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Amchitka Island, Alaska, Environmental Sampling Report, 2016 Results

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Abbreviations

ADEC	Alaska Department of Environmental Conservation
AEC	U.S. Atomic Energy Commission
Am	americium (isotope)
AMP	ammonium molybdophosphate
AMS	Accelerator Mass Spectrometry
ANL	Argonne National Laboratory
ANOVA	analysis of variance
APIA	Aleutian Pribilof Islands Association Inc.
AWG	Amchitka Working Group
Bq/kg	becquerels per kilogram
Bq/L	becquerels per liter
COC	chain-of-custody
CRESP	Consortium for Risk Evaluation and Stakeholder Participation II
Cs	cesium (isotope)
CTD	conductivity, temperature, and depth
DIL	derived intervention level
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DQO	data quality objective
DRI	Desert Research Institute
EPA	U.S. Environmental Protection Agency
FAO	Food and Agriculture Organization
FDA	Food and Drug Administration
ft	feet
g	grams
I	iodine (isotope)
IAEA	International Atomic Energy Agency
ICP-MS	inductively coupled plasma mass spectrometry
L	liters
LLNL	Lawrence Livermore National Laboratory
LM	Office of Legacy Management
LTHMP	Long-Term Hydrologic Monitoring Program

LTS&M	Long-Term Surveillance and Maintenance
LTSP	Long-Term Surveillance Plan
MDA	minimum detectable activity
MOU	Memorandum of Understanding
MT	magnetotelluric
NADA	Nondetects and Data Analysis for Environmental Data
pCi/kg	picocuries per kilogram
pCi/L	picocuries per liter
Pu	plutonium (isotope)
Q-Q	quantile-quantile
RBC	risk-based concentration
RDL	relative detection limit
R/V	research vessel
SAGe	Small Anode Germanium
SD	standard deviation
SI	International System of Units
spp.	multiple species, undefined (follows *genus*)
TU	tritium units
U	uranium (isotope)
UAF	University of Alaska Fairbanks
USFWS	U.S. Fish and Wildlife Service
WHO	World Health Organization

Executive Summary

This report documents the results of the 2016 environmental sampling effort conducted by the U.S. Department of Energy (DOE) Office of Legacy Management (LM) at the Amchitka, Alaska, Site, where three underground nuclear tests were conducted between 1965 and 1971. Located in the Aleutian Islands between the Bering Sea and the North Pacific Ocean, the Amchitka site is the most remote of DOE's LM sites requiring long-term stewardship. Although Amchitka Island is currently uninhabited, the surrounding marine environment is ecologically rich and fished both commercially and for subsistence purposes by people (known as Aleut) living on neighboring islands. Nearly 50 years have passed since the last Amchitka test; in that time, numerous hydrological, geophysical, and biological investigations have been conducted by DOE, its predecessor agencies, stakeholders, and other organizations. These investigations were designed to address two primary questions. First, has there been any release of anthropogenic radionuclides into the marine environment as a result of the former underground detonations? Second, is subsistence- and commercial-catch seafood potentially harvested from the region safe to eat with respect to radionuclides?

Except for tritium detected in surface water shortly after one of the tests, results of these combined investigations, including the most recent environmental sampling event documented herein, provide no evidence that test-related radionuclides have migrated from the detonation zones to the freshwater or marine environments on or around Amchitka Island. Hydrologic modeling predicted that radionuclide arrival to the seafloor would not occur for at least 2200 years, the simulation time frame used in the groundwater model. Even if the model predicted much shorter arrival times (e.g., as early as the present time), conclusive evidence of contaminant migration would be difficult to establish because of factors such as dilution, mixing, and the input of radionuclides from other sources. Conclusive evidence of the safety of the surrounding food resource can be established, however. Consistent with the findings of previous environmental monitoring and risk evaluations, cesium-137 (^{137}Cs), plutonium-239 (^{239}Pu), and plutonium-240 (^{240}Pu) levels measured in biota samples collected in 2016 near Amchitka are below both site-specific risk-based consumption levels and established international food safety guidelines.

Site Description and History

Amchitka Island, near the western end of the Aleutian Islands, is approximately 1340 miles west-southwest of Anchorage, Alaska. The island is part of the Aleutian Island Unit of the Alaska Maritime National Wildlife Refuge, which is administered by the U.S. Fish and Wildlife Service (USFWS). Since World War II, Amchitka has been used by several U.S. government agencies for various military and research activities. From 1943 to 1950, it was used as a forward air base for the U.S. Armed Forces. In the 1960s and early 1970s (between 1965 and 1971), the U.S. Department of Defense and the U.S. Atomic Energy Commission conducted three underground nuclear tests on Amchitka Island. The first test, Long Shot, was conducted in 1965 to provide data that would improve the United States' capability of detecting underground nuclear explosions. The second, Milrow, was conducted in 1969 as a means to study the feasibility of detonating a larger device. Cannikin, the third nuclear test on the island and the largest underground nuclear test conducted in the United States, was detonated on

November 6, 1971. During the late 1980s and early 1990s, the U.S. Navy constructed and operated a radar station on the island.

Previous Environmental Studies

Of the numerous studies conducted by DOE and other agencies and investigators since 1970, none have identified any risk to human health and the environment, nor (except for tritium measurements shortly after the Long Shot test) was there evidence of contaminant migration after the former underground tests were conducted. In 2004, the Consortium for Risk Evaluation and Stakeholder Participation II (CRESP) undertook a major biological and geophysical study of the shore and marine environment at and around Amchitka, as well as at a nearby reference island (background site), Kiska. CRESP's investigation concluded that levels of anthropogenic radionuclides detected in the marine environment were below human and ecological risk concerns. CRESP also found no geophysical or biological evidence of radionuclide migration from the Amchitka test shots. In 2006, the Desert Research Institute (DRI) updated their previous (2002) groundwater flow and transport model to incorporate the new magnetotelluric and bathymetric survey data collected by CRESP. Although some contaminant migration is expected eventually, for all three test sites—Long Shot, Milrow, and Cannikin—DRI's second model predicted that it would take thousands of years for radionuclides to reach the seafloor. Related assumptions allowed for radionuclide decay and retardation processes that would limit contaminant concentrations of the few mobile radionuclides. The results of these studies were drawn upon heavily in DOE's establishment of data quality objectives (DQOs) for later monitoring efforts: the first undertaken in 2011 and the second being the 2016 environmental sampling effort, the subject of this report.

DOE 2011 Investigation

As a follow-up to the 2004 CRESP evaluation, DOE, in collaboration with the Alaska Department of Environmental Conservation, USFWS, Aleutian Pribilof Islands Association Inc., University of Alaska-Fairbanks, and Argonne National Laboratory, undertook an extensive sampling of marine and terrestrial biota in June 2011. A purpose of the monitoring was to develop a baseline of activity concentrations for selected radionuclides in biota, water, and soil on Amchitka Island. A similar sampling event was conducted at Adak Island, approximately 200 miles east of Amchitka, used as the background or reference area unaffected by the underground nuclear tests. The scope of the effort included sampling a wide variety of species representing different trophic levels and analyzing tissue samples for ^{137}Cs, ^{239}Pu, ^{240}Pu, and other potential test-related radionuclides common to those evaluated by CRESP in 2004. In addition to sampling of biota, seawater samples collected off coastline transects (focusing on Cannikin) were analyzed for tritium. The major focus of the 2011 investigation and report was to evaluate food safety. This was done by collecting the data necessary (biologic sampling), evaluating food consumption survey data, and developing a risk assessment addressing five different diet scenarios assuming subsistence diets.

Based on the 2011 data collected for Amchitka and the subsequent risk assessment, subsistence- and commercial-catch seafood was determined to be safe for human consumption, consistent with CRESP's previous findings. For most diet scenarios, corresponding risk estimates, calculated assuming life-long consumption of subsistence seafood, were below 1×10^{-5} (1 in 100,000), the level considered safe by the State of Alaska Department of Environmental

Conservation (ADEC). Also, based on the radionuclide levels measured in biota and seawater samples and statistical comparisons with the background site sample results, no indication of contaminant migration from the detonation zones to the marine environment was found. A factor considered in the interpretation of these and later (2016) sampling results, as well as corresponding analytical scopes, was the Fukushima nuclear accident. On March 11, 2011, about three months before LM's first biological sampling event, a 9.1 magnitude earthquake and subsequent massive tsunami struck the island of Japan, severely damaging several reactors at the Fukushima Daiichi Nuclear Power Plant. This nuclear accident caused the release of radioactive materials into the atmosphere and the coastal marine environment. The radioactivity releases into the Northwest Pacific Ocean were unprecedented and, given the magnitude of the Fukushima ^{137}Cs input, ultimately complicated LM's interpretations of the 2011 and 2016 Amchitka sampling program analytical results.

