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MARSHALL ISLANDS DOSE ASSESSMENT AND RADIOLOGICAL PROGRAM

BIKINI · ENEWETAK · RONGELAP · UTRŌK

Individual Radiation Protection Monitoring in the Marshall Islands: Utrōk Atoll (2005–2006)

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May 2007

As a hard copy supplement to the Marshall Islands Program web site (http://eed.llnl.gov/mi/), this document provides an overview of the individual radiological surveillance monitoring program established for the Utrōk Atoll population group along with a full disclosure of all verified measurement data (2005–2006). The Utrōk whole body counting facility has been temporarily stationed on Majuro Atoll and, in cooperation with the Utrōk Atoll Local Government, serves as a national facility open to the general public.

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INTRODUCTION

The United States Department of Energy has recently implemented a series of strategic initiatives to address long-term radiological surveillance needs at former U.S. nuclear test sites in the Marshall Islands. The plan is to engage local atoll communities in developing shared responsibilities for implementing radiation 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 local 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 three separate locations in the Marshall Islands including Utrōk Atoll (Figure 1). These facilities 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 and may enter the body of local residents through ingestion of locally grown foods. Whole body counting provides a direct measure of internally deposited cesium-137 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 (AMS). High-quality bioassay measurements based on AMS are providing more reliable and accurate baseline measurements, and could potentially be used to track and assess intakes of plutonium associated with resettlement.

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 environmental studies program is to develop fundamental scientific data on the behavior of key radionuclides in the environment.

Figure 1. Majuro whole body counter with the honorable President Note of the Republic of the Marshall Islands sitting in the chair (Dedication Ceremony for the opening of the Utrōk Atoll Whole Body Counting Facility on Majuro Atoll, January 2004) (Photo TFH).

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 Marshall Islands Program web site (http://eed.llnl.gov/mi/), this document provides an overview of the individual radiation protection monitoring program established on Majuro Atoll along with a full disclosure of all verified measurement data (2005–2006). Readers are advised that an additional feature of the associated web site is a provision where users are able to calculate and track doses delivered to volunteers (de-identified information only) participating in the Marshall Islands Radiological Surveillance Monitoring Program.

BRIEF HISTORY OF NUCLEAR TESTING IN THE MARSHALL ISLANDS

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

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

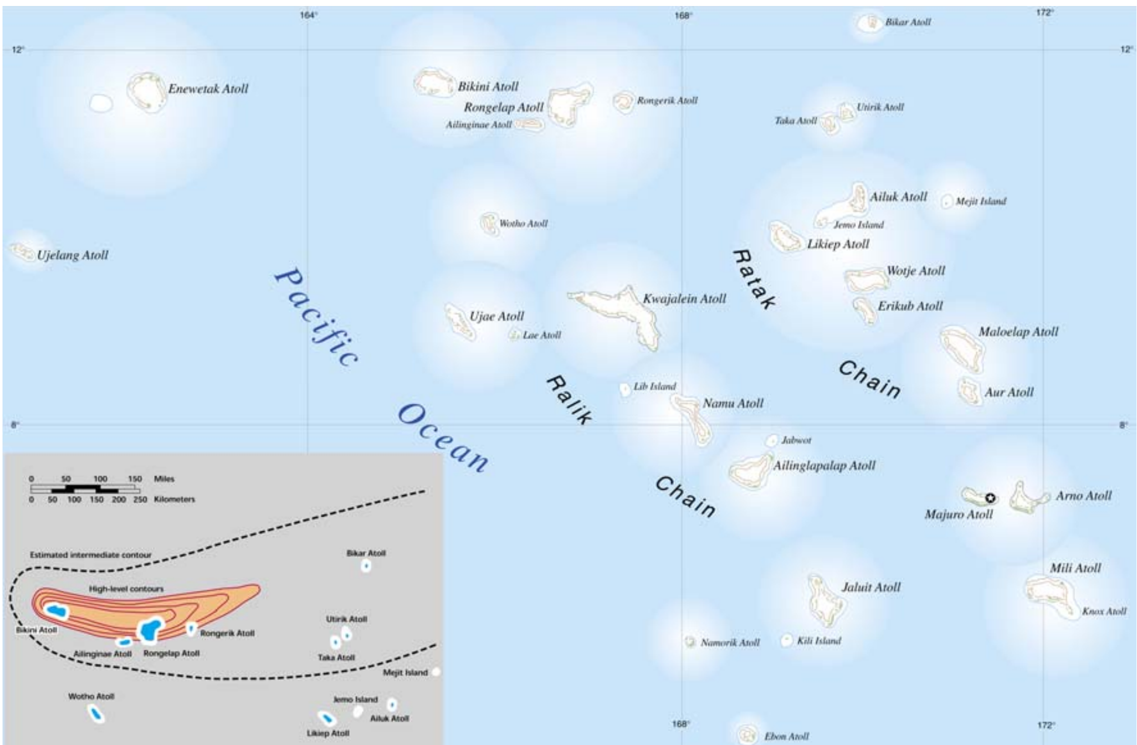
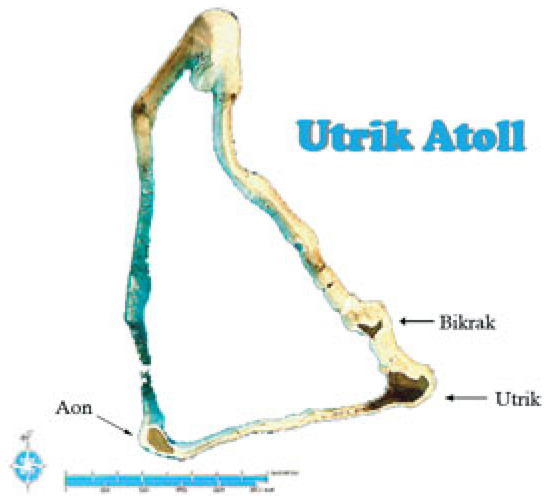


Figure 2. Map of the Republic of Marshall Islands showing the fallout pattern from the Bravo nuclear test conducted on March 1 of 1954.

UTRŌK ATOLL

People & Events | Historical Data



People and Events on Utrŏk Atoll

Utrōk Atoll is located about 500 kilometers east of Bikini Atoll. The atoll experienced significant 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 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 leaders 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; 1997b). More recently, the United States Department of Energy has developed a series of initiatives to address long-term radiological 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 (Figure 3). 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. 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 local population as well as those people living or working elsewhere in the northern Marshall Islands.

[#] Majuro is the capital city of the Republic of the Marshall Islands and is the main hub for the local airline.

Figure 3. Whole Body Counting program technicians in charge of the Utrōk Whole Body Counting Facility (Majuro Atoll, Republic of the Marshal Islands). Mr. Sherwood Tibon (standing) and Ms. Lolieta Chee (seated).

Historical Data

Today, exposure to residual fallout contamination on Utrōk Atoll represents only a small fraction of the dose that people receive from natural sources of background radiation in the Marshall Islands. The radiological dose delivered to inhabitants living on Utrōk Atoll from residual fallout contamination in the environment is dominated by the external exposure and ingestion of 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 4 mrem (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 scientist from the Lawrence Livermore National Laboratory appear to be in excellent agreement with estimates 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 on Utrōk 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 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 remedial actions taking into account the relative cost/benefit as well as social and economic factors.

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 Utrōk Atoll population group and to other program volunteers in the Marshall Islanders

What is Whole Body Counting?

The whole body counting systems installed in the Marshall Islands contain large volume sodium iodide radiation detectors that measure gamma-rays coming from radionuclides deposited in the body. The detector systems are modeled after the 'Masse-Bolton Chair' design (Figure 3) and can be used to detect high-energy, gamma-emitting radionuclides 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.

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

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 check 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 Oak Ridge National Laboratory Intercomparison Studies Program (ISP). These performance test samples are distributed around each of the facilities including a *mirror* whole body counting system 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 the 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 13.30 criteria for accuracy and measurement precision (Kehl *et al.*, 2007).

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

Figure 4. A *Massic-Bolton* whole body counter with calibration phantom.

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). 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 this type of radiation protection monitoring program lies in the fact that whole body count data provides a direct measure of radionuclide uptake into local populations. Information about potential *high-end* health risks and seasonal fluctuations in the body burden of cesium-137 within various Marshallese atoll 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 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 monitor resettled populations and provide assurance that radiation related health risks remain at or below these 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 the body of people. The biokinetic behavior of cesium-137 inside the human body is well known and allows information from the whole body counter to be converted to a radiation dose. The radiation dose is what is used to quantify the potential health risks associated with radiation exposure. The dosimetric data graphics displayed on the Marshall Islands web site 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 equivalent is given in units of rem, the conventional units used by federal and state agencies in the United States. The SI unit of dose equivalent is the joule per kilogram or sievert (Sv). Doses from exposure to environmental radioactivity (natural or manmade) are normally expressed as $1/1000^{th}$ of the base unit, i.e., in millirem (mrem) or millisievert (mSv). 1 mSv is equal to 100 mrem.

Information Note: The methodologies for computing doses from the whole body counting and plutonium urinalysis programs have recently been outlined in a Technical Basis Document (refer to *Daniels et al.*, 2007). This new methodology uses a 50 y dose commitment and complies more fully with ICRP methodology. The algorithms developed to allow users to compute doses directly from measurement data posted on the web site are also consistent with this new methodology.

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 Oak Ridge National Laboratory Intercomparison Studies Program (ISP). The ISP was specifically designed to support whole body counting facilities to comply with requirements of 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 DOE 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) per sample. 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, 2005). 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 a whole body count measurement (*i*) shows how close the measured activity is to the reference (known) value of the test sample. The relative bias (%, B_r) for any whole body count facility can then be calculated as the average of the individual relative biases B_{ri} as defined by;

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

where N is the number of measurements performed within each facility.

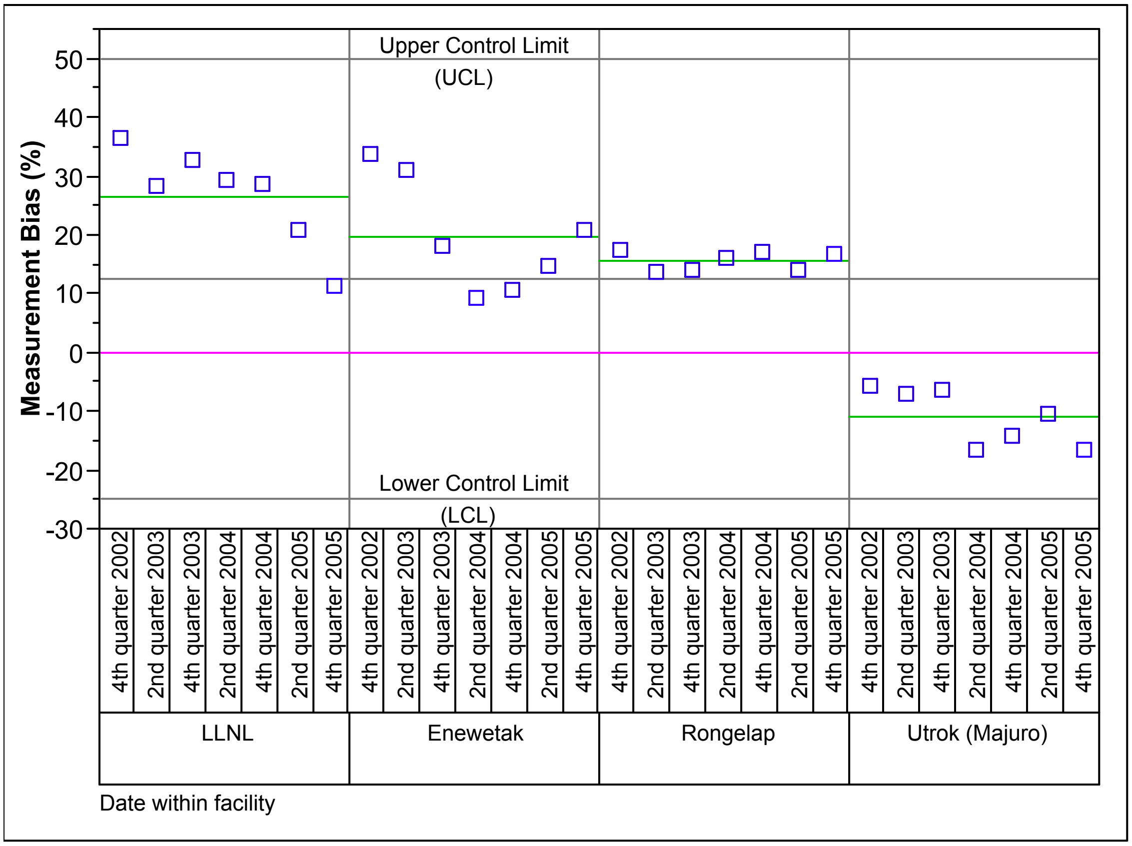
The mean relative bias statistic for the LLNL, Rongelap, Enewetak and Utrōk (Majuro) facilities based on performance evaluation exercises conducted between 2002 and 2005 was 25%, 15.4%, 19.6% and -5.4%, respectively. This compares with ANSI 13.30 acceptance criteria used in the United States for radiobioassay service laboratory quality control, performance testing, and accreditation of -25% to +50%. The results for each performance evaluation exercise conducted between 2002 and 2005 are shown graphically in Figure 4 with the 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 the ANSI 13.30 standard criteria for radiobioassay service laboratory quality control, performance testing, and accreditation is less than or equal to 40%. The mean relative precision statistic for the LLNL, Rongelap, Enewetak and Utrōk (Majuro) facilities based on performance evaluation exercises conducted between 2002 and 2005 was 8.9%, 1.6%, 9.5% and 16.7%, respectively.

