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Concetration and Distribution of Depleted Uranium (DU) and Beryllium (Be) in Soil and Air on Illeginni Island at Kwajalein Atoll after the Final Land-Impact Test

W. L. Robison, T. F. Hamilton, R. E. Martinelli, F. J. Gouveia, S. R. Kehl, T. R. Lindman, S. C. Yakuma

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Disclaimer

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Error in original 2006 manuscript

The original publication of this paper, UCRL-TR-222048, May 2006 entitled "The Concentration and Distribution of Depleted Uranium (DU) and Beryllium (Be) in Soil and Air on Illeginni Island at Kwajalein Atoll" contained printing errors in the final version of the paper that occurred while the authors were in the Marshall Islands. During the final printing process the "symbols" in some cases were lost and the typing reverted back to the alphabetic letter. Thus, the micro grams per gram ($\mu g\ g^{-1}$) reverted to milligrams per gram ($mg\ g^{-1}$) that is different by a factor of 1000. This happened in some instances in the text and in the Appendix headings. The units were not affected in the Table or Figures.

The lead author apologizes for these errors and any confusion they may have caused. Please discard the original May 2006 report listed above and use this 2010 revised version where those errors have been corrected. Also this 2010 version contains summaries of the U and Be data in 0.5 acre plots to correspond with EPA recommendations and the latest (December 2009) screening levels from the U.S. EPA.

Concentration and Distribution of Depleted Uranium (DU) and Beryllium (Be) in Soil and Air on Illeginni Island at Kwajalein Atoll after the Final Land-Impact Test

William L. Robison, Terry F. Hamilton, Roger E. Martinelli, Frank J. Gouveia, Steven R. Kehl, Terry R. Lindman, and Stephen C. Yakuma

Abstract

Re-entry vehicles on missiles launched from Vandenberg Air Force base in California re-enter at the Western Test Range, the Regan Test Site (RTS) at Kwajalein Atoll. An Environmental Assessment (EA) was written at the beginning of the program to assess potential impact of DU and Be, the major RV materials of interest from a health and environmental perspective, for both ocean and land impacts. The chemical and structural form of Be and DU in RVs is such that they are insoluble in soil water and seawater. Thus, they are not toxic to plant life on the island (no soil to plant uptake). Similarly, due to their insolubility in sea water there is no uptake of either element by fish, mollusks, shellfish, sea mammals, etc. No increase in either element has been observed in sea life around Illeginni Island where deposition of DU and Be has occurred.

The critical terrestrial exposure pathway for U and Be is inhalation. Concentration of both elements in air over the test period (1989 to 2006) is lower by a factor of nearly 10,000 than the most restrictive U.S. guideline for the general public. Uranium concentrations in air are also lower by factors of 10 to 100 than concentrations of U in air in the U.S. measured by the EPA (Keith et al., 1999). U and Be concentrations in air downwind of deposition areas on Illeginni Island are essentially indistinguishable from natural background concentrations of U in air at the atolls. Thus, there are no health related issues associated with people using the island.

Introduction

Lawrence Livermore National Laboratory (LLNL) has supported the United States Air Force (USAF)/Department of Energy (DOE) Peacekeeper and Minuteman ballistic missile flight test program for LLNL and Los Alamos National Laboratory (LANL) re-entry vehicles (RVs) from 1988 through 2006 for tests targeted for the Western Test Range, the Reagan Test Site (RTS), at the U. S. Army base at Kwajalein Atoll (USAKA). Re-entry vehicles on missiles launched from Vandenberg Air Force base in California re-enter at the RTS. Some RVs are targeted in the vicinity of Illeginni Island (Figure 1) at the helipad end of the island. LLNL has supported scoring, recovery operations of RV materials, and assessments of the environmental and health impacts of associated materials in the targeted area.

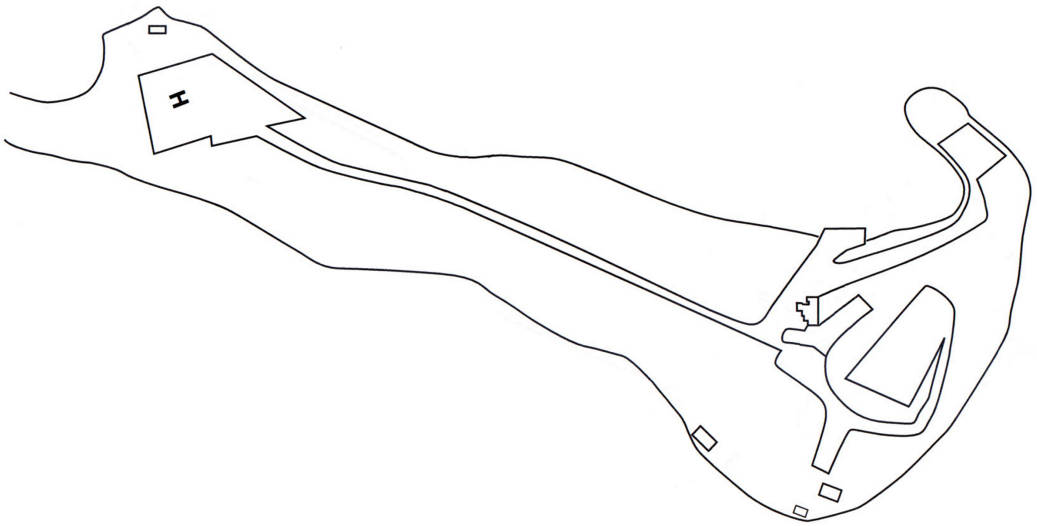

Figure 1. General map of Illeginni Island

Background

An environmental Assessment (EA) was written at the beginning of the program to assess potential impact of DU and Be, the major RV materials of interest from a health and environmental perspective (Robison and Shinn, 1988), if land impact should occur. A more extensive EA was written in 1992 (Robison and Cederwall, 1992). Periodic reports have been submitted by LLNL over the years to USAKA and RTS range commanders detailing the U and Be concentrations in soil and air at Illeginni Island as a result of land impacts (Robison and Shinn, 1990; Robison, 1992). Moreover, letters have been submitted after each mission to the USAKA commanding officer and Range Operations commander describing whether or not there was a land impact. If there was a land impact then recovery operations were begun to look for classified components and air samplers were deployed to determine the concentration of U (DU plus natural U) and Be in air. Surface soil samples were also collected and analyzed for U (DU plus natural U) and Be. These data were sent to the USAKA commanding officer and range command personnel. Recently, the USAF completed a thorough, updated EA (USAF, 2004) that included LLNL data previously supplied to USAKA.

Although DU is radioactive (much less so than natural U) it is not a radiological health concern but a toxicity health concern (Keith et al., 1999; Durante and Pugliese, 2002, Bleise et al., 2003; Assimakopoulos, 2003; Meinrath et al., 2003; Mc Diarmid et al., 2004). The chemical and structural form of the Be and DU in RVs is such that they are insoluble in soil water and seawater. Thus, they are not toxic to plant life on the island (no soil to plant uptake). A good demonstration is the flourishing plant life on the island where Du and Be have been deposited. Concentrations of **soluble**

Be in soil have to exceed about 2 μg g^{-1} for plants to start showing toxic effects (see review by Shinn et al., 1988). As a result of the lack of uptake of Be and U by plants on Illeginni, there is no exposure to humans from the ingestion pathway from consumption of coconuts, *Pandanus* fruit, or other food crops.

Similarly, due to insolubility of the two materials in sea water there is no uptake of either element by fish, mollusks, shellfish, sea mammals, etc. If either material were even slightly soluble in sea water the soluble ions would rapidly mix with the worlds oceans and be indistinguishable from the natural concentration of 3 mg L^{-1} for U and 6 ng L^{-1} for Be in sea water (McWright, 1996). No increase in either element has been observed in sea life around Illeginni Island where deposition of DU and Be has occurred (Robison et al., 2005). As a result, there is no impact on marine flora and fauna and there would be no exposure to humans from ingestion of marine foods.