2016 Environmental Sampling Event

In collaboration with the Amchitka Working Group and developed using an iterative strategic planning process, four biological species were selected for analysis in 2016: rockweed (*Fucus distichus*, representing sessile primary producer species) and four resident fish species: rockfish (*Sebastes* multiple species [spp.]), greenling (*Hexagrammos* spp.), Irish lord (*Hemilepidotus* spp.), and Dolly Varden (*Salvelinus malma*). Consistent with the 2011 sampling, Adak was again used as the reference island in 2016. The species sampled were identified based on diet information representing some of the subsistence- and commercial-catch seafood in the western Aleutian Islands. Biological sampling began May 12, 2016, and continued through May 23, 2016. Biota samples were analyzed for ^{137}Cs, cesium-134 (^{134}Cs; to help identify a Fukushima signature), ^{239}Pu, and ^{240}Pu. One of the DQOs established in the sampling plan was to use lower detection limits than those used in 2011. Although this objective was achieved for biota samples (laboratory analyses took over 2 years to complete), it also complicated the interpretation of between-year trends for some radionuclides, in particular ^{239}Pu.

As a continuation of the abiotic sampling conducted in 2011, seawater samples were collected from 40 locations off the coast of Long Shot (the focus of the 2016 sampling effort) and from several locations at remaining study transects (Milrow, Cannikin, and the reference site). Limited freshwater sampling was also conducted. Overall, a total of 168 biological samples and 50 seawater samples were collected. Seawater and freshwater samples were analyzed for tritium, ^{137}Cs, and ^{134}Cs in accordance with the sampling plan. Analysis for iodine-129 was also added for a few seawater samples.

Summary of 2016 Environmental Sampling Results

In establishing the DQOs for the 2016 sampling effort, a major focus was on comparing the 2016 results with corresponding results from 2011. Because the 2011 investigation indicated that seafood was safe to eat based on the radionuclide levels measured at that time, if 2016 results were equivalent to or lower than those levels, then previous conclusions regarding food safety and the lack of evidence of contaminant migration would be maintained.

<u>Biota Sampling Results</u>

- For all species, the mean ^{137}Cs content measured in biota samples from Amchitka in 2016—0.6 picocuries per kilogram (pCi/kg) for rockweed and 1.8–2.8 pCi/kg for marine fish—was

lower than corresponding 2011 results. A possible explanation for these findings is the difference in analytical methods—beta spectrometry in 2011 and higher-resolution gamma spectrometry in 2016. Another possible explanation is the more prominent Fukushima signature in 2011, as indicated by ^{134}Cs beta interferences identified in the 2011 biota samples. For these reasons, between-year statistical comparisons were not determined. Mean ^{137}Cs levels measured in biota samples from Amchitka in 2016 were also lower than those measured in samples collected from Adak, which served as the background location. However, no statistically significant interisland differences were found for the fish species sampled; that is, Amchitka results were similar to those from Adak.

- Given the greater laboratory sensitivity achieved in 2016, ^{239}Pu was measured in the majority of fish and algal samples from Amchitka in 2016 and overall about half of those from Adak, albeit mostly at or near the detection limits of the instrument. This was not the case in 2011, when ^{239}Pu was measured in only a small subset of biota samples. For all species, mean ^{239}Pu levels were lower in 2016 than in 2011 (the 2011 mean levels were estimated by substituting nondetects with detection limit values). The between-year differences likely are an artifact of the change in measurement sensitivity between the two years rather than a true decrease in concentration.
- Based on 2016 results, statistically significant interisland differences in detection frequency or ^{239}Pu activity concentrations were found for all resident marine fish species. Both measures (^{239}Pu detection frequencies and tissue concentrations) were higher in samples from Amchitka relative to Adak. However, these differences are not considered biologically significant because ^{239}Pu levels measured in marine fish (0.003–0.028 pCi/kg) were about 2–3 orders of magnitude lower than corresponding risk-based levels (risk estimates were less than 1×10^{-8}).
- Based on initial reporting by the laboratory in 2018, only four samples contained detectable levels of ^{240}Pu (results were ≤ 0.1 pCi/kg). Although passing quality assurance requirements, these results were later determined to be anomalous and therefore not considered as quantitative. Despite these reported anomalies, ^{240}Pu levels of ≤ 0.1 pCi/kg are at least two orders of magnitude below corresponding conservative risk-based levels.
- Of the 167 biota samples analyzed for cesium, no reportable ^{134}Cs was detected in fish or algae samples except for three Dolly Varden (two from Adak) and a single rockfish sample, also collected from Adak. As ^{134}Cs has a half-life of only 2 years, these results likely indicate a Fukushima-derived contaminant signature.

In summary, the 2016 biota sampling results continue to demonstrate that seafood harvested near Amchitka Island is safe for consumption. Risk estimates calculated assuming life-long consumption of subsistence seafood, and maximum concentrations measured in 2016 biota samples, were 1×10^{-6} and 3×10^{-6} for Amchitka and Adak, respectively. These levels are consistent with those derived based on 2011 results and are lower than the 1×10^{-5} risk level used by the State of Alaska as a benchmark for acceptable risk. Cesium-137 is the primary contributor to the total risk, a portion of which likely reflects a Fukushima signature. Additionally, there is no indication of contaminant migration from the detonation zones based on the criteria defined in the sampling plan but, as acknowledged at the outset, such determinations are difficult because of dilution, mixing, and other sources of anthropogenic radionuclides.

Seawater Sampling Results

Tritium levels measured in Amchitka seawater samples in 2016 ranged from 1.1–2.5 picocuries per liter (pCi/L); the mean concentration was 1.5 pCi/L. These levels are comparable to those measured in 2011 (1.2–2.2 pCi/L), as well as those measured in samples from Adak.

Tritium activities measured in 2016 were also below the 5.4 pCi/L trigger level established by the Amchitka Working Group. The 5.4 pCi/L guideline was derived after considering reported ranges of both pre- (1.3–1.9 pCi/L) and post-Fukushima (1.35–5.4 pCi/L) background (global fallout) levels measured in the North Pacific Ocean.

Given the low tritium levels relative to these ranges and similar activity concentrations at Adak and Amchitka, there continues to be no evidence that test-related radionuclides have migrated to the marine environment.

Cesium-137 was detected in all seawater and freshwater samples but at low levels: 0.033–0.068 pCi/L in samples from Amchitka and 0.048–0.050 pCi/L in those from Adak. All results are well below the 0.216 pCi/L criterion established in the sampling plan as a trigger level for further action. No reportable levels of ^{134}Cs were measured in 2016 water samples.

Summary and Conclusions

In summary, previous conclusions regarding food safety are maintained given that 2016 results are less than 2011 results. Corresponding risk estimates, calculated assuming life-long consumption of subsistence seafood and maximum radionuclide concentrations measured in biota, were below 1×10^{-5} (1 in 100,000), the level considered safe by ADEC. Radionuclide levels measured in biota samples collected in the marine environment around Amchitka are also well below international food safety guidelines. As such, based on sampling results to date, seafood harvested from the marine environment surrounding Amchitka remains safe for human consumption. Tritium concentrations measured in seawater samples are well within both pre- and post-Fukushima background ranges; most results were well below the 5.4 pCi/L trigger established by the Amchitka Working Group. Questions to consider in the future relate to how biota and seawater should be monitored over time to best meet long-term objectives, in particular the continued evaluation of food safety.

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1.0 Introduction

This report documents the results of the 2016 environmental sampling effort conducted by the U.S. Department of Energy (DOE) Office of Legacy Management (LM) at the Amchitka, Alaska, Site, where three underground nuclear tests were conducted between 1965 and 1971 (Figure 1). This sampling event was the second major endeavor of this nature undertaken by DOE since LM assumed responsibility for long-term surveillance activities on October 1, 2006. The Long-Term Surveillance and Maintenance (LTS&M) Plan, first issued in 2008 (DOE 2008), described the overall objectives of the site environmental monitoring program, including the scope of LM's first environmental sampling event conducted in 2011. The most recent Long-Term Surveillance Plan (LTSP) (DOE 2014a) describes how LM plans to conduct its mission to protect human health and the environment at the site, including seismic surveillance, inspections, environmental monitoring, and maintaining open communication with stakeholders.

Located in the western portion of the Aleutian Islands between the Bering Sea and the Pacific Ocean, the Amchitka site is the most remote of DOE's LM sites requiring long-term stewardship. Amchitka Island, approximately 1340 miles west-southwest of Anchorage, Alaska, is part of the Aleutian Islands Unit of the Alaska Maritime National Wildlife Refuge, which is administered by the U.S. Fish and Wildlife Service (USFWS). Although Amchitka Island is uninhabited and has been for well over a century, the surrounding marine environment is biologically rich and fished both commercially and for subsistence purposes by persons (known as Aleut) living on neighboring islands.

Between 1965 and 1971, the U.S. Department of Defense (DOD) and the U.S. Atomic Energy Commission (AEC) conducted three underground nuclear tests on the island: (1) Long Shot, detonated on October 29, 1965; (2) Milrow, detonated on October 2, 1969; and (3) Cannikin, the largest underground nuclear test conducted in the United States, detonated on November 6, 1971. These underground nuclear tests were the catalysts for numerous hydrological, geophysical, and biological investigations conducted by DOE, its predecessor agencies, stakeholders, and other organizations. To date, apart from elevated near-surface tritium activity concentrations measured shortly after the Long Shot test, results of these combined studies provide no evidence that migration of test-related radionuclides from the detonation zones has occurred.

