-2012	0.00	0.11	NaI_WBC	NR
UT00056	Adult	Female	26-Apr-2012	0.00	0.11	NaI_WBC	NR
UT00068	Adult	Male	22-Dec-2010	0.00	0.11	NaI_WBC	NR
UT00071	Adult	Female	25-Feb-2010	0.00	0.11	NaI_WBC	NR
UT00071	Adult	Female	2-Nov-2010	0.00	0.11	NaI_WBC	NR
UT00071	Adult	Female	22-Mar-2012	0.00	0.10	NaI_WBC	NR
UT00078	Adult	Female	11-Nov-2010	0.00	0.11	NaI_WBC	NR
UT00085	Adult	Male	25-Feb-2010	0.00	0.10	NaI_WBC	NR
UT00093	Adult	Female	3-Jun-2010	0.27 ± 0.05	0.23	NaI_WBC	NR
UT00093	Adult	Female	22-Nov-2010	0.00	0.12	NaI_WBC	NR, Mej
UT00094	Adult	Male	3-Jun-2010	0.48 ± 0.07	0.33	NaI_WBC	NR, Mej
UT00094	Adult	Male	22-Nov-2010	0.27 ± 0.06	0.28	NaI_WBC	NR, Mej

ID#	Age Type	Gender	Count Date	^{137}Cs (kBq)		Method Code	Notes
				Value	MDA		
UT00095	Adult	Female	22-Nov-2010	0.00	0.11	NaI_WBC	NR
UT00104	Adult	Male	21-Jun-2010	0.00	0.10	NaI_WBC	NR
UT00104	Adult	Male	14-Jun-2012	0.00	0.11	NaI_WBC	NR
UT00105	Adult	Male	7-Dec-2010	0.00	0.11	NaI_WBC	NR
UT00105	Adult	Male	23-Jan-2012	0.00	0.11	NaI_WBC	NR
UT00107	Adult	Female	21-Mar-2012	0.00	0.10	NaI_WBC	NR
UT00110	Adult	Female	27-Oct-2010	0.00	0.11	NaI_WBC	NR
UT00111	Adult	Female	1-Feb-2012	0.00	0.11	NaI_WBC	NR
UT00112	Adult	Female	4-Jun-2010	0.00	0.10	NaI_WBC	NR
UT00112	Adult	Female	1-Feb-2012	0.00	0.11	NaI_WBC	NR
UT00113	Adult	Male	25-Apr-2012	0.59 ± 0.07	0.31	NaI_WBC	NR, Mej
UT00115	Adult	Male	2-Nov-2010	0.00	0.11	NaI_WBC	NR
UT00119	Adult	Male	3-Oct-2012	0.00	0.10	NaI_WBC	NR
UT00123	Adult	Female	21-Sep-2012	0.00	0.10	NaI_WBC	NR
UT00137	Adult	Female	27-Oct-2010	0.00	0.10	NaI_WBC	NR
UT00143	Adult	Female	28-Mar-2012	0.49 ± 0.06	0.29	NaI_WBC	NR
UT00145	Adult	Female	2-Nov-2010	0.00	0.10	NaI_WBC	NR
UT00145	Adult	Female	30-Aug-2012	0.00	0.10	NaI_WBC	NR

ID#	Age Type	Gender	Count Date	^{137}Cs (kBq)		Method Code	Notes
				Value	MDA		
UT00156	Adult	Male	3-Oct-2012	0.00	0.10	NaI_WBC	NR
UT00164	Adult	Male	20-Aug-2012	0.00	0.10	NaI_WBC	NR
UT00180	Adult	Female	31-May-2010	0.06 ± 0.03	0.15	NaI_WBC	NR, Ail
UT00181	Adult	Male	31-May-2010	0.28 ± 0.06	0.27	NaI_WBC	NR, Ail
UT00187	Adult	Female	3-Nov-2010	0.00	0.11	NaI_WBC	NR
UT00195	Adult	Female	16-Apr-2012	0.00	0.10	NaI_WBC	NR
UT00199	Adult	Female	21-Mar-2012	0.00	0.10	NaI_WBC	NR
UT00206	Adult	Female	27-Sep-2012	0.00	0.10	NaI_WBC	NR
UT00214	Adult	Female	28-Mar-2012	0.00	0.10	NaI_WBC	NR
UT00225	Adult	Male	8-Jun-2010	0.00	0.11	NaI_WBC	NR
UT00225	Adult	Male	19-Oct-2010	0.00	0.11	NaI_WBC	NR
UT00230	Adult	Male	16-Aug-2012	0.00	0.10	NaI_WBC	NR
UT00236	Adult	Male	31-Jul-2012	0.00	0.11	NaI_WBC	NR
UT00237	Adult	Female	22-Feb-2010	0.00	0.10	NaI_WBC	NR
UT00237	Adult	Female	11-May-2010	0.00	0.10	NaI_WBC	NR
UT00237	Adult	Female	28-Oct-2010	0.00	0.10	NaI_WBC	NR
UT00237	Adult	Female	11-Sep-2012	0.00	0.10	NaI_WBC	NR
UT00238	Adult	Male	6-Dec-2010	0.00	0.10	NaI_WBC	NR