When RVs impact on land, particles of DU and Be are dispersed on the soil surface over small areas of the island. Some amounts of both materials are also deposited deeper in soil within the crater produced by RV land impact. Inhalation of Be and DU is considered the critical pathway for exposure to DU distributed on the ground surface (Bleise et al., 2003; Keith et al., 1999). Leaching into a drinking water supply can also be an issue for some U and Be compounds but because of the chemical and structural form of the U and Be on Illeginni, and the lack of a fresh water supply because the ground water is saline and non-potable, inhalation is the critical route of exposure.

Thus, DU and Be in surface soil provide a potential source of exposure to people via inhalation if the materials, as a result of wind-driven processes, are re-suspended from the soil surface. U.S. federal guidelines for U and Be are directed primarily toward the inhalation pathway and guidelines are thus given as concentrations in air. Included in this report are the latest and most restrictive guidance.

The most restrictive United States guidance is for the general public. Work-area standards are significantly higher than those for the general public. The U.S. Environmental Protection Agency (EPA) guideline for Be for the general public is 0.01 μg m^{-3} in air (40 CFR 61.32, 2009). For comparison, Occupational Safety and Health Administration (OSHA) workplace 8-h time-weighted average is 2 μg m^{-3} and the 15-minute time-weighted average is 25 μg m^{-3} (29 CFR 1910.1000, 2003). The OSHA guidelines have been adopted by the U.S. Department of Energy [DOE] (10CFR part 850, 1999) and are updated to concur with any OSHA changes.

The Nuclear Regulatory Commission (NRC)/EPA guideline for U for the general public is 0.18 μg m^{-3} in air (10 CFR part 20, Appendix B, 2003). The latest

Screening Level from EPA (2009) is 0.31μg m^{-3}.

In this report, data for Be and U in air at Illeginni Island will be compared to the more restrictive general public guidelines.

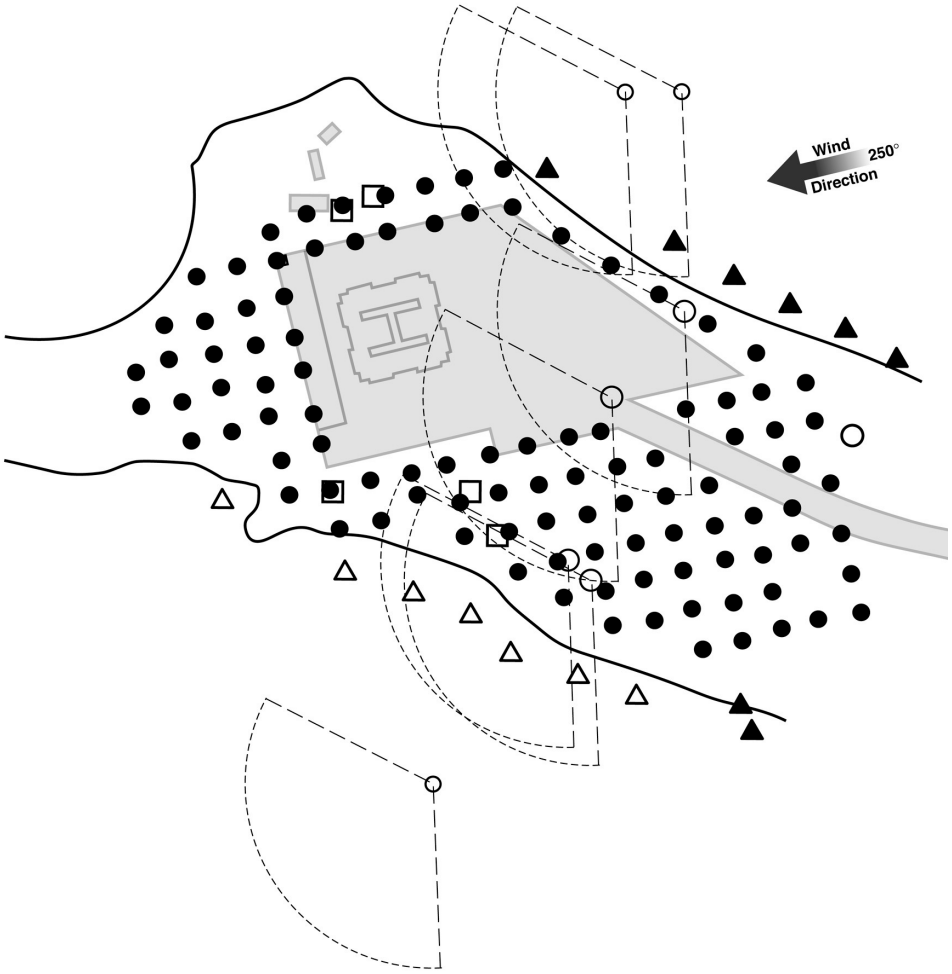

Figure 2. Map of the area on Illeginni Island where deposition of materials occurred. The round, open circles represent the impact point for those tests that deposited some U, Be, and coral on the island. The dashed lines indicate the angle that coral and RV materials were ejected upon impact. The open squares show the location of the hi-volume air samplers that were used to collect re-suspended surface soil to determine the concentration of U and Be in air. All the air-sampler sites are downwind of the major deposition areas. The solid and open triangles indicate the locations of marine sediments collected for analysis of U and Be. Most of the impacts were in the deep ocean represented by the open circle and ejection angles off the island.

Methods

Soils samples

The impact points of the re-entry vehicles, and the associated distribution pattern are shown in Figure 2. Because re-suspension of U and Be from surface soil is of

primary concern, soil samples were collected in August 2005 from 0 to 5 cm depth at various grid locations (black dots in Figure 2) that comprised the deposition area for all the mission. Soil samples were collected by digging a small trench about 40 cm long by 20 cm wide by 15 cm deep. A stainless steel tool, 15 cm by 15 cm by 5 cm, was used to collect each 5-cm soil sample; it was washed between sample collections to avoid any contamination from the previously collected sample. Each sample was put into a clean plastic bag, sealed, labeled, and shipped to LLNL for processing and analysis of U and Be. Four soil profiles (0-5 cm, 5-10 cm, 10-15 cm, and 15-20 cm) were also collected to determine the depth distribution of U and Be in soil in the area of deposition. These samples were collected in a similar manner as the 0-5 cm samples except a backhoe was used to dig a deeper and wider trench so that incremental profile samples could be easily collected without worrying about contamination of deeper samples from above layers of soil. Coordinates (X axis first, Y axis second) of soil profile samples are 06, 05; 05.5, 05.5; 04.5, 05.5; and 05.5, 05.5. The location can be determined using Figure 3.

Bulk soils were prepared for chemical analysis by placing them in metal cans and drying them to constant weight in large convection ovens. Lids were placed on the cans and the dried material homogenized for 24-h by agitation on a rolling mill. Large chunks of hard coral soil and pebbles were removed prior to sample analysis by sieving samples through a 16-mesh (1.6 mm) NBS screen.

Chemical analysis of soil samples was performed on 1-g aliquots of sample matrix placed in acid leached polypropylene digestion vessels along with 20 g of concentrated nitric acid and hydrogen peroxide mixture. Dissolution of sediment samples was completed by treating any residue with a combination of nitric and hydrofluoric acid. All samples were then evaporated to near dryness, re-hydrated in 2% ultra-pure nitric acid, and filtered through a 0.45 mm syringe-filter to constant volume. Appropriate gravimetric dilutions were then prepared for chemical analysis by serial dilution of the stock digest.

Beryllium and U were measured by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) with addition of 1 ppm of lithium-6 (^{6}Li) (for Be analysis) and 1 ppb of uranium-233 (^{233}U) (for U analysis) as internal standard. Control samples included blanks and approximately 10% of blind replicates prepared from the stock digest. A series of MAPEP (Mixed Analyte Performance Evaluation Program, an analytical performance testing program run by DOE), inter-comparison soils were also prepared and analyzed as quality control samples for the Be and U analyses.