The combined mean relative bias and relative precision statistic across all the Marshall Islands whole body counting facilities was 12.6% and 20.5%, respectively. Consequently, whole body count facilities in the Marshall Islands have consistently passed ANSI 13.30 performance criteria for relative measurement bias and precision.



[Statistical reference lines include the null value (----); UCL (Upper Control Limit) = 50% (– - –); LCL (Lower Control Limit) = -25% (– - –); individual facility mean (——); and the overall or combined facility mean (-----)]

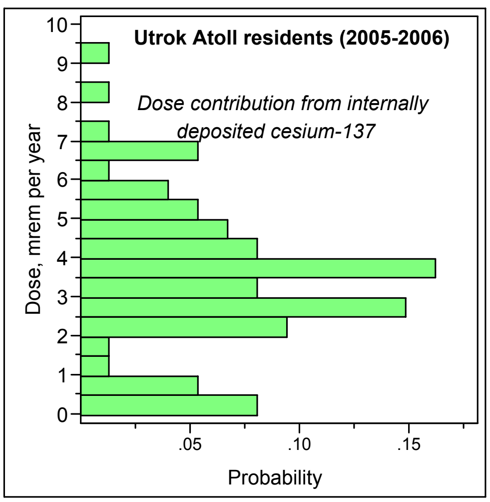
Figure 5. Multivar gage plot showing performance of whole body counting facilities for bi-annual performance evaluation exercises (2002–2005).

Doses Delivered to the Utrōk Atoll Population Group as well as other volunteers in the Marshall Islanders

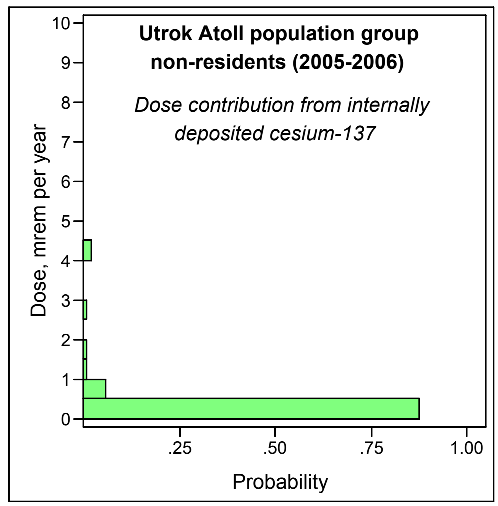
The individual dosimetric data from the whole body counting program (2005–2006) on Majuro Atoll are available on the Marshall Islands web site.

Dose distribution plots of the committed effective dose equivalent from internally deposited cesium-137 are shown in Figures 6a and Figure 6b for various groups of program volunteers. The Utrōk Atoll cohort group (Figure 6a) has been subdivided into those program volunteers who reside on Utrōk Atoll and those who live elsewhere in the Marshall Islands, largely on Majuro Atoll. Similarly, the Marshall Islands cohort group (Figure 6b) has been subdivided into those program volunteers who reside in the northern Marshall Islands and those who live on the southern atolls (including Majuro).

The population average committed effective dose equivalent for program volunteers living on Utrōk Atoll over the past two years was 3.5±2.0 mrem (N=74) (Figure 12a). This compares with population average doses observed for this same resident population group during 2003 and 2004 of 1.6±1.4 mrem (N = 25) and 3.0±1.8 mrem (N = 21), respectively. As observed in previous years, most people from the Utrōk population group who were resident on Majuro Atoll or elsewhere in the southern Marshall Islands did not acquire a measurable body burden of cesium-137.



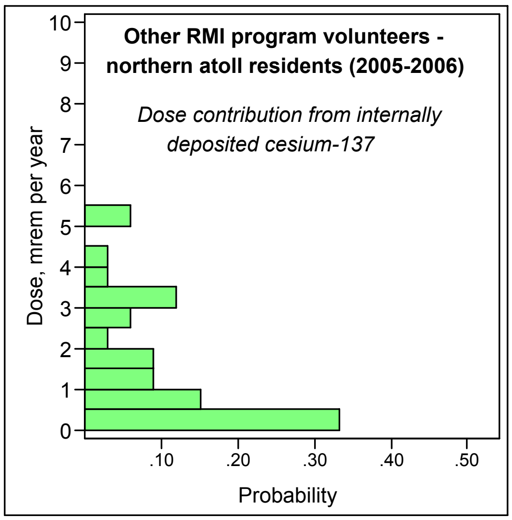
Moments: Mean = 3.5; Median = 3.5; Std. Dev. = 2.0; Std. Err. Mean = 0.23; Upper Confidence Interval Mean = 3.9; Lower Confidence Interval Mean = 3.0; N = 74



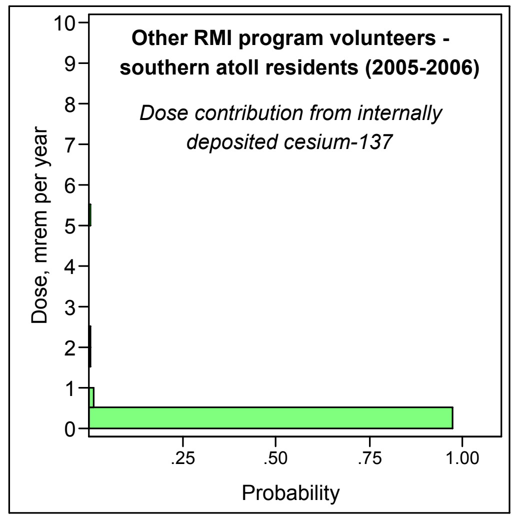
Moments: Mean = 0.2; Median = 0.0; Std. Dev. = 0.8; Std. Err. Mean = 0.08; Upper Confidence Interval Mean = 0.38; Lower Confidence Interval Mean = 0.05; N = 82

Figure 6a. Dose distribution plots of the committed effective dose equivalent delivered to the Utrōk Atoll population group during 2005–2006 (i) Utrōk Atoll residents (to left) versus (ii) the corresponding non-residents from the Utrōk population group living elsewhere in the Marshall Islands (to right), annualized to the year of measurement.

Similarly, the population average committed effective dose equivalent for program volunteers living elsewhere in the northern Marshall Islands over the past two years (excluding Enewetak and Utrōk residents, and resettlement workers and visitors on Rongelap Atoll) was 1.6±1.6 mrem (N=33) (Figure 6b). The vast majority of these program volunteers came from Ailuk and Likiep Atolls. The corresponding population average committed effective dose equivalent for program volunteers living on southern atolls was <0.1 mrem (N=287). It should be noted that the body burdens of cesium-137 measured in most volunteers from that southern atolls (including Majuro Atoll) were below the critical level of the measurements (L_c ~ 0.05 kBq) and, for the purposes of calculating summary statistics, was assigned a dose equal to zero.



Moments: Mean = 1.6; Median = 1.2; Std. Dev. = 0.4; Std. Err. Mean = 0.28; Upper Confidence Interval Mean = 2.1; Lower Confidence Interval Mean = 1.0; N = 33



Moments: Mean = 0.05; Median = 0.0; Std. Dev. = 2.0; Std. Err. Mean = 0.03; Upper Confidence Interval Mean = 0.1; Lower Confidence Interval Mean = 0.01; N = 287

Figure 6b. Dose distribution plots of the committed effective dose equivalent delivered to other program volunteers from the Marshall Islands (2005–2006) (i) Northern atoll residents (to left) versus (ii) Southern atoll residents (to right), annualized to the year of measurement.

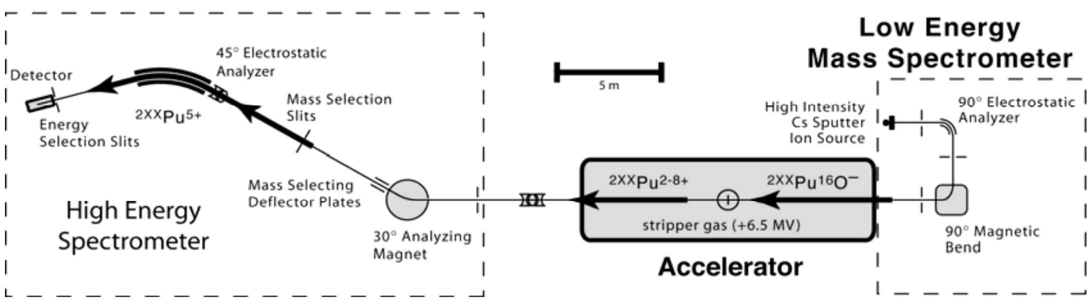
Although the whole body burdens of cesium-137 are generally low and equate to annualized dose contributions of less than 5 mrem, these data do show than people living on Utrōk Atoll and elsewhere in the northern Marshall Islands are more likely to receive a measurable dose from internally deposited cesium-137.

Summary

All volunteers participating in the whole body counting program on Majuro Atoll during 2005–2006 received annualized doses from cesium-137 ingestion of less than 10 mrem. The committed effective dose equivalent from internally deposited cesium-137 within the Utrōk Atoll population group as well as for other program volunteers can be compared with the natural background Effective Dose Equivalent (EDE) of 140 mrem per year in the Marshall Islands and 300 mrem per year in the United States. Internal doses from internally deposited cesium-137 for all program volunteers independent of where they live is also well below the annual dose criteria of 100 mrem per year, excluding medical irradiation, imposed in 10CRF Part 20 (NRC, 2004) for protection of the public. The Republic of the Marshall Islands Nuclear Claims Tribunal has adopted a standard for cleanup of radioactively contaminated sites in the Marshall Islands of 15 mrem (0.15 mSv) per year. With the knowledge that cesium-137 ingestion is a major contributor to dose from exposure to residual fallout contamination in the Marshall Islands, data derived from the whole body counting program provides a direct measure of doses delivered to program volunteers under present-day conditions for comparison to applicable cleanup standards or guidelines. The results from the whole body counting program on Majuro appear to demonstrate that residents living on Utrōk Atoll are not being exposed to significantly elevated levels of cesium-137 in their diets. It is, however, recommended that the monitoring program be continued in order to accurately assess doses based on population group, age and gender, and to identify potential individuals at higher risk from radiation exposure, especially for those people living on Utrōk as well as other atolls in the northern Marshall Islands.

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 detection and measurement of plutonium isotopes by 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 plutonium-239.

What is Plutonium Urinalysis Monitoring?

Plutonium urinalysis is a very sensitive *in-vitro* bioassay measurement technique used to determine the amount of plutonium in human urine as a means of estimating the systemic burden (or total amount of plutonium) in the human body. Plutonium urinalysis tests are performed by collecting urine from individuals over a 24-hour period. 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 they 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 in 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 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; 1997).

Inhalation exposure can be estimated from the product of the soil concentration, resuspension enhancement factors and inhalation dose conversion factors for radionuclides of interest. These estimates show that the projected dose contribution from exposure to plutonium in the Marshall Islands is less that 5% of the total lifetime dose from exposure to residual fallout contamination in the environment (Robison *et al.*, 1980; 1982; 1997b). 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 man. 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 plutonium uptake in resettled and resettling populations.

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

Plutonium urinalysis is a measurement technique that ultimately provides information on the amount of plutonium people have in their bodies. Although plutonium is expected to be a minor contributor to the total manmade dose, it is a concern to people living in the northern Marshall Islands who are potentially exposed to elevated levels of plutonium in the environment from close-in or regional fallout deposition. Consequently, the United States Department of Energy has agreed to monitor resettlement workers and perform a limited number of urinalysis tests on island residents using advanced measurement technologies available at the Lawrence Livermore National Laboratory. The measurement technique currently employed at the Lawrence Livermore National Laboratory is based on Accelerator Mass Spectrometry. AMS is about 200 to 400 times more sensitive than monitoring techniques commonly employed in 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.*, 2004). Fission Track Analysis 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 offers a greatly improved potential for assessing uptakes associated with low-level chronic exposure to plutonium in the environment.

Under the Marshall Islands Plutonium Urinalysis Program, urine samples were initially sent to the University of Utah for analysis of plutonium using fission track analysis. Fission is a process where heavy nuclei such as plutonium and uranium break up into two large fragments. Fission may occur spontaneously or be induced by collisions with neutrons. During fission track analysis samples are exposed to a source of neutrons in a reactor 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.

More recently, scientists from the Lawrence Livermore National Laboratory have developed a low-level detection technique for determination of plutonium isotopes in bioassay samples based Accelerator Mass Spectrometry (Brown *et al.*, 2004; Hamilton *et al.*, 2004; Hamilton *et al.*, 2007). 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 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 source specific exposures to Bravo fallout as well as from other specific nuclear events.

Method Validation

Method validation is the process used to monitor and document the quality of the measurement data. 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 Spectrometric is well suited for detection of μBq concentrations of plutonium-239 and plutonium-240 in urine (Figure 7) (Marchetti *et al.*, 2002). An independent report on the results of this intercomparison exercise was recently published in the open scientific literature (McCurdy *et al.*, 2005). This study demonstrated that accelerator mass spectrometry provided more precise and higher quality results than comparative methods.