Following up on earlier investigations and in accordance with the LTS&M Plan (DOE 2008), LM conducted a major environmental sampling in June 2011. This study entailed analysis of radionuclide content in samples from 14 biological species (algae, invertebrates, and fish) and analysis of tritium in seawater and freshwater samples. Samples were collected from the three Amchitka test shot locations (Cannikin, Long Shot, and Milrow) and at a background or reference site, Adak Island, about 200 miles to the east (Figure 1). Consistent with previous investigations, results of the 2011 environmental sampling did not identify test-related radionuclide seepage into the terrestrial or marine environments. Results of the associated risk assessment, a major focus of the 2011 effort, confirmed that subsistence- and commercial-catch seafood harvested from the region is safe for human consumption.

To follow up on that investigation, and in accordance with the LTSP requiring that site inspections and environmental monitoring be conducted every 5 years, DOE conducted the second environmental sampling event in May–June 2016. The results of that effort are documented herein.

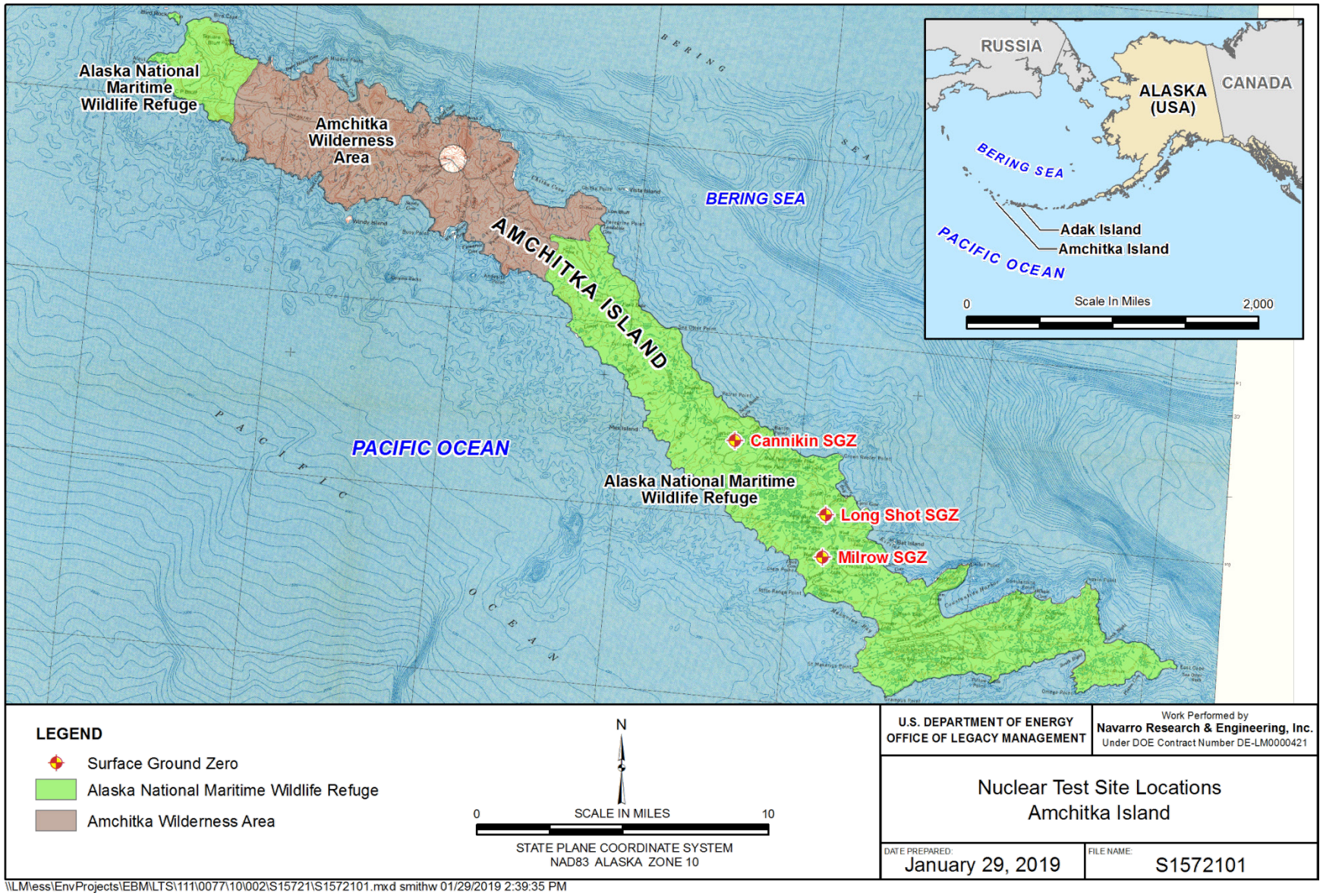

Figure 1. Amchitka Test Site Locations

LM developed the specific objectives of the 2016 environmental sampling event in collaboration with a group of stakeholders representing the federal government, the State of Alaska, the University of Alaska, and the Aleutian Pribilof Island Association Inc. (APIA), collectively referred to as the Amchitka Working Group (AWG). As described in the following sections, a specific project goal for the 2016 environmental sampling event was to update previous assessments of food safety. This would be achieved largely by comparing the 2016 sampling results with 2011 sampling results, which indicated no evidence of test-related contaminant migration and no risk to human health from consumption of subsistence- and commercial-catch seafood.

1.1 Sampling and Data Quality Objectives

As part of LM's long-term stewardship and monitoring for the Amchitka site, the 2016 environmental sampling effort included a biomonitoring component (collection and analysis of algae and fish tissue) and seawater and freshwater sampling to address the objective of identifying potential migration of test-related radionuclides from the detonation zones. Between 2014 and early 2016, LM met several times with AWG to plan the 2016 sampling event. These collaborations culminated in the development of the 2016 Environmental Sampling Plan (DOE 2016a), which determined the species, media, and radionuclides for assessment; corresponding sample locations and numbers; and which analytical techniques might be best suited to reduce uncertainties in the analysis. An overarching goal was to select laboratory analytical methods with sufficiently low detection sensitivity to measure the baseline activities of radionuclides in sampled biota and seawater. Meeting this objective would improve assessments of food safety, potentially fill information gaps stemming from previous nondetect results, and support future statistical trend analyses.

Following up on previous work, consideration was also given to the possible complexities in interpreting background activity concentrations of target radionuclides due to releases from the Fukushima Daiichi facility nuclear accident to the atmosphere and marine environment that occurred in March 2011. The accident resulted from a 9.1 magnitude earthquake and subsequent tsunami that occurred just 3 months before the June 2011 environmental sampling event. Subsequent radioactivity releases into the Northwest Pacific Ocean were unprecedented and ultimately complicated LM's interpretations of the 2011 and 2016 radiocesium analytical results.

Before outlining specific data quality objectives (DQOs) developed for sampling of biotic and abiotic compartments, some clarification of the terminology used in the 2016 sampling plan is warranted, in particular the language used to frame the DQOs. Many of the DQOs focused on identifying "leakage"—that is, the potential for contaminant migration from the detonation zone, where the detonation zone includes the former cavity, the collapse chimney, and surrounding fractures created by the detonation. The term has been used often in reporting results of early site investigations (e.g., Dasher et al. 2002) and more recently in establishing the DQOs for the 2016 sampling event (DOE 2016a). However, radionuclide levels in seawater and biota potentially indicating "leakage" have never been estimated or established, in part because of the uncertainties associated with groundwater flow and radionuclide transport processes. These uncertainties are compounded by other factors such as dilution and mixing due to ocean currents and the input of anthropogenic radionuclides from other sources (e.g., the 2011 Fukushima nuclear accident). Because of these complex environmental processes, and the uncertainties inherent in their characterization, conclusive evidence of test-related leakage would be difficult

to detect or identify. Migration of radionuclides from the detonation zones might be suspected if contaminant levels were significantly greater than levels attributed to global fallout (background) or if an unexpected assemblage of radionuclides were detected.[1] Such anomalies in results would trigger further evaluation and potentially additional sampling. However, even then, attribution of those results to the former underground tests would be inconclusive. Given other radionuclide sources in the North Pacific and the resulting complexity of the background environment, attributing low levels of radionuclides to the Amchitka tests is difficult. For these reasons, DOE's primary focus is on the protection of human health and the environment, in particular ensuring food safety.

1.1.1 Biological Sampling

Results of biota sampling conducted in 2011 indicated that radionuclide levels were protective of the subsistence diet and were similar to levels found at the background reference location, Adak Island (DOE 2013). Based on these findings, 2016 sampling efforts focused on collection of algae and resident fish species to determine if there has been any statistically significant change in concentration. Specific objectives are outlined below:

- Collect rockweed algae and three resident marine fish species—greenling, rockfish, and Irish lords—to identify the presence and accumulation of test-related radionuclides.
- Study areas include coastline transects adjacent to the three Amchitka Island sites (Cannikin, Milrow, and Long Shot) and coastline transects along the north and south portions of Adak Island, the background reference site.
- Collect Dolly Varden fish from freshwater bodies, Cannikin Lake on Amchitka Island, and an Adak Island lake.
- Analyze all biota samples for cesium-134 (^{134}Cs), cesium-137 (^{137}Cs), plutonium-239 (^{239}Pu), and plutonium-240 (^{240}Pu) using adequately sensitive analytical methods and detection limits.

