U.S. DEPARTMENT OF ENERGY

Report on the Status of the Runit Dome in the Marshall Islands

Report to Congress
June 2020

United States Department of Energy
Washington, DC 20585

Message from the Secretary

The Department of Energy (DOE) is committed to fulfilling the United States' commitments to the health and safety of the people of the Marshall Islands from the effects of the nuclear weapons testing conducted in the past.

This is the DOE Report to Congress regarding the status of the Runit Dome in the Marshall Islands, as outlined in Section 364 of Public Law 116-92, *National Defense Authorization Act for Fiscal Year 2020*.

Pursuant to statutory requirements, this report is being provided to the following members of Congress:

- **The Honorable James Inhofe**
  Chairman, Senate Committee on Armed Services

- **The Honorable Jack Reed**
  Ranking Member, Senate Committee on Armed Services

- **The Honorable Deb Fischer**
  Chairman, Subcommittee on Strategic Forces
  Senate Committee on Armed Services

- **The Honorable Martin Heinrich**
  Ranking Member, Subcommittee on Strategic Forces
  Senate Committee on Armed Services

- **The Honorable Adam Smith**
  Chairman, House Committee on Armed Services

- **The Honorable William "Mac" Thornberry**
  Ranking Member, House Committee on Armed Services

- **The Honorable Jim Cooper**
  Chairman, Subcommittee on Strategic Forces
  House Committee on Armed Services

- **The Honorable Michael Turner**
  Ranking Member, Subcommittee on Strategic Forces
  House Committee on Armed Services

If you have any questions or need additional information, please contact me or Mr. Shawn Affolter, Deputy Assistant Secretary for Senate Affairs, or Mr. Christopher Morris, Deputy Assistant Secretary for House Affairs, Office of Congressional and Intergovernmental Affairs, at (202) 586-5450.

Sincerely,

Dan Brouillette

Executive Summary

This is the United States (U.S.) Department of Energy (Department or DOE) Report to Congress regarding the status of the Runit Dome (also known as the Cactus Crater containment structure) in the Marshall Islands. The report includes a brief background regarding the Runit Dome and addresses the Matters for Inclusion outlined in Section 364 of Public Law 116-92, *National Defense Authorization Act for Fiscal Year 2020*.

The Runit Dome is a containment structure on Runit Island, located on Enewetak Atoll. Enewetak Atoll is a former U.S. atmospheric nuclear weapons test site located in the Republic of the Marshall Islands, approximately 2,300 miles west of Hawaii in the northwest Pacific Ocean. In 1947, prior to the start of nuclear weapons testing on Enewetak, the approximately 150 residents of Enewetak Atoll were relocated to Ujelang Atoll, approximately 155 miles southwest of Enewetak. The people of Enewetak returned to their ancestral homeland in 1980 following an extensive cleanup and rehabilitation program; however, Runit Island has remained uninhabited. The containment structure, built in the late 1970s, contains over 100,000 cubic yards of radioactively contaminated soil and debris that were encapsulated in concrete (waste pile) inside an unlined nuclear test crater, the Cactus Crater, on the north end of Runit Island. The waste pile was subsequently covered over by a non-load bearing, exterior concrete cap to help protect it from natural erosion. The site has remained a concern to the people of Enewetak and their leadership.

The overall conclusions of this report are:

- The Runit Dome is not in any immediate danger of collapse or failure, and the exterior concrete covering the containment structure is still serving its intended purpose, effectively reducing the wind and water erosion of the waste pile below.

- The main risk posed by the dome will be derived from the flow of contaminated groundwater from beneath the containment structure into the local marine environment. To date, there are no data to suggest that the dome, or more specifically, the radioactive material encapsulated within the containment structure, is currently having a measurable adverse effect on the surrounding environment, or is expected to have any adverse effect on the environment in 5, 10, or 20 years. However, DOE is in the process of establishing a groundwater radiochemical analysis program that is designed to provide scientifically substantiated data that can be used to determine what, if any, effects the dome contents are having, or will have, on the surrounding environment now and in the future.

- Individual radiological protection monitoring data collected from the Department's Marshall Islands Program indicate that radiation dose rates to individuals on Enewetak from internal exposure to fallout radionuclides are well below international standards for radiological protection of the public; i.e., 100 millirem (mrem) per year. There is no

evidence to suggest that the containment structure represents a significant source of radiation exposure relative to other sources of residual radioactive fallout contamination on the atoll.

- The most notable and immediate impact of rising sea levels on the Cactus Crater containment structure is that associated with the physical effects of storm surge and wave-driven flooding. DOE's proposed groundwater radiochemical analysis program is designed to provide some understanding of possible effects of forcing events, such as storm surge, on changes in groundwater quality. It is anticipated that any measured or modeled effects of storm events may help provide a better understanding of the long-term consequences of sea level rise on the mass-transport of dome-derived radionuclides into the environment.

- The Department is in continual communication with the Government and people of the Marshall Islands regarding activities associated with the Runit Dome, as detailed further in this report.

DOE remains committed to fulfilling the United States' commitments regarding the health and safety of the people of the Marshall Islands from the effects of past nuclear weapons testing. This report contains assessments and summaries of environmental and health-related data collected by DOE and its predecessor organizations. Additional detail may be found in the published documents listed in the References and Suggested Reading section of this report, which are available upon request from the Department through the Office of Environment, Health, Safety and Security.

STATUS OF THE RUNIT DOME IN THE MARSHALL ISLANDS

Table of Contents

I. Legislative Language

Section 364 of Public Law 116-92, *National Defense Authorization Act for Fiscal Year 2020* states*:*

SEC. 364. REPORT ON RUNIT DOME.

(a) REPORT REQUIRED. — Not later than 180 days after the date of the enactment of this Act, the Secretary of Energy shall submit to the Committees on Armed Services of the Senate and House of Representatives a report on the status of the Runit Dome in the Marshall Islands.

(b) MATTERS FOR INCLUSION. — The report required by subsection (a) shall include each of the following:

(1) A detailed plan to repair the dome to ensure that it does not have any harmful effects to the local population, environment, or wildlife, including the projected costs of implementing such plan.

(2) The effects on the environment that the dome has currently and is projected to have in 5 years, 10 years, and 20 years.