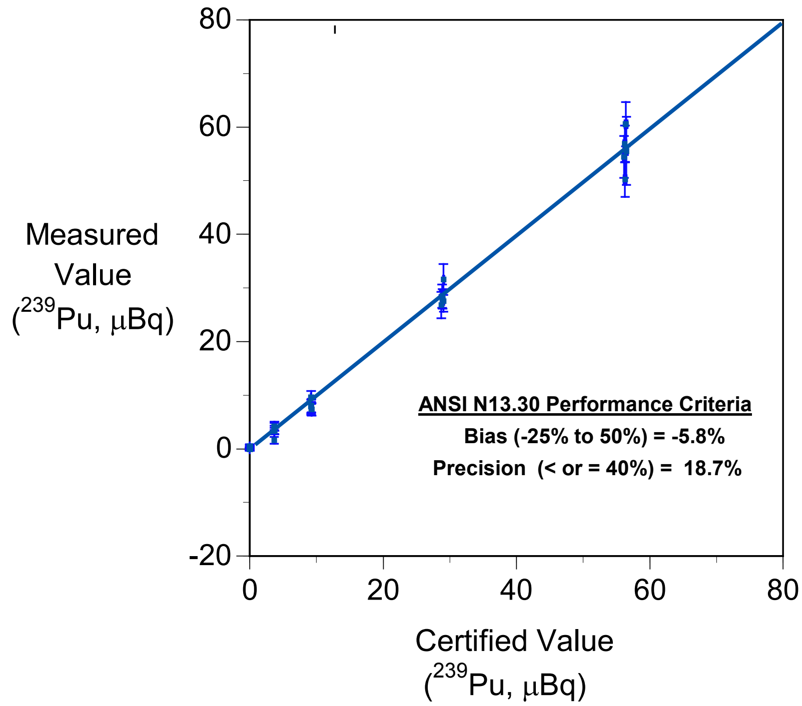


Figure 7. Results of an interlaboratory exercise conducted by National Institute of Standards and Technology (NIST) on determination of plutonium-239 in synthetic urine in the microBecquerel (μBq) range.

We also continue to test the performance of the technique by analyzing externally-prepared quality control natural urine samples artificially spiked with known amounts of plutonium. These quality control performance test samples are prepared under contract with the Oak Ridge National Laboratory and analyzed along with routine bioassay samples collected from the Marshall Islands. The activity concentration of plutonium-239 in the quality control samples is keep below 200 μBq in order to avoid possible cross-contamination problems, and the plutonium-240/plutonium-239 atom ratio approximates that observed in integrated worldwide fallout deposition, i.e., ~0.2. The results of the quality control 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 N13.30 performance criteria for accuracy and precision before acceptance of any routine bioassay measurement data. The average combined measurement bias and precision based on spiked quality samples analyzed under the Marshall Islands Program (2001–2006) were 1.1% and ±6.8% for plutonium-239, and 4.6% and ±11.1% for plutonium-240, respectively. The results of the plutonium-239 measurements are shown in Figure 8. Based on the results from these performance tests we consider that the methodologies employed under the Marshall Islands Urinalysis Monitoring Program represent the current state-of-the-art in the field for a routine plutonium bioassay program.

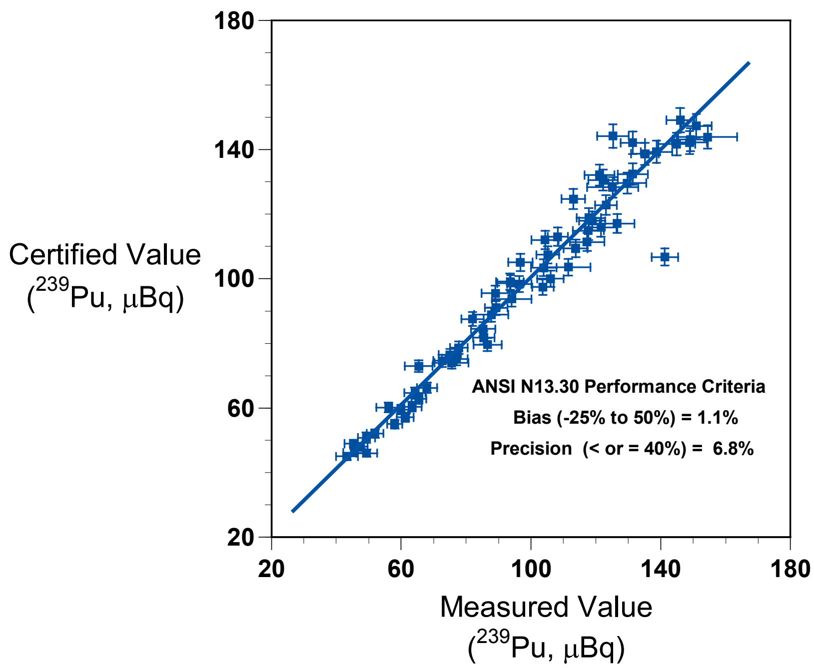


Figure 8. Analyses of externally prepared natural matrix spiked quality control performance evaluation test samples (2001–2006) prepared by the Oak Ridge National Laboratory.

Plutonium Urinalysis Monitoring on Utrōk Atoll

Individual measurement data from the Marshall Islands Plutonium Urinalysis Monitoring Program on Utrōk Atoll are available on the Marshall Islands web site (http://eed.llnl.gov/mi/).

We have only recently initiated a bioassay program to assess urinary excretion rates of plutonium from Utrōk Atoll residents. The bioassay 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. The aim of the bioassay program is to develop a statistically meaningful, high quality baseline dataset comparable to what has been done 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 12 mrem (0.12 mSv) (Robison *et al.*, 1999) but these estimates have never been substantiated by individual bioassay testing due largely to technical limitations in measuring such low levels of plutonium in urine. Moreover, we question the quality and reliable of historical bioassay data developed for the Utrōk Atoll population group. These data indicate that the systemic burden of plutonium in Utrōk Atoll residents is relatively high and variable and, for the most part, are not consistent with other baseline bioassay measurements performed at the Lawrence Livermore National Laboratory using accelerator mass spectrometry.

Preliminary data on the urinary excretion of plutonium from Utrōk Atoll residents ranged from –0.20 to 0.47 μBq per 24-h void with an error-weighted average of 0.11 μBq per 24-h void. The compares with an error-weighted average of –0.01 μBq obtained in a compatible set of field blanks (N=7). All the measurement data from Utrōk Atoll are well below the occupational action level established under the latest Department regulation 10 CFR 835 in the United States for *in vitro* bioassay monitoring of plutonium-239 (Hamilton et al., 2007). Moreover, the individual bioassay samples all contained less than the critical level needed to accurately determine if plutonium was actually present in the sample or not (L_c ~0.25 μBq). As a consequence, the bioassay measurement data are characterized by high relative measurement uncertainties and are not conducive to performing detailed individual dose assessments. Nonetheless, we are able to present some preliminary conclusions about the systemic uptake of plutonium and the associated dose delivered to this resident population based on statistical analyses of the combined data.

Based on the error-weighted, average values in the urinary excretion of plutonioum-239, the population average committed effective dose equivalent delivered to Utrōk Atoll residents from internally deposited plutonium is around 1.3 mrem (or 13 μSv). The maximal dose observed on Utrōk Atoll from internally deposited plutonium was 5.6 mrem (or 56 μSv). Please note that the annualized dose criteria developed for remediation of radioactively contaminated sites (NCRP, 2004) is usually based on estimates of the total effective dose equivalent (TEDE) over 50 years and consists of the sum of the committed dose due to intakes of radionuclides (of which, plutonium is just one potential component) and the deep dose equivalent from external exposures experienced during the measurement year.

Plans for the Future

Some of the early urinary excretion data for plutonium in the Marshall Islands is of questionable quality because of the poor quantification sensitivity of the methods employed and/or from the general lack of adequate quality control. In addition to expanding on the plutonium bioassay database for Utrōk Atoll, we plan to develop comparative high-quality baseline data for other atoll population groups including those people who resettle Rongelap Atoll.

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 Marshallese populations, we will be better able to track and monitor potential long-term changes in exposure conditions on the atolls, especially in relation to assessing 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 changing land-use patterns.

MEASUREMENT DATA FROM THE INDIVIDUAL RADIOLOGICAL SURVEILLANCE PROGRAM

Introduction | Individual Measurement Database

Introduction

The individual (de-identified) measurement data for Utrōk Atoll as well as for other program volunteers on Majuro Atoll are accessible on the Marshall Islands web site (http://eed.llnl.gov/mi/) using menu driven routines (Figure 9).

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 (^{239}Pu) and plutonium-240 (^{240}Pu) in bioassay (urine) samples indicates the presence of internally deposited (systemic) plutonium in the body. At Livermore, plutonium bioassay measurements are performed using a state-of-the-art technology based on Accelerator Mass Spectrometry (AMS) (Hamilton *et al.*, 2004, 2007; Brown *et al.*, 2004). Under the Marshall Islands Plutonium Urinalysis Program, the urinary excretion of plutonium from program volunteers is usually described in activity units, expressed as micro-Becquerel (μBq) of $^{239+240}$Pu (the sum of the ^{239}Pu and ^{240}Pu activity) excreted (lost) per day (d^{-1}); where 1 μBq d^{-1} = 10^{-6} Bq d^{-1} and 1 Bq = 1 t s^{-1}.

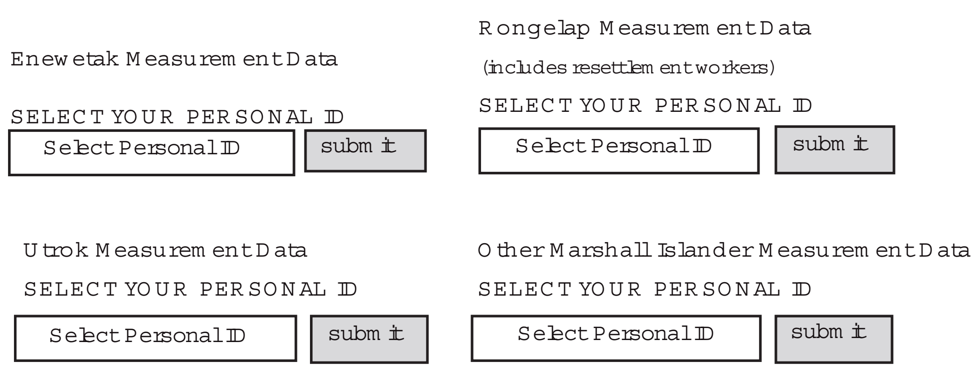


Figure 9. Layout of the menu structure used to access individual radiological protection monitoring data from the Marshall Islands web site (http://eed.llnl.gov/mi/).

Individual Measurement Database

The Marshall Islands web site provides electronic access to verified whole body counting and plutonium urinalysis data developed under the Marshall Islands Individual

Radiological Surveillance Program at the Lawrence Livermore National Laboratory (1999–present). Please note that measurement data developed for Utrōk Atoll are given a UT prefix identification number whereas people from other atolls (with exception of those people living on Enewetak and resettlement workers on Rongelap) and non-nationals are given an MI prefix identification number.

DOSIMETRIC DATA AND METHODOLOGY

Introduction | Dose Methodology

Introduction

The individual (de-identified) dosimetric data for Utrōk Atoll as well as for other program volunteers on Majuro Atoll are accessible on the Marshall Islands web site (http://eed.llnl.gov/mi/) using menu driven routines (Figure 10).

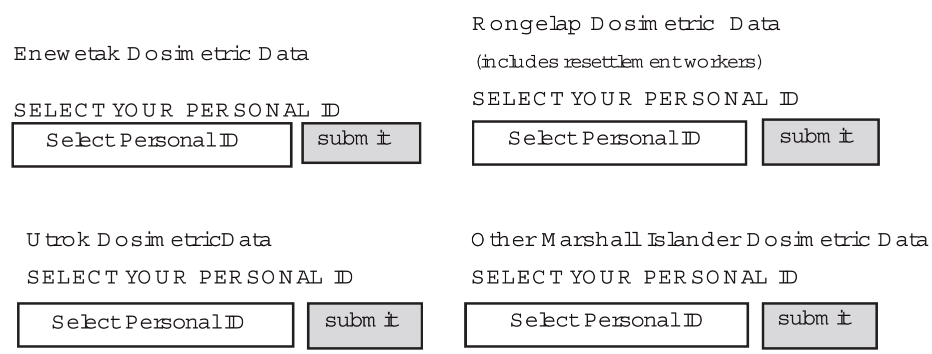


Figure 10. Layout of the menu structure used to access individual dosimetric monitoring data from the Marshall Islands web site (http://eed.llnl.gov/mi/).

In general, nuclear transformations emit energy and/or particles in the form of gamma rays, beta particles and alpha particles. Tissues in the human body may adsorb these emissions with the potential for any deposited energy to cause damage and disrupt biological function of cells. The general term used to quantify the extent of any health risk from radiation exposure is referred to as the dose. The equivalent dose is defined by the average absorbed dose in an organ or tissue weighed by the average quality factor for the type and energy of the radiation causing the dose. The effective dose equivalent (as applied to the whole body) is the sum of the average dose equivalent for each tissue weighted by tissue weighing factors. The 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 y 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).

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, but exclude dose contributions from external radiation exposure and from other internally deposited radionuclides such as strontium-90 (refer 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 10 mrem (0.1 mSv) 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 the 10 mrem level, 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 web site or hard copy reports while these investigations are on-going. The Lawrence Livermore National Laboratory Marshall Islands Program action level (10 mrem) 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 (15 mrem). 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 Dr. 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 10 mrem investigation level. In some cases, doses in excess of 10 mrem 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 × 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.