ID#	Age Type	Gender	Count Date	^{137}Cs (kBq)		Method Code	Notes
				Value	MDA		
UT00238	Adult	Male	22-Aug-2012	0.00	0.10	NaI_WBC	NR
UT00247	Adult	Female	23-Aug-2010	0.00	0.11	NaI_WBC	NR
UT00251	Adult	Female	2-Nov-2010	0.00	0.10	NaI_WBC	NR
UT00253	Adult	Male	19-Apr-2012	0.00	0.11	NaI_WBC	NR
UT00254	Adult	Male	20-Sep-2012	0.00	0.11	NaI_WBC	NR
UT00266	Adult	Male	13-Sep-2012	0.00	0.10	NaI_WBC	NR
UT00299	Adult	Male	2-Aug-2012	0.00	0.11	NaI_WBC	NR
UT00302	Adult	Female	22-Dec-2010	0.21 ± 0.05	0.23	NaI_WBC	NR
UT00302	Adult	Female	17-Aug-2012	0.00	0.10	NaI_WBC	NR
UT00324	Adult	Female	11-Nov-2010	0.00	0.10	NaI_WBC	NR
UT00324	Adult	Female	20-Aug-2012	0.00	0.10	NaI_WBC	NR
UT00327	Adult	Female	19-Mar-2010	0.00	0.10	NaI_WBC	NR
UT00327	Adult	Female	2-Jun-2010	0.00	0.11	NaI_WBC	NR
UT00327	Adult	Female	20-Oct-2010	0.00	0.10	NaI_WBC	NR
UT00331	Adult	Male	25-Feb-2010	0.00	0.10	NaI_WBC	NR
UT00343	Adult	Male	16-Aug-2012	0.00	0.11	NaI_WBC	NR
UT00346	Adult	Male	8-Mar-2010	0.00	0.10	NaI_WBC	NR
UT00379	Teenager	Male	11-May-2010	0.00	0.10	NaI_WBC	NR

ID#	Age Type	Gender	Count Date	^{137}Cs (kBq)		Method Code	Notes
				Value	MDA		
UT00381	Adult	Female	12-Oct-2010	0.00	0.10	NaI_WBC	NR
UT00389	Adult	Male	11-May-2010	0.00	0.10	NaI_WBC	NR
UT00400	Adult	Female	27-Dec-2010	0.00	0.11	NaI_WBC	NR
UT00416	Adult	Female	11-Nov-2010	0.15 ± 0.06	0.26	NaI_WBC	NR
UT00422	Adult	Female	16-Apr-2012	0.00	0.10	NaI_WBC	NR
UT00428	Adult	Male	9-Feb-2012	0.00	0.12	NaI_WBC	NR
UT00454	Adult	Male	13-Feb-2012	0.00	0.11	NaI_WBC	NR
UT00460	Adult	Female	30-Jan-2012	0.00	0.11	NaI_WBC	NR
UT00487	Adult	Female	20-Aug-2012	0.00	0.10	NaI_WBC	NR
UT00489	Adult	Female	15-May-2012	0.00	0.11	NaI_WBC	NR
UT00496	Adult	Female	20-Aug-2012	0.00	0.10	NaI_WBC	NR
UT00500	Adult	Male	10-Jan-2012	0.00	0.11	NaI_WBC	NR
UT00502	Adult	Male	8-Aug-2012	0.00	0.11	NaI_WBC	NR
UT00511	Adult	Female	19-Jun-2012	0.00	0.11	NaI_WBC	NR
UT00518	Adult	Male	26-Jun-2012	0.00	0.11	NaI_WBC	NR
UT00520	Adult	Female	20-Aug-2012	0.00	0.10	NaI_WBC	NR
UT00523	Teenager	Male	13-Sep-2012	0.00	0.11	NaI_WBC	NR
UT00524	Teenager	Female	2-Oct-2012	0.00	0.10	NaI_WBC	NR

ID#	Age Type	Gender	Count	Date	^{137}Cs (kBq)		Method Code	Notes
					Value	MDA		
UT00580	Adult	Female	3-Feb-2012		0.00	0.11	NaI_WBC	NR
UT00670	Adult	Male	26-Mar-2012		0.00	0.11	NaI_WBC	NR
UT00671	Adult	Female	28-Mar-2012		0.00	0.10	NaI_WBC	NR
UT00691	Adult	Female	6-Feb-2012		0.00	0.11	NaI_WBC	NR

RU = Utrōk Resident; NR = nonresident citizen of the Utrōk population group; Ail = volunteer known to have worked or lived on Ailuk Atoll during the measurement year; Bik = volunteer known to have worked or lived on Bikini Atoll during the measurement year; Ene = volunteer known to have worked or lived on Enewetak Atoll during the measurement year; Mej = volunteer known to have worked or lived on Mejit Atoll during the measurement year.

Table A2. Plutonium-239 urinalysis bioassay data (μBq per 24-void) developed for the Marshall Islands Program (2010-2012).

ID#	Age Type	Gender	Collection Date	Radionuclide Concentration (μBq per 24 h void)		Method Code	Notes
				^{239}Pu	MDA		
EK03000	Adult	Female	2010-2012	0.08 ± 0.08	0.2	CAMS/LLNL	EPG, Kona, HI
EK03001	Adult	Female	2010-2012	-0.01 ± 0.07	0.2	CAMS/LLNL	EPG, Kona, HI
EK03002	Adult	Male	2010-2012	0.14 ± 0.10	0.2	CAMS/LLNL	EPG, Kona, HI
EK03003	Adult	Female	2010-2012	0.44 ± 0.12	0.2	CAMS/LLNL	EPG, Kona, HI
EK03004	Adult	Male	2010-2012	0.09 ± 0.09	0.2	CAMS/LLNL	EPG, Kona, HI
EK03006	Adult	Male	2010-2012	0.07 ± 0.09	0.2	CAMS/LLNL	EPG, Kona, HI
EK03007	Adult	Female	2010-2012	0.20 ± 0.10	0.2	CAMS/LLNL	EPG, Kona, HI
EK03008	Adult	Male	2010-2012	0.11 ± 0.16	0.5	CAMS/LLNL	EPG, Kona, HI
EK03009	Adult	Male	2010-2012	0.21 ± 0.11	0.2	CAMS/LLNL	EPG, Kona, HI
EK03012	Adult	Female	2010-2012	0.07 ± 0.09	0.2	CAMS/LLNL	EPG, Kona, HI
EK03013	Adult	Female	2010-2012	0.06 ± 0.08	0.2	CAMS/LLNL	EPG, Kona, HI
EK03014	Adult	Female	2010-2012	0.04 ± 0.16	0.5	CAMS/LLNL	EPG, Kona, HI
EK03015	Adult	Male	2010-2012	0.17 ± 0.18	0.5	CAMS/LLNL	EPG, Kona, HI
EK03016	Adult	Female	2010-2012	-0.11 ± 0.15	0.5	CAMS/LLNL	EPG, Kona, HI
EK03017	Adult	Male	2010-2012	-0.17 ± 0.14	0.5	CAMS/LLNL	EPG, Kona, HI
EK03018	Adult	Male	2010-2012	-0.10 ± 0.15	0.5	CAMS/LLNL	EPG, Kona, HI
EK03019	Adult	Male	2010-2012	-0.33 ± 0.12	0.5	CAMS/LLNL	EPG, Kona, HI