(3) An assessment of the current condition of the outer constructs of the dome.

(4) An assessment of the current and long-term safety to local humans posed by the site.

(5) An assessment of how rising sea levels might affect the dome.

(6) A summary of interactions between the Government of the United States and the Government of the Marshall Islands about the dome.

(c) FORM OF REPORT. — The report required by subsection (a) shall be submitted in unclassified form and made publicly available.

II. Introduction

This is the United States (U.S.) Department of Energy (Department or DOE) Report to Congress regarding the status of the Runit Dome (also known as the Cactus Crater containment structure) in the Marshall Islands. The report includes a brief background regarding the location, origin, and construction of the Runit Dome, and addresses the Matters for Inclusion outlined in Section 364 of Public Law (P.L.) 116-92, *National Defense Authorization Act for Fiscal Year 2020*.

The Runit Dome is a containment structure on Runit Island, located on Enewetak Atoll. Enewetak Atoll is a former U.S. atmospheric nuclear weapons test site located in the Republic of the Marshall Islands (RMI), approximately 2,300 miles west of Hawaii in the northwest Pacific Ocean (see Appendix). In 1947, prior to the start of nuclear weapons testing on Enewetak, the

approximately 150 residents of Enewetak Atoll were relocated to Ujelang Atoll, approximately 155 miles southwest of Enewetak. The people of Enewetak returned to their ancestral homeland in 1980, following an extensive cleanup and rehabilitation program. However, the Defense Nuclear Agency, DOE, Department of the Interior, and the people of Enewetak determined that Runit Island should remain indefinitely quarantined due to the possibility of subsurface levels of plutonium, and in 1980, high-chief (Iroij) Johannes Peter announced that Runit Island was henceforth "off-limits" (DNA, 1981). Runit Island has remained uninhabited to the present day.

The Runit Dome is approximately 114 meters (374 feet) in diameter, has an apex of 7.4 meters (24.3 feet), and contains over 100,000 cubic yards of radiologically contaminated soil and debris that were collected and encapsulated in concrete (waste pile) inside an unlined nuclear test crater, the Cactus Crater, on the north end of Runit Island.

Between 1946 and 1958, the U.S. conducted 67 atmospheric nuclear weapons tests in the Marshall Islands, 43 of which were conducted at Enewetak Atoll. Radioactive fallout from these tests resulted in environmental contamination. Key fallout radionuclides remaining in the environment include the fission products cesium-137 (^{137}Cs) and strontium-90 (^{90}Sr), as well as alpha-emitting plutonium (Pu) isotopes (e.g., ^{239}Pu, ^{240}Pu), and americium-241 (^{241}Am). Of these radionuclides, ^{137}Cs is the largest contributor to radiation doses. ^{137}Cs, with a physical half-life of 30 years, emits gamma radiation that poses a hazard through external exposure or when inhaled or ingested. Indeed, ^{137}Cs in the soil is the largest contributor to external radiation dose in the Marshall Islands, and consumption of ^{137}Cs contained in locally grown foods is the largest contributor to the internal dose. The isotopes ^{239}Pu, with a half-life of 24,000 years, and ^{240}Pu, with a half-life of 6,560 years, emit alpha particles that pose a hazard when inhaled or ingested. The main pathway for exposure to Pu in the northern Marshall Islands is the inhalation of contaminated dust particles that are suspended into the air during operations that disrupt contaminated soil. Also, radioactive debris deposited in lagoon sediments formed a reservoir and potential long-term source for remobilization and transfer of Pu through the marine food chain. However, the individual radiological protection monitoring data collected from the Department's Marshall Islands Program, as discussed in Section III of this report, indicate that radiation dose rates on Enewetak from internal exposure to fallout radionuclides are well below international standards for radiological protection of the public; i.e., 100 millirem (mrem) per year.

In the mid to late 1970s, the U.S. conducted cleanup operations at the Enewetak Atoll by stripping off successive layers of contaminated soil to reduce the level of Pu in surface soils. The waste soil and other radiologically contaminated debris were mixed with cement grout, placed inside the crater formed from the Cactus nuclear weapons test, and covered with a circular, dome-shaped concrete cap to help protect the waste pile below from natural erosion (DNA, 1981). The sum of transuranic (TRU) elements, e.g., Pu isotopes and ^{241}Am, of contaminated soil placed inside the crater was estimated to be approximately 545 giga Becquerel [GBq] (DNA, 1981), or about 0.8 percent of the total TRU inventory found in

Enewetak lagoon sediment (Noshkin et al., 1980). Construction of the containment structure was completed in 1979.

The Runit Dome consists of three design elements (Hamilton, 2013, see Appendix):

- A keywall, consisting of 99 concrete sections, 0.62 meters (24.4 inches) thick, resting on bedrock, designed to prevent scouring and undercutting of the containment structure;
- A waste pile, consisting of radiologically contaminated soil mixed with concrete and other encapsulation agents, and other contaminated debris, structural steel, and concrete; and
- A cap, composed of 357 trapezoidal-shaped concrete panels, 0.45 meters (17.7 inches) thick, designed to protect the encapsulated material from erosion.

The site has remained a concern to the people of Enewetak and their leadership. After the construction of the Runit Dome, the United States was required to monitor the containment structure under the United Nations' Trusteeship of the Marshall Islands. Visual surveys were conducted in June and December 1982, June 1983, and January 1984.

In 1986, Congress passed P.L. 99–239, *Compact of Free Association Act of 1985*, which, among other things, required the U.S. and the Government of the Marshall Islands to enter a separate agreement that would come into effect simultaneously with the Compact. In that agreement, among other things, the U.S. agreed to provide dosimetry and bioassay services and related assistance to the people of the Marshall Islands, and the Government of the Marshall Islands assumed responsibility for, and control of, the utilization of areas in the Marshall Islands affected by the nuclear testing program, thereby ending the U.S. role and responsibility for the Runit Dome.