Corresponding decision rules were as follows:

- If radionuclide concentrations measured in rockweed and marine fish species are statistically equivalent to or lower than those measured in 2011, these results will affirm previous determinations of food safety.
- If the Amchitka Island site radionuclide concentrations measured in 2016 are higher than those measured in 2011 concentrations but equal to or lower than corresponding 2016 Adak concentrations, these results would indicate an absence of evidence of radionuclide migration from the detonation zones to the sampled marine environment.
- If radionuclide concentrations measured in biota from 2016 at Amchitka Island sites are higher than those measured in 2011 for rockweed and the three marine fish species and also higher than corresponding 2016 Adak data, AWG would discuss the need for follow-up activities. These activities could include confirmatory reanalysis of samples or obtaining additional samples for analysis.

[1] In addition to global fallout, other potential sources of radionuclide contamination include radioactive wastes intentionally discharged into the marine environment by the former Soviet Union. Layton et al. (1997) list a number of anthropogenic sources of radionuclides in the arctic, including submarine reactors dumped in the Kara Sea, various waste disposal incidents, and nuclear submarine accidents in the Sea of Japan.

1.1.2 Seawater and Freshwater Sampling

In 2011, seawater samples were collected along inferred offshore fault traces (at Cannikin, Milrow, and Long Shot) and analyzed for tritium. Measured tritium concentrations in seawater were low, similar to North Pacific regional concentrations. The 2016 seawater sampling effort was more focused, planned in an area off Long Shot, where previous groundwater modelling (Hassan et.al. 2002) indicated that contaminant migration was most likely to occur. However, the primary goal of the 2016 seawater and freshwater sampling program was to establish a baseline for future comparisons and trending analysis.

Following the Fukushima Daiichi nuclear power plant accident in March 2011, AWG questioned whether the subsequent direct release of radionuclides into the atmosphere and Pacific Ocean might affect background activity concentrations of target radionuclides in the Aleutian marine environment. To help evaluate the extent to which Fukushima might be contributing to the background radiation on Amchitka and Adak Islands, the analytical program was expanded to include cesium isotopes (^{134}Cs and ^{137}Cs, not analyzed in seawater samples collected in 2011) as well as tritium. Specific data quality objectives included:

- Sample seawater in an area off Long Shot and analyze for tritium (the primary analyte of interest), ^{134}Cs, and ^{137}Cs. All three analytes are often-used tracers for biochemical research in evaluating fallout from events such as Fukushima (e.g., Povinec et al. 2013). Although ^{239}Pu and ^{240}Pu were included in the planned analytical suite (DOE 2016a), these isotopes were not analyzed in aqueous samples collected in 2016.
- Collect comparison seawater samples offshore from the other two detonation sites (Milrow and Cannikin) and the reference area (Adak North and Adak South) and test for the same radionuclides.
- Collect freshwater samples opportunistically from both island lakes (e.g., Cannikin Lake on Amchitka) and test for the same radionuclides.
- Ensure that laboratory methods are adequately sensitive to detect 0.3 picocurie per liter (pCi/L) (or 0.01 becquerel per liter [Bq/L]) or lower tritium levels, consistent with the detection limits achieved in 2011.

Corresponding decision rules were as follows:

- If tritium, ^{134}Cs, and ^{137}Cs concentrations in seawater from Long Shot are similar to North Pacific regional data (i.e., not statistically different), no further action would be taken until the next sampling event, scheduled for 2021.
- If tritium, ^{134}Cs, and ^{137}Cs concentrations in seawater from Long Shot are statistically higher than North Pacific regional data but lower than trigger levels established below (referred to as “hot spot concentration values” in the sampling plan [DOE 2016a]), AWG would convene to discuss possible follow-up actions or investigations.
- Trigger levels established for tritium and ^{137}Cs were 5.4 pCi/L (0.2 Bq/L) and 0.216 pCi/L (0.008 Bq/L), respectively. These levels were derived based on the North American background range reported in combined oceanographic studies cited by Dasher (2017). Although exceedance of these trigger levels would not necessarily indicate migration of

test-related radionuclides nor a health risk, such findings would be a catalyst for AWG to convene and discuss a path forward before the 2021 sampling event.[2]

This report summarizes the work that was performed in the collection of the data to meet these DQOs, presents the results of the laboratory analyses from all the samples collected, and provides an updated assessment of food safety described previously.

1.2 Stakeholder Participation

Stakeholder participation has played a key role in LM's work on Amchitka Island. As identified at the outset, LM developed the specific objectives of the 2016 environmental sampling event and associated analytical program in collaboration with the following stakeholders, collectively referred to as AWG: APIA, the Alaska Department of Environmental Conservation (ADEC), the University of Alaska Fairbanks (UAF), Argonne National Laboratory (ANL), and USFWS. Their roles are briefly summarized below.

LM has a Memorandum of Understanding (MOU) with USFWS, the purpose of which is to define the roles and responsibilities of both agencies, specify the means of access to and egress from Amchitka, and explain how LM will exercise institutional controls. In accordance with the MOU, USFWS issued access permits to LM prior to the 2016 environmental sampling event.

LM provides a financial assistance grant to ADEC and regularly meets with their representatives. ADEC has partnered with UAF to provide technical support on the Amchitka project.

LM provides a financial assistance grant to APIA, a federally recognized tribal organization of the Aleut people in Alaska and an important component of LM's mission at Amchitka. APIA represents the interests of the Aleuts and assists LM with communications with the Aleut people and ADEC.

APIA also participates in developing work scope related to the LM mission on Amchitka, participates in regular planning meetings, and assisted with sample collection during the 2016 sampling event.

LM retained ANL through a work order to help develop the biological sampling plan (DOE 2016a) and provide technical support as required. As done for the 2011 environmental sampling, LM retained Lawrence Livermore National Laboratory (LLNL) through a work order to provide support in the radionuclide analysis of all biological and abiotic samples collected in 2016. The University of Miami Rosenstiel School of Marine and Atmospheric Science performed the tritium analyses on all seawater and freshwater samples.

[2] The 5.4 pCi/L trigger established for tritium is well below established levels indicating a potential health risk. The U.S. Environmental Protection Agency has established a drinking water standard (maximum contaminant level) of 20,000 pCi/L for tritium based on an allowable annual dose of 4 millirems per year. Although not relevant to this analysis because seawater is not potable unless filtered, this standard does provide a context for interpreting the low tritium levels measured in seawater around Amchitka. Similarly, the 0.216 pCi/L trigger established for ^{137}Cs is nearly 3 orders of magnitude lower than the corresponding maximum contaminant level of 200 pCi/L (also not relevant). As discussed above, the 5.4 pCi/L and 0.216 pCi/L DQOs for tritium and cesium (respectively) were established mainly to identify exceedances of post-Fukushima derived fallout.

2.0 Background

The Amchitka site has a long and varied history, in terms of both cultural aspects (being home to the Aleut) and the previous underground nuclear tests and ensuing environmental investigations. This section briefly summarizes key aspects of the site history and the results of previous environmental studies. More detailed site background information is provided in the current and previous long-term surveillance plans (DOE 2014a; DOE 2008). Table 1 provides a summary of key events or investigations germane to this report.

2.1 Amchitka Island History

Since World War II, Amchitka has been used by several U.S. government agencies for various military and research activities. From 1943 to 1950, it was used as a forward air base for the U.S. Armed Forces. During the middle 1960s and early 1970s, DOD and AEC used portions of the island as sites for underground nuclear tests. During the late 1980s and early 1990s, the U.S. Navy constructed and operated a radar station on the island.

Between 1965 and 1971, three underground nuclear tests were conducted on Amchitka Island. DOD, in conjunction with AEC, conducted the first nuclear test (named Long Shot) in 1965 to provide data that would improve the United States' capability of detecting underground nuclear explosions. The second nuclear test (Milrow) was a weapons-related test conducted by AEC in 1969 as a means to study the feasibility of detonating a much larger device. Cannikin, the third nuclear test on Amchitka and the largest in U.S. history, was a weapons-related test detonated on November 6, 1971. Detonation depths ranged from approximately 2300 feet (ft) below ground surface (at Long Shot) to nearly 6000 ft at Cannikin (Table 1).

Radioactive fission products remain in and around the subsurface cavities formed by the nuclear tests. Although data collected since the detonations do not indicate that radionuclides have migrated into the marine environment, hydrologic modeling has indicated that, over time, some of the subsurface residual radionuclides may migrate away from the blast cavities and eventually reach the near-surface marine environment (Hassan et al. 2002). However, for all test sites, predicted breakthrough of radionuclides is not expected to occur for at least 2200 years, the simulation time frame used in a later verification model (Hassan and Chapman 2006).