Suspended Surface-Soil Samples (Air Filter Samples)

Concentration of U and Be in air were determined using high-volume air samplers running at approximately 60 $m^3\ h^{-1}$(2100 $ft^3\ h^{-1}$)

for a period of 30 to 40 days. The samplers are designed to collect the total suspended solids. There is no cut off at 10 to 20 μm particle size that is the upper limit for particles that can be inhaled and deposited in the deep lung. Consequently, data for concentrations of soil in air in this report overestimate the respirable component that could reach the deep lung. Filters were exchanged after 2 weeks of continuous running to avoid overloading the filters. Total air passed through each Whatman 41 cellulose filter (8" x 10") ranged from 10,000 to 22,000 m^3 (350,000 to 777,000 ft^3). The total amount of air filtered over the 40-day sampling program was about 232,000 m^3 (8,180,000 ft^3). Average TSP (total suspended particles) in air based on analysis of the filters was 54 μg m^{-3}.

The filters were each dried (at 80° C) and weighed then placed in a plastic bag that is sealed prior to transport to the field. The clean filters are placed in air samplers using surgeon gloves to avoid contamination of the filter. At the end of the sampling period filters are collected, again using surgeon gloves, and placed in clean plastic bags for transport to LLNL.

Upon return to LLNL the filters were dried, weighed, dry-ashed and then analyzed for U and Be. The ashing process starts at 100° C increasing by 100° C increments for 3 days to 400° C. They are held at 400° C for 48 h at which time the ashed sample is allowed to slowly cool to room temperature. The ashed sample is then weighed.

Dissolution and preparation for U and Be analysis of the ashed samples is the same as that described above for soils.

Results

Cumulative effects of the test program from 1990 to 2006 are presented in this report. Tests that produced some deposition of U and Be on Illeginni Island were GT02, 1990; GT10, 1992; GT17, 1995; GT22, 1996, and GT32, 2003. Impact locations on or near Illeginni Island and the normal wind direction are shown in Figure 2. Results are based on 106 samples collected in the deposition area of the island (Figure 3). U concentration is listed on top and Be concentration on the bottom at each soil sampling point (black dots). An additional 12 samples were obtained in the process of collecting four soil profiles. Concentration of U and Be outside the area represented by data shown in Figure 3 is essentially at the natural background concentration of U and Be in coral soil, 1.7 μg g^{-1} and 0.002 μg g^{-1}, respectively (Robison et al., 2005).

Distribution with soil depth of U and Be in four soil profiles in the Illeginni deposition area is shown in Figs. 4 and 5, respectively. There is a definite decline in concentration with depth and the concentration approaches background levels below 10-15 cm with one exception for each element. The U and Be concentration in each soil sample and replicate sample are listed in the Appendix along with coordinate positions shown in Fig. 3.

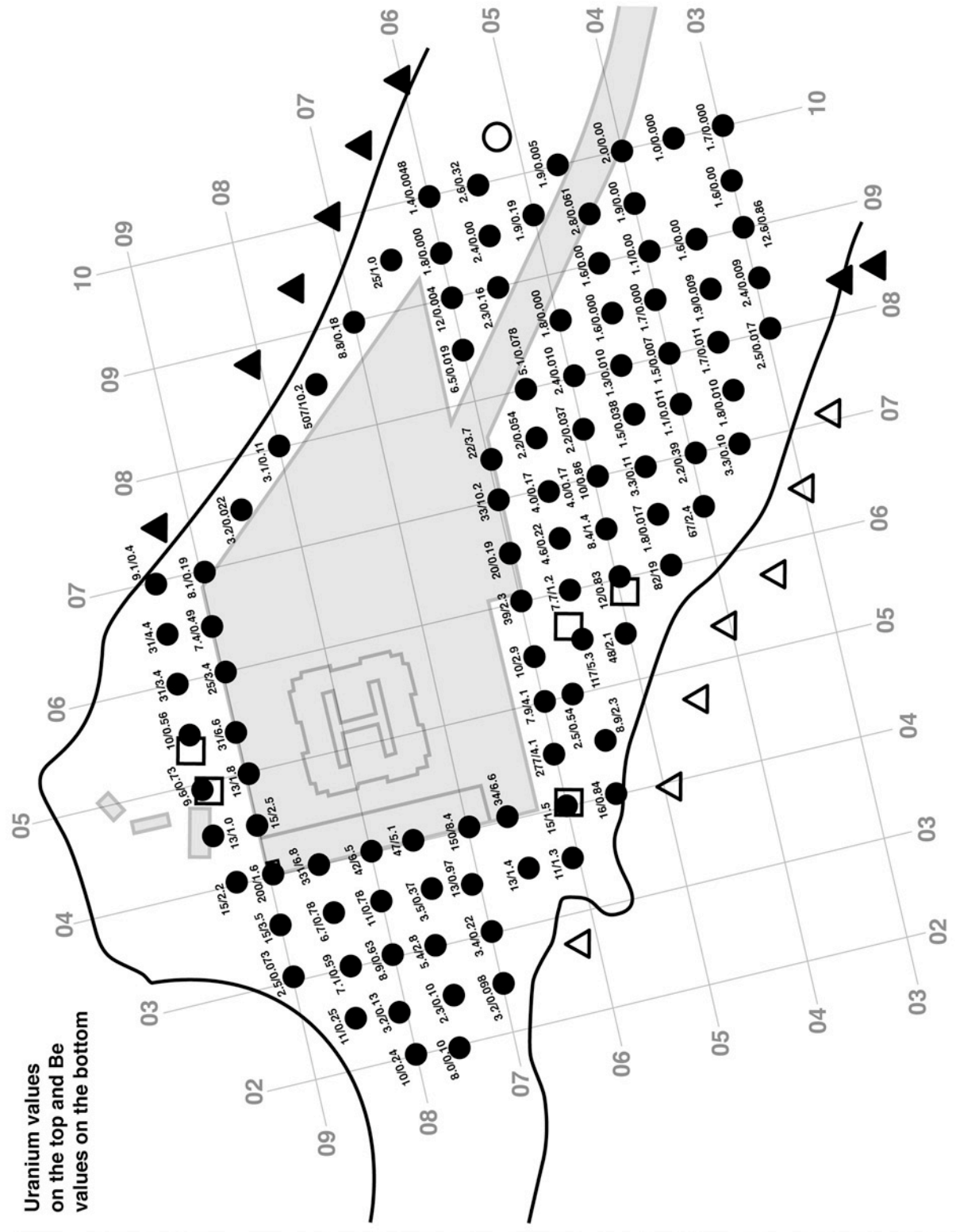

Figure 3. Illeginni Island sampling grid with U and Be data at each sample location. Uranium and Be concentration is in μg g^{-1}. Uranium concentration is the top number at each dot and Be concentration is the lower number at each dot

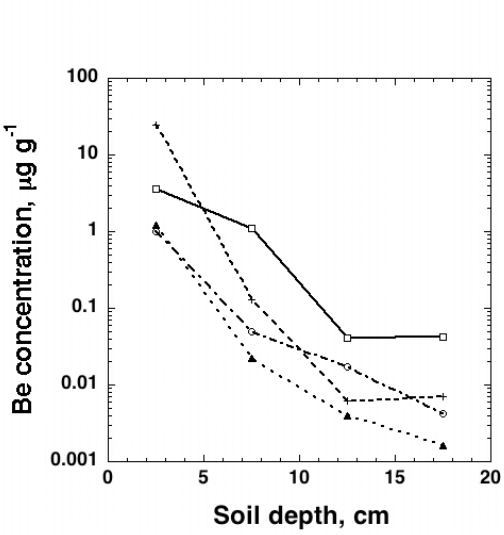

Figure 4. The Beryllium concentration in soil as a function of the depth in the soil profile in the deposition area on Illeginni Island.