ACKNOWLEDGMENTS

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GLOSSARY OF TERMS

Absorbed Dose

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

Activity

Activity is the rate of transformation or decay of a radioactive material. The 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 1.4 mSv (140 mrem) per year and is significantly less than what most people receive in most 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 the 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 every 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 conventional unit for committed effective dose equivalence (CEDE) used by federal and state agencies within the United States is the rem. The international scientific (SI) unit of committed effective dose equivalent is called a sievert (Sv). One Sv is the same as 100 rem. Chronic doses are usually reported in units of mSv (1×10^{-3} Sv) or mrem (1×10^{-3} 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 adsorbed dose at a point in tissue multiplied by a biological effectiveness factor or quality factor for the particular types of radiation to cause biological damage. The conventional unit of dose equivalents used by federal and state agencies in the United States is the rem. A 100 rem dose to an adult will normally produce some clinical signs of radiation sickness and requires hospitalization. The International System (SI) unit for dose equivalent is the joule per kilogram (J kg^{-1}) and is called the sievert (Sv). 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 effective dose equivalent is usually expressed in units of millirem (mrem). The International System (SI) unit for dose equivalent is the joule per kilogram ($J\ kg^{-1}$) and is called the sievert (Sv). One Sv is the same as 100 rem.

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 or Radiation

That portion of the dose equivalent delivered by ionizing radiation originating from a source outside the body of an organism (e.g., also know 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 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 (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-Vito

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

In-Vivo

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

Indirect bioassay

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 (or mrem)

A generic term to describe the amount of radiation a person receives. Dose is measured in units of thousands of a roentegen equivalent man (rem). The millirem (normally abbreviated as mrem) is the preferred unit used by federal and state agencies in the United States. Dose is a general term used in the general field of radiological protection. The common International System (SI) unit for dose is the millisievert (mSv). One mSv is the same as 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 I

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

The following tables provide full disclosure of whole body counting and plutonium bioassay measurements data developed for the Utrōk Atoll population group as well as for other program volunteers on Majuro Atoll (2005–2006)

Table A1.1. Whole body count data developed for the Utrōk Atoll population group (2005–2006).

ID#	Age Type	Gender	Count Date	Cs-137 (kBq)			Method Code	Notes
				value		MDA		
UT00151	Adult	Male	2005-04-25	0.00	± 0.00	0.12	NaI_WBC	
UT00245	Adult	Female	2006-10-03	0.00	± 0.00	0.10	NaI_WBC	
UT00001	Adult	Male	2006-06-21	0.00	± 0.00	0.10	NaI_WBC	
UT00002	Adult	Male	2005-03-17	0.00	± 0.00	0.12	NaI_WBC	
UT00002	Adult	Male	2006-03-31	0.00	± 0.00	0.10	NaI_WBC	
UT00017	Adult	Female	2005-03-23	0.00	± 0.00	0.11	NaI_WBC	
UT00037	Adult	Female	2005-06-08	0.00	± 0.00	0.10	NaI_WBC	
UT00068	Adult	Male	2006-04-17	0.00	± 0.00	0.10	NaI_WBC	
UT00072	Adult	Female	2005-03-21	0.00	± 0.00	0.12	NaI_WBC	
UT00073	Adult	Female	2005-01-18	0.00	± 0.00	0.11	NaI_WBC	
UT00095	Adult	Female	2005-09-19	0.00	± 0.00	0.11	NaI_WBC	
UT00098	Adult	Female	2005-03-29	0.00	± 0.00	0.11	NaI_WBC	
UT00106	Adult	Female	2005-09-17	0.00	± 0.00	0.10	NaI_WBC	
UT00111	Adult	Female	2005-12-28	0.00	± 0.00	0.10	NaI_WBC	
UT00123	Adult	Female	2005-01-06	0.00	± 0.00	0.11	NaI_WBC	
UT00124	Teenager	Male	2005-02-16	0.00	± 0.00	0.11	NaI_WBC	
UT00125	Adult	Male	2005-02-23	0.00	± 0.00	0.11	NaI_WBC	
UT00125	Adult	Male	2006-08-16	0.00	± 0.00	0.11	NaI_WBC	
UT00130	Adult	Male	2005-03-17	0.00	± 0.00	0.11	NaI_WBC	
UT00131	Adult	Female	2005-03-21	0.00	± 0.00	0.12	NaI_WBC	
UT00132	Adult	Male	2005-03-21	0.00	± 0.00	0.12	NaI_WBC	
UT00133	Adult	Female	2005-03-22	0.00	± 0.00	0.11	NaI_WBC	
UT00134	Adult	Male	2005-03-23	0.00	± 0.00	0.12	NaI_WBC	
UT00135	Adult	Female	2005-03-23	0.00	± 0.00	0.11	NaI_WBC	
UT00137	Adult	Female	2005-03-23	0.00	± 0.00	0.11	NaI_WBC	
UT00138	Adult	Male	2005-03-24	0.00	± 0.00	0.12	NaI_WBC	
UT00139	Adult	Female	2005-03-24	0.00	± 0.00	0.12	NaI_WBC	
UT00140	Adult	Male	2005-03-29	0.00	± 0.00	0.12	NaI_WBC	
UT00141	Adult	Male	2005-03-24	0.00	± 0.00	0.12	NaI_WBC	
UT00142	Adult	Female	2005-03-29	0.00	± 0.00	0.12	NaI_WBC	
UT00144	Adult	Male	2005-03-31	0.00	± 0.00	0.12	NaI_WBC	
UT00146	Adult	Female	2005-06-08	0.00	± 0.00	0.10	NaI_WBC	
UT00147	Adult	Male	2005-06-08	0.00	± 0.00	0.10	NaI_WBC	
UT00148	Adult	Male	2005-06-09	0.00	± 0.00	0.11	NaI_WBC	
UT00149	Adult	Male	2005-03-24	0.00	± 0.00	0.12	NaI_WBC	
UT00152	Adult	Female	2005-04-26	0.00	± 0.00	0.11	NaI_WBC	
UT00153	Adult	Male	2005-04-26	0.00	± 0.00	0.11	NaI_WBC	

Table A1.1. Continued

ID#	Age Type	Gender	Count Date	Cs-137 (kBq)			Method Code	Notes
				value		MDA		
UT00154	Adult	Male	2005-06-09	0.00	± 0.00	0.11	NaI_WBC	
UT00155	Adult	Female	2005-06-09	0.00	± 0.00	0.10	NaI_WBC	
UT00166	Adult	Female	2005-06-17	0.00	± 0.00	0.10	NaI_WBC	
UT00168	Adult	Female	2005-06-29	0.00	± 0.00	0.10	NaI_WBC	
UT00180	Adult	Female	2005-08-16	0.00	± 0.00	0.10	NaI_WBC	
UT00181	Adult	Male	2005-08-16	0.00	± 0.00	0.11	NaI_WBC	
UT00184	Adult	Female	2005-08-17	0.00	± 0.00	0.10	NaI_WBC	
UT00188	Adult	Female	2005-08-18	0.00	± 0.00	0.10	NaI_WBC	
UT00192	Adult	Female	2005-08-25	0.00	± 0.00	0.10	NaI_WBC	
UT00193	Adult	Female	2005-08-25	0.00	± 0.00	0.10	NaI_WBC	
UT00194	Adult	Female	2005-08-25	0.00	± 0.00	0.10	NaI_WBC	
UT00195	Adult	Female	2005-08-25	0.00	± 0.00	0.10	NaI_WBC	
UT00196	Adult	Male	2005-08-25	0.00	± 0.00	0.10	NaI_WBC	
UT00197	Adult	Male	2005-08-25	0.00	± 0.00	0.10	NaI_WBC	
UT00198	Adult	Male	2005-09-17	0.00	± 0.00	0.10	NaI_WBC	
UT00199	Adult	Female	2005-09-17	0.00	± 0.00	0.10	NaI_WBC	
UT00206	Adult	Female	2005-10-24	0.00	± 0.00	0.10	NaI_WBC	
UT00208	Adult	Male	2005-12-28	0.00	± 0.00	0.10	NaI_WBC	
UT00210	Adult	Male	2006-01-31	0.00	± 0.00	0.10	NaI_WBC	
UT00220	Adult	Male	2006-04-17	0.00	± 0.00	0.10	NaI_WBC	
UT00224	Adult	Male	2006-06-09	0.00	± 0.00	0.10	NaI_WBC	
UT00225	Adult	Male	2006-06-09	0.00	± 0.00	0.10	NaI_WBC	
UT00230	Adult	Male	2006-07-12	0.00	± 0.00	0.11	NaI_WBC	
UT00231	Adult	Female	2006-07-18	0.00	± 0.00	0.10	NaI_WBC	
UT00233	Adult	Male	2006-07-20	0.00	± 0.00	0.10	NaI_WBC	
UT00234	Adult	Female	2006-07-24	0.00	± 0.00	0.10	NaI_WBC	
UT00236	Adult	Male	2006-07-25	0.00	± 0.00	0.11	NaI_WBC	
UT00238	Adult	Male	2006-07-25	0.00	± 0.00	0.11	NaI_WBC	
UT00240	Teenager	Male	2006-08-02	0.00	± 0.00	0.10	NaI_WBC	
UT00243	Adult	Female	2006-08-28	0.00	± 0.00	0.10	NaI_WBC	
UT00244	Teenager	Female	2006-08-28	0.00	± 0.00	0.10	NaI_WBC	
UT00246	Adult	Male	2006-10-03	0.00	± 0.00	0.10	NaI_WBC	
UT00251	Adult	Female	2006-12-12	0.00	± 0.00	0.10	NaI_WBC	
UT00221	Adult	Male	2006-04-27	0.00	± 0.00	0.11	NaI_WBC	
UT00167	Adult	Male	2005-06-28	0.00	± 0.00	0.11	NaI_WBC	
UT00065	Adult	Female	2005-11-19	0.00	± 0.00	0.12	NaI_WBC	
UT00071	Adult	Female	2006-10-10	0.00	± 0.00	0.12	NaI_WBC	
UT00187	Adult	Female	2005-08-18	0.00	± 0.00	0.11	NaI_WBC	

Table A1.1. Continued

ID#	Age Type	Gender	Count Date	Cs-137 (kBq) value		Cs-137 (kBq) MDA	Method Code	Notes
UT00190	Adult	Female	2005-08-23	0.00	± 0.00	0.11	NaI_WBC	
UT00191	Adult	Female	2005-08-23	0.00	± 0.00	0.11	NaI_WBC	
UT00212	Adult	Female	2006-03-21	0.00	± 0.00	0.11	NaI_WBC	
UT00229	Adult	Male	2006-07-12	0.00	± 0.00	0.11	NaI_WBC	
UT00176	Adult	Female	2005-07-29	0.00	± 0.00	0.10	NaI_WBC	
UT00226	Adult	Female	2006-10-25	0.10	± 0.04	0.18	NaI_WBC	
UT00226	Adult	Female	2006-07-10	0.10	± 0.04	0.20	NaI_WBC	
UT00213	Adult	Female	2006-03-21	0.10	± 0.04	0.20	NaI_WBC	
UT00094	Adult	Male	2005-03-12	0.11	± 0.05	0.23	NaI_WBC	
UT00228	Adult	Male	2006-07-10	0.12	± 0.03	0.16	NaI_WBC	
UT00141	Adult	Male	2006-09-06	0.12	± 0.04	0.17	NaI_WBC	
UT00211	Adult	Female	2006-01-31	0.12	± 0.06	0.28	NaI_WBC	
UT00237	Adult	Female	2006-07-25	0.12	± 0.04	0.19	NaI_WBC	
UT00239	Adult	Male	2006-07-27	0.13	± 0.05	0.24	NaI_WBC	
UT00235	Teenager	Female	2006-07-25	0.13	± 0.04	0.17	NaI_WBC	
UT00061	Adult	Male	2005-11-26	0.14	± 0.06	0.29	NaI_WBC	
UT00076	Adult	Female	2006-03-22	0.16	± 0.05	0.23	NaI_WBC	
UT00143	Adult	Female	2005-03-29	0.18	± 0.07	0.31	NaI_WBC	
UT00214	Adult	Female	2006-03-21	0.21	± 0.07	0.33	NaI_WBC	
UT00145	Adult	Female	2005-06-08	0.25	± 0.07	0.33	NaI_WBC	
UT00061	Adult	Male	2005-03-10	0.30	± 0.07	0.31	NaI_WBC	
UT00077	Adult	Female	2005-03-12	0.30	± 0.07	0.32	NaI_WBC	
UT00222	Adult	Female	2006-05-16	0.32	± 0.07	0.32	NaI_WBC	
UT00031	Adult	Male	2006-01-28	0.33	± 0.07	0.34	NaI_WBC	
UT00182	Adult	Female	2005-08-17	0.35	± 0.07	0.31	NaI_WBC	
UT00065	Adult	Female	2005-03-10	0.36	± 0.07	0.32	NaI_WBC	
UT00114	Adult	Male	2005-10-18	0.36	± 0.07	0.32	NaI_WBC	
UT00062	Adult	Male	2005-03-10	0.36	± 0.07	0.33	NaI_WBC	
UT00215	Adult	Female	2006-03-21	0.41	± 0.07	0.32	NaI_WBC	
UT00065	Adult	Female	2006-11-13	0.41	± 0.06	0.26	NaI_WBC	
UT00071	Adult	Female	2006-03-22	0.42	± 0.07	0.33	NaI_WBC	
UT00114	Adult	Male	2006-10-16	0.43	± 0.07	0.32	NaI_WBC	
UT00071	Adult	Female	2005-08-16	0.43	± 0.08	0.37	NaI_WBC	
UT00150	Adult	Male	2005-04-25	0.43	± 0.08	0.36	NaI_WBC	
UT00129	Adult	Female	2005-03-12	0.46	± 0.08	0.35	NaI_WBC	
UT00170	Adult	Female	2005-07-08	0.46	± 0.07	0.32	NaI_WBC	
UT00127	Adult	Female	2006-03-22	0.46	± 0.07	0.32	NaI_WBC	
UT00209	Adult	Female	2006-01-28	0.46	± 0.07	0.31	NaI_WBC	