Apart from anthropogenic radionuclides released shortly after the Long Shot test, there has been no exposure to humans or the environment from the detonations (Merritt and Fuller 1977; DOE 1982; DOE 2000; Dasher et al. 2002; Consortium for Risk Evaluation and Stakeholder Participation II [CRESP] 2005; Burger et al. 2006; Burger et al. 2007a; Burger et al. 2007b). Because no feasible technology exists for removing the subsurface radioactivity associated with the nuclear test cavities, LM conducts monitoring near these sites to protect human health and the environment. The potential for residual radionuclide release from the former tests and the fact that the Aleutian Islands have, at times, been home to a tribal community (the Aleuts) reliant on subsistence foods, has been the catalyst for many environmental investigations over the years.

Table 1. Amchitka Site History Relevant to Biomonitoring Report

Year/Period	Activities/Event
Early History	
1943–1950	Amchitka Island used as a forward air base for the U.S. Armed Forces.
October 29, 1965	The first of three underground nuclear tests—Long Shot—was conducted by DOD and AEC. The test was detonated at a depth of 2297 ft below ground surface with a yield of 80 kilotons.
October 2, 1969	The second test, Milrow, was a high-yield (about 1 megaton) weapons calibration test detonated at a depth of 4003 ft below ground surface.
November 6, 1971	The third and final test on the island—Cannikin—was detonated at a depth of 5873 ft below ground surface with a yield of less than 5 megatons. Cannikin remains the largest underground nuclear test in U.S. history.
Late 1980s–Early 1990s	The U.S. Navy constructed and operated a radar station on the island.
Early Biological Monitoring	
1965–1979	Various environmental assessment programs implemented, including the Amchitka Bioenvironmental Program (1967–1973) and the Amchitka Radiobiological Program (1970–1979).
1980–2000	The results of the 1997 Long-Term Hydrologic Monitoring Program radiobiological sampling and analysis at Amchitka indicated no evidence of migration from the underground test cavities into the terrestrial or freshwater environments on Amchitka (DOE 2000; Dasher et al. 2002).
2000–Present	
2004–2005	In the summer of 2004, CRESP conducted extensive sampling of marine biota to assess food safety. The study culminated in a report (CRESP 2005) that found no geophysical or biological evidence of radionuclide migration into the marine environment from the Amchitka test shots. All results for marine organisms tested were well below published human health food safety standards and guidelines.
October 1, 2006	LM assumed responsibility for long-term surveillance activities.
September 2008	LTS&M Plan issued (DOE 2008), focused on scoping of 2011 biomonitoring. This plan was later superseded by the 2014 LTSP (DOE 2014a).
March 11, 2011	A 9.1 magnitude earthquake and subsequent massive tsunami struck the island of Japan, severely damaging several reactors at the Fukushima Daiichi Nuclear Power Plant and releasing radioactive materials into the environment.
June 2011	In accordance with the 2008 LTS&M Plan, a team led by LM collected biological and seawater samples from the marine and terrestrial environments of Amchitka adjacent to the three detonation sites and at a background or reference site, Adak Island, 200 miles to the east. Based on the radionuclide analysis results, a risk assessment was developed to assess food safety.
September 2013	LM issued a report documenting the results of the 2011 investigation (DOE 2013). This report confirmed that subsistence- and commercial-catch seafood potentially harvested from the region is safe to eat. Consistent with previous reports, no evidence of radionuclide migration from the detonation zones was found.
June 23, 2014	A 7.9-magnitude earthquake occurred 15 miles northwest of Amchitka Island at a depth of 73 miles (118 kilometers).
July 2014	Amchitka site LTSP updated and reissued (DOE 2014a).
May–June 2016	Following 2 years of scoping and planning, LM conducted the second environmental sampling event: 168 biota samples and approximately 50 sea and freshwater samples were collected at the Amchitka Island transects (Cannikin, Milrow, and Long Shot) and at the reference island, Adak.

2.2 Previous Environmental Studies

Numerous and extensive environmental and biological studies have been conducted on and around Amchitka since the early 1970s to detect potential radionuclide migration from the detonation zones via the most likely pathway, groundwater transport and discharge into the ocean. This section summarizes those studies and investigations.

2.2.1 Early Studies (1977–2001)

The Environment of Amchitka Island, Alaska (Merritt and Fuller 1977) is a multidisciplinary work that provides a concise review of the geology, ecology, and radionuclides in air, water, and biota with an emphasis on "the search for and identity of radionuclides of Amchitka origin in the samples and [contributing] to the general knowledge of the distribution of radionuclides in the environment." This evaluation found no evidence that any test-related radionuclides had escaped from the three underground nuclear test sites at Amchitka except for trace quantities of radionuclides, principally tritium, in water and soil gas samples taken in the immediate vicinity of the Long Shot test.

The Amchitka Radiobiological Program began in 1970 and continued through 1979. The program's principal objective was to collect biological and groundwater samples for radiobiological analyses and to determine the extent of radionuclide contamination from worldwide atmospheric fallout and from the detonation of the three underground nuclear tests on Amchitka Island. Migration of radionuclides from the underground test sites would be suspected if the concentration of radionuclides were significantly greater than that which could be attributed to worldwide fallout or if an unexpected assemblage of radionuclides were detected. In the *Amchitka Radiobiological Program Final Report July 1970 to December 1979* (DOE 1982), it was determined that no radionuclides from the underground sites were detected except for tritium vented from the Long Shot test, which produced increased tritium concentrations in surface water and freshwater plants near the site.

Another DOE program that monitored Amchitka Island radioactivity levels in groundwater was the Off-Site Environmental Monitoring Program for the Nevada Test Site and Other Test Areas Used for Underground Nuclear Detonations. Amchitka Island monitoring under this program began in 1977; since then, sampling has occurred intermittently. Samples were collected from 1977 through 1989, in 1991, in 1993, in 1997, and in 2001. The U.S. Environmental Protection Agency (EPA) carried out this program and monitored Amchitka Island to measure levels and trends of radioactivity in the offsite environment surrounding testing areas to ensure that radioactive levels complied with existing radiation protection levels or standards. Over time, the program became known as the Long-Term Hydrological Monitoring Program (LTHMP).

In 1997, the LTHMP at Amchitka Island was expanded to include radiobiological sampling and analyses. This change was based on the results of a survey of selected aquatic biota that Greenpeace conducted on the island (Greenpeace 1996). Greenpeace speculated that several long-lived anthropogenic radionuclides were migrating into the surface environment from nuclear test cavities several thousand feet below the surface of the island (DOE 2000). Briefly summarized, the results of the 1997 LTHMP radiobiological sampling indicated no evidence of radionuclide migration from the underground test cavities into the terrestrial or freshwater environments on Amchitka Island (DOE 2000; Dasher et al. 2002).

2.2.2 CRESP 2004

In 2004, CRESP, a group of independent universities, prepared the *Amchitka Independent Science Assessment: Biological and Geophysical Aspects of Potential Radionuclide Exposures in the Amchitka Marine Environment* (CRESP 2005).[3] The biological component of the CRESP study entailed sampling a wide range of marine biota, including marine algae; invertebrates and fish from the intertidal zone to a 90-ft depth; and seabirds nesting on the island surface and the coast. Species selection was designed to represent several trophic levels, including primary producers, filter-feeders and grazers, and low to high level predators. Samples were collected in the marine environment at and around Amchitka and at Kiska Island, the reference (background) site selected for the study. Biota tissue samples were analyzed for a large suite of radionuclides, including ^{137}Cs, americium-241 (^{241}Am), and plutonium and uranium isotopes.

Results of the biota sampling indicated that radionuclide levels measured in marine organisms were well below published human health food safety standards and guidelines. The results were also within the range found in biota from other marine environments in the Northern Hemisphere and far below those found in known contaminated marine areas such as the Irish Sea (in the vicinity of the Sellafield nuclear reprocessing plant). In summarizing the results of the geophysical component of the investigation, CRESP concluded that substantial localized discharge of freshwater through the ocean floor within the study area was not indicated based on ocean floor salinity measurements. Therefore, no specific preferential pathway for contaminant migration from the test sites was found (e.g., groundwater flow through geologic faults).

In summary, the CRESP investigation did not find either geophysical or biological evidence of radionuclide migration into the marine environment from the Amchitka test shots. Subsequent additional analyses of biological samples for ^{137}Cs and actinides were documented in an addendum (CRESP 2006a) to the 2005 report. This addendum confirmed CRESP's original findings, drawing the following conclusions: (1) the foods tested are safe to eat, with radionuclide levels below published human health guidance levels; (2) data do not suggest that radionuclides in biota collected from Amchitka are attributable to the Amchitka test shots; and (3) a combination of sedentary and mobile organisms at different trophic levels is recommended for a continued biomonitoring program at Amchitka. At about the same time CRESP issued the addendum, they also formalized their recommendations regarding future biomonitoring at Amchitka (CRESP 2006b).