In 2012, Congress passed P.L. 112-149, *Insular Areas Act of 2011*, which amended the *Compact of Free Association Amendments Act of 2003* by assigning Cactus Crater containment monitoring and reporting requirements to the Secretary of Energy (Secretary). Effective January 1, 2012, the Secretary was required to "periodically (but not less frequently than every 4 years) conduct -- (I) a visual study of the concrete exterior of the Cactus Crater containment structure on Runit Island; and (II) a radiochemical analysis of the groundwater surrounding and in the Cactus Crater containment structure on Runit Island." 48 U.S.C. 1921b(f)(1)(B)(i). The Secretary was also directed to submit to Congress a report describing the results of each visual survey and the radiochemical analysis and "a determination on whether the surveys and analyses indicate any significant change in the health risks to the people of Enewetak from the contaminants within the Cactus Crater containment structure." 48 U.S.C. 1921b(f)(1)(B)(ii)(II).

DOE completed visual surveys of the concrete exterior of the Cactus Crater containment structure in 2013 (Hamilton 2013) and 2018 (scheduled to be published in calendar year 2020). The results from these surveys are used in addressing some of the Matters for Inclusion in the next section of this report.

The radiochemical analysis of groundwater as stipulated in the *Insular Areas Act of 2011* requires having access to suitable groundwater sampling wells. DOE has developed plans to drill and install a series of groundwater monitoring wells within and surrounding the Runit Dome. This phase of the project is presently on hold in response to international travel restrictions imposed as a result of the Covid-19 pandemic.

III. Runit Dome Status

This section provides responses to each of the Matters for Inclusion outlined in Section 364 of P.L. 116-92, *National Defense Authorization Act for Fiscal Year 2020*. Additional details may be found in the published documents listed in the References and Suggested Reading section of this report, which may be obtained upon request from the Department through the Office of Environment, Health, Safety and Security.

1. Detailed plan to repair the dome to ensure that it does not have any harmful effects to the local population, environment, or wildlife, including the projected costs of implementing such plan.

Based on historical data and results from recent surveys, the exterior concrete covering the Cactus Crater containment structure is still serving its intended purpose, effectively reducing natural erosion of the waste pile below. The dome is not in any immediate danger of collapse or failure.

Visual surveys as recently as 2018 found that although some cracks, chipping, and spalling of the concrete cap were evident, the exterior concrete contained in the cap appears to be providing an effective and erosion resistant seal for the encapsulated radioactive material within the containment structure. The observed cracks and spalls do not form sites for external or internal radiation exposure that impact or endanger human health, the environment, or wildlife. Nonetheless, DOE has performed preventative maintenance on exterior surfaces of the containment structure to aid in determining whether any changes are occurring between visual surveys and to address public perception about possible deterioration of the concrete. Non-destructive and destructive testing of concrete cores collected from the cap show the strength properties of the concrete remain strong (Hamilton 2020b, 2020c).

DOE believes that no further maintenance of the dome is required at this time beyond conducting periodic preventative maintenance of the exterior concrete and eradication of rooting vines infiltrating the voids between concrete cap segments. Results from the groundwater monitoring program will ultimately be used to make an informed decision about management of the site. In the interim, DOE will continue to provide preventative maintenance of the external concrete.

2. Effects on the environment that the dome has currently and is projected to have in 5 years, 10 years, and 20 years.

There are no data to suggest that the dome, or more specifically, the radioactive material encapsulated within the containment structure, is currently having a measurable adverse effect on the surrounding environment or is expected to have any adverse effect on the environment in 5, 10, or 20 years. However, DOE is in the process of establishing a groundwater radiochemical analysis program that is designed to provide scientifically substantiated data that can be used to determine what, if any, effects the dome contents are having, or will have, on the surrounding environment now and in the future.

The key pathway for exposure to radioactive materials contained in the Cactus Crater containment structure is from leakage of contaminated groundwater entering the local marine environment, and the subsequent uptake of dome derived fallout contamination into the marine food chain.

DOE recently re-established two borehole locations, one in an area outside the containment structure and one in the containment structure, drilled by the National Academy of Sciences in 1980. Although water depth sensor data from the boreholes indicate that groundwater level inside the containment structure rises and falls with changes in the ocean tide, limited radiochemical analysis of water samples collected from the boreholes, the nearshore lagoon, and the open ocean indicate that, in general, levels of fallout contamination in the dome groundwater far exceed those observed in open ocean waters from across the Marshall Islands. The same is true in comparing the level of ^{137}Cs and iodine-129 (^{129}I) contamination in dome groundwater with that observed in Enewetak lagoon waters. This is not true for Pu isotopes. Similar levels of Pu contamination have been observed in the dome groundwater and the lagoon waters. This can be explained by the fact that there is over 100 times more Pu as TRU contamination freely available in the lagoon sediments compared with that stabilized in the containment structure as a concrete-encased, contaminated-soil mixture (67,800 GBq vs. 545 GBq, respectively). Consequently, the main source of Pu in the lagoon water is from slow and continuous dissolution of sedimentary sources of Pu inside the lagoon, not from leakage of radioactive waste from the containment structure.

Isotopic analyses appear to support this view, showing that elevated levels of Pu observed in lagoon waters in the vicinity of Runit Island appear to be derived from the dissolution of sedimentary sources of Pu into solution rather than from the leakage of waste from the containment structure. As a result, any leakage of dome fallout contamination from Cactus Crater into the marine environment is difficult to distinguish from existing levels of contamination in the lagoon. This situation is not likely to change in the foreseeable future as the total amount of TRU waste (including Pu isotopes) encapsulated in Cactus Crater is dwarfed by the TRU inventory available for re-solubilization in local lagoon sediments. Moreover, the annual dissolution rate of sedimentary Pu released into the surrounding water column represents a very small fraction (<< 1 percent) of the remaining sedimentary inventory of Pu in the lagoon. Therefore, this existing source of Pu contamination in the lagoon is likely to

dominate observed distributions of Pu acquired by local marine biota for the foreseeable future.

DOE also recently analyzed banded corals. The skeletal material laid down by banded corals accumulates radionuclides, such as Pu, in proportionate amounts to the concentrations observed in the surrounding water column. Consequently, analysis of aged coral sections can provide an effective retrospective assessment tool to monitor for changes in the level of fallout contamination in the marine environment over the life history of the coral. This methodology is analogous to tracking pollutants in tree rings. Retrospective analysis of Pu in an aged coral core collected in the lagoon off the Cactus Crater containment structure clearly shows that the Pu contamination in local lagoon waters has decreased significantly since the early 1960s (Figure 1). These data provide compelling evidence that contamination in the waste pile within the Runit Dome has had, and continues to have, a negligible impact on the wider marine environment.