ID#	Age Type	Gender	Collection Date	Radionuclide Concentration (μBq per 24 h void)		Method Code	Notes
				^{239}Pu	MDA		
EK03020	Adult	Female	2010-2012	-0.04 ± 0.15	0.5	CAMS/LLNL	EPG, Kona, HI
EK03021	Adult	Female	2010-2012	-0.27 ± 0.13	0.5	CAMS/LLNL	EPG, Kona, HI
EN00002	Adult	Male	2010-2012	0.12 ± 0.14	0.3	CAMS/LLNL	RE
EN00009	Adult	Male	2010-2012	0.83 ± 0.26	0.4	CAMS/LLNL	RE
EN00010	Adult	Male	2010-2012	0.07 ± 0.10	0.3	CAMS/LLNL	RE
EN00010	Adult	Male	2010-2012	0.48 ± 0.24	0.4	CAMS/LLNL	RE
EN00024	Adult	Male	2010-2012	0.44 ± 0.21	0.4	CAMS/LLNL	RE
EN00025	Adult	Male	2010-2012	0.35 ± 0.12	0.2	CAMS/LLNL	EPG, Kona, HI
EN00030	Adult	Male	2010-2012	0.09 ± 0.14	0.3	CAMS/LLNL	RE
EN00035	Adult	Male	2010-2012	0.03 ± 0.13	0.3	CAMS/LLNL	RE
EN00044	Adult	Male	2010-2012	0.39 ± 0.16	0.3	CAMS/LLNL	RE, Northern Is.
EN00044	Adult	Male	2010-2012	0.43 ± 0.17	0.3	CAMS/LLNL	RE, Northern Is.
EN00048	Adult	Male	2010-2012	0.03 ± 0.08	0.2	CAMS/LLNL	EPG, Kona, HI
EN00051	Adult	Male	2010-2012	0.23 ± 0.19	0.4	CAMS/LLNL	RE, Northern Is.
EN00053	Adult	Male	2010-2012	0.21 ± 0.17	0.5	CAMS/LLNL	EPG, Kona, HI
EN00057	Adult	Male	2010-2012	0.42 ± 0.18	0.3	CAMS/LLNL	RE
EN00060	Adult	Male	2010-2012	0.42 ± 0.17	0.3	CAMS/LLNL	RE

ID#	Age Type	Gender	Collection Date	Radionuclide Concentration (μBq/24 h void)		Method Code	Notes
				^{239}Pu	MDA		
EN00069	Adult	Male	2010-2012	0.13 ± 0.14	0.3	CAMS/LLNL	RE
EN00076	Adult	Male	2010-2012	0.26 ± 0.14	0.3	CAMS/LLNL	RE
EN00084	Adult	Male	2010-2012	0.64 ± 0.36	0.4	CAMS/LLNL	RE
EN00086	Adult	Male	2010-2012	0.56 ± 0.16	0.3	CAMS/LLNL	RE, Northern Is.
EN00086	Adult	Male	2010-2012	0.47 ± 0.18	0.3	CAMS/LLNL	RE, Northern Is.
EN00094	Adult	Male	2010-2012	0.43 ± 0.16	0.3	CAMS/LLNL	RE, Northern Is.
EN00095	Adult	Male	2010-2012	0.09 ± 0.15	0.3	CAMS/LLNL	RE
EN00095	Adult	Male	2010-2012	0.09 ± 0.14	0.3	CAMS/LLNL	RE
EN00116	Adult	Male	2010-2012	0.72 ± 0.24	0.4	CAMS/LLNL	RE
EN00131	Adult	Male	2010-2012	0.43 ± 0.24	0.4	CAMS/LLNL	RE
EN00139	Adult	Male	2010-2012	0.05 ± 0.13	0.3	CAMS/LLNL	RE, Northern Is.
EN00141	Adult	Male	2010-2012	0.58 ± 0.25	0.3	CAMS/LLNL	RE, Northern Is.
EN00141	Adult	Male	2010-2012	0.77 ± 0.29	0.4	CAMS/LLNL	RE, Northern Is.
EN00159	Adult	Male	2010-2012	0.19 ± 0.15	0.4	CAMS/LLNL	RE
EN00161	Adult	Male	2010-2012	0.38 ± 0.14	0.3	CAMS/LLNL	RE, Northern Is.
EN00180	Adult	Male	2010-2012	0.53 ± 0.27	0.3	CAMS/LLNL	RE
EN00184	Adult	Male	2010-2012	0.91 ± 0.28	0.3	CAMS/LLNL	RE, Northern Is., Inv