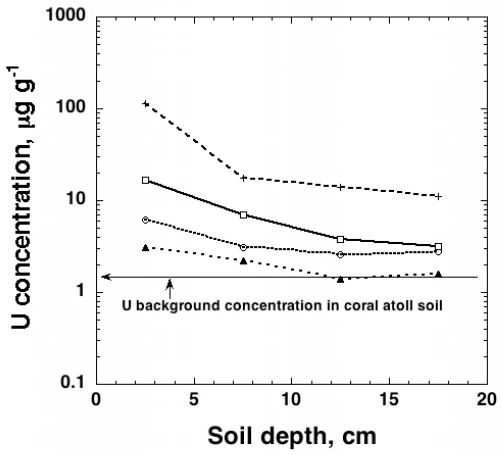

Figure 5. The Uranium concentration in soil as a function of depth in the soil profile in the deposition area on Illeginni Island.

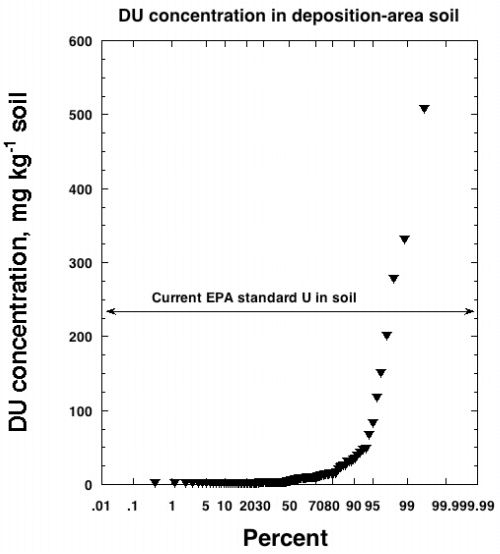

Figure 6. The cumulative distribution of U concentration in soil in the deposition area on Illeginni Island.

The cumulative distribution of the DU concentration data in soil (Fig. 6) shows that only three of 117 samples (when the soil profiles are included) exceed the EPA screening level. All of the Be concentration data for the soil samples are far below the EPA screening level (Fig. 7).

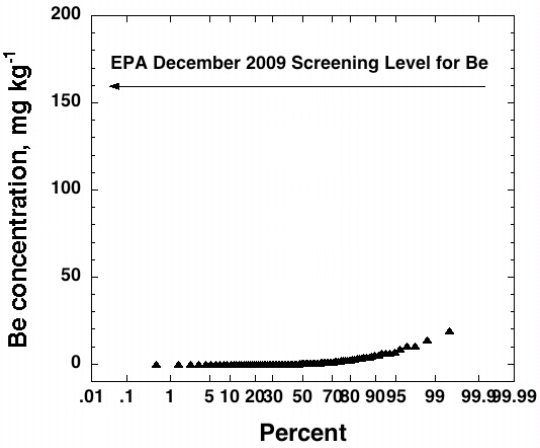

Figure 7. The cumulative distribution of Be concentration in soil in the deposition area on Illeginni Island.

The EPA guidance for soil sampling recommends that multiple samples be collected in 0.5 acre-size parcels of land. Different sampling distributions are allowed but the number of samples collected must be sufficient to collectively represent the parcel. Results from analysis of these samples are averaged to compare with the EPA Screening Levels. In discussions of our sampling density with EPA we were told it was more than sufficient to meet their requirements.

The deposition area on Illeginni was divided into parcels 0.5 acres in size as shown in Fig. 8. Average concentration for DU in each of these parcels is shown in Table 1 and the average Be concentration in Table 2.The average U and Be concentration in all the parcels is far below the current (2009) EPA screening levels for the two elements.

As discussed above, the most important data are concentration of U and Be in air because inhalation of U and Be is the critical exposure pathway. Results of the concentration of U and Be in air downwind of the deposition area at Illeginni as a function of time (missions) is shown in Figure 9. Concentration of both elements in air over the entire test period is nearly a factor of 10,000 lower than the most restrictive guideline for the general public. Uranium concentrations in air are also lower by factors of 10 to 100 than concentrations of U in air in the U.S. measured by the EPA (Keith et al., 1999). U and Be concentrations in air downwind of the deposition areas on Illeginni Island are essentially indistinguishable from natural background concentrations of U and Be in air at the atolls.

Discussion

DU and Be from the missile flight test program is deposited over a small section of land on Illeginni Island near the helipad at the northwest end of the island (compare Figure 2 deposition area around the helipad with Figure 1 showing the entire island). Concentrations of U and Be in air downwind of the deposition area are lower by a factor of nearly10, 000 than the most restrictive U.S. federal guideline for the general public. Even so, the amount of re-suspended particulates containing U and Be can be expected to further decrease as vegetation redevelops in the deposition area reducing the amount of wind-driven re-suspended particulates from soil surface.

Moreover, high-volume air samplers used to collect re-suspended soil particulates to measure the U and Be concentrations are designed to collect total suspended particulates (TSP). This means particle sizes up to 50 μm or more are collected. The particle size upper limit for entering the deep lung where U and Be could be lodged or transferred to the blood is between 10 and 20 μm. Thus, the TSP we measure on our filters is really an overestimate of what can really be deposited in the deep lung and any U or Be attached to particles greater than about 20 μm would not be transferred to the blood stream. Consequently, concentrations of U and Be in air shown in Figure 6 error on the safe side.

Analysis of soil profile samples show some distribution with depth of U and Be from 1990 to 2006. Some of the distribution below the top 5 cm of soil could be due to mechanical disturbance between successive missions. But rainfall, flooding, and general