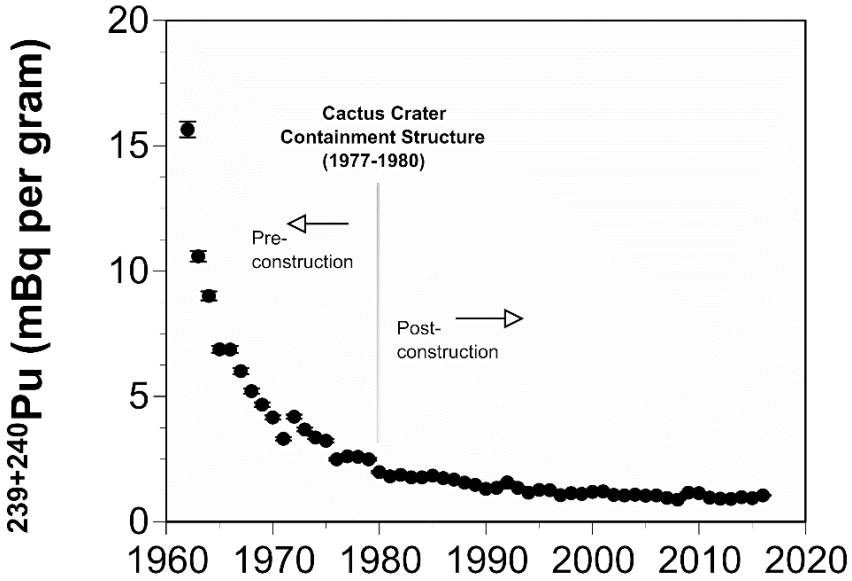


Figure 1. Analysis of Pu in a coral core sample collected in offshore water from the Runit Dome.

DOE is currently in the process of implementing the groundwater radiochemical analysis program as required by the *Insular Areas Act of 2011*. However, this phase of the project is presently on hold due to international travel restrictions. The following information describes the activities to be conducted once access to the atoll is restored.

The initial task under this project is to establish a network of groundwater monitoring boreholes surrounding and in the Cactus Crater containment structure. The flow of contaminated groundwater away from the site boundary into the marine environment will be controlled by the solubilization potential of radionuclides encapsulated in the waste pile and

local groundwater hydrology. In turn, these interactions and the mass-transport of fallout contamination will be influenced by forcing events, such as diurnal tides, storms, and periods of high rainfall. Groundwater monitoring boreholes will be strategically placed along forcing lines predicted by the direction of prevailing winds and the ocean reef break. DOE's plan is to place three well clusters in the containment structure, two well clusters around the containment structure, and one well cluster away from the containment structure as a control (identified in red, green, and grey, respectively, in Figure 2, below). This arrangement will allow for a determination of water table shape, gradient magnitude, and flow direction. Full implementation of a proposed groundwater monitoring program under the *Insular Areas Act of 2011* will enable the dynamics of these processes to be studied in a scientifically credible manner. Results stemming from these studies will then be used to develop a conceptual model of mass-transport of fallout radionuclides into the marine environment under different release scenarios. The goal is to produce a site-specific dose assessment and quantitative risk analysis that describes conditions that may affect the health status of the people of Enewetak now and in the future.

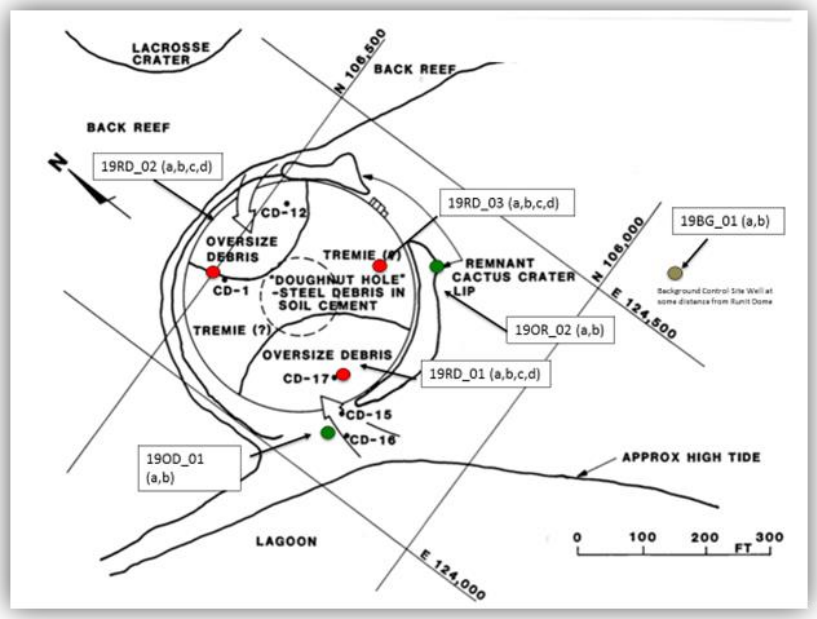


Figure 2. Schematic cross-section showing proposed locations of groundwater monitoring wells surrounding and in the Runit Dome containment structure (schematic modified after Ristvet, 1980).

3. Assessment of the current condition of the outer constructs of the dome.

As stated in response to Element 1, visual surveys and structural testing of the cap from as recently as 2018 indicate that although some superficial cracks, chipping, and spalling of the concrete are evident, the exterior concrete covering the Cactus Crater containment structure is still serving its intended purpose, effectively reducing the natural erosion of the waste pile

below by wind and water. Any concerns about the imminent failure or collapse of the structure are unfounded.

As with most concrete pads and structures, cracks often appear in aged concrete from long-term drying shrinkage. Similarly, the chipped edges and spalls observed in the concrete cap are likely caused by thermal movement of the slabs due to expansion and contraction. Both destructive and non-destructive testing of the concrete cap was recently conducted to determine the viability of placing a drill rig on the cap. Non-Destructive Testing (NDT) techniques based on Ground Penetrating Radar (GPR) for sub-grade evaluation, Impact Echo (IE) for concrete thickness and condition, and Spectral Analysis of Surface Waves (SASW) for overall concrete condition have been performed (Hamilton 2020c). These data show that the structure is not in any immediate danger of collapse or failure. The concrete cap segments are sitting in intimate contact with the encapsulated waste pile below with very few voided or poorly consolidated areas. In general, analyses of contemporary concrete core samples show that the exterior concrete remains well-cemented, appears to be properly consolidated and cured, and has satisfactory strength and binding properties. Cracks observed along the exterior portion of concrete do not appear to be adversely affecting the strength properties or overall integrity of the concrete. These data, along with compression and load capacity strength testing of the concrete, indicate that the structure can support the weight of a drilling rig and provide added confidence that the drilling and groundwater sampling borehole installation project, as required to comply with the *Insular Areas Act of 2011,* can be conducted in a safe manner.