Table A1.1. Continued

ID#	Age Type	Gender	Count Date	Cs-137 (kBq)			Method Code	Notes
				value		MDA		
UT00042	Adult	Female	2006-08-11	0.47	± 0.07	0.33	NaI_WBC	
UT00173	Adult	Female	2005-07-08	0.48	± 0.07	0.32	NaI_WBC	
UT00183	Adult	Female	2006-03-22	0.48	± 0.07	0.32	NaI_WBC	
UT00012	Adult	Male	2006-10-25	0.48	± 0.07	0.30	NaI_WBC	
UT00043	Adult	Male	2006-08-11	0.49	± 0.07	0.33	NaI_WBC	
UT00062	Adult	Male	2005-12-03	0.49	± 0.07	0.34	NaI_WBC	
UT00070	Adult	Male	2006-01-28	0.49	± 0.07	0.33	NaI_WBC	
UT00066	Adult	Female	2005-03-10	0.51	± 0.07	0.33	NaI_WBC	
UT00031	Adult	Male	2005-03-10	0.51	± 0.07	0.33	NaI_WBC	
UT00061	Adult	Male	2006-07-12	0.52	± 0.06	0.28	NaI_WBC	
UT00070	Adult	Male	2005-03-10	0.52	± 0.08	0.35	NaI_WBC	
UT00175	Adult	Female	2005-07-08	0.53	± 0.07	0.31	NaI_WBC	
UT00058	Adult	Male	2005-03-10	0.54	± 0.08	0.34	NaI_WBC	
UT00066	Adult	Female	2006-11-13	0.55	± 0.06	0.26	NaI_WBC	
UT00160	Adult	Male	2006-03-21	0.56	± 0.07	0.32	NaI_WBC	
UT00227	Adult	Female	2006-07-10	0.56	± 0.07	0.30	NaI_WBC	
UT00218	Adult	Male	2006-03-21	0.56	± 0.07	0.30	NaI_WBC	
UT00165	Adult	Male	2005-06-09	0.57	± 0.06	0.27	NaI_WBC	
UT00171	Adult	Female	2005-07-08	0.58	± 0.08	0.34	NaI_WBC	
UT00128	Adult	Male	2006-01-28	0.58	± 0.07	0.33	NaI_WBC	
UT00174	Adult	Female	2005-07-08	0.60	± 0.08	0.36	NaI_WBC	
UT00076	Adult	Female	2005-03-12	0.61	± 0.07	0.33	NaI_WBC	
UT00185	Adult	Male	2005-08-17	0.62	± 0.07	0.32	NaI_WBC	
UT00071	Adult	Female	2005-03-08	0.62	± 0.07	0.33	NaI_WBC	
UT00070	Adult	Male	2005-01-19	0.62	± 0.07	0.32	NaI_WBC	
UT00183	Adult	Female	2005-08-17	0.62	± 0.08	0.37	NaI_WBC	
UT00217	Adult	Male	2006-03-21	0.63	± 0.08	0.33	NaI_WBC	
UT00223	Adult	Male	2006-05-16	0.64	± 0.08	0.34	NaI_WBC	
UT00066	Adult	Female	2005-11-07	0.65	± 0.08	0.34	NaI_WBC	
UT00157	Teenager	Male	2005-06-10	0.67	± 0.06	0.28	NaI_WBC	
UT00216	Adult	Male	2006-03-21	0.67	± 0.07	0.31	NaI_WBC	
UT00114	Adult	Male	2005-03-10	0.67	± 0.08	0.33	NaI_WBC	
UT00113	Adult	Male	2005-03-10	0.68	± 0.08	0.34	NaI_WBC	
UT00177	Adult	Male	2005-08-16	0.68	± 0.08	0.35	NaI_WBC	
UT00248	Adult	Male	2006-10-25	0.68	± 0.08	0.35	NaI_WBC	
UT00158	Teenager	Male	2005-06-10	0.69	± 0.07	0.31	NaI_WBC	
UT00178	Adult	Female	2005-08-16	0.69	± 0.08	0.34	NaI_WBC	
UT00113	Adult	Male	2006-10-11	0.69	± 0.07	0.30	NaI_WBC	

Table A1.1. Continued

ID#	Age Type	Gender	Count Date	Cs-137 (kBq)			Method Code	Notes
				value		MDA		
UT00058	Adult	Male	2006-10-25	0.71	± 0.07	0.32	NaI_WBC	
UT00127	Adult	Female	2005-03-08	0.74	± 0.08	0.34	NaI_WBC	
UT00189	Adult	Male	2005-08-18	0.74	± 0.07	0.32	NaI_WBC	
UT00128	Adult	Male	2005-03-10	0.75	± 0.08	0.33	NaI_WBC	
UT00060	Adult	Male	2006-11-13	0.77	± 0.08	0.32	NaI_WBC	
UT00069	Adult	Male	2006-01-21	0.78	± 0.07	0.30	NaI_WBC	
UT00172	Adult	Female	2005-07-08	0.82	± 0.08	0.34	NaI_WBC	
UT00189	Adult	Male	2006-10-26	0.83	± 0.09	0.37	NaI_WBC	
UT00249	Adult	Male	2006-10-25	0.83	± 0.08	0.34	NaI_WBC	
UT00186	Adult	Male	2005-08-17	0.84	± 0.07	0.31	NaI_WBC	
UT00162	Teenager	Male	2005-06-10	0.85	± 0.08	0.34	NaI_WBC	
UT00113	Adult	Male	2005-10-19	0.87	± 0.08	0.36	NaI_WBC	
UT00207	Adult	Female	2005-11-29	0.88	± 0.08	0.34	NaI_WBC	
UT00089	Adult	Male	2006-06-09	0.88	± 0.08	0.32	NaI_WBC	
UT00156	Teenager	Male	2005-06-10	0.92	± 0.08	0.33	NaI_WBC	
UT00250	Adult	Male	2006-10-25	0.93	± 0.09	0.38	NaI_WBC	
UT00242	Adult	Female	2006-08-11	0.95	± 0.08	0.35	NaI_WBC	
UT00160	Adult	Male	2005-06-10	0.95	± 0.08	0.32	NaI_WBC	
UT00060	Adult	Male	2005-11-19	0.96	± 0.11	0.48	NaI_WBC	
UT00113	Adult	Male	2006-06-21	1.01	± 0.08	0.33	NaI_WBC	
UT00034	Adult	Male	2006-10-25	1.06	± 0.09	0.38	NaI_WBC	
UT00186	Adult	Male	2006-10-25	1.07	± 0.09	0.36	NaI_WBC	
UT00241	Adult	Female	2006-08-11	1.10	± 0.08	0.33	NaI_WBC	
UT00179	Adult	Male	2005-08-16	1.19	± 0.08	0.32	NaI_WBC	
UT00164	Adult	Male	2005-06-13	1.28	± 0.09	0.35	NaI_WBC	
UT00161	Adult	Male	2005-06-10	1.31	± 0.08	0.33	NaI_WBC	
UT00169	Adult	Female	2005-07-08	1.32	± 0.09	0.35	NaI_WBC	
UT00159	Adult	Male	2005-06-10	1.34	± 0.09	0.33	NaI_WBC	
UT00029	Adult	Male	2006-10-25	1.41	± 0.09	0.34	NaI_WBC	
UT00163	Adult	Male	2005-06-13	1.78	± 0.10	0.37	NaI_WBC	

Table A1.2. Whole body count data developed for other program volunteers (excluding residents living on Enewetak Atoll and the Rongelap Atoll resettlement workers) (2005–2006).

ID#	Age Type	Gender	Count Date	Cs-137 (kBq)			Method Code	Notes
				value		MDA		
EN00003	Adult	Male	2006-12-11	0.39	± 0.05	0.24	NaI_WBC	
EN00118	Adult	Male	2005-04-26	0.00	± 0.00	0.11	NaI_WBC	
EN00119	Adult	Male	2006-01-23	0.00	± 0.00	0.11	NaI_WBC	
EN00132	Adult	Male	2005-02-21	0.00	± 0.00	0.12	NaI_WBC	
EN00171	Adult	Male	2006-10-26	0.00	± 0.00	0.11	NaI_WBC	
EN00200	Adult	Male	2005-02-18	0.00	± 0.00	0.12	NaI_WBC	
EN00200	Adult	Male	2005-10-17	0.00	± 0.00	0.11	NaI_WBC	
EN00222	Adult	Female	2006-12-11	0.00	± 0.00	0.10	NaI_WBC	
EN00289	Adult	Male	2006-04-07	0.00	± 0.00	0.10	NaI_WBC	MI00548[a]
EN00316	Adult	Female	2005-07-19	0.00	± 0.00	0.11	NaI_WBC	
EN00328	Adult	Male	2006-01-21	0.00	± 0.00	0.10	NaI_WBC	
EN00429	Adult	Male	2006-12-11	0.00	± 0.00	0.10	NaI_WBC	
EN00447	Adult	Male	2006-10-04	0.00	± 0.00	0.10	NaI_WBC	
EN00448	Adult	Male	2005-02-21	0.00	± 0.00	0.12	NaI_WBC	
EN00590	Teenager	Female	2005-03-23	0.00	± 0.00	0.11	NaI_WBC	
EN00777	Adult	Male	2006-12-11	0.58	± 0.07	0.31	NaI_WBC	
EN00783	Adult	Female	2005-07-12	0.23	± 0.04	0.18	NaI_WBC	
EN00787	Adult	Female	2006-10-06	0.00	± 0.00	0.10	NaI_WBC	
MI00003	Adult	Male	2005-03-15	0.00	± 0.00	0.11	NaI_WBC	
MI00003	Adult	Male	2005-05-31	0.00	± 0.00	2.97	NaI_WBC	
MI00003	Adult	Male	2006-06-27	0.00	± 0.00	0.11	NaI_WBC	
MI00003	Adult	Male	2006-07-19	0.00	± 0.00	0.11	NaI_WBC	
MI00037	Adult	Male	2005-08-30	0.27	± 0.05	0.23	NaI_WBC	
MI00042	Adult	Male	2005-03-23	0.00	± 0.00	0.11	NaI_WBC	
MI00047	Adult	Male	2005-01-05	0.00	± 0.00	0.11	NaI_WBC	
MI00069	Adult	Male	2006-12-08	0.00	± 0.00	0.10	NaI_WBC	
MI00102	Adult	Male	2005-05-10	0.65	± 0.07	0.32	NaI_WBC	
MI00109	Adult	Male	2005-08-03	0.00	± 0.00	0.11	NaI_WBC	
MI00119	Adult	Female	2005-05-10	0.45	± 0.07	0.33	NaI_WBC	
MI00144	Adult	Female	2006-08-28	0.00	± 0.00	0.10	NaI_WBC	
MI00202	Adult	Female	2005-08-02	0.14	± 0.05	0.21	NaI_WBC	
MI00240	Adult	Female	2005-06-01	0.36	± 0.07	0.32	NaI_WBC	
MI00275	Adult	Female	2006-06-21	0.00	± 0.00	0.11	NaI_WBC	
MI00282	Adult	Female	2005-09-19	0.00	± 0.00	0.10	NaI_WBC	
MI00283	Adult	Female	2005-09-17	0.00	± 0.00	0.10	NaI_WBC	
MI00288	Adult	Male	2005-09-17	0.00	± 0.00	0.10	NaI_WBC	
MI00289	Adult	Male	2005-09-17	0.00	± 0.00	0.10	NaI_WBC	
MI00294	Adult	Male	2005-09-17	0.00	± 0.00	0.10	NaI_WBC	
MI00299	Adult	Female	2006-10-11	0.54	± 0.07	0.29	NaI_WBC	
MI00299	Adult	Female	2006-06-21	0.74	± 0.07	0.32	NaI_WBC	
MI00301	Adult	Female	2005-09-17	0.00	± 0.00	0.10	NaI_WBC	