ID#	Age Type	Gender	Collection Date	Radionuclide Concentration (μBq per 24 h void)		Method Code	Notes
				^{239}Pu	MDA		
EN00185	Adult	Male	2010-2012	0.11 ± 0.14	0.3	CAMS/LLNL	RE, Northern Is.
EN00199	Adult	Female	2010-2012	0.27 ± 0.19	0.4	CAMS/LLNL	RE
EN00201	Adult	Female	2010-2012	0.23 ± 0.15	0.3	CAMS/LLNL	RE
EN00222	Adult	Female	2010-2012	0.06 ± 0.10	0.3	CAMS/LLNL	RE
EN00226	Adult	Male	2010-2012	0.64 ± 0.28	0.4	CAMS/LLNL	RE
EN00226	Adult	Male	2010-2012	0.27 ± 0.16	0.4	CAMS/LLNL	RE
EN00237	Adult	Female	2010-2012	0.04 ± 0.13	0.3	CAMS/LLNL	RE
EN00238	Adult	Male	2010-2012	0.44 ± 0.24	0.4	CAMS/LLNL	RE
EN00258	Adult	Female	2010-2012	-0.002 ± 0.13	0.3	CAMS/LLNL	RE
EN00267	Adult	Female	2010-2012	0.54 ± 0.17	0.3	CAMS/LLNL	RE, Northern Is.
EN00267	Adult	Female	2010-2012	0.07 ± 0.14	0.3	CAMS/LLNL	RE, Northern Is.
EN00269	Adult	Female	2010-2012	0.43 ± 0.14	0.3	CAMS/LLNL	RE, Northern Is.
EN00303	Adult	Female	2010-2012	0.20 ± 0.15	0.4	CAMS/LLNL	RE
EN00312	Adult	Female	2010-2012	0.11 ± 0.12	0.3	CAMS/LLNL	RE
EN00317	Adult	Female	2010-2012	-0.05 ± 0.12	0.3	CAMS/LLNL	RE
EN00330	Adult	Female	2010-2012	0.55 ± 0.15	0.3	CAMS/LLNL	RE
EN00336	Adult	Female	2010-2012	-0.01 ± 0.16	0.5	CAMS/LLNL	EPG, Kona, HI

ID#	Age Type	Gender	Collection Date	Radionuclide Concentration (μBq per 24 h void)		Method Code	Notes
				^{239}Pu	MDA		
EN00373	Adult	Female	2010-2012	-0.05 ± 0.09	0.3	CAMS/LLNL	RE, Northern Is.
EN00373	Adult	Female	2010-2012	0.28 ± 0.17	0.3	CAMS/LLNL	RE, Northern Is.
EN00379	Adult	Male	2010-2012	0.21 ± 0.13	0.3	CAMS/LLNL	RE
EN00398	Adult	Male	2010-2012	0.58 ± 0.29	0.3	CAMS/LLNL	RE
EN00399	Adult	Female	2010-2012	0.71 ± 0.19	0.3	CAMS/LLNL	RE
EN00403	Adult	Male	2010-2012	0.46 ± 0.16	0.3	CAMS/LLNL	RE, Northern Is.
EN00407	Adult	Female	2010-2012	0.43 ± 0.13	0.2	CAMS/LLNL	EPG, Kona, HI
EN00408	Adult	Female	2010-2012	0.28 ± 0.19	0.4	CAMS/LLNL	RE
EN00412	Adult	Male	2010-2012	0.46 ± 0.17	0.3	CAMS/LLNL	RE
EN00415	Adult	Male	2010-2012	0.49 ± 0.23	0.5	CAMS/LLNL	RE
EN00421	Adult	Female	2010-2012	1.09 ± 0.25	0.5	CAMS/LLNL	EPG, RH, Inv
EN00422	Adult	Male	2010-2012	0.36 ± 0.24	0.3	CAMS/LLNL	RE
EN00440	Adult	Female	2010-2012	0.46 ± 0.20	0.4	CAMS/LLNL	RE
EN00467	Adult	Male	2010-2012	0.50 ± 0.25	0.4	CAMS/LLNL	RE
EN00482	Adult	Male	2010-2012	0.19 ± 0.15	0.3	CAMS/LLNL	RE
EN00517	Adult	Male	2010-2012	-0.16 ± 0.09	0.3	CAMS/LLNL	RE
EN00517	Adult	Male	2010-2012	-0.08 ± 0.12	0.3	CAMS/LLNL	RE

ID#	Age Type	Gender	Collection Date	Radionuclide Concentration (μBq per 24 h void)		Method Code	Notes
				^{239}Pu	MDA		
EN00538	Adult	Female	2010-2012	0.21 ± 0.13	0.3	CAMS/LLNL	RE
EN00540	Adult	Male	2010-2012	0.21 ± 0.18	0.5	CAMS/LLNL	RE, Northern Is.
EN00540	Adult	Male	2010-2012	0.26 ± 0.18	0.4	CAMS/LLNL	RE, Northern Is.
EN00543	Adult	Male	2010-2012	0.47 ± 0.20	0.3	CAMS/LLNL	RE
EN00553	Adult	Male	2010-2012	0.35 ± 0.12	0.2	CAMS/LLNL	EPG, Kona, HI
EN00554	Adult	Female	2010-2012	0.23 ± 0.11	0.2	CAMS/LLNL	EPG, Kona, HI
EN00557	Adult	Female	2010-2012	0.22 ± 0.11	0.2	CAMS/LLNL	EPG, Kona, HI
EN00577	Adult	Male	2010-2012	0.14 ± 0.14	0.3	CAMS/LLNL	RE
EN00598	Teenager	Male	2010-2012	0.21 ± 0.14	0.3	CAMS/LLNL	RE
EN00619	Teenager	Male	2010-2012	0.12 ± 0.15	0.3	CAMS/LLNL	RE
EN00708	Adult	Male	2010-2012	-0.16 ± 0.09	0.3	CAMS/LLNL	RE, Northern Is.
EN00732	Adult	Female	2010-2012	0.05 ± 0.11	0.4	CAMS/LLNL	RE
EN00735	Adult	Male	2010-2012	0.11 ± 0.12	0.3	CAMS/LLNL	RE
EN00735	Adult	Male	2010-2012	0.31 ± 0.20	0.4	CAMS/LLNL	RE
EN00735	Adult	Male	2010-2012	0.25 ± 0.17	0.3	CAMS/LLNL	RE
EN00795	Adult	Male	2010-2012	0.57 ± 0.24	0.4	CAMS/LLNL	RE
EN00807	Adult	Male	2010-2012	0.02 ± 0.10	0.3	CAMS/LLNL	RE