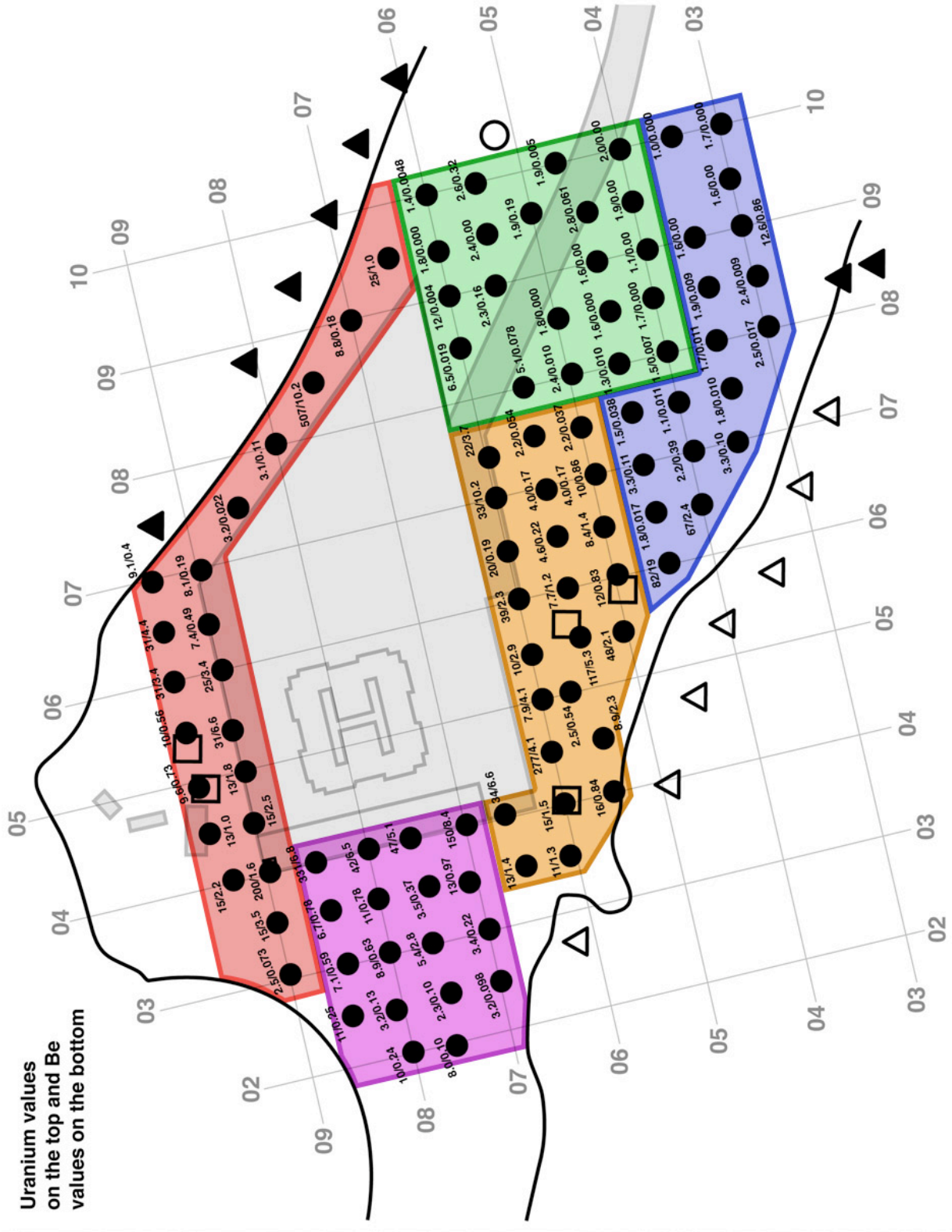

Figure 8. The deposition area divided into five 0.5 acre plots (colored red, green, blue, purple, and orange) over which the U and Be concentrations were averaged to comply with EPA procedures and recommendations.

Coord.	Blue	Coord.	Green	Coord.	Orange	Coord.	purple	Coord.	Red
08, 04	1.5	08.5, 06	6.5	03.5, 06.5	13	02.5, 08.5	11	04, 09.2	15
08.5, 04	1.7	09, 06	12	04, 06.5	35	03, 08.5	7.1	04.5, 09.5	13
09, 04	1.1	09.5, 06	1.8	03.5, 06	11	03.5, 08.5	6.7	05, 09.5	9.5
09.5, 04	1.9	10, 06	1.4	04, 06	15	04, 08.5	331	05.5, 09.5	10
10, 04	2.0	08, 05.5	5.1	04.5, 06	277	02, 08	10	06, 09.7	31
08, 03.5	1.7	09, 05.5	2.3	05, 06	7.9	02.5, 08	3.2	06.5, 09.5	30
08.5, 03.5	1.9	09.5, 05.5	2.4	05.5, 06	10	03, 08	8.9	07, 09.5	9.1
09, 3.5	1.6	10, 05.5	2.6	06, 06	39	03.5, 08	11	03, 09	2.5
10, 3.5	1.0	08, 05	2.4	06.5, 06	20	04, 08	42	03.5, 09	15
08, 03	2.5	08.5, 05	1.8	07, 06	33	02, 07.5	8	04, 09	200
08.5, 03	2.4	09.5, 05	1.9	07.5, 06	22	02.5, 07.5	2.3	04.5, 09	15
09, 03	12.6	08, 04.5	1.3	04, 05.5	16	03, 07.5	5.4	05, 09	13
09.5, 03	1.6	08.5, 04	1.6	04.5, 05.5	8.9	03.5, 07.5	3.5	05.5, 09	31
10, 03	13	09, 04	1.6	05, 05.7	2.5	04, 07.5	47	06, 09	25
06, 04.5	82	09.5, 04.5	2.8	05.5, 05.5	155	02.5,07	3.2	06.5, 09	7.4
06.5, 04.5	1.8	10, 04.5	1.9	06, 05.5	7.7	03, 07	3.4	07, 09	8.1
07, 04.5	3.3	08, 04	1.5	06.5, 05.5	4.6	03.5, 07	13	07.5, 08.5	3.2
07.5, 04.5	1.5	08.5, 04	1.7	07, 05.5	4.0	04, 07	150	08, 08	3.1
08, 04.5	1.3	09, 04	1.1	07.5, 05.5	2.2	**Median**	**8.5**	08.5, 07.5	507
06.5, 04	67	09.5, 04	1.8	05.5, 05	48	**Mean**	**37**	09, 07	8.8
07, 04	2.2	10, 04	2.0	06, 05	12	**No.**	**18**	09.5, 06.5	25
07.5, 04	1.1	**Median**	**1.9**	06.5, 05	8.4	**Stdev**	**81**	08.5, 06	6.5
08, 04	1.5	**Mean**	**2.7**	07, 05	10	**Stderr**	**19**	09, 06	1.6
07, 03.5	3.3	**No.**	**21**	07.5, 05	2.2			09.5, 06	1.6
07.5, 03.5	1.8	**Stdev**	**2.5**	**Median**	**12**			10, 06	1.4
08, 03.5	1.7	**Stderr**	**0.54**	**Mean**	**32**			08, 05.5	5.1
08, 03	2.5			**No.**	**24**			09, 05.5	2.3
Median	**1.8**			**Stdev**	**61**			09.5, 05.5	2.4
Mean	**8.0**			**Stderr**	**12**			10, 05.5	2.6
No.	**27**							**Median**	**9.1**
Stdev	**19**							**Mean**	**35**
Stderr	**3.8**							**No.**	**29**
								Stdev	**98**
								Stderr	**18**

EPA December 2009 Screening Levels
U = 230 mg kg^{-1}

Table 1. Concentration of U in soil subsequent to the Peacekeeper and Minuteman flight-tests at Illeginni Island. Listed are the individual data points and mean values for the five half-acre deposition areas labeled red, green, blue, purple, and orange. The December 2009 EPA Screening Level for residential sites for U in soil is also listed. The numbers in red are the mean of 1 to 6 replicate samples.

Coord.	Blue	Coord.	Green	Coord.	Orange	Coord.	purple	Coord.	Red
08, 04	0.007	08.5, 06	0.019	03.5, 06.5	1.4	02.5, 08.5	0.25	04, 09.2	2.2
08.5, 04	0.00	09, 06	0.004	04, 06.5	6.6	03, 08.5	0.59	04.5, 09.5	1
09, 04	0.00	09.5, 06	0	03.5, 06	1.3	03.5, 08.5	0.78	05, 09.5	0.73
09.5, 04	0.00	10, 06	0.0048	04, 06	1.5	04, 08.5	6.8	05.5, 09.5	0.56
10, 04	0.00	08, 05.5	0.078	04.5, 06	4.1	02, 08	0.24	06, 09.7	3.4
08, 03.5	0.11	09, 05.5	0.16	05, 06	4.1	02.5, 08	0.13	06.5, 09.5	4.4
08.5, 03.5	0.009	09.5, 05.5	0	05.5, 06	2.9	03, 08	0.63	07, 09.5	0.4
09, 3.5	0.00	10, 05.5	0.32	06, 06	2.3	03.5, 08	0.78	03, 09	0.073
10, 3.5	0.00	08, 05	0.01	06.5, 06	0.19	04, 08	6.5	03.5, 09	3.5
08, 03	0.017	08.5, 05	0.00	07, 06	10.2	02, 07.5	0.1	04, 09	1.6
08.5, 03	0.009	09.5, 05	0.19	07.5, 06	3.7	02.5, 07.5	2.3	04.5, 09	2.5
09, 03	0.86	08, 04.5	0.010	04, 05.5	0.84	03, 07.5	2.8	05, 09	1.8
09.5, 03	0.00	08.5, 04	0.00	04.5, 05.5	2.3	03.5, 07.5	0.37	05.5, 09	6.6
10, 03	0	09, 04	0.00	05, 05.7	0.54	04, 07.5	5.1	06, 09	3.4
06, 04.5	19	09.5, 04.5	0.061	05.5, 05.5	5.3	02.5,07	0.098	06.5, 09	0.49
06.5, 04.5	0.017	10, 04.5	0.005	06, 05.5	1.2	03, 07	0.22	07, 09	0.19
07, 04.5	0.11	08, 04	0.007	06.5, 05.5	0.22	03.5, 07	0.97	07.5, 08.5	0.022
07.5, 04.5	0.038	08.5, 04	0.00	07, 05.5	0.2	04, 07	8.4	08, 08	0.11
08, 04.5	0.01	09, 04	0.00	07.5, 05.5	0.054	**Median**	**0.71**	08.5, 07.5	10.2
06.5, 04	2.4	09.5, 04	0.00	05.5, 05	2.1	**Mean**	**2.1**	09, 07	0.18
07, 04	0.39	10, 04	0.0	06, 05	0.83	**No.**	**18**	09.5, 06.5	1.0
07.5, 04	0.011	**Median**	**0.00**	06.5, 05	1.4	**Stdev**	**2.7**	08.5, 06	0.019
08, 04	0.007	**Mean**	**0.04**	07, 05	0.86	**Stderr**	**0.6**	09, 06	0.004
07, 03.5	0.10	**No.**	**21**	07.5, 05	0.037			09.5, 06	0.00
07.5, 03.5	0.010	**Stdev**	**0.1**	**Median**	**1.4**			10, 06	0.005
08, 03.5	0.011	**Stderr**	**0.02**	**Mean**	**2.3**			08, 05.5	0.078
08, 03	0.017			**No.**	**24**			09, 05.5	0.16
Median	**0.01**			**Stdev**	**2.4**			09.5, 05.5	0.00
Mean	**0.86**			**Stderr**	**0.5**			10, 05.5	0.32
No.	**27**							**Median**	**0.49**
Stdev	**3.7**							**Mean**	**1.5**
Stderr	**0.7**							**No.**	**29**
								Stdev	**2.3**
								Stderr	**0.4**