Although the biota sampling and analysis conducted by CRESP was useful in demonstrating that concentrations of target radionuclides measured in marine species were safe relative to risk guidelines, the minimum detectable activities (MDAs) used in the study were high, resulting in a large proportion of nondetects for some isotopes.[4] This (the low MDAs) was one of the factors considered by LM and AWG in developing the scope of the 2011 environmental sampling program, summarized in the following section.

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[3] The summary provided here is very brief relative to the detailed and comprehensive evaluation published by CRESP. The full report can be found at: http://www.cresp.org/projects/amchitka/amchitka-final-report.

[4] The high detection limits reported by CRESP (2005) stemmed in part from the small sample weights or sizes—most were 100 grams, in contrast to larger sample weights (1000 grams) used in only a small portion of CRESP samples and in LM's later studies.

2.2.3 Hydrologic Modeling (Desert Research Institute 2002, 2006)

One of the studies drawn upon in CRESP's 2005 report was the groundwater flow and transport model developed by the Desert Research Institute (DRI) in 2002 (Hassan et al. 2002). Using two-dimensional numerical simulations, this initial model indicated that, if contaminant migration from the test cavities were to occur, the shortest arrival times would be at the Long Shot site (Hassan et al. 2002). This prediction was based on the relatively shallow detonation depth (2297 ft) at Long Shot relative to the other test sites, 4003 ft at Milrow and 5873 ft at Cannikin. As such, the travel distance from the cavity to the seafloor is shortest for Long Shot and longest for Cannikin. DRI updated this model in 2006 to incorporate the new magnetotelluric (MT) and bathymetric survey data collected by CRESP, which allowed reduction in uncertainty in some of the parameters incorporated in the initial model (Hassan and Chapman 2006). CRESP's MT surveys were used to determine the salinity and porosity structure of the subsurface; bathymetric surveys were used to map areas offshore from the Long Shot and Cannikin sites.

According to DRI, significant uncertainty reduction was achieved in the second (2006) model; this applied to several model parameters, including recharge, conductivity, and porosity. Using the new porosities developed based on CRESP's MT data, no breakthrough resulted for any of the three test sites within the 2200 year model time frame, despite ignoring all retardation mechanisms (sorption, radionuclide trapping in the melt glass, matrix diffusion, and radioactive decay) (Hassan and Chapman 2006).[5] In summary, although some contaminant migration is expected eventually, for all three test sites—Long Shot, Milrow, and Cannikin—DRI's most recent model predicts that it would take thousands of years for radionuclides to reach the seafloor, allowing for radioactive decay, dispersion, and retardation processes to significantly reduce concentrations of mobile radionuclides.

2.2.4 2011 Biomonitoring Event

As a continuation of the previous environmental monitoring described above, in the summer of 2011 LM collected biological and seawater samples from the marine and terrestrial environment of Amchitka Island adjacent to the three detonation sites. Samples were also collected at a background site, Adak Island, about 200 miles to the east. Differing from the reference site previously used by CRESP (Kiska Island, about 60 miles northwest of Amchitka), LM, in collaboration with AWG, selected Adak as the background location for the 2011 sampling event. This decision was based in part on logistics (Adak is easier to access than Kiska) but also on AWG's determination that, like Kiska, Adak would represent an area uninfluenced by underground nuclear tests. The scope of the 2011 biological monitoring program entailed sampling a wide variety of species representing different trophic levels for test-related radionuclides. In developing this program, two primary objectives drove the species selection. The first objective was to include species (and radionuclides) common to those assessed by

[5] According to DRI (Hassan and Chapman 2006), the distribution of fracture porosity used in the 2002 model was deliberately skewed toward lower values. Given the inverse relationship between porosity and groundwater velocity, these assumptions yielded shorter groundwater travel times. CRESP's 2004 MT data indicated much higher, and more tightly bounded, porosities than those used in the 2002 model. For example, in the 2006 model update for Long Shot (associated with the shortest travel distance), the entire velocity distribution shifted about four orders of magnitude toward the lower side using the new CRESP data (Hassan and Chapman 2006). The latter explains the predicted absence of breakthrough, as particles move very slowly away from the cavity and need thousands of years to reach the seafloor.

CRESP (2005; 2006a) to allow comparison of the results. Because subsistence- and commercial-catch species near Amchitka continue to be harvested for consumption, the second objective was to target those species most likely to be a food source and to verify that those species continue to be safe to eat. Ultimately, 350 biological samples were collected, representing the following 15 marine and terrestrial species.[6]

Primary Producers

- Dragon kelp (*Eualaria fistulosa*)*
- Rockweed (*Fucus distichus*)*†
- Reindeer lichen (*Cladina reindeer lichen*)

Grazers/Filter Feeders

- Gumboot or Pacific chiton (*Cryptochiton stelleri*)*
- Horse mussel (*Modiolus modiolus*)*
- Sea urchin (*Strongylocentrotus polyacanthus*)*

Lower Predators

- Dolly Varden (*Salvelinus malma*)†
- Irish lord (*Hemilepidotus jordani* and *H. hemilepidotus*)*†
- Rock greenling (*Hexagrammos lagocephalus*)*†

Medium Trophic Level

- Rockfish (*Sebastes melanops* and *S. cilatus*)*†
- Glaucous-winged gull (*Larus glaucescens*) egg
- Goose egg

Top Trophic Level

- North Pacific giant octopus (*Enteroctopus dofleini*)
- Pacific cod (*Gadus macrocephalus*)
- Pacific halibut (*Hippoglossus stenolepis*)

In the summary above, asterisks (*) denote species that were the primary focus of the 2011 biological sampling program, with at least 15 samples collected. For remaining species, total sample numbers were less than 6, and no more than 3 samples were collected at a given island. Of the species listed above, five (followed by †) were sampled by LM in 2016: rockweed, Dolly Varden, Irish lord, greenling, and rockfish. Intended as visual overviews, Figure 2 and Figure 3 provide a matrix of the species and analytes evaluated for the nonaqueous component of the 2011 environmental sampling program. For primary species assessed (greater than or equal to 15 samples), Figure 2 illustrates the total number of samples collected at both Amchitka and Adak islands by analyte and the corresponding proportions of detects and nondetects. For each species, dark blue bar segments denote the number of results with detectable levels of a given isotope based on wet weight concentration. Pale blue bar segments denote the number of samples with results below the MDA.

[6] Trophic level categories guided by the summaries in CRESP (2006b).

Notes:
Species listed in general order or trophic level or mobility.
For each species, dark blue bar segments denote the number of results with detectable levels of a given isotope (based on wet weight concentration). Pale blue bar segments denote the number of samples with results below the MDA.
For each species/isotope combination, the corresponding number of samples collected at Amchitka and the reference site, Adak Island, is listed above the bars.

Figure 2. Overview of 2011 Biota Sampling for Key Species

Notes:
This table illustrates the relative number of detections versus nondetects (results below the MDA) for species or media with ≤3 samples collected per island. For each species/media group, dark blue bar segments denote the number of results with detectable levels of a given isotope.
Pale blue bar segments denote the number of samples with results below the MDA.

Figure 3. Secondary Species/Media Sampled in 2011

Figure 3 presents similar information but for those species (or media) with limited numbers of samples (less than six). As shown in these figures, biological samples were analyzed for ^{137}Cs and the following actinides: ^{241}Am, ^{239}Pu, ^{240}Pu, and uranium isotopes (^{234}U, ^{235}U, and ^{238}U). A small subset of samples (reindeer lichen, soil, and sediment) was analyzed for both ^{134}Cs and ^{137}Cs, mainly to track any Fukushima-related fallout or atmospheric deposition.

In addition to sampling of biota, seawater samples were collected off coastline transects (focusing on Cannikin) and analyzed for tritium. This abiotic component was included because previous studies and contaminant transport modeling predicted that tritium would be the leading indicator of migration from the detonation zones. Sampling results would then be used to develop a baseline of tritium concentrations near Amchitka and at the reference site (Adak). Environmental sampling began on June 20, 2011, and continued through July 21, 2011. Overall, a total of 350 biological samples and 166 seawater samples were collected (DOE 2013). Sampling results and subsequent data interpretations are summarized below.

For the biological component of the 2011 environmental sampling program, two major endpoints were evaluated: (1) interisland comparisons of radionuclide concentrations; and (2) a major focus of the 2011 investigation and report, food safety. Regarding the first endpoint, the 2011 monitoring report (DOE 2013) concluded that, overall, radionuclide concentrations measured in species collected from Amchitka were not significantly different from levels measured in samples from Adak (the reference location). Although there was a pattern toward slightly higher concentration (half a standard error of the mean, for example, for uranium) in samples collected at the Amchitka site, the measurements that showed the most deviation had limited data above the MDAs (DOE 2013). Although 2011 results were compared to those from CRESP's 2004 investigation, ultimately these comparisons were not meaningful due to the high MDAs (and thus large proportion of nondetects) reported by CRESP for most radionuclides.