ID#	Age Type	Gender	Collection Date	Radionuclide Concentration (μBq per 24 h void)		Method Code	Notes
				^{239}Pu	MDA		
EN00838	Adult	Male	2010-2012	0.82 ± 0.29	0.4	CAMS/LLNL	RE
EN00850	Adult	Male	2010-2012	0.39 ± 0.22	0.3	CAMS/LLNL	RE
EN00850	Adult	Male	2010-2012	0.27 ± 0.17	0.4	CAMS/LLNL	RE
EN00883	Adult	Male	2010-2012	0.10 ± 0.16	0.3	CAMS/LLNL	RE
EN00884	Adult	Male	2010-2012	0.37 ± 0.14	0.3	CAMS/LLNL	RE
EN00885	Adult	Male	2010-2012	0.70 ± 0.28	0.4	CAMS/LLNL	RE
EN00887	Adult	Male	2010-2012	0.13 ± 0.18	0.3	CAMS/LLNL	RE, Northern Is.
EN00904	Adult	Female	2010-2012	0.66 ± 0.18	0.3	CAMS/LLNL	RE
EN00906	Adult	Male	2010-2012	0.57 ± 0.26	0.4	CAMS/LLNL	RE
EN00909	Adult	Female	2010-2012	0.16 ± 0.09	0.2	CAMS/LLNL	RE
EN00927	Adult	Male	2010-2012	0.07 ± 0.10	0.3	CAMS/LLNL	RE, Northern Is.
EN00938	Adult	Male	2010-2012	0.28 ± 0.21	0.3	CAMS/LLNL	RE
EN01066	Adult	Male	2010-2012	0.98 ± 0.32	0.5	CAMS/LLNL	RE, Inv
EN01080	Adult	Male	2010-2012	0.10 ± 0.11	0.3	CAMS/LLNL	RE, Northern Is.
EN01113	Adult	Male	2010-2012	0.05 ± 0.14	0.3	CAMS/LLNL	RE, Northern Is.
MI00093	Adult	Female	2010-2012	-0.06 ± 0.10	0.3	CAMS/LLNL	UPG, NR
MI00103	Adult	Male	2010-2012	0.25 ± 0.12	0.3	CAMS/LLNL	GP
MI001081	Adult	Female	2010-2012	0.19 ± 0.19	0.9	CAMS/LLNL	RPG, NR, CHS

ID#	Age Type	Gender	Collection Date	Radionuclide Concentration (μBq per 24 h void)		Method Code	Notes
				^{239}Pu	MDA		
MI00275	Adult	Female	2010-2012	0.35 ± 0.14	0.3	CAMS/LLNL	RPG, NR
MI00277	Adult	Female	2010-2012	0.90 ± 0.18	0.3	CAMS/LLNL	RPG, NR, CHS
MI00279	Adult	Female	2010-2012	0.16 ± 0.19	0.9	CAMS/LLNL	RPG, NR
MI00280	Adult	Female	2010-2012	0.16 ± 0.16	0.5	CAMS/LLNL	RPG, NR, CHS
MI00280	Adult	Female	2010-2012	0.66 ± 0.22	0.9	CAMS/LLNL	RPG, NR, CHS
MI00280	Adult	Female	2010-2012	0.52 ± 0.17	0.3	CAMS/LLNL	RPG, NR, CHS
MI00280	Adult	Female	2010-2012	0.03 ± 0.12	0.3	CAMS/LLNL	RPG, NR, CHS
MI00285	Adult	Male	2010-2012	0.90 ± 0.23	0.9	CAMS/LLNL	RPG, NR, CHS, Inv
MI00285	Adult	Male	2010-2012	0.28 ± 0.15	0.3	CAMS/LLNL	RPG, NR, CHS
MI00285	Adult	Male	2010-2012	0.27 ± 0.15	0.3	CAMS/LLNL	RPG, NR, CHS
MI00289	Adult	Male	2010-2012	0.90 ± 0.24	0.9	CAMS/LLNL	RPG, NR, CHS, Inv
MI00289	Adult	Male	2010-2012	0.29 ± 0.15	0.3	CAMS/LLNL	RPG, NR
MI00290	Adult	Male	2010-2012	2.29 ± 0.33	0.9	CAMS/LLNL	RPG, NR, CHS, Inv
MI00290	Adult	Male	2010-2012	0.25 ± 0.14	0.3	CAMS/LLNL	RPG, NR, CHS
MI00296	Adult	Female	2010-2012	0.27 ± 0.18	0.5	CAMS/LLNL	RPG, NR, CHS
MI00296	Adult	Female	2010-2012	0.29 ± 0.11	0.3	CAMS/LLNL	RPG, NR, CHS
MI00297	Adult	Female	2010-2012	0.20 ± 0.14	0.3	CAMS/LLNL	RPG, NR, CHS

ID#	Age Type	Gender	Collection Date	Radionuclide Concentration (μBq per 24 h void)		Method Code	Notes
				^{239}Pu	MDA		
MI00299	Adult	Female	2010-2012	0.84 ± 0.21	0.3	CAMS/LLNL	GP
MI00301	Adult	Female	2010-2012	0.56 ± 0.22	0.5	CAMS/LLNL	RU
MI00302	Adult	Female	2010-2012	1.75 ± 0.30	0.9	CAMS/LLNL	UPG, NR, CHS, Inv
MI00302	Adult	Female	2010-2012	0.25 ± 0.16	0.3	CAMS/LLNL	RPG, NR,CHS
MI00493	Adult	Female	2010-2012	0.52 ± 0.22	0.9	CAMS/LLNL	RPG, NR, CHS
MI00493	Adult	Female	2010-2012	0.20 ± 0.13	0.3	CAMS/LLNL	RPG, NR, CHS
MI00496	Adult	Male	2010-2012	0.20 ± 0.16	0.5	CAMS/LLNL	RPG, NR, CHS
MI00826	Adult	Female	2010-2012	0.17 ± 0.18	0.9	CAMS/LLNL	RPG, NR, CHS
MI00865	Adult	Male	2010-2012	0.06 ± 0.12	0.3	CAMS/LLNL	RE
MI00938	Adult	Female	2010-2012	0.71 ± 0.23	0.9	CAMS/LLNL	RPG, NR, CHS
MI00938	Adult	Female	2010-2012	0.42 ± 0.17	0.3	CAMS/LLNL	RPG, NR, CHS
MI00940	Adult	Male	2010-2012	-0.08 ± 0.12	0.5	CAMS/LLNL	RPG, NR, CHS
MI00940	Adult	Male	2010-2012	0.89 ± 0.24	0.9	CAMS/LLNL	RPG, NR, CHS
MI00940	Adult	Male	2010-2012	0.52 ± 0.19	0.3	CAMS/LLNL	RPG, NR, CHS
MI00940	Adult	Male	2010-2012	0.67 ± 0.19	0.3	CAMS/LLNL	RPG, NR, CHS
MI00945	Adult	Female	2010-2012	0.13 ± 0.15	0.5	CAMS/LLNL	RPG, NR, CHS
MI00945	Adult	Female	2010-2012	0.35 ± 0.19	0.9	CAMS/LLNL	RPG, NR, CHS