Table A.1.2. Continued

ID#	Age Type	Gender	Count Date	Cs-137 (kBq)			Method Code	Notes
				value		MDA		
MI00312	Adult	Male	2005-02-22	0.00	± 0.00	0.11	NaI_WBC	
MI00312	Adult	Male	2006-10-04	0.00	± 0.00	0.11	NaI_WBC	
MI00320	Adult	Male	2005-02-01	0.00	± 0.00	0.11	NaI_WBC	
MI00321	Adult	Male	2005-02-01	0.00	± 0.00	0.11	NaI_WBC	
MI00322	Adult	Male	2005-02-08	0.00	± 0.00	0.11	NaI_WBC	
MI00323	Adult	Male	2005-02-08	1.06	± 0.08	0.34	NaI_WBC	
MI00324	Teenager	Unknown	2005-02-16	0.00	± 0.00	0.11	NaI_WBC	
MI00325	Adult	Male	2005-02-16	0.00	± 0.00	0.11	NaI_WBC	
MI00326	Adult	Male	2005-02-17	0.00	± 0.00	0.11	NaI_WBC	
MI00327	Adult	Male	2005-02-18	0.00	± 0.00	0.11	NaI_WBC	
MI00328	Adult	Male	2005-02-18	0.00	± 0.00	0.11	NaI_WBC	
MI00329	Adult	Male	2005-02-18	0.00	± 0.00	0.11	NaI_WBC	
MI00330	Teenager	Male	2005-02-18	0.00	± 0.00	0.11	NaI_WBC	
MI00331	Teenager	Male	2005-02-18	0.00	± 0.00	0.11	NaI_WBC	
MI00332	Teenager	Male	2005-02-18	0.00	± 0.00	0.11	NaI_WBC	
MI00333	Teenager	Male	2005-02-18	0.00	± 0.00	0.11	NaI_WBC	
MI00334	Teenager	Male	2005-02-18	0.00	± 0.00	0.11	NaI_WBC	
MI00335	Adult	Male	2005-02-18	0.00	± 0.00	0.11	NaI_WBC	
MI00336	Teenager	Male	2005-02-21	0.00	± 0.00	0.11	NaI_WBC	
MI00337	Pre-Teen	Male	2005-02-22	0.00	± 0.00	0.11	NaI_WBC	
MI00338	Pre-Teen	Male	2005-02-22	0.00	± 0.00	0.11	NaI_WBC	
MI00339	Teenager	Male	2005-02-22	0.00	± 0.00	0.11	NaI_WBC	
MI00340	Adult	Male	2005-02-22	0.00	± 0.00	0.11	NaI_WBC	
MI00341	Adult	Male	2005-02-22	0.00	± 0.00	0.12	NaI_WBC	
MI00341	Adult	Male	2006-12-08	1.05	± 0.08	0.33	NaI_WBC	
MI00342	Adult	Male	2005-02-23	0.00	± 0.00	0.12	NaI_WBC	
MI00343	Adult	Female	2005-03-02	0.00	± 0.00	0.11	NaI_WBC	
MI00344	Adult	Female	2005-03-03	0.00	± 0.00	0.11	NaI_WBC	
MI00345	Adult	Female	2005-10-19	0.43	± 0.07	0.32	NaI_WBC	
MI00345	Adult	Female	2005-03-10	0.63	± 0.08	0.35	NaI_WBC	
MI00346	Adult	Female	2006-03-29	0.00	± 0.00	0.11	NaI_WBC	
MI00346	Adult	Female	2006-06-21	0.00	± 0.00	0.11	NaI_WBC	
MI00346	Adult	Female	2005-03-16	0.19	± 0.06	0.28	NaI_WBC	
MI00347	Adult	Female	2005-03-22	0.00	± 0.00	0.11	NaI_WBC	
MI00348	Adult	Female	2005-03-22	0.00	± 0.00	0.11	NaI_WBC	
MI00349	Adult	Male	2005-03-22	0.00	± 0.00	0.12	NaI_WBC	
MI00350	Adult	Male	2005-03-23	0.00	± 0.00	0.12	NaI_WBC	
MI00351	Adult	Female	2005-03-23	0.00	± 0.00	0.11	NaI_WBC	
MI00352	Adult	Female	2005-03-23	0.00	± 0.00	0.12	NaI_WBC	
MI00353	Adult	Female	2005-03-23	0.00	± 0.00	0.11	NaI_WBC	
MI00354	Adult	Female	2005-03-23	0.00	± 0.00	0.11	NaI_WBC	

Table A1.2. Continued

ID#	Age Type	Gender	Count Date	Cs-137 (kBq) value		Cs-137 (kBq) MDA	Method Code	Notes
MI00355	Adult	Male	2005-03-23	0.88	± 0.08	0.32	NaI_WBC	
MI00356	Adult	Female	2005-03-29	0.00	± 0.00	0.12	NaI_WBC	
MI00357	Adult	Male	2005-03-29	0.00	± 0.00	0.12	NaI_WBC	
MI00358	Teenager	Male	2005-03-29	0.00	± 0.00	0.12	NaI_WBC	
MI00359	Adult	Female	2005-03-29	0.00	± 0.00	0.11	NaI_WBC	
MI00360	Adult	Female	2005-03-29	0.00	± 0.00	0.12	NaI_WBC	
MI00361	Adult	Female	2005-03-29	0.00	± 0.00	0.12	NaI_WBC	
MI00362	Teenager	Female	2005-03-29	0.00	± 0.00	0.11	NaI_WBC	
MI00363	Adult	Male	2005-03-31	0.00	± 0.00	0.12	NaI_WBC	
MI00364	Adult	Male	2005-03-31	0.00	± 0.00	0.12	NaI_WBC	
MI00365	Adult	Male	2005-04-11	0.00	± 0.00	0.11	NaI_WBC	
MI00366	Adult	Female	2005-04-25	0.00	± 0.00	0.11	NaI_WBC	
MI00367	Adult	Female	2005-04-25	0.00	± 0.00	0.11	NaI_WBC	
MI00368	Adult	Female	2005-04-25	0.00	± 0.00	0.11	NaI_WBC	
MI00369	Adult	Male	2005-04-26	0.00	± 0.00	0.11	NaI_WBC	
MI00370	Adult	Male	2005-04-26	0.00	± 0.00	0.11	NaI_WBC	
MI00371	Adult	Female	2005-04-26	0.00	± 0.00	0.11	NaI_WBC	
MI00372	Adult	Female	2005-04-26	0.00	± 0.00	0.11	NaI_WBC	
MI00373	Adult	Female	2005-04-26	0.00	± 0.00	0.11	NaI_WBC	
MI00374	Adult	Female	2005-04-26	0.00	± 0.00	0.11	NaI_WBC	
MI00375	Adult	Male	2005-04-27	0.00	± 0.00	0.11	NaI_WBC	
MI00376	Adult	Male	2005-04-27	0.00	± 0.00	0.12	NaI_WBC	
MI00377	Adult	Male	2005-04-27	0.00	± 0.00	0.11	NaI_WBC	
MI00378	Adult	Male	2005-04-27	0.38	± 0.07	0.32	NaI_WBC	
MI00379	Adult	Male	2005-04-27	0.00	± 0.00	0.12	NaI_WBC	
MI00380	Adult	Male	2005-04-27	0.13	± 0.07	0.30	NaI_WBC	
MI00381	Adult	Female	2005-04-27	0.00	± 0.00	0.11	NaI_WBC	
MI00382	Adult	Female	2005-04-27	0.00	± 0.00	0.11	NaI_WBC	
MI00383	Adult	Female	2005-04-27	0.00	± 0.00	0.11	NaI_WBC	
MI00384	Adult	Female	2005-04-27	0.00	± 0.00	0.11	NaI_WBC	
MI00385	Adult	Male	2005-04-29	0.12	± 0.06	0.28	NaI_WBC	
MI00386	Teenager	Male	2005-04-29	0.00	± 0.00	0.12	NaI_WBC	
MI00387	Adult	Male	2005-04-29	0.00	± 0.00	0.11	NaI_WBC	
MI00388	Adult	Female	2005-04-29	0.00	± 0.00	0.11	NaI_WBC	
MI00389	Adult	Male	2005-04-29	0.00	± 0.00	0.11	NaI_WBC	
MI00390	Adult	Male	2005-04-29	0.00	± 0.00	0.11	NaI_WBC	
MI00391	Adult	Male	2005-04-29	0.00	± 0.00	0.12	NaI_WBC	
MI00392	Adult	Male	2005-04-29	0.00	± 0.00	0.12	NaI_WBC	
MI00393	Adult	Male	2005-05-04	0.00	± 0.00	0.12	NaI_WBC	
MI00394	Teenager	Male	2005-05-04	0.00	± 0.00	0.12	NaI_WBC	
MI00395	Teenager	Male	2005-05-04	0.00	± 0.00	0.11	NaI_WBC	

Table A1.2. Continued

ID#	Age Type	Gender	Count Date	Cs-137 (kBq)			Method Code	Notes
				value		MDA		
MI00396	Adult	Male	2005-05-04	0.00	± 0.00	0.11	NaI_WBC	
MI00397	Adult	Male	2005-05-04	0.14	± 0.05	0.22	NaI_WBC	
MI00398	Adult	Male	2005-05-04	0.00	± 0.00	0.12	NaI_WBC	
MI00399	Adult	Female	2005-05-04	0.00	± 0.00	0.11	NaI_WBC	
MI00400	Adult	Female	2005-05-04	0.00	± 0.00	0.11	NaI_WBC	
MI00401	Teenager	Female	2005-05-04	0.00	± 0.00	0.11	NaI_WBC	
MI00402	Adult	Male	2005-05-04	0.00	± 0.00	0.11	NaI_WBC	
MI00404	Adult	Female	2005-05-10	0.00	± 0.00	0.10	NaI_WBC	
MI00406	Adult	Female	2005-05-13	0.00	± 0.00	0.11	NaI_WBC	
MI00407	Adult	Female	2005-05-13	0.00	± 0.00	0.10	NaI_WBC	
MI00408	Adult	Male	2005-05-16	0.49	± 0.08	0.34	NaI_WBC	
MI00409	Adult	Male	2005-06-03	0.00	± 0.00	0.10	NaI_WBC	
MI00410	Adult	Female	2005-06-03	0.00	± 0.00	0.10	NaI_WBC	
MI00411	Adult	Female	2005-06-03	0.00	± 0.00	0.10	NaI_WBC	
MI00412	Adult	Female	2005-06-07	0.00	± 0.00	0.11	NaI_WBC	
MI00413	Adult	Female	2005-06-07	0.00	± 0.00	0.10	NaI_WBC	
MI00414	Adult	Female	2005-06-08	0.00	± 0.00	0.10	NaI_WBC	
MI00415	Adult	Male	2005-06-08	0.00	± 0.00	0.10	NaI_WBC	
MI00416	Adult	Female	2005-06-08	0.00	± 0.00	0.10	NaI_WBC	
MI00417	Adult	Female	2005-06-08	0.00	± 0.00	0.10	NaI_WBC	
MI00418	Adult	Male	2005-06-09	0.00	± 0.00	0.10	NaI_WBC	
MI00418	Adult	Male	2006-08-28	0.00	± 0.00	0.10	NaI_WBC	
MI00419	Adult	Male	2005-06-10	0.73	± 0.09	0.38	NaI_WBC	
MI00420	Adult	Female	2005-06-15	0.00	± 0.00	0.10	NaI_WBC	
MI00421	Adult	Male	2005-06-17	0.00	± 0.00	0.10	NaI_WBC	
MI00422	Adult	Female	2005-06-20	0.00	± 0.00	0.10	NaI_WBC	
MI00423	Adult	Female	2005-06-20	0.00	± 0.00	0.10	NaI_WBC	
MI00424	Adult	Female	2005-06-20	0.00	± 0.00	0.10	NaI_WBC	
MI00425	Adult	Female	2005-06-20	0.00	± 0.00	0.10	NaI_WBC	
MI00426	Adult	Female	2005-06-22	0.00	± 0.00	0.11	NaI_WBC	
MI00427	Adult	Female	2005-06-22	0.00	± 0.00	0.10	NaI_WBC	
MI00428	Adult	Male	2005-06-27	0.00	± 0.00	0.10	NaI_WBC	
MI00429	Adult	Male	2005-06-27	0.00	± 0.00	0.10	NaI_WBC	
MI00430	Adult	Male	2005-06-28	0.00	± 0.00	0.10	NaI_WBC	
MI00431	Teenager	Male	2005-06-28	0.00	± 0.00	0.10	NaI_WBC	
MI00432	Adult	Male	2005-06-29	0.00	± 0.00	0.12	NaI_WBC	
MI00433	Adult	Female	2005-06-29	0.00	± 0.00	0.10	NaI_WBC	
MI00434	Adult	Male	2005-06-29	0.00	± 0.00	0.11	NaI_WBC	
MI00435	Adult	Female	2005-07-11	0.00	± 0.00	0.10	NaI_WBC	
MI00436	Adult	Male	2005-07-12	0.00	± 0.00	0.11	NaI_WBC	
MI00437	Adult	Male	2005-07-12	0.00	± 0.00	0.10	NaI_WBC	