4. Assessment of the current and long-term safety to local humans posed by the site.

Individual radiological protection monitoring data collected from the Department's Marshall Islands Program indicate that the people on Enewetak are not being exposed to levels of fallout contamination of concern to human health. There is no evidence to suggest that the containment structure represents a significant source of radiation exposure relative to other sources of residual radioactive fallout contamination on the atoll.

Over the past two decades, DOE, together with the Enewetak Ujelang Local Government (EULG), has developed a comprehensive individual radiological protection monitoring program on Enewetak Atoll, based on whole-body counting and Pu urinalysis bioassay. The Enewetak Radiological Laboratory on Enewetak Island is operated and maintained by Marshallese technicians, with scientists from Lawrence Livermore National Laboratory (LLNL) providing oversight, technical support services, and reporting (see https://marshallislands.llnl.gov/dose_report/index.php). ^{137}Cs is a major contributor to the manmade dose on Enewetak through consumption of local marine and terrestrial foods. While ingestion of ^{137}Cs from consumption of locally grown food tree crops is by far the most dominant exposure pathway, the whole-body counting program is by default also monitoring for potential dietary intakes of ^{137}Cs from consumption of fish and other marine foods, including those collected in the vicinity of the Cactus Crater containment structure. Similarly,

DOE has been performing periodic collections of bioassay samples on Enewetak to assess potential exposures of the local population to Pu isotopes in the environment.

The monitoring results indicate that the people of Enewetak are being adequately protected from exposure to internally deposited ^{137}Cs, and that the concentration of Pu observed in Enewetak residents is well within the normal range expected for people exposed to world-wide fallout contamination in the environment. The average annual effective dose from internally deposited ^{137}Cs in the adult male population on Enewetak over the four decades has ranged from <0.01 to about 0.05 millisievert (mSv) (<1 to 5 mrem), trending towards lower doses. The most widely accepted international standard for the protection of the public from radiation exposure is 1 mSv (100 mrem) per year above background. The population average urinary excretion rate of Pu from Enewetak residents is <1 micro Becquerel (µBq) per 24-hour void, compared with a measurement background of ~0.01 µBq observed in compatible sets of field blank samples (https://marshallislands.llnl.gov/plutonium.php). In general, the concentration of Pu observed in bioassay samples collected from Enewetak residents is well within the normal daily range of around 2-4 µBq expected for people exposed to worldwide fallout contamination in the northern hemisphere (NRC, 1994 and references therein). As such, there is no evidence to show that people living on Enewetak have acquired measurable quantities of Pu in their bodies above background.

Together, the individual radiological protection monitoring program based on whole-body counting and Pu bioassay show that the Enewetak population average internal dose rates from exposure to fallout radionuclides are in the range of a few mrem per year, or well below international standards for radiological protection of the public; i.e., 100 mrem per year. The continuing individual monitoring program will provide ongoing assessments of any significant changes in radiological conditions as they occur in real time, and of long-term safety to humans across Enewetak Atoll as a whole, not just that associated with the Cactus Crater containment structure. The monitoring program provides a more direct measure of human exposure to key fallout radionuclides, such as ^{137}Cs and Pu across Enewetak Atoll, independent of dietary assumptions and questions about possible leakage of radioactive waste from Cactus Crater. Results from the monitoring program show that the people on Enewetak are not being exposed to levels of fallout contamination of concern to human health.

The main safety concern to humans associated with leakage of radioactive waste from the Cactus Crater containment structure is the uptake of fallout radioactivity in marine foods. However, leakage of radioactive waste from the containment structure into the marine environment will continue to be dwarfed by the solubilization of sedimentary sources of Pu in the lagoon. While the potential does exist for contaminated dome groundwater to flow into the near-field, subsurface marine environment and possibly form highly localized contamination regimes in and around outflow points in the lagoon or on the ocean reef, any dome-derived groundwater reaching outflow points in the lagoon will be very rapidly diluted and possibly continue to be masked by local sources of marine contamination.

A full quantitative, site-specific assessment of the current and long-term risks posed by the Cactus Crater containment structure cannot be fully realized until the results of the proposed groundwater monitoring program, conducted in response to the *Insular Areas Act of 2011*, are known. The goal is to produce a site-specific dose assessment and quantitative risk analysis that describes conditions that may affect the health status of the people of Enewetak now and into the future.

5. Assessment of how rising sea levels might affect the dome.

Sea level rise is a critical concern for people living on low-lying island areas, such as the RMI. The most notable and immediate impact of rising sea levels on the Cactus Crater containment structure would be that associated with the physical effects of storm surge and wave-driven flooding.

An artificial riprap wall, which is located on the ocean-side of the containment structure and comprised of large-size quarry blast rock, rejected key wall sections, and smaller size rocks and aggregate, provides some protection of the containment structure along the ocean reef. Less protection exists on the lagoon side of the containment structure. The ocean beach front adjacent to the containment structure was inundated by a high-tide storm event in 2009 (Hamilton, 2013). Storm surge opened a sandy channel extending up from the ocean reef towards the containment structure, depositing sand, rubble, and vegetative debris over the bottom segments on the western side of the containment structure. The storm surge also filled in one of two historical groundwater sampling boreholes established on land adjacent to the containment structure with debris. Similar physical forcing events produced by strong westerly winds and high swells within the lagoon could also lead to wave-induced over-wash of lower sections of the dome.

The likely scenario of sea-level rise intensifying wave-driven flooding of the dome is consistent with effects of model simulations reported for Roi-Namur Island on Kwajalein Atoll (Storlazzi *et al.*, 2018). Any future increase in the severity and frequency of storms or other major climactic forcing events may affect local groundwater hydrology beneath the containment structure and potentially increase the flow of contaminated groundwater into the lagoon or onto the ocean reef. However, no definitive data exists on how these events might impact on the environment.