ID#	Age Type	Gender	Collection Date	Radionuclide Concentration (μBq per 24 h void)		Method Code	Notes
				^{239}Pu	MDA		
MI01022	Adult	Male	2010-2012	0.07 ± 0.12	0.3	CAMS/LLNL	RE, Northern Is.
MI01073	Adult	Female	2010-2012	0.32 ± 0.18	0.5	CAMS/LLNL	RPG, NR, CHS
MI01073	Adult	Female	2010-2012	0.26 ± 0.14	0.3	CAMS/LLNL	RPG, NR, CHS
MI01114	Adult	Female	2010-2012	-0.06 ± 0.12	0.5	CAMS/LLNL	UPG, NR
MI01160	Adult	Male	2010-2012	0.99 ± 0.29	0.5	CAMS/LLNL	RPG, NR, CHS, Inv
MI01160	Adult	Male	2010-2012	1.33 ± 0.28	0.9	CAMS/LLNL	RPG, NR, CHS, Inv
MI01161	Adult	Female	2010-2012	0.03 ± 0.15	0.5	CAMS/LLNL	RPG, NR, CHS
MI01161	Adult	Female	2010-2012	-0.05 ± 0.16	0.9	CAMS/LLNL	RPG, NR, CHS
MI01185	Adult	Female	2010-2012	0.03 ± 0.12	0.3	CAMS/LLNL	RPG, NR
MI01190	Adult	Female	2010-2012	0.97 ± 0.22	0.3	CAMS/LLNL	GP, Inv
MI01193	Adult	Female	2010-2012	0.32 ± 0.17	0.5	CAMS/LLNL	RPG, NR, CHS
MI01193	Adult	Female	2010-2012	-0.12 ± 0.09	0.3	CAMS/LLNL	RPG, NR, CHS
MI01194	Adult	Male	2010-2012	0.50 ± 0.21	0.5	CAMS/LLNL	RPG, NR
MI01194	Adult	Male	2010-2012	0.20 ± 0.13	0.3	CAMS/LLNL	RPG, NR
MI01215	Adult	Female	2010-2012	0.69 ± 0.25	0.9	CAMS/LLNL	RPG, NR, CHS
MI01215	Adult	Female	2010-2012	0.52 ± 0.18	0.3	CAMS/LLNL	RPG, NR, CHS
MI01217	Adult	Female	2010-2012	8.52 ± 0.57	0.9	CAMS/LLNL	RPG, NR, CHS, O, Inv

ID#	Age Type	Gender	Collection Date	Radionuclide Concentration (μBq per 24 h void)		Method Code	Notes
				^{239}Pu	MDA		
MI01217	Adult	Female	2010-2012	0.13 ± 0.13	0.3	CAMS/LLNL	RPG, NR, CHS
MI01238	Adult	Female	2010-2012	0.06 ± 0.15	0.5	CAMS/LLNL	RPG, NR
MI01529	Adult	Female	2010-2012	1.07 ± 0.28	0.5	CAMS/LLNL	GP, Inv
MI01529	Adult	Female	2010-2012	0.18 ± 0.12	0.3	CAMS/LLNL	GP
MI01608	Adult	Male	2010-2012	1.42 ± 0.21	0.3	CAMS/LLNL	RPG, NR, CHS, Inv
MI01620	Adult	Female	2010-2012	-0.04 ± 0.13	0.5	CAMS/LLNL	GP
MI01620	Adult	Female	2010-2012	-0.06 ± 0.09	0.3	CAMS/LLNL	GP
MI01620	Adult	Female	2010-2012	-0.09 ± 0.09	0.3	CAMS/LLNL	GP
MI01732	Adult	Male	2010-2012	0.95 ± 0.24	0.9	CAMS/LLNL	RPG, NR, CHS, Inv
MI01751	Adult	Female	2010-2012	0.30 ± 0.20	0.9	CAMS/LLNL	RPG, NR
MI01751	Adult	Female	2010-2012	0.36 ± 0.13	0.3	CAMS/LLNL	RPG, NR
MI01754	Adult	Male	2010-2012	0.50 ± 0.14	0.3	CAMS/LLNL	RPG, NR, CHS
MI01754	Adult	Male	2010-2012	0.12 ± 0.13	0.3	CAMS/LLNL	RPG, NR, CHS
MI01764	Adult	Female	2010-2012	0.49 ± 0.17	0.3	CAMS/LLNL	GP
MI01796	Adult	Female	2010-2012	0.36 ± 0.16	0.3	CAMS/LLNL	GP
MI01995	Adult	Male	2010-2012	0.39 ± 0.20	0.9	CAMS/LLNL	RPG, NR
MI01995	Adult	Male	2010-2012	0.02 ± 0.09	0.3	CAMS/LLNL	RPG, NR