Food safety was assessed by evaluating available subsistence diet information and developing a risk assessment addressing five different diet scenarios, assuming life-long consumption of subsistence- and commercial-catch seafood (DOE 2013). Risk estimates were derived for each radionuclide-dietary component combination using conservative intake assumptions. The risk estimates derived for the 2011 environmental sampling event confirmed CRESP's previous conclusions regarding food safety. For most diet scenarios, risk estimates were below 1×10^{-5} (1 in 100,000), the level used by the State of Alaska (ADEC) as the benchmark for acceptable risk.[7] In some cases, risk estimates using Amchitka data were slightly higher (by 1×10^{-6}) than those using Adak data, a marginal difference and lower than the 1×10^{-5} guideline.

In summary, based on results of the 2011 environmental sampling program, seafood harvested at and around Amchitka (and Adak, the reference island) is considered safe for consumption.

Tritium activity measured in seawater samples collected in the marine environment surrounding Amchitka ranged from 1.2–2.2 pCi/L, mostly within the 1.4–2.8 pCi/L range measured in samples collected near Adak. These levels are comparable to pre-Fukushima (global fallout) levels reported for the North Pacific (Dasher 2017).

[7] The only exceptions were total risks estimated for the Nikolski diet (corresponding to much higher consumption of fish), for which maximum risks for Amchitka and Adak were equivalent: 2.3×10^{-5}.

To facilitate understanding of the evolution of the biomonitoring program at the Amchitka site, this section concludes with a summary of the similarities and differences between the last three biomonitoring efforts: CRESP 2004, LM's 2011 sampling event, and (the focus of this report) LM's 2016 environmental sampling. Table 2 presents a matrix of analytes and marine species analyzed previously relative to those selected for sampling and analysis in 2016 (shaded).

Table 2. Summary of Marine Species Sampled in 2004 (CRESP), 2011, and 2016

Species	^{137}Cs	^{241}Am	^{239,240}Pu	^{234}U	^{235}U	^{238}U
Dragon kelp	X	X	X	X	X	X
Rockweed	X	X	X	X	X	X
Gumboot or Pacific chiton	X	X	●	●	●	●
Horse mussel	X	X	X	X	X	X
Sea urchin	X	X	●	●	●	●
Rockfish	X	X	X	X	X	X
Red or yellow Irish lord	X	X	X	X	X	X
Rock greenling	X	X	●	●	●	●
Pacific halibut	X	X	X	X	X	X
Pacific cod	X	X	X	X	X	X
Octopus	X	X	●	●	●	●
Dolly Varden	X	X	●	●	●	●
Glaucous-winged gull eggs	X	X	●	●	●	●

X sampled in 2004 and 2011

● sampled in 2011 (but not 2004)

sampled in 2016

Notes:

1. The analytes listed correspond to the suite addressed in 2011 (DOE 2013). CRESP (2005) evaluated others, including iodine-129, cobalt-60, europium-152, strontium-90, and technetium-99, none of which were detected in any biological samples.
2. This table excludes the species reindeer lichen and the analyte ^{134}Cs. As shown in Figure 3, these were analyzed (along with ^{137}Cs) in only a few reindeer lichen and corresponding soil and sediment samples in 2011.

As shown in Table 2, the 2016 environmental sampling program was smaller in scope relative to the 2011 effort, in terms of both the species and analytes selected for assessment. This refinement resulted from examination of 2011 findings (e.g., radionuclide concentrations and corresponding risk profiles), stakeholder discussions, and logistical and safety considerations. Rationales for exclusion of species and analytes not retained in the 2016 sampling program are summarized below.

Five biological species were sampled in 2016: rockweed (a primary producer); lower predators Dolly Varden, rock greenling (greenling), and Irish lord; and, representing the medium trophic level, rockfish. Of the marine species sampled in 2011 but not 2016, all except cod and halibut required the assistance of divers to collect the samples. These included dragon kelp, chiton, horse (and blue) mussel, sea urchin, and octopus. After numerous planning meetings and discussions, LM in collaboration with AWG elected to focus on resident marine species that could be easily obtained (e.g., by hand, hook-and-line, traps, or netting). For example, although both dragon kelp (*Eualaria fistulosa*) and rockweed (*Fucus* multiple species [spp.]) are good bioindicators

(CRESP 2006b), rockweed can be collected from the shoreline, whereas dragon kelp (a nearshore subtidal species) can only be collected using a dive team. Based on 2011 sampling results (DOE 2013), actinide concentrations in both of these species were generally similar, so rockweed was selected as the representative primary producer species in 2016.

Although Pacific cod and halibut can be caught by hook-and-line (fishing) methods, only four to five samples were collected in 2011 at both Amchitka and Adak combined (Figure 3), precluding any meaningful statistical comparisons. Furthermore, using the most conservative mix of intake assumptions[8], total risks for cod and halibut caught near Amchitka were 9×10^{-8} and 6×10^{-7}, respectively, below the 1×10^{-5} guideline. Corresponding risks for Adak were similar.

Relative to the analytical suite used in 2011 (DOE 2013), only ^{137}Cs, ^{239}Pu, and ^{240}Pu were retained in 2016 for biological sampling (DOE 2016a). All byproducts of nuclear detonations (fallout is the main source of cesium in the environment), these three isotopes received the most focus in CRESP's work (CRESP 2005). Plutonium isotopes, also only present from anthropogenic sources, have been the focus of site-related work by Dasher et al. (2002) and others. Remaining actinides, ^{241}Am and uranium isotopes, were not addressed for the reasons outlined below.

For the species retained in 2016 (rockweed and the four fish species), ^{241}Am was detected in only a small percentage of samples collected from Amchitka in 2011: 6 of 27 rockweed, 4 of 27 greenling, 3 of 27 Irish lord, 3 of 26 rockfish, and 0 of 2 Dolly Varden (DOE 2013). In 2011, ^{241}Am was detected (albeit at very low concentrations) in the majority of dragon kelp samples. The highest ^{241}Am concentrations (maximum of 0.2 picocuries per kilogram [pCi/kg] wet weight) were found in grazers/filter feeders: chiton, horse mussel, and sea urchin. Americium-241 levels in all fish species were consistently at or below the MDA. There was no statistical difference (where measures allowed) in the mean ^{241}Am content of marine vegetation and fauna between the Amchitka and Adak sites except for levels found in rockweed ($p < 0.01$, higher at Adak) and chiton ($p = 0.02$, higher at Amchitka) (Hamilton et al. 2012). Finally, in an early evaluation of potential test-related radionuclides, Dasher et al. (2002) concluded that trace levels of ^{241}Am in environmental samples cannot be used to uniquely identify radionuclides from specific Amchitka tests.

Although the 2011 biological monitoring report (DOE 2013) concluded that ^{234}U and ^{238}U (along with ^{137}Cs) contributed most to the risk estimates, these uranium isotopes were not retained in the 2016 analytical sampling program because they are primarily naturally occurring. This natural occurrence is evidenced by the high detection frequencies of both ^{234}U and ^{238}U across species found in both the 2004 (CRESP 2005) and 2011 (DOE 2013) investigations. On an activity basis, ^{234}U and ^{238}U occur in nature in equal proportions, whereas ^{235}U (a decay product of ^{239}Pu and also analyzed in 2004 and 2011) is present in nature at much lower levels, about one-tenth of ^{234}U and ^{238}U (CRESP 2005). An anthropogenic (e.g., test-related) origin would be indicated by an increased proportion of ^{235}U (e.g., > 0.1). Based on 2011 sampling results for all species, mean ^{234}U/^{238}U ratios for Amchitka samples were about 1.3 and comparable to those from Adak (DOE 2013). Mean ^{235}U/^{238}U ratios were consistent at about 0.04 for both Amchitka and Adak (DOE 2013), indicating a natural (versus anthropogenic) provenance.

[8] Based on maximum radionuclide concentrations for the Nikolski diet, with the highest fish consumption rates of the five diet scenarios evaluated in the 2011 biological monitoring report (DOE 2013, Table 16 and Table 28).

LLNL also found no quantifiable levels of anthropogenic uranium based on ^{236}U detection and measurement in samples collected during the 2011 sampling event (Hamilton et al. 2012).[9] Regarding uranium magnitudes, CRESP found no significant interisland differences in either uranium isotope radionuclide concentrations or in the proportion of levels above the MDA.[10] In 2011 samples, where measures allowed, there was no statistical difference in the uranium content of individual species of vegetation and fauna between sites with the exception for rockfish (based on total uranium, $p = 0.0024$) (Hamilton et al. 2012).

The final difference in radionuclides selected for analysis in biota in 2016 (versus 2011) was the inclusion of ^{134}Cs in 2016, to facilitate identification of a Fukushima fingerprint (if there was one). The analytical suite for sampling of seawater and freshwater samples also differed between 2011 and 2016, with the program expanded in 2016 to include not only tritium but ^{134}Cs and ^{137}Cs.

Although not prescribed in the 2016 sampling plan (DOE 2016a), as requested by stakeholders, a small subset of aqueous samples was also analyzed for iodine-129 (^{129}I). Iodine-129 is a product of nuclear weapons testing and has been associated with the Amchitka tests, albeit at very low levels. Iodine-129 was included in CRESP's 2004 investigation because it was considered, along with ^{137}Cs, a primary isotope of interest for human health and ecological receptors. However, it was not detected in any of the 71 biota samples collected (CRESP 2005).