The proposed drilling and groundwater sampling installation project, in response to the *Insular Areas Act of 2011*, is designed to provide some understanding of possible effects of forcing events, such as storm surge on changes in groundwater quality. The baseline groundwater sampling program will be conducted over a period of not less than 12 to 18 months (Hamilton 2013) and involve high-resolution sampling and radiochemical analysis of groundwater every four to six weeks. Initial baseline measurements are needed to establish boundary conditions for interpreting any changes observed in water quality under the *Insular Areas Act of 2011*.

Contemporary measurements on the height of groundwater beneath the containment structure show the hydrologic system is responding to the influence of diurnal tidal cycles. The groundwater can equally be expected to respond to major short-term forcing conditions imposed by storm surge and possible flooding events. Baseline measurements encompassing at least a full seasonal cycle of climactic conditions will be used to elucidate the effects of different forcing conditions on groundwater quality and the possible mass-transport of radioactive contaminants away from the site boundary. Moreover, it is anticipated that any measured or modeled effects of storm events may help provide a better understanding of the long-term consequences of sea level rise on mass-transport of dome-derived radionuclides.

6. Summary of interactions between the Government of the United States and the Government of the Marshall Islands about the dome.

The U.S. Government, through DOE, has had many interactions with the RMI Government regarding the Runit Dome. The most frequent method of interaction between DOE and RMI officials is informal meetings scheduled in Majuro, the capital of the RMI. DOE typically requests meetings with the national (Senator) and local (Mayor) government officials from each of the four atolls (Enewetak, Bikini, Rongelap, and Utrōk) prior to conducting any field activities, to provide an update on current program goals, obtain permission to access sites, and to invite the officials to participate in activities. After-action meetings are also conducted to discuss activities completed and planned. These meetings provide an opportunity for RMI officials to ask questions and share any concerns they may have with DOE. Invitations have also been extended on various occasions to staff from various government agencies, such as the Marshall Islands Marine Resources Authority (MIMRA), to participate in field missions.

The following is a summary of recent formal interactions conducted with RMI officials regarding the Runit Dome.

August 6, 2015: The U.S. Ambassador to the Marshall Islands accompanied a delegation from DOE and the RMI, led by the Science Director of the LLNL Marshall Islands Dose Assessment & Radioecology Program, to inspect the condition of the Cactus Crater containment structure in the aftermath of Tropical Storm Nangka.

August 5, 2016: The U.S. Ambassador accompanied DOE officials, including the Associate Under Secretary for Environment, Health, Safety and Security and the Director of the Office of Health and Safety, as well as the Science Director of the LLNL Marshall Islands Dose Assessment & Radioecology Program on a visit to Enewetak Island to meet with the local community and tour the whole body counting facility. The delegation also viewed the Runit Dome and Runit Island. The Mayor of Enewetak travelled with the group and RMI national government officials were also invited.

December 6, 2016: The Science Director of the LLNL Marshall Islands Dose Assessment & Radioecology Program met with the Mayor of the Enewetak Ujelang Local Government (EULG)

to discuss preliminary results of analyses of dome groundwater collected from a re-constituted borehole from inside the Runit Dome.

December 14, 2017: The Science Director of the LLNL Marshall Islands Dose Assessment & Radioecology Program provided an informal briefing for the RMI Minister-in-Assistance and the Senator from Enewetak on the Runit Dome.

October 9, 2018: The U.S. Ambassador accompanied a delegation from DOE, led by the Science Director of the LLNL Marshall Islands Dose Assessment & Radioecology Program, on a tour of the Cactus Crater containment structure to review field operations conducted in support of the *Insular Areas Act of 2011*. RMI officials were also invited.

January 14, 2019: LLNL hosted the RMI National Nuclear Commission (NNC), as well as DOE officials, the U.S. Ambassador to the Marshall Islands, and the RMI Ambassador to the United States in Livermore, California, for a forum on nuclear legacy issues in the Marshall Islands. LLNL provided presentations on the work completed and planned for the Runit Dome under the *Insular Areas Act of 2011*.

May 15-16, 2019: The Science Director of the LLNL Marshall Islands Dose Assessment & Radioecology Program offered a presentation at the 2019 DOE/RMI Annual Meeting in Majuro on the DOE monitoring activities at the Runit Dome under the *Insular Areas Act of 2011*. This meeting was attended by DOE officials, including the Associate Under Secretary for Environment, Health, Safety and Security, the U.S. Ambassador to the Marshall Islands and other officials from the U.S. Embassy, officials from the U.S. Army Garrison Kwajalein Atoll, and Representatives from the RMI national and local government. DOE also responded through the U.S. Embassy after the meeting to issues raised concerning the Runit Dome. Previous annual meetings, which are sometimes held less than annually due to scheduling conflicts, that included discussions of the Runit Dome, were held at the U.S. Army Garrison Kwajalein Atoll on October 11-12, 2017, and in Majuro on January 8-9, 2015.

July 2, 2019: DOE responded to a letter received from the RMI Minister of Justice on May 20, 2019, requesting construction of a fence around the perimeter of Runit Island. DOE indicated it was currently evaluating the request, but noted some challenges, including funding constraints, complex installation logistics, and long-term integrity and maintenance issues.

November 1, 2019: DOE officials met in Majuro with the Senator and Mayor of Enewetak Atoll. During the meeting, DOE officials provided a brief update on the drilling project planned as part of the implementation of the groundwater monitoring program for the Runit Dome.

December 3, 2019: DOE officials joined the U.S. Ambassador to the Marshall Islands for a meeting in Majuro with the RMI Minister of Foreign Affairs and Trade and staff. During the meeting, DOE officials provided an update on the activities completed and planned for the Runit Dome under the *Insular Areas Act of 2011*.

IV. Conclusion

The Runit Dome is a containment structure on Runit Island, located on Enewetak Atoll. Enewetak Atoll is a former U.S. atmospheric nuclear weapons test site located in the RMI, approximately 2,300 miles west of Hawaii in the northwest Pacific Ocean. The Runit Dome, which was built in the late 1970s, contains over 100,000 cubic yards of contaminated soil and debris that were encapsulated in concrete inside an unlined nuclear test crater, the Cactus Crater, on the north end of Runit Island. The site has remained a concern to the people of Enewetak and their leadership.