ID#	Age Type	Gender	Collection Date	Radionuclide Concentration (μBq per 24 h void)		Method Code	Notes
				^{239}Pu	MDA		
MI02079	Adult	Female	2010-2012	-0.15 ± 0.08	0.3	CAMS/LLNL	RPG, NR
MI02114	Adult	Female	2010-2012	0.22 ± 0.15	0.3	CAMS/LLNL	RPG, NR
MI02116	Adult	Male	2010-2012	0.27 ± 0.15	0.3	CAMS/LLNL	GP
MI02137	Adult	Female	2010-2012	0.10 ± 0.13	0.3	CAMS/LLNL	GP
MI02677	Adult	Male	2010-2012	0.10 ± 0.12	0.3	CAMS/LLNL	GP
MI02799	Adult	Female	2010-2012	-0.12 ± 0.08	0.3	CAMS/LLNL	GP
MI02914	Adult	Female	2010-2012	-0.09 ± 0.09	0.3	CAMS/LLNL	RPG, NR
MI02915	Adult	Male	2010-2012	0.11 ± 0.13	0.3	CAMS/LLNL	RPG, NR
MI02921	Adult	Male	2010-2012	-0.10 ± 0.09	0.3	CAMS/LLNL	RPG, NR, CHS
MI02922	Adult	Female	2010-2012	-0.10 ± 0.09	0.3	CAMS/LLNL	RPG, NR
MI02931	Adult	Male	2010-2012	0.30 ± 0.16	0.3	CAMS/LLNL	RPG, NR
RR00087	Adult	Male	2010-2012	0.38 ± 0.16	0.3	CAMS/LLNL	RPG, NR
RR00240	Adult	Male	2010-2012	0.00 ± 0.11	0.3	CAMS/LLNL	RPG, NR
UT00015	Adult	Female	2010-2012	-0.09 ± 0.09	0.3	CAMS/LLNL	UPG, NR
UT00015	Adult	Female	2010-2012	-0.06 ± 0.17	0.9	CAMS/LLNL	UPG, NR
UT00015	Adult	Female	2010-2012	-0.09 ± 0.10	0.3	CAMS/LLNL	UPG, NR
UT00015	Adult	Female	2010-2012	0.12 ± 0.13	0.3	CAMS/LLNL	UPG, NR

ID#	Age Type	Gender	Collection Date	Radionuclide Concentration (μBq/24 h void)		Method Code	Notes
				^{239}Pu	MDA		
UT00056	Adult	Female	2010-2012	0.01 ± 0.11	0.3	CAMS/LLNL	UPG, NR, CHS
UT00058	Adult	Male	2010-2012	0.15 ± 0.13	0.3	CAMS/LLNL	RU
UT00060	Adult	Male	2010-2012	0.04 ± 0.12	0.3	CAMS/LLNL	RU
UT00062	Adult	Male	2010-2012	0.15 ± 0.15	0.3	CAMS/LLNL	RU, CHS
UT00065	Adult	Female	2010-2012	0.25 ± 0.15	0.3	CAMS/LLNL	RU
UT00066	Adult	Female	2010-2012	-0.03 ± 0.11	0.3	CAMS/LLNL	RU, CHS
UT00076	Adult	Female	2010-2012	0.27 ± 0.13	0.3	CAMS/LLNL	RU
UT00103	Adult	Female	2010-2012	0.24 ± 0.12	0.3	CAMS/LLNL	UPG, NR, CHS
UT00105	Adult	Male	2010-2012	1.52 ± 0.31	0.3	CAMS/LLNL	UPG, NR, CHS, Inv
UT00107	Adult	Female	2010-2012	0.44 ± 0.17	0.3	CAMS/LLNL	UPG, NR
UT00113	Adult	Male	2010-2012	0.29 ± 0.13	0.3	CAMS/LLNL	UPG, NR, CHS
UT00113	Adult	Male	2010-2012	0.46 ± 0.17	0.3	CAMS/LLNL	UPG, NR, CHS
UT00114	Adult	Male	2010-2012	0.43 ± 0.13	0.3	CAMS/LLNL	RU
UT00207	Adult	Female	2010-2012	0.28 ± 0.14	0.3	CAMS/LLNL	RU
UT00284	Adult	Female	2010-2012	-0.09 ± 0.09	0.3	CAMS/LLNL	UPG, NR, CHS
UT00488	Adult	Female	2010-2012	0.04 ± 0.11	0.3	CAMS/LLNL	RU
Field Blank	-	-	2010-2012	-0.05 ± 0.13	0.5	CAMS/LLNL	

ID#	Age Type	Gender	Collection Date	Radionuclide Concentration (μBq per 24 h void)		Method Code	Notes
				^{239}Pu	MDA		
Field Blank	-	-	2010-2012	0.06 ± 0.14	0.5	CAMS/LLNL	
Field Blank	-	-	2010-2012	-0.14 ± 0.11	0.5	CAMS/LLNL	
Field Blank	-	-	2010-2012	0.34 ± 0.14	0.3	CAMS/LLNL	
Field Blank	-	-	2010-2012	0.09 ± 0.10	0.3	CAMS/LLNL	
Field Blank	-	-	2010-2012	0.24 ± 0.12	0.3	CAMS/LLNL	
Field Blank	-	-	2010-2012	0.09 ± 0.10	0.3	CAMS/LLNL	
Field Blank	-	-	2010-2012	0.03 ± 0.09	0.3	CAMS/LLNL	
Field Blank	-	-	2010-2012	0.04 ± 0.10	0.3	CAMS/LLNL	
Field Blank	-	-	2010-2012	-0.08 ± 0.10	0.3	CAMS/LLNL	
Field Blank	-	-	2010-2012	0.25 ± 0.17	0.3	CAMS/LLNL	
Field Blank	-	-	2010-2012	0.16 ± 0.17	0.3	CAMS/LLNL	
Field Blank	-	-	2010-2012	0.01 ± 0.12	0.3	CAMS/LLNL	
Field Blank	-	-	2010-2012	0.08 ± 0.13	0.3	CAMS/LLNL	
Field Blank	-	-	2010-2012	0.14 ± 0.13	0.4	CAMS/LLNL	
Field Blank	-	-	2010-2012	-0.07 ± 0.11	0.4	CAMS/LLNL	
Field Blank	-	-	2010-2012	0.02 ± 0.12	0.4	CAMS/LLNL	
Field Blank	-	-	2010-2012	0.36 ± 0.21	0.4	CAMS/LLNL	