EPA December 2009 Screening Levels
Be = 160 mg kg^{-1}

Table 2. Concentration of Be in soil subsequent to the Peacekeeper and Minuteman flight-tests at Illeginni Island. Listed are the individual data points and mean values for the five half-acre deposition areas labeled red, green, blue, purple, and orange. The December 2009 EPA Screening Level for residential sites for U in soil is also listed. The numbers in red are the mean of 1 to 6 replicate samples.

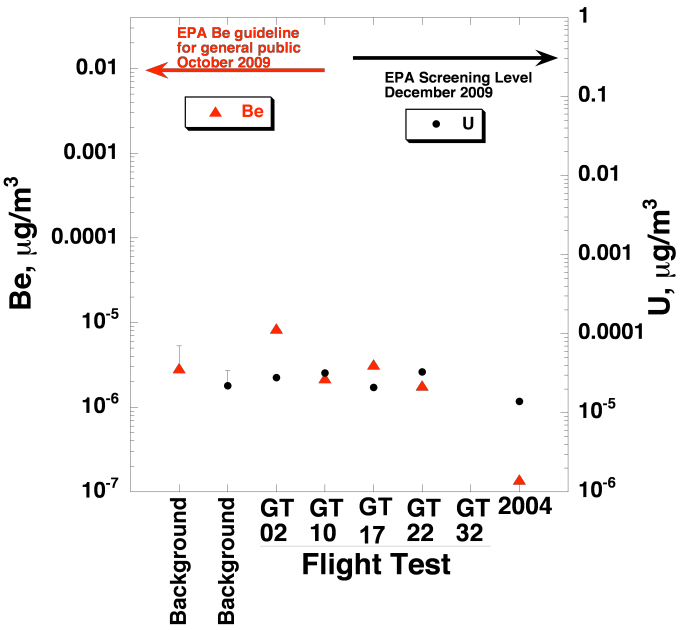

Figure 9. The concentration of U and Be in air at Illeginni Island. The upper error bars (1 standard deviation) are shown for the series of U and Be background

weathering processes can also distribute fine particles of U and Be, or fine soil particles containing DU and Be, deeper into the soil profile. In either case the amount of DU/Be-containing particles of respirable size in surface soil will likely decrease somewhat with time due to both processes.

Guidelines in the U.S. for U in drinking water and are in the mg L^{-1} range. Any DU or Be that might possibly be transported to the Illeginni ground water that is about 3 m below the ground surface would be in the ng L^{-1} or pg L^{-1} range (1 million to 1 billion times lower than the drinking water standards). Furthermore, the ground water at the northwest end of the island where DU and BE deposition occurred is saline and not potable. If some DU and BE should reach the ground water on Illeginni in soluble form it will communicate with the ocean waters and be indistinguishable from world wide background concentrations of U and Be in the ocean.

Concentration of DU and Be is at background concentrations at gridline 9 and 10 on the X axis up to gridline 6 on the Y axis in Figure 3. The rest of the island to the right of gridline 10 on the X axis (down the road leading to the rest of the island) has background concentrations of U and Be in the soil. To the left of gridline 1 on the X axis (not shown on Figure 3) the U and Be concentrations in soil are essentially at background concentrations. Thus, data displayed in Figure 3 does define the contaminated portion of Illeginni Island.

The larger quantities of DU and Be deposited in the ocean have no significant impact on marine flora and fauna nor on humans as a result of their insolubility in sea water as described in the Background section of this paper.

Conclusions

The critical route of exposure for U and Be at Illeginni Island is inhalation as it is anywhere these two materials are distributed on the soil surface. Measured concentrations of U and Be in air down wind of the deposition area are lower by a factor of nearly10, 000 than the most restrictive U.S. federal guidelines for the general public. Also, concentrations of U in air at Illeginni are less by a factor of 10 to 100 than U concentrations in air in the U.S. measured by the EPA (Keith et al., 1999) and they are indistinguishable from natural background concentrations of U and Be in air at the atolls. Thus, there are no health related issues associated with people using the island for any type of activity.

Concentrations of U and Be in soil in some parts of the relatively small deposition area of Illeginni Island do exceed their natural background concentrations in coral atoll soils. But the concentrations are well below the Current EPA Screening Levels for these elements in soil. Because of the chemical and structural form of U and Be in the RVs they are insoluble in ground water and seawater. Thus, as described in this paper, there is neither an effect on island plants or animals nor on the marine flora and fauna as a result of the missile flight tests.

Units used

1part per thousand = I milligram g^{-1} =1mg g^{-1} = 10^{-3} g g^{-1} = 0.001 g g^{-1}
1 part per million = 1 microgram g^{-1} = 1 μg g^{-1} = 10^{-6} g g^{-1} = 0.000001 g g^{-1}
1 part per billion = 1 nanogram g^{-1} =1 ng g^{-1} = 10^{-9} g g^{-1} = 0.000000001 g g^{-1}
1 part per trillion = 1 picogram g^{-1} = 1 pg g^{-1} = 10^{-12} g g^{-1} = 0.000000000001 g g^{-1}

The units “milligrams per kilogram” is the same concentration as “micrograms per g”.