The Runit Dome is not in any immediate danger of collapse or failure, and the exterior concrete covering the containment structure is still serving its intended purpose, effectively reducing the natural erosion of the waste pile below by wind and water. Visual surveys of the exterior concrete of the Cactus Crater containment structure have revealed the presence of cracks and spalls in the concrete cap. However, these cracks and spalls in the exterior concrete cap do not form sites for external or internal radiation exposure that impact or endanger human health or the environment, or wildlife. DOE has performed preventative maintenance on exterior surfaces of the containment structure, which will aid in the determination of any changes that may occur in the condition of the concrete in the future. Any concerns about the imminent failure or collapse of the structure are unfounded.

The main safety concern to humans associated with leakage of radioactive waste from the Cactus Crater containment structure is the uptake of fallout radioactivity in marine foods. There are no data to suggest that the Cactus Crater containment structure, or more specifically, the radioactive material encapsulated in Cactus Crater, is currently having a measurable adverse effect on the surrounding environment or on the health of the people of Enewetak. However, DOE is in the process of establishing a groundwater radiochemical analysis program that is designed to provide scientifically substantiated data that can be used to determine what, if any, effects the dome contents are having, or will have, on the surrounding environment now and in the future. Long-term trends in the concentration of Pu in lagoon waters derived from retrospective analysis of a coral core collected off Runit Island show levels of Pu in lagoon waters are systematically decreasing. These data provide compelling evidence that the construction of the Runit Dome has had, and continues to have, a negligible impact on the wider marine environment.

Individual radiological protection monitoring data collected from the Department's Marshall Islands Program indicate that radiation dose rates to individuals on Enewetak from internal exposure to fallout radionuclides are well below international standards for radiological protection of the public; i.e., 100 mrem per year. There is no evidence to suggest that the containment structure represents a significant source of radiation exposure relative to other sources of residual radioactive fallout contamination on the atoll. The continuing individual monitoring program will provide ongoing assessments of any significant changes in radiological conditions as they occur in real time, and of long-term safety to humans across Enewetak Atoll

as a whole. In addition, DOE's groundwater radiochemical analysis program is intended to produce a site-specific dose assessment and quantitative risk analysis that describes conditions that may affect the health status of the people of Enewetak now and into the future.

The Cactus Crater containment structure remains vulnerable to wave driven over wash and flooding caused by storm surge and potential effects of sea level rise. DOE's groundwater radiochemical analysis program is also designed to provide some understanding of possible effects of forcing events, such as storm surge, on changes in groundwater quality. It is anticipated that any measured or modeled effects of storm events may help provide a better understanding of the long-term consequences of sea-level rise on mass-transport of dome derived radionuclides.

The Department consistently communicates with the Government and people of the Marshall Islands regarding activities associated with the Runit Dome and remains committed to maintaining this open dialogue in the future.

V. References and Suggested Reading

The following references contain additional details that support the assessments and summaries provided in this report. Additional information may be obtained upon request from the Department through the Office of Environment, Health, Safety and Security.

DNA (1980). *Fact Sheet-Enewetak Operation*, Defense Nuclear Agency (DNA), Washington D.C.

DNA (1981). *The Radiological Cleanup of Enewetak Atoll*, Defense Nuclear Agency (DNA), Washington, D.C.

DOE (1982). *Enewetak Radiological Support Project*, Final Report, NVO-213, edited by B. Friesen and Holmes & Narver, Inc., U.S. Department of Energy (DOE), Nevada Operation Office, Las Vegas, Nevada.

Hamilton, T.F. (2013). *A Visual Description of the Concrete Exterior of the Cactus Crater Containment Structure*, Report, Lawrence Livermore National Laboratory, LLNL-TR-648143.

Hamilton T.F. (2015). *LLNL Marshal Islands Program Briefing Slides*, Lawrence Livermore National Laboratory, LLNL-PRES-665899. U.S. DOE-GRMI Annual Meeting, Majuro, January 12-13, 2015.

Hamilton T.F. (2016). *Talking Points: Enewetak Ujelang (EULG) Local Government Briefing*, Lawrence Livermore National Laboratory, LLNL-PRES-713239.

Hamilton T.F. (2017). *Science Program Briefing: The Runit Dome Project, Briefing Slides*, Lawrence Livermore National Laboratory, LLNL-PRES-739333. U.S. DOE-GRMI Annual Meeting, Kwajalein Atoll, October 12-13, 2017.

Hamilton T.F. (2018). *Fact Sheet: The Runit Island Waste Containment Structure*, Lawrence Livermore National Laboratory, LLNL-BR-755391.

Hamilton, T.F. (2019a). *Science Program Briefing: Public Law 112-149 Continued Monitoring of Runit Island*, Lawrence Livermore National Laboratory, LLNL-PRES-774030. U.S. DOE-GRMI Annual Meeting, Majuro, May 15-16, 2019.

Hamilton, T.F. (2019b). *Runit Dome Drilling Animation, Public Law 112-149 Continued Monitoring of Runit Dome*, Lawrence Livermore National Laboratory, LLNL-PRES-776890.

Hamilton T.F. (2020a). *Web based mosaic and interactive showing results of a drone visual survey of the exterior concrete of the Cactus Crater containment structure on Runit Island, Enewetak Atoll*. https://marshallislands.llnl.gov/, Lawrence Livermore National Laboratory (under construction).

Hamilton, T.F. (2020b). *Runit Project: Data Report—Exterior Concrete Core Test Results*, Lawrence Livermore National Laboratory, LLNL-TR-810020.

Hamilton, T.F. (2020c). *Runit Project: Data Report—Non-destructive Testing and Evaluation Investigation of Runit Island Containment Structure*, Lawrence Livermore National Laboratory, LLNL-TR-810290.

Hamilton, T.F., P. Nyholm, J.S. Stewart and A.S. Connel (2018). *Runit Dome 3-D Animation*. Lawrence Livermore National Laboratory, LLNL-VIDEO-765357.

Hamilton, T.F., P. Nyholm, and J.S. Wynn (2019). *Runit Dome Flyover*, Lawrence Livermore National Laboratory, LLNL-VIDEO-765358.