ID#	Age Type	Gender	Collection Date	Radionuclide Concentration (μBq per 24 h void)		Method Code	Notes
				^{239}Pu	MDA		
Field Blank	-	-	2010-2012	0.14 ± 0.13	0.4	CAMS/LLNL	
Field Blank	-	-	2010-2012	0.06 ± 0.15	0.4	CAMS/LLNL	
Field Blank	-	-	2010-2012	-0.07 ± 0.11	0.4	CAMS/LLNL	
Field Blank	-	-	2010-2012	0.13 ± 0.14	0.4	CAMS/LLNL	
Field Blank	-	-	2010-2012	0.22 ± 0.19	0.9	CAMS/LLNL	
Field Blank	-	-	2010-2012	0.31 ± 0.19	0.9	CAMS/LLNL	
Field Blank	-	-	2010-2012	0.33 ± 0.20	0.9	CAMS/LLNL	
Field Blank	-	-	2010-2012	0.04 ± 0.17	0.9	CAMS/LLNL	
Field Blank	-	-	2010-2012	0.15 ± 0.18	0.9	CAMS/LLNL	
Field Blank	-	-	2010-2012	2.65 ± 0.33	0.9	CAMS/LLNL	O
Field Blank	-	-	2010-2012	0.13 ± 0.18	0.9	CAMS/LLNL	
Field Blank	-	-	2010-2012	-0.11 ± 0.16	0.9	CAMS/LLNL	
Field Blank	-	-	2010-2012	-0.13 ± 0.15	0.9	CAMS/LLNL	
Field Blank	-	-	2010-2012	-0.08 ± 0.08	0.3	CAMS/LLNL	
Field Blank	-	-	2010-2012	0.20 ± 0.13	0.3	CAMS/LLNL	
Field Blank	-	-	2010-2012	-0.10 ± 0.08	0.3	CAMS/LLNL	
Field Blank	-	-	2010-2012	-0.13 ± 0.08	0.3	CAMS/LLNL	

ID#	Age Type	Gender	Collection Date	Radionuclide Concentration (μBq per 24 h void)		Method Code	Notes
				^{239}Pu	MDA		
Field Blank	-	-	2010-2012	-0.12 ± 0.09	0.3	CAMS/LLNL	
Field Blank	-	-	2010-2012	0.08 ± 0.13	0.3	CAMS/LLNL	
Field Blank	-	-	2010-2012	-0.08 ± 0.10	0.3	CAMS/LLNL	
Field Blank	-	-	2010-2012	0.06 ± 0.14	0.3	CAMS/LLNL	
Field Blank	-	-	2010-2012	0.62 ± 0.18	0.3	CAMS/LLNL	
Field Blank	-	-	2010-2012	0.09 ± 0.13	0.3	CAMS/LLNL	
Field Blank	-	-	2010-2012	0.13 ± 0.13	0.3	CAMS/LLNL	
Field Blank	-	-	2010-2012	-0.19 ± 0.09	0.3	CAMS/LLNL	
Field Blank	-	-	2010-2012	0.00 ± 0.13	0.3	CAMS/LLNL	
Field Blank	-	-	2010-2012	0.00 ± 0.12	0.3	CAMS/LLNL	
Field Blank	-	-	2010-2012	-0.06 ± 0.10	0.3	CAMS/LLNL	
Field Blank	-	-	2010-2012	-0.11 ± 0.09	0.3	CAMS/LLNL	
Field Blank	-	-	2010-2012	-0.13 ± 0.09	0.3	CAMS/LLNL	
Field Blank	-	-	2010-2012	-0.06 ± 0.10	0.3	CAMS/LLNL	
Field Blank	-	-	2010-2012	-0.08 ± 0.09	0.3	CAMS/LLNL	
Field Blank	-	-	2010-2012	-0.03 ± 0.11	0.3	CAMS/LLNL	
Field Blank	-	-	2010-2012	-0.10 ± 0.09	0.3	CAMS/LLNL	

ID#	Age Type	Gender	Collection Date	Radionuclide Concentration (μBq per 24 h void)		Method Code	Notes
				^{239}Pu	MDA		
Field Blank	-	-	2010-2012	-0.19 ± 0.07	0.3	CAMS/LLNL	
Field Blank	-	-	2010-2012	-0.13 ± 0.08	0.3	CAMS/LLNL	
Field Blank	-	-	2010-2012	-0.18 ± 0.07	0.3	CAMS/LLNL	
Field Blank	-	-	2010-2012	-0.03 ± 0.07	0.2	CAMS/LLNL	
Field Blank	-	-	2010-2012	0.15 ± 0.10	0.2	CAMS/LLNL	
Field Blank	-	-	2010-2012	0.20 ± 0.11	0.2	CAMS/LLNL	
Field Blank	-	-	2010-2012	-0.05 ± 0.14	0.5	CAMS/LLNL	
Field Blank	-	-	2010-2012	-0.12 ± 0.15	0.5	CAMS/LLNL	
Field Blank	-	-	2010-2012	-0.05 ± 0.15	0.5	CAMS/LLNL	
Field Blank	-	-	2010-2012	-0.24 ± 0.13	0.5	CAMS/LLNL	

EPG = Enewetak-Ujelang Population Group; RPG = Rongelap Population Group; UPG = Utrōk Population Group; ER = Enewetak Atoll Resident; UR= Utrōk Atoll Resident; NR = Nonresident; GP = General Marshallese Population.

CHS = Comprehensive Health Services/DOE patient.

Northern Is. = Individual who has worked or lived on the northern islands of Enewetak (several weeks to months).

Field Blank = Procedural Field Blanks were collected in the Marshall Islands and handled in exactly the same manner as bioassay samples. The results provide a measure of the background concentration of plutonium introduced as part of sample handling and analysis procedures.

O = Outlier, not included in subsequent analysis; Inv = Data under investigation with initial request to resample.

Note 1. Data acquired for bioassay sample UT00104 collected 9-Sep-2011 with a measured ^{239}Pu content of 1097 μBq was rejected after an initial outlier QA investigation showed the sample was contaminated, i.e., secondary analysis by MCICP-MS of residual AMS cathode material revealed the sample contained an usually high ^{240}Pu/^{239}Pu mass ratio not normally attributed to environmental contamination from weapons fallout.

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