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APPENDIX

Appendix. Uranium and Be concentration in soil samples from Illeginni Island, Kwajalein Atoll

Soil Sample Identification Soil depth: grid location	U µg g^{-1} dry wt.	Mean U µg g^{-1} dry wt.	U Stdev	Be µg g^{-1} dry wt.	Mean Be µg g^{-1} dry wt.	Be Stdev
0-5 cm; 02,08	10.3			0.21		
Blind Replicate Sample	9.7	**10.0**	0.44	0.26	**0.24**	0.04
0-5 cm; 03,08	8.9	8.9		0.63	0.63	
0-5 cm; 02.5,08	3.2	3.2		0.13	0.13	
0-5 cm; 02,07.5	8.3			0.13		
Blind Replicate Sample	7.6	**8.0**	0.53	0.071	**0.10**	0.038
0-5 cm; 02.5,07	3.2	3.2		0.098	0.098	
0-5 cm; 03,07	3.4	3.4		0.22	0.22	
0-5 cm; 03,07.5	5.4	5.4		0.28	0.28	
0-5 cm; 03,09	2.7			0.079		
Blind Replicate Sample	2.2	**2.5**	0.35	0.067	**0.073**	0.009
0-5 cm; 03,08.5	7.1	7.1		0.59	0.59	
0-5 cm; 04,09	730			1.4		
Blind replicate sample	24			2.0		
Blind replicate sample	23			1.5		
Blind replicate sample	24	**200**	353	1.4	**1.6**	0.24
0-5 cm; 04,08.5	304			9.6		
Blind replicate sample	355			8.8		
Blind replicate sample	265			4.8		
Blind replicate sample	347			5.1		
Blind replicate sample	383	**331**	47	6.0	**6.8**	2.2
0-5 cm; 03.5,09.2	15.4	15.4		2.2	2.2	
0-5 cm; 04.08	42.8			4.7		
Blind replicate sample	43.4			4.6		
Blind replicate sample	41.0			11.3		
Blind replicate sample	41.9	**42.3**	1.0	5.2	**6.5**	3.2
0-5 cm; 04,07.5	45.3			8.5		
Blind Replicate Sample	28.5			4.3		
Blind Replicate Sample	56.1			4.5		
Blind Replicate Sample	53.4			4.6		
Blind Replicate Sample	52.1	**47.1**	11	3.8	**5.1**	1.9
0-5 cm; 04,07	138			7.27		
Blind Replicate Sample	177			8.9		
Blind Replicate Sample	124			4.6		
Blind Replicate Sample	146			7.1		
Blind Replicate Sample	160			5.8		
Blind Replicate Sample	155	**150**	19	16.9	**8.4**	4.4
0-5 cm; 04,06.5	34.0			7.2		
Blind Replicate Sample	32.1			7.6		
Blind Replicate Sample	41.9			7.0		
Blind Replicate Sample	30.7	**34.7**	5.0	4.7	**6.6**	1.3
0-5 cm; 04,06	15.0	15.0		1.5	1.5	
0-5 cm; 04,05.6	16.0	16.0		0.84	0.84	
0-5 cm; 03.5,06	13.4			1.4		
Blind Replicate Sample	7.7	**10.6**	4.0	1.2	**1.3**	0.16
0-5 cm; 03.5,07	13.2	13.2		0.97	0.97	
0-5 cm;03.5,08	10.5	10.5		0.78	0.78	
0-5 cm; 03.5,09	15.2	15.2		3.5	3.5	
0-5 cm; 04.5,09	14.6	14.6		2.5	2.5	
0-5 cm; 05,09	13.1	13.1		1.8	1.8	
0-5 cm; 05.5,09	32.9			5.5		
Blind Replicate Sample	28.7			7.2		
Blind Replicate Sample	26.8			5.3		
Blind Replicate Sample	37.1	**31.4**	4.6	8.4	**6.6**	1.5
0-5 cm; 06,09	24.7	24.7		3.4	3.4	
0-5 cm; 06.5,09	7.4	7.4		0.49	0.49	
0-5 cm; 07,09	8.1	8.1		0.19	0.19	
0-5 cm; 07,09.2	9.1	9.1		0.4	0.4	
0-5 cm; 04.5,09.4	13.1	13.1		1.0	1.0	
0-5 cm;05,09.5	9.6	9.6		0.73	0.73	
0-5 cm; 05.5,09.5	10.1	10.1		0.56	0.56	
0-5 cm; 06,09.7	33.6			4.5		
Blind Replicate Sample	23.4			2.3		
Blind Replicate Sample	44.5			4.1		
Blind Replicate Sample	23.2	**31.2**	10	2.6	3.4	1.1
0-5 cm; 06.5,09.5	26.5			2.3		
Blind Replicate Sample	38.8			6.2		

Blind Replicate Sample	30.8			5.0		
Blind Replicate Sample	28.5	**31.2**	5.4	4.1	4.4	1.6
0-5 cm; 07.5,08.5	3.2	3.2		0.022	0.022	
0-5 cm; 08,08	3.1	3.1		0.11	0.11	
0-5 cm; 08.5,07.5	315			7.3		
Blind Replicate Sample	473			15.3		
Blind Replicate Sample	519			7.3		
Blind Replicate Sample	494			12.9		
Blind Replicate Sample	545	**507**	90	8.2	**10.2**	3.7
0-5 cm; 09,07	8.8	8.8		0.18	0.18	
0-5 cm; 09.5,06.5	25.3	25.3		1.0	1.0	
0-5 cm; 10.06	1.6			0.000		
Blind Replicate Sample	1.0			0.020		
Blind Replicate Sample	1.6			0.00049		
Blind Replicate Sample	1.3			0.00050		
Blind Replicate Sample	1.2	**1.4**	0.27	0.00049	**0.0043**	0.0089
0-5 cm; 10,05.5	2.6	2.6		0.032	0.032	
0-5 cm; 10,04.5	1.9	1.9		0.005	0.005	
0-5 cm; 10,04	2.0	2.0		0.000	0.000	
0-5 cm; 10,03.5	1.0	1.0		-0.001	-0.001	
0-5 cm; 10,03	1.7	1.7		-0.001	-0.001	
0-5 cm; 09.5,06	1.8			-0.001		
Blind Replicate Sample	1.5	**1.6**	0.24	0.009	**0.0039**	0.0073
0-5 cm; 09.3,05.5	2.4	2.4		-0.001	-0.001	
0-5 cm; 09.5,05	2.3			0.010		
Blind Replicate Sample	1.5	**1.9**	0.53	0.029	**0.019**	0.013
0-5 cm; 09.5,04.5	2.8			0.053		
Blind Replicate Sample	2.8	**2.8**		0.070	**0.061**	0.012
0-5 cm; 09.5,04	1.4	1.4		-0.001	-0.001	
0-5 cm; 09.5,03	1.4			-0.005		
Blind Replicate Sample	1.7	**1.6**	0.23	0.002	**-0.001**	0.0055
0-5 cm; 09,06	11.6	11.6		0.086	0.086	
0-5 cm; 09,05.5	2.3	2.3		0.016	0.016	
0-5 cm; 09,04.5	1.6	1.6		-0.001	-0.001	
0-5 cm; 09,04	1.1	1.1		-0.001	-0.001	
0-5 cm; 09,03.5	1.6	1.6		-0.001	-0.001	
0-5 cm; 08.5,06	6.5	6.5		0.192	0.192	
0-5 cm; 08.5,05	1.8			-0.001		
Blind Replicate Sample	2.0			0.00050		
Blind Replicate Sample	1.8			0.00049		
Blind Replicate Sample	1.8	**1.8**	0.088	0.00049	**0.00008**	0.0008
0-5 cm; 08.5,004.5	1.6	1.6		-0.005	-0.005	
0-5 cm; 08.5,04	1.7	1.7		-0.001	-0.001	
0-5 cm; 08.5,03.5	1.9	1.9		0.009	0.009	
0-5 cm; 08.5,03	2.4	2.4		0.009	0.009	
0-5 cm; 08,05.5	5.1	5.1		0.078	0.078	
0-5 cm; 08,05	2.4	2.4		0.010	0.010	
0-5 cm; 08,04.5	1.7			0.009		
Blind Replicate Sample	0.85	**1.3**	0.64	0.012	**0.010**	0.0018
0-5 cm; 08,04	1.5	1.5		0.007	0.007	
0-5 cm; 08,03.5	1.7	1.7		0.011	0.011	
0-5 cm; 08,03	2.5	2.5		0.017	0.017	
0-5 cm; 07.5,06	22.1	22.1		3.729	3.729	
0-5 cm; 07.5,05.5	2.2			0.059		
Blind Replicate Sample	2.3	**2.2**	0.056	0.050	**0.054**	0.0060
0-5 cm; 07.5,05	2.2	2.2		0.037	0.037	
0-5 cm; 07.5,04.5	1.6			0.014		
Blind Replicate Sample	1.4			0.00049		
Blind Replicate Sample	1.6			0.00050		
Blind Replicate Sample	1.5	**1.5**		0.00050	**0.0038**	0.0066
0-5 cm; 07.5,04	1.4			0.011		
Blind Replicate Sample	0.7	**1.1**	0.53	0.011	**0.011**	
0-5 cm; 07.5,03.5	2.3			0.010		
Blind Replicate Sample	1.3	**1.8**	0.72	0.010	**0.010**	
0-5 cm; 07,06	46.5			29.4		
Blind Replicate Sample	31.9			7.0		
Blind Replicate Sample	31.7			7.5		
Blind Replicate Sample	32.6			6.6		
Blind Replicate Sample	28.2			4.8		
Blind Replicate Sample	28.8	**33.3**	6.7	6.0	**10.2**	9.4