Table A1.2. Continued

ID#	Age Type	Gender	Count Date	Cs-137 (kBq) value		Cs-137 (kBq) MDA	Method Code	Notes
MI00438	Adult	Male	2005-07-12	0.00	± 0.00	0.10	NaI_WBC	
MI00439	Adult	Female	2005-07-12	0.00	± 0.00	0.11	NaI_WBC	
MI00440	Adult	Male	2005-07-12	0.00	± 0.00	0.11	NaI_WBC	
MI00441	Adult	Male	2005-07-12	0.40	± 0.07	0.32	NaI_WBC	
MI00442	Adult	Male	2005-07-13	0.00	± 0.00	0.10	NaI_WBC	
MI00443	Adult	Male	2005-07-13	0.00	± 0.00	0.11	NaI_WBC	
MI00444	Adult	Female	2005-07-15	0.00	± 0.00	0.10	NaI_WBC	
MI00445	Adult	Female	2005-07-18	0.00	± 0.00	0.10	NaI_WBC	
MI00446	Adult	Female	2005-07-18	0.00	± 0.00	0.10	NaI_WBC	
MI00447	Adult	Male	2005-07-18	0.00	± 0.00	0.10	NaI_WBC	
MI00448	Adult	Male	2005-07-18	0.00	± 0.00	0.10	NaI_WBC	
MI00449	Adult	Male	2005-07-18	0.00	± 0.00	0.10	NaI_WBC	
MI00450	Adult	Male	2005-07-18	0.00	± 0.00	0.10	NaI_WBC	
MI00451	Adult	Female	2005-07-18	0.00	± 0.00	0.10	NaI_WBC	
MI00452	Teenager	Male	2005-07-19	0.00	± 0.00	0.10	NaI_WBC	
MI00453	Teenager	Male	2005-07-19	0.00	± 0.00	0.10	NaI_WBC	
MI00454	Teenager	Male	2005-07-19	0.00	± 0.00	0.10	NaI_WBC	
MI00455	Teenager	Male	2005-07-19	0.00	± 0.00	0.10	NaI_WBC	
MI00456	Teenager	Male	2005-07-19	0.00	± 0.00	0.10	NaI_WBC	
MI00457	Teenager	Male	2005-07-19	0.00	± 0.00	0.10	NaI_WBC	
MI00458	Adult	Female	2005-07-19	0.00	± 0.00	0.10	NaI_WBC	
MI00459	Adult	Female	2005-07-19	0.00	± 0.00	0.10	NaI_WBC	
MI00460	Adult	Female	2005-07-20	0.00	± 0.00	0.11	NaI_WBC	
MI00461	Adult	Male	2005-07-21	0.00	± 0.00	0.10	NaI_WBC	
MI00462	Adult	Female	2005-07-21	0.00	± 0.00	0.10	NaI_WBC	
MI00463	Adult	Male	2005-07-21	0.00	± 0.00	0.10	NaI_WBC	
MI00464	Adult	Male	2005-07-26	0.00	± 0.00	0.10	NaI_WBC	
MI00465	Adult	Male	2005-07-26	0.12	± 0.04	0.20	NaI_WBC	
MI00466	Adult	Male	2005-07-29	0.00	± 0.00	0.10	NaI_WBC	
MI00468	Adult	Male	2005-08-02	0.00	± 0.00	0.10	NaI_WBC	
MI00469	Adult	Female	2005-08-02	0.00	± 0.00	0.10	NaI_WBC	
MI00470	Adult	Male	2005-08-03	0.35	± 0.07	0.31	NaI_WBC	
MI00471	Adult	Male	2005-08-04	0.44	± 0.06	0.29	NaI_WBC	
MI00472	Adult	Male	2005-08-04	0.00	± 0.00	0.10	NaI_WBC	
MI00473	Adult	Male	2005-08-04	0.00	± 0.00	0.10	NaI_WBC	
MI00474	Adult	Female	2005-08-04	0.26	± 0.05	0.23	NaI_WBC	
MI00475	Adult	Male	2005-08-12	0.12	± 0.04	0.20	NaI_WBC	
MI00476	Adult	Male	2005-08-15	0.00	± 0.00	0.11	NaI_WBC	
MI00477	Adult	Male	2005-08-15	0.00	± 0.00	0.11	NaI_WBC	
MI00478	Adult	Male	2005-08-15	0.00	± 0.00	0.10	NaI_WBC	
MI00479	Adult	Male	2005-08-15	0.44	± 0.07	0.30	NaI_WBC	

Table A1.2. Continued

ID#	Age Type	Gender	Count Date	Cs-137 (kBq)			Method Code	Notes
				value		MDA		
MI00480	Adult	Female	2005-08-16	0.00	± 0.00	0.10	NaI_WBC	
MI00481	Adult	Female	2005-08-16	0.00	± 0.00	0.10	NaI_WBC	
MI00482	Adult	Female	2005-08-16	0.54	± 0.07	0.31	NaI_WBC	
MI00483	Adult	Male	2005-08-16	0.60	± 0.07	0.31	NaI_WBC	
MI00484	Adult	Male	2005-08-16	1.00	± 0.08	0.35	NaI_WBC	
MI00485	Adult	Male	2005-08-17	0.00	± 0.00	0.10	NaI_WBC	
MI00486	Teenager	Female	2005-08-17	0.00	± 0.00	0.10	NaI_WBC	
MI00487	Adult	Female	2005-08-17	0.30	± 0.06	0.29	NaI_WBC	
MI00488	Adult	Male	2005-08-18	0.00	± 0.00	0.11	NaI_WBC	
MI00489	Adult	Male	2005-08-18	0.00	± 0.00	0.10	NaI_WBC	
MI00490	Adult	Female	2005-08-18	0.00	± 0.00	0.10	NaI_WBC	
MI00491	Adult	Female	2005-08-18	0.00	± 0.00	0.10	NaI_WBC	
MI00492	Adult	Male	2005-08-18	0.00	± 0.00	0.10	NaI_WBC	
MI00493	Adult	Female	2005-09-19	0.00	± 0.00	0.10	NaI_WBC	
MI00494	Adult	Female	2005-09-19	0.00	± 0.00	0.10	NaI_WBC	
MI00510	Adult	Male	2005-10-27	0.00	± 0.00	0.10	NaI_WBC	
MI00511	Adult	Male	2005-10-28	0.00	± 0.00	0.10	NaI_WBC	
MI00512	Adult	Male	2005-11-08	0.00	± 0.00	0.10	NaI_WBC	
MI00513	Adult	Female	2005-11-16	0.00	± 0.00	0.10	NaI_WBC	
MI00514	Adult	Male	2006-01-12	0.00	± 0.00	0.10	NaI_WBC	
MI00515	Adult	Male	2006-01-12	0.00	± 0.00	0.10	NaI_WBC	
MI00516	Adult	Male	2006-01-12	0.00	± 0.00	0.10	NaI_WBC	
MI00517	Adult	Male	2006-01-13	0.00	± 0.00	0.10	NaI_WBC	
MI00518	Adult	Male	2006-01-13	0.00	± 0.00	0.10	NaI_WBC	
MI00519	Adult	Male	2006-01-13	0.00	± 0.00	0.10	NaI_WBC	
MI00520	Adult	Male	2006-01-13	0.00	± 0.00	0.10	NaI_WBC	
MI00521	Adult	Male	2006-01-13	0.00	± 0.00	0.10	NaI_WBC	
MI00522	Adult	Male	2006-01-13	0.00	± 0.00	0.10	NaI_WBC	
MI00523	Adult	Male	2006-01-18	0.00	± 0.00	0.10	NaI_WBC	
MI00524	Adult	Male	2006-01-24	0.00	± 0.00	0.10	NaI_WBC	
MI00525	Adult	Male	2006-01-24	0.00	± 0.00	0.10	NaI_WBC	
MI00526	Teenager	Male	2006-01-25	0.00	± 0.00	0.10	NaI_WBC	
MI00527	Teenager	Female	2006-01-25	0.00	± 0.00	0.10	NaI_WBC	
MI00528	Adult	Male	2006-01-25	0.00	± 0.00	0.10	NaI_WBC	
MI00529	Adult	Female	2006-01-25	0.00	± 0.00	0.10	NaI_WBC	
MI00530	Adult	Female	2006-01-25	0.00	± 0.00	0.10	NaI_WBC	
MI00531	Adult	Female	2006-01-25	0.00	± 0.00	0.10	NaI_WBC	
MI00532	Adult	Female	2006-01-25	0.00	± 0.00	0.10	NaI_WBC	
MI00533	Adult	Male	2006-01-25	0.00	± 0.00	0.10	NaI_WBC	
MI00534	Adult	Male	2006-01-25	0.00	± 0.00	0.10	NaI_WBC	
MI00535	Adult	Female	2006-01-31	0.00	± 0.00	0.10	NaI_WBC	

Table A1.2. Continued

ID#	Age Type	Gender	Count Date	Cs-137 (kBq)			Method Code	Notes
				value		MDA		
MI00536	Teenager	Male	2006-01-31	0.00	± 0.00	0.10	NaI_WBC	
MI00537	Adult	Male	2006-01-31	0.00	± 0.00	0.10	NaI_WBC	
MI00538	Adult	Male	2006-03-07	0.00	± 0.00	0.10	NaI_WBC	
MI00539	Adult	Male	2006-03-14	0.00	± 0.00	0.10	NaI_WBC	
MI00540	Adult	Male	2006-03-14	0.00	± 0.00	0.10	NaI_WBC	
MI00541	Adult	Male	2006-03-14	0.00	± 0.00	0.10	NaI_WBC	
MI00542	Adult	Male	2006-03-14	0.00	± 0.00	0.10	NaI_WBC	
MI00543	Adult	Male	2006-03-20	0.07	± 0.04	0.20	NaI_WBC	
MI00544	Adult	Male	2006-03-29	0.00	± 0.00	0.10	NaI_WBC	
MI00545	Adult	Female	2006-03-30	0.00	± 0.00	0.10	NaI_WBC	
MI00546	Adult	Female	2006-03-31	0.00	± 0.00	0.10	NaI_WBC	
MI00547	Adult	Male	2006-04-04	0.00	± 0.00	0.10	NaI_WBC	
MI00549	Adult	Male	2006-04-17	0.00	± 0.00	0.10	NaI_WBC	
MI00550	Adult	Male	2006-04-17	0.00	± 0.00	0.10	NaI_WBC	
MI00551	Adult	Female	2006-06-09	0.00	± 0.00	0.11	NaI_WBC	
MI00552	Adult	Female	2006-06-09	0.00	± 0.00	0.10	NaI_WBC	
MI00553	Adult	Male	2006-06-12	0.00	± 0.00	0.10	NaI_WBC	
MI00554	Adult	Male	2006-06-12	0.00	± 0.00	0.10	NaI_WBC	
MI00554	Adult	Male	2006-10-31	0.00	± 0.00	0.11	NaI_WBC	
MI00555	Adult	Male	2006-06-20	0.00	± 0.00	0.10	NaI_WBC	
MI00556	Adult	Male	2006-07-18	0.00	± 0.00	0.10	NaI_WBC	
MI00557	Adult	Male	2006-07-18	0.00	± 0.00	0.11	NaI_WBC	
MI00558	Adult	Female	2006-07-19	0.00	± 0.00	0.11	NaI_WBC	
MI00559	Adult	Female	2006-07-19	0.00	± 0.00	0.11	NaI_WBC	
MI00560	Adult	Female	2006-07-19	0.00	± 0.00	0.10	NaI_WBC	
MI00561	Adult	Female	2006-07-19	0.00	± 0.00	0.10	NaI_WBC	
MI00562	Adult	Female	2006-07-20	0.00	± 0.00	0.10	NaI_WBC	
MI00563	Adult	Female	2006-07-20	0.00	± 0.00	0.10	NaI_WBC	
MI00564	Adult	Female	2006-07-20	0.00	± 0.00	0.10	NaI_WBC	
MI00565	Adult	Female	2006-07-20	0.00	± 0.00	0.10	NaI_WBC	
MI00566	Adult	Female	2006-07-20	0.00	± 0.00	0.10	NaI_WBC	
MI00567	Adult	Female	2006-07-20	0.00	± 0.00	0.10	NaI_WBC	
MI00568	Adult	Female	2006-07-20	0.00	± 0.00	0.10	NaI_WBC	
MI00569	Adult	Male	2006-07-24	0.00	± 0.00	0.10	NaI_WBC	
MI00570	Adult	Male	2006-07-25	0.00	± 0.00	0.11	NaI_WBC	
MI00571	Adult	Male	2006-07-25	0.00	± 0.00	0.11	NaI_WBC	
MI00572	Adult	Male	2006-07-25	0.00	± 0.00	0.10	NaI_WBC	
MI00573	Adult	Male	2006-07-25	0.08	± 0.03	0.15	NaI_WBC	
MI00574	Adult	Female	2006-07-26	0.00	± 0.00	0.10	NaI_WBC	
MI00575	Adult	Female	2006-07-26	0.13	± 0.05	0.22	NaI_WBC	
MI00576	Adult	Female	2006-07-26	0.00	± 0.00	0.11	NaI_WBC	