Hamilton T.F. and R.W. Chen (2019). R*unit Dome Groundwater Bore Hole Drilling Animation_V2.0*, Lawrence Livermore National Laboratory, LLNL-WEB-777157.

H&N (1983a). *Structural Monitoring of Cactus Crater Storage Facility (Runit Dome*), Holmes & Narver Report A83, Field Survey December 1982, Energy Support Division, Pacific Operations, DOE/NV Technical Information Resource Center, Las Vegas, NV.

H&N (1983b). *Structural Monitoring of Cactus Crater Storage Facility, Runit Dome*, Holmes & Narver Report B83, Field Survey June 29, 1983, Energy Support Division, Pacific Operations, DOE/NV Technical Information Resource Center, Las Vegas, NV.

H&N (1984). *Structural Monitoring of Cactus Crater Storage Facility, Runit Dome*, Holmes & Narver Report A84, Field Survey January 4, 1984, Energy Support Division, Pacific Operations, DOE/NV Technical Information Resource Center, Las Vegas, NV.

H&N (1990). *Runit Dome Survey*, Holmes & Narver Report E.091, Energy Support Division, Pacific Operations, DOE/NV Technical Information Resource Center, Las Vegas, NV.

Master Plan (1975). Enewetak Atoll Master Plan for Island Rehabilitation and Resettlement, March 1975, TTPI/H&N, Volume I.

Noshkin, V.E. (1980). *Transuranium radionuclides in components of the benthic environment of Enewetak Atoll,* In: Transuranic Elements in the Environment; ed. W.C. Hanson, U.S. Department of Commerce, National Technical Information Service, Springfield, VA; DOE/TIC 22800, p 578-601.

NRC (1994). *Radiological Assessments for Resettlement of Rongelap in the Republic of the Marshall Islands*, National Research Council, National Academy Press, 1994, 108 pp.

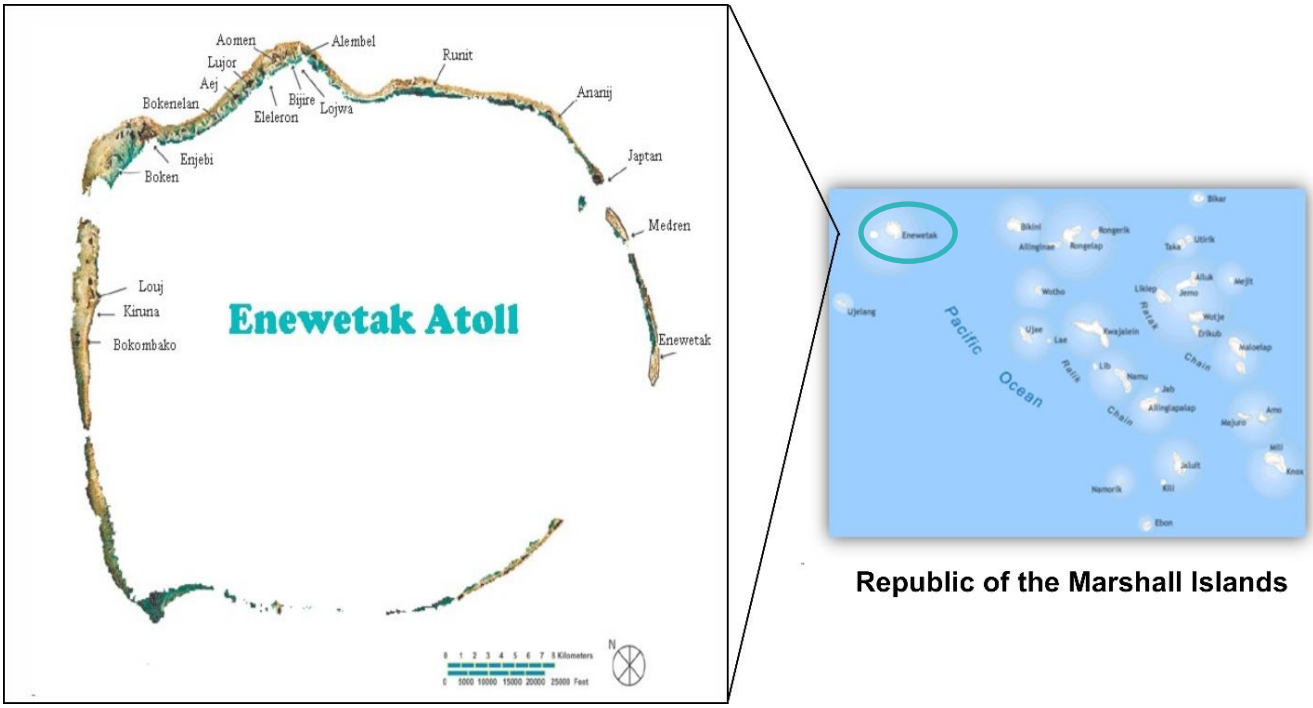
NSTec (2008*). Field Survey of Cactus Crater Storage Facility (Runit Dome)*, Report A08, National Security Technologies, LLC, Environmental Management Directorate, Las Vegas, DOE/NV/25946-569.

NV-140 (1973), *Enewetak Radiological Survey*, Volume I, II and III, United States Atomic Energy Commission, Nevada Operations Office, Las Vegas, Nevada.

Ristvet, B.L. (1980). *Summary of drilling operations conducted at Cactus Dome, Runit Island, Enewetak Atoll, in support of the National Academy of Sciences investigations, 11-28 March 1980*, Defense Nuclear Agency, Kirtland Air Force Base, NM.

Storlazzi, C.D., S.B. Gingerich, A. van Dongeren, O.M. Cheriton, P.W. Swarzenski, E. Quataert, C.I. Voss, D.W. Field, H. Annamalai, G.A. Piniak and R. McCall (2018). *Most atolls will be uninhabitable by the mid-21st century because of sea-level rise exacerbating wave-driven flooding*, Sci. Adv., 4.

VI. Appendix



Map of Enewetak Atoll in the Marshall Islands

Cactus Crater before (left) and after (right) construction of the Cactus Crater containment structure (i.e., Runit Dome)

Design elements of the Cactus Crater containment structure