0-5 cm; 07,05.5	5.5			0.22		
Blind Replicate Sample	2.5	**4.0**	2.1	0.11	**0.17**	0.080
0-5 cm; 07,05	10.0	10.0		0.86	0.86	
0-5 cm; 07,04.5	3.3	3.3		0.11	0.11	
0-5 cm; 07,04	2.2	2.2		0.039	0.039	
0-5 cm; 07,03.5	3.3	3.3		0.10	0.10	
0-5 cm; 06.5,06	19.5	19.5		1.9	1.9	
0-5 cm; 06.5,05.5	4.6	4.6		0.22	0.22	
0-5 cm; 06.5,05	8.4	8.4		1.4	1.4	
0-5 cm; 06.5,04.5	1.8	1.8		0.017	0.017	
0-5 cm; 06.5,04	68.7			1.93		
Blind Replicate Sample	67.5			2.00		
Blind Replicate Sample	70.1			2.15		
Blind Replicate Sample	64.3			2.82		
Blind Replicate Sample	66.3	**67.4**	2.2	3.20	**2.4**	0.56
0-5 cm; 06,06	67.9			1.87		
Blind Replicate Sample	33.7			2.00		
Blind Replicate Sample	31.8			2.27		
Blind Replicate Sample	32.1			2.96		
Blind Replicate Sample	31.6	**39.4**	16	2.43	**2.3**	0.43
0-5 cm; 06,05.5	7.7	7.7		1.19	1.2	
0-5 cm; 06,05	12.4	12.4		0.83	0.83	
0-5 cm; 06,04.5	83.2			16.8		
Blind Replicate Sample	78.6			17.9		
Blind Replicate Sample	80.5			20.6		
Blind Replicate Sample	85.1			20.0		
Blind Replicate Sample	84.2	**82.3**	2.7	20.5	**19.2**	1.7
0-5 cm; 05.5,06	12.9			2.7		
Blind Replicate Sample	7.6	**10.2**	3.7	3.1	2.9	0.30
0-5 cm; 05.5,05.5	543			0.55		
Blind Replicate Sample	82			0.59		
Blind Replicate Sample	102			0.56		
Blind Replicate Sample	68			0.52		
Blind Replicate Sample	62			0.43		
Blind Replicate Sample	73	**155**	190	0.53	**0.53**	0.055
0-5 cm; 05.5,05	23.6			4.0		
Blind Replicate Sample	77.7			2.1		
Blind Replicate Sample	47.0			1.6		
Blind Replicate Sample	46.8			1.5		
Blind Replicate Sample	46.6	**48.3**	19	1.6	**2.1**	1.0
005,06	7.9	7.9		4.1	4.1	
0-5 cm; 05,05.5	2.5	2.5		0.54	0.54	
0-5 cm; 04.5,06	308			6.4		
Blind Replicate Sample	298			3.6		
Blind Replicate Sample	274			3.3		
Blind Replicate Sample	247			2.8		
Blind Replicate Sample	268			4.4		
Blind Replicate Sample	267	**277**	22	4.3	**4.1**	1.3
0-5 cm; 04.5,05.5	8.9	8.9		2.3	2.3	
0-5 cm; 03.5,06.5	13.1	13.1		1.4	1.4	
0-5 cm; 03.5,07.5	3.5	3.5		0.37	0.37	
0-5 cm; 03.5,08.5	6.7	6.7		0.78	0.78	
0-5 cm; 02.5,08.5	10.8	10.8		0.25	0.25	
0-5 cm; 02.5 ,07.5	2.3	2.3		0.10	0.10	
0-5 cm; 06,05	6.1	6.1		1.0	1.0	
5-10 cm; 06,05	3.1	3.1		0.049	0.049	
10-15 cm; 06,05	2.6	2.6		0.017	0.017	
15-20 cm; 06,05	2.5			0.015		
Blind Replicate Sample	3.2			not used	More than 1000X the mean value	
Blind Replicate Sample	4.9			0.0005		
Blind Replicate Sample	4.0			0.0005		
Blind Replicate Sample	4.2	**3.7**	0.94	0.0005	**0.0042**	0.007
0-5 cm; 05.5,05.5	2.8			1.5		
Blind Replicate Sample	3.4	**3.1**	0.39	0.95	**1.2**	0.36
5-10 cm; 05.5,05.5	2.0			0.027		
Blind Replicate Sample	2.4			0.019		
Blind Replicate Sample	2.1	**2.2**	0.23	0.019	**0.022**	0.005
10-15 cm; 05.5,05.5	1.4	1.4		0.004	0.004	
15-20 cm; 05.5,05.5	1.5			0.005		
Blind Replicate Sample	1.8			0.00050		

Blind Replicate Sample	1.8			0.00050		
Blind Replicate Sample	1.5	**1.6**	0.18	0.00050	**0.0016**	0.0021
0-5 cm; 04.5,05.5	18.4			5.0		
Blind Replicate Sample	14.8			3.4		
Blind Replicate Sample	17.0	**16.7**	1.8	2.3	**3.6**	1.4
5-10 cm; 04.5,05.5	8.3			1.3		
Blind Replicate Sample	6.1			0.7		
Blind Replicate Sample	6.0			0.6		
Blind Replicate Sample	7.7	**7.0**	1.2	2.0	**1.1**	0.65
10-15 cm; 04.5, 05.5	4.1			0.13		
Blind Replicate Sample	4.0			0.01		
Blind Replicate Sample	3.9			0.02		
Blind Replicate Sample	3.5	**3.8**	0.28	0.01	**0.041**	0.060
15-20 cm; 04.5,05.5	3.3			0.053		
Blind Replicate Sample	3.3			0.040		
Blind Replicate Sample	3.1			0.037		
Blind Replicate Sample	3.1	**3.2**	0.11	0.040	**0.042**	0.0071
0-5 cm; 06,04.5	160			34.1		
Blind Replicate Sample	116			24.9		
Blind Replicate Sample	84			18.6		
Blind Replicate Sample	120			30.7		
Blind Replicate Sample	93	**114**	30	13.8	**24.4**	8.4
5-10 cm; 06,04.5	17.3			0.14		
Blind Replicate Sample	19.6			0.12		
Blind Replicate Sample	17.6			0.15		
Blind Replicate Sample	16.9	**17.8**	1.2	0.11	**0.13**	0.019
10-15 cm; 06,04.5	13.5			0.023		
Blind Replicate Sample	13.6			0.00050		
Blind Replicate Sample	14.9			0.00048		
Blind Replicate Sample	14.1	**14.0**	0.65	0.00048	**0.0062**	0.011
15-20 cm; 06,04.5	13.9			0.017		
Blind Replicate Sample	7.5			0.017		
	12.2			0.00050		
Blind Replicate Sample	11.6			0.00050		
Blind Replicate Sample	10.9	**11.2**	2.3	0.00050	**0.0070**	0.0089
(bottle labeled 033 & 047)	3.267			0.036		
Mean		**24**			**1.6**	
Stdev		**66**			**3.4**	
Median		**6.5**			**0.19**	
No.		**117**			**117**	
Stderr		**6.1**			**0.32**	
Maximum		**507**			**24**	
Minimum		**1.0**			**0.0**	
		Uranium			**Beryllium**	