Table A1.2. Continued

ID#	Age Type	Gender	Count Date	Cs-137 (kBq) value		Cs-137 (kBq) MDA	Method Code	Notes
MI00577	Adult	Female	2006-07-26	0.20	± 0.05	0.22	NaI_WBC	
MI00578	Adult	Female	2006-07-27	0.00	± 0.00	0.10	NaI_WBC	
MI00579	Adult	Female	2006-07-27	0.00	± 0.00	0.10	NaI_WBC	
MI00580	Adult	Female	2006-08-02	0.00	± 0.00	0.10	NaI_WBC	
MI00581	Adult	Female	2006-08-02	0.00	± 0.00	0.10	NaI_WBC	
MI00582	Adult	Female	2006-08-03	0.00	± 0.00	0.10	NaI_WBC	
MI00583	Adult	Female	2006-08-03	0.00	± 0.00	0.11	NaI_WBC	
MI00584	Adult	Female	2006-08-03	0.00	± 0.00	0.10	NaI_WBC	
MI00585	Adult	Female	2006-08-03	0.00	± 0.00	0.11	NaI_WBC	
MI00586	Adult	Male	2006-08-03	0.00	± 0.00	0.11	NaI_WBC	
MI00587	Adult	Male	2006-08-03	0.00	± 0.00	0.11	NaI_WBC	
MI00588	Adult	Female	2006-08-03	0.00	± 0.00	0.11	NaI_WBC	
MI00589	Adult	Male	2006-08-03	0.00	± 0.00	0.10	NaI_WBC	
MI00590	Adult	Female	2006-08-09	0.00	± 0.00	0.11	NaI_WBC	
MI00591	Adult	Male	2006-08-14	0.00	± 0.00	0.11	NaI_WBC	
MI00592	Adult	Male	2006-08-14	0.00	± 0.00	0.11	NaI_WBC	
MI00593	Adult	Female	2006-08-16	0.00	± 0.00	0.10	NaI_WBC	
MI00594	Adult	Male	2006-08-16	0.00	± 0.00	0.10	NaI_WBC	
MI00595	Adult	Male	2006-08-16	0.00	± 0.00	0.11	NaI_WBC	
MI00596	Adult	Female	2006-08-16	0.07	± 0.04	0.18	NaI_WBC	
MI00597	Adult	Male	2006-08-16	0.00	± 0.00	0.11	NaI_WBC	
MI00597	Adult	Male	2006-09-27	0.00	± 0.00	0.10	NaI_WBC	
MI00598	Adult	Female	2006-08-22	0.00	± 0.00	0.11	NaI_WBC	
MI00599	Adult	Male	2006-08-24	0.00	± 0.00	0.10	NaI_WBC	
MI00600	Adult	Male	2006-08-28	0.00	± 0.00	0.11	NaI_WBC	
MI00601	Adult	Male	2006-08-28	0.00	± 0.00	0.10	NaI_WBC	
MI00602	Adult	Male	2006-08-28	0.00	± 0.00	0.10	NaI_WBC	
MI00603	Adult	Male	2006-08-28	0.00	± 0.00	0.10	NaI_WBC	
MI00604	Adult	Male	2006-08-28	0.00	± 0.00	0.10	NaI_WBC	
MI00605	Adult	Female	2006-08-28	0.00	± 0.00	0.10	NaI_WBC	
MI00606	Adult	Female	2006-08-30	0.00	± 0.00	0.10	NaI_WBC	
MI00607	Adult	Female	2006-09-04	0.06	± 0.03	0.15	NaI_WBC	
MI00608	Adult	Female	2006-09-06	0.00	± 0.00	0.10	NaI_WBC	
MI00609	Adult	Female	2006-09-08	0.00	± 0.00	0.10	NaI_WBC	
MI00610	Adult	Female	2006-09-08	0.00	± 0.00	0.10	NaI_WBC	
MI00611	Adult	Female	2006-09-08	0.00	± 0.00	0.10	NaI_WBC	
MI00612	Adult	Female	2006-09-08	0.00	± 0.00	0.10	NaI_WBC	
MI00613	Adult	Female	2006-09-08	0.00	± 0.00	0.10	NaI_WBC	
MI00614	Adult	Female	2006-09-08	0.00	± 0.00	0.10	NaI_WBC	
MI00615	Adult	Female	2006-09-08	0.00	± 0.00	0.10	NaI_WBC	
MI00616	Adult	Female	2006-09-08	0.00	± 0.00	0.10	NaI_WBC	

Table A1.2. Continued

ID#	Age Type	Gender	Count Date	Cs-137 (kBq) value		MDA	Method Code	Notes
MI00617	Adult	Male	2006-09-08	0.00	± 0.00	0.10	NaI_WBC	
MI00618	Adult	Female	2006-09-14	0.00	± 0.00	0.10	NaI_WBC	
MI00619	Adult	Female	2006-09-18	0.00	± 0.00	0.10	NaI_WBC	
MI00620	Adult	Female	2006-09-18	0.00	± 0.00	0.10	NaI_WBC	
MI00621	Adult	Female	2006-09-19	0.00	± 0.00	0.10	NaI_WBC	
MI00622	Adult	Male	2006-09-27	0.00	± 0.00	0.10	NaI_WBC	
MI00623	Adult	Male	2006-09-27	0.00	± 0.00	0.10	NaI_WBC	
MI00624	Adult	Female	2006-10-03	0.00	± 0.00	0.10	NaI_WBC	
MI00625	Adult	Female	2006-10-03	0.00	± 0.00	0.10	NaI_WBC	
MI00626	Adult	Female	2006-10-03	0.00	± 0.00	0.10	NaI_WBC	
MI00627	Adult	Male	2006-10-03	0.16	± 0.05	0.24	NaI_WBC	
MI00628	Adult	Male	2006-10-03	0.00	± 0.00	0.10	NaI_WBC	
MI00629	Adult	Female	2006-10-03	0.00	± 0.00	0.10	NaI_WBC	
MI00630	Adult	Female	2006-10-04	0.00	± 0.00	0.10	NaI_WBC	
MI00631	Adult	Female	2006-10-04	0.00	± 0.00	0.10	NaI_WBC	
MI00632	Adult	Female	2006-10-04	0.00	± 0.00	0.10	NaI_WBC	
MI00633	Adult	Female	2006-10-04	0.00	± 0.00	0.10	NaI_WBC	
MI00634	Adult	Female	2006-10-06	0.00	± 0.00	0.10	NaI_WBC	
MI00635	Adult	Female	2006-10-06	0.00	± 0.00	0.10	NaI_WBC	
MI00636	Adult	Male	2006-10-09	0.00	± 0.00	0.11	NaI_WBC	
MI00637	Adult	Male	2006-10-09	0.00	± 0.00	0.11	NaI_WBC	
MI00638	Adult	Male	2006-10-11	0.00	± 0.00	0.10	NaI_WBC	
MI00639	Adult	Male	2006-10-11	0.00	± 0.00	0.10	NaI_WBC	
MI00640	Adult	Male	2006-10-11	0.00	± 0.00	0.10	NaI_WBC	
MI00641	Adult	Male	2006-10-11	0.00	± 0.00	0.10	NaI_WBC	
MI00642	Adult	Male	2006-10-13	0.00	± 0.00	0.11	NaI_WBC	
MI00643	Adult	Female	2006-10-18	0.00	± 0.00	0.10	NaI_WBC	
MI00644	Adult	Female	2006-11-02	0.00	± 0.00	0.10	NaI_WBC	
MI00645	Adult	Male	2006-11-02	0.00	± 0.00	0.10	NaI_WBC	
MI00646	Adult	Female	2006-11-02	0.00	± 0.00	0.11	NaI_WBC	
MI00647	Adult	Female	2006-11-02	0.00	± 0.00	0.10	NaI_WBC	
MI00648	Adult	Male	2006-11-03	0.00	± 0.00	0.10	NaI_WBC	
MI00649	Adult	Male	2006-11-03	0.00	± 0.00	0.11	NaI_WBC	
MI00650	Adult	Male	2006-11-03	0.00	± 0.00	0.11	NaI_WBC	
MI00651	Adult	Male	2006-11-03	0.00	± 0.00	0.11	NaI_WBC	
MI00652	Adult	Male	2006-11-03	0.15	± 0.05	0.21	NaI_WBC	
MI00653	Adult	Male	2006-11-03	0.00	± 0.00	0.11	NaI_WBC	
MI00655	Adult	Male	2006-12-04	0.00	± 0.00	0.10	NaI_WBC	
MI00656	Adult	Male	2006-12-04	0.00	± 0.00	0.11	NaI_WBC	
MI00657	Adult	Male	2006-12-04	0.00	± 0.00	0.10	NaI_WBC	
MI00658	Adult	Male	2006-12-04	0.00	± 0.00	0.10	NaI_WBC	

Table A1.2. Continued

ID#	Age Type	Gender	Count Date	Cs-137 (kBq) value		MDA	Method Code	Notes
MI00659	Adult	Male	2006-12-05	0.00	± 0.00	0.11	NaI_WBC	
MI00660	Adult	Male	2006-12-05	0.00	± 0.00	0.11	NaI_WBC	
MI00661	Adult	Male	2006-12-11	0.00	± 0.00	0.10	NaI_WBC	
MI00662	Adult	Male	2006-12-11	0.00	± 0.00	0.11	NaI_WBC	
MI00663	Adult	Male	2006-12-11	0.00	± 0.00	0.10	NaI_WBC	
MI00664	Teenager	Male	2006-12-12	0.00	± 0.00	0.10	NaI_WBC	
MI00665	Adult	Male	2006-12-12	0.00	± 0.00	0.11	NaI_WBC	
MI00666	Adult	Male	2006-12-12	0.00	± 0.00	0.10	NaI_WBC	
MI00667	Adult	Male	2006-12-12	0.00	± 0.00	0.10	NaI_WBC	
MI00668	Adult	Male	2006-12-12	0.00	± 0.00	0.10	NaI_WBC	
MI00669	Adult	Male	2006-12-12	0.00	± 0.00	0.11	NaI_WBC	
MI00670	Adult	Male	2006-12-12	0.00	± 0.00	0.10	NaI_WBC	
MI00671	Adult	Female	2006-12-13	0.00	± 0.00	0.10	NaI_WBC	
MI00672	Adult	Female	2006-12-13	0.00	± 0.00	0.10	NaI_WBC	
MI00673	Adult	Female	2006-12-13	0.00	± 0.00	0.10	NaI_WBC	
RR00012	Adult	Male	2006-11-03	0.00	± 0.00	0.10	NaI_WBC	
RR00016	Adult	Male	2006-12-13	0.00	± 0.00	0.10	NaI_WBC	MI00674[a]
RR00045	Adult	Male	2006-07-18	0.14	± 0.05	0.22	NaI_WBC	
RR00072	Adult	Male	2005-03-11	0.00	± 0.00	0.12	NaI_WBC	
RR00092	Adult	Male	2006-10-31	0.00	± 0.00	0.10	NaI_WBC	
RR00099	Adult	Female	2005-09-19	0.00	± 0.00	0.10	NaI_WBC	
RR00144	Adult	Male	2006-01-13	0.17	± 0.06	0.29	NaI_WBC	
RR00196	Adult	Male	2006-07-20	0.00	± 0.00	0.10	NaI_WBC	UT00232[a]
RR00200	Adult	Male	2006-08-22	0.00	± 0.00	0.11	NaI_WBC	
RR00243	Adult	Male	2006-12-13	0.00	± 0.00	0.10	NaI_WBC	
RR00276	Adult	Male	2006-01-31	1.15	± 0.08	0.33	NaI_WBC	

[a] Duplicated ID number

Table A2. Plutonium urinalysis data from Utrōk Atoll (2005–2006).

ID#	Age Type	Gender	Count Date	μBq per 24 h void				Notes
				^{239}Pu		^{240}Pu		
UT00160	Adult	Male	22-Mar-06	0.16	± 0.24	-0.17	± 0.57	
UT00212	Adult	Female	24-Mar-06	-0.01	± 0.17	-0.17	± 0.50	
UT00213	Adult	Female	22-Mar-06	0.21	± 0.21	-0.17	± 0.36	
UT00214	Adult	Female	22-Mar-06	0.19	± 0.20	0.12	± 0.35	
UT00215	Adult	Female	22-Mar-06	0.06	± 0.18	0.18	± 0.40	
UT00216	Adult	Male	22-Mar-06	0.13	± 0.19	-0.17	± 0.37	
UT00217	Adult	Male	22-Mar-06	0.23	± 0.24	-0.17	± 0.50	
UT00218	Adult	Male	22-Mar-06	0.00	± 0.15	-0.17	± 0.31	
UT00029	Adult	Male	23-Oct-06	0.47	± 0.31	0.33	± 0.50	
UT00250	Adult	Male	23-Oct-06	0.46	± 0.32	0.76	± 0.69	
UT00186	Adult	Male	23-Oct-06	0.39	± 0.25	-0.16	± 0.37	
UT00062	Adult	Male	23-Oct-06	0.05	± 0.19	0.13	± 0.36	
UT00058	Adult	Male	23-Oct-06	0.35	± 0.25	0.16	± 0.38	
UT00034	Adult	Male	23-Oct-06	0.34	± 0.25	0.17	± 0.40	
UT00012	Adult	Male	23-Oct-06	0.30	± 0.23	-0.16	± 0.37	
UT00189	Adult	Male	23-Oct-06	0.20	± 0.26	-0.16	± 0.52	
UT00226	Adult	Female	23-Oct-06	-0.20	± 0.16	-0.16	± 0.45	
UT00248	Adult	Male	23-Oct-06	0.03	± 0.17	0.10	± 0.34	
UT00249	Adult	Male	23-Oct-06	-0.04	± 0.16	-0.16	± 0.36	
UT00061	Adult	Male	23-Oct-06	0.05	± 0.18	0.44	± 0.48	
Field Blank	–	–	24-Mar-06	-0.06	± 0.14	-0.17	± 0.33	
Field Blank	–	–	24-Mar-06	0.00	± 0.15	0.09	± 0.32	
Field Blank	–	–	28-Mar-06	0.00	± 0.15	-0.17	± 0.31	
Field Blank	–	–	28-Mar-06	-0.06	± 0.14	-0.17	± 0.34	
Field Blank	–	–	11-Aug-06	0.13	± 0.20	-0.16	± 0.36	
Field Blank	–	–	11-Aug-06	0.06	± 0.17	0.15	± 0.35	
Field Blank	–	–	11-Aug-06	-0.05	± 0.16	-0.16	± 0.34	

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