[9] Uranium-236 was not included in the 2011 analytical suite but was quantified in some samples by LLNL. Corresponding MDAs were reported to be relatively high, however (Hamilton et al. 2012).

[10] Interspecies differences were found, however, with *Fucus* (rockweed) having significantly higher levels for ^{234}U, ^{235}U, and ^{238}U than the other species (CRESP 2005).

3.0 Methods

This section documents the species, media, and radionuclides assessed as part of the 2016 environmental sampling effort, corresponding field sampling methods and locations, laboratory methods and associated detection limits, and the generalized data analysis and visualization approaches used in subsequent sections of this report. As the surface water sampling effort was distinct from the biota sampling in a number of regards, some aspects related to this effort are addressed in greater detail in Section 6.0.

3.1 Species, Media, and Radionuclides Selected for Assessment

Table 3 summarizes the species and media sampled in 2016, in accordance with the environmental sampling plan (DOE 2016a). Sample numbers listed in this table were determined in accordance with the sampling plan and with assistance from UAF's statistician to ensure an adequate number of samples from both Amchitka Island sites and Adak Island sites. Greater detail is provided in Sections 3.1.1 and 3.1.2 for biological and water sampling, respectively.

Table 3. Sample Types, Numbers, and Radionuclides Selected for Analysis

Sample/Media Type	No. of Samples	^{134}Cs $t_{1/2}$ = 2.06	^{137}Cs $t_{1/2}$ = 30.17	^{239}Pu $t_{1/2}$ = 24,110	^{240}Pu $t_{1/2}$ = 6500	Tritium $t_{1/2}$ = 12.3	^{129}I $t_{1/2}$ = 1.57×10^{7}
Marine Littoral Zone Species							
Rockweed[a] (*Fucus distichus*)	15	X	X	X	X		
Ocean (Fish) Species							
Greenling[a] (*Hexagrammos* spp.)	50	X	X	X	X		
Irish lord[a] (*Hemilepidotus* spp.)	50	X	X	X	X		
Rockfish[a] (*Sebastes* spp.)	50	X	X	X	X		
Freshwater Species							
Dolly Varden[b] (*Salvelinus malma*)	3	X	X	X	X		
Seawater and Freshwater							
Ocean/Seawater[c]		44	44			44	10
Freshwater		2	2			2	2

Notes:
[a] Collected from offshore at all three test sites and North and South Adak.
[b] One Dolly Varden was collected from Amchitka Island (Cannikin Lake); two were collected from Adak (Andrew Lake).
[c] Seawater sampling focused offshore from Long Shot (40 locations), where field measurements—conductivity, temperature, and depth—were also obtained (Section 6.0). Sample numbers listed above exclude 4 duplicate samples. Limited seawater samples at other locations (one each at Cannikin, Milrow, Adak North, and Adak South).
[d] Freshwater sampling limited and colocated with Dolly Varden fish collection.

Abbreviation:
$t_{1/2}$ = half-life in years

The primary radionuclides of interest were ^{137}Cs, ^{239}Pu, and ^{240}Pu, analytes common to all previous environmental investigations at the site. Interpretation of ^{137}Cs results—that is, distinguishing between potentially site or test-related impacts versus global fallout—is complicated by post-2011 Fukushima fallout. To assist in this distinction, ^{134}Cs, with a very short half-life of 2 years, was also analyzed in all biota and aqueous samples. Although ^{129}I was not slated for analysis in the sampling plan (DOE 2016a), LM opted to have it analyzed on a small subset of water samples (n=12).[11]

3.1.1 Biota

Based on these findings and the DQOs outlined in Section 1.1, the following biological (algae and resident fish) species were sampled in May–June 2016:

- Rockweed (*Fucus distichus*), a species of brown algae, n = 15[12]
- Greenling (*Hexagrammos* spp.), n = 50
- Irish lord ((*Hemilepidotus* spp.), n = 50
- Rockfish (*Sebastes* spp.), n = 50
- Dolly Varden (*Salvelinus malma*), n = 3

Samples of rockweed, greenling, Irish lord, and rockfish were collected from each of the main Amchitka Island study transects (Milrow, Cannikin, and Long Shot), as well as from Adak Island, the reference (background) area. Landlocked Dolly Varden were collected from lakes on Amchitka and Adak islands. Photographs of the primary producer rockweed and the four fish species are shown in Figure 4 and Figure 5, respectively. Corresponding sample locations are addressed in the following section and shown in Figure 6 through Figure 13.

3.1.2 Seawater and Freshwater Sampling

In accordance with the DQOs defined above, seawater samples were collected from 40 locations off the coast of Long Shot (the focus of the 2016 sampling), one sample from each of the remaining study transects (Cannikin and Milrow), and two samples from the reference site (Adak North and Adak South). Two freshwater samples were also collected, one from Amchitka Island (Cannikin Lake) and one from Adak (Andrew Lake).

As summarized in Table 3, all aqueous samples were analyzed for tritium, the primary focus; ^{134}Cs; and ^{137}Cs. Twelve of the 46 samples were analyzed for ^{129}I. For seawater samples collected off Long Shot, conductivity, temperature, and depth (CTD) measurements, along with other measurements taken by UAF staff, were also obtained as discussed in Section 6.0.

[11] A long-lived radioisotope with a half-life of 16 million years, ^{129}I is produced naturally by spallation of atmospheric xeon and natural uranium fission. It is present in the ocean at very low levels. Although the Fukushima nuclear accident released ^{129}I to the marine environment, inputs were much smaller than those determined for radiocesium. Only small incremental increases in ^{129}I seawater concentrations in excess of the pre-existing fallout levels were observed (Buesseler et al. 2017). Although currently not considered a primary indicator of Fukushima-related inputs, given its long half-life, ^{129}I may be useful in the future as an ocean circulation tracer of Fukushima releases (Buesseler et al. 2017).

[12] n = sample number; spp denotes multiple species.

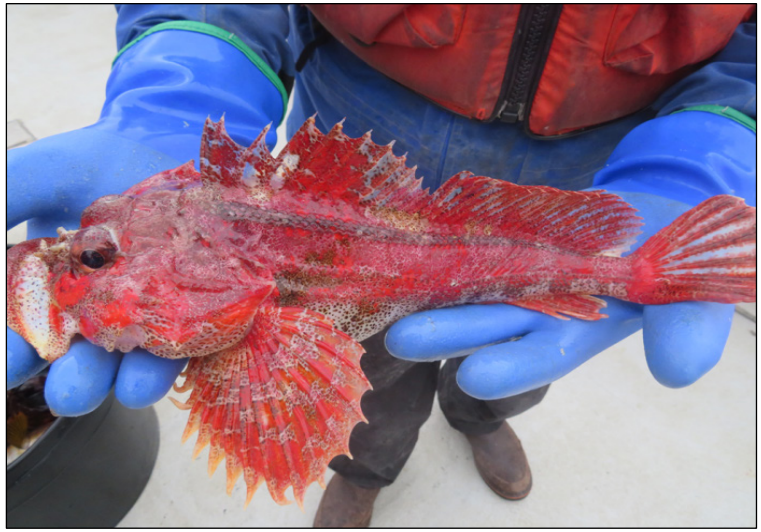
a.

b.

*Figure 4. Rockweed (*Fucus distichus*), from 2016 Sampling Event*
n = 15 samples
(a) Distant view; (b) zoom view

*Rockfish (*Sebastes *spp.), n = 50*

*Greenling (*Hexagrammos *spp.), n = 50 samples*



*Irish lord (*Hemilepidotus *spp.), n = 50 samples*

*Dolly Varden (*Salvelinus malma*), n = 3 samples*

Figure 5. Fish Species Sampled in 2016

3.2 Study Locations and Sampling Sites

The Amchitka and Adak sample locations are shown in Figure 6 and Figure 7, respectively. Adak Island, approximately 200 miles east of Amchitka Island, was selected as the reference location, consistent with the approach used in 2011. By the end of the 2016 environmental sampling effort, LM had collected 168 biota samples and 46 aqueous samples.

The potential release boundaries associated with each of the three test sites and used to guide selection of sample locations are shown in Figure 8. In this figure, for each test location, a first and second edge are depicted where hydrologic modeling predicted the distribution of the location of the plume edges (first and second edge) would be on the bathymetric profile (DOE 2016a). The first and second edge are equivalent to the model-predicted plume after accounting for matrix diffusion effects.

Figure 9 through Figure 13 show the locations of the individual samples collected from the three sites on Amchitka and two areas on Adak. The sample identification nomenclature used in these figures is summarized in Table 4. This nomenclature reflects the following standard labeling system for all the samples collected:
[Species or sample material]-[Site Location]-[Sample Number].

Table 4. Sample ID Nomenclature Used for 2016 Environmental Sampling

Species/Media to be Sampled	Species/Media Identification Prefix
Rockweed (*Fucus distichus*)	FUCU
Greenling (*Hexagrammos* spp.)	GREN
Irish lord (*Hemilepidotus* spp.)	ILOR
Rockfish (*Sebastes* spp.)	ROCK
Dolly Varden (*Salvelinus malma*)	DOLL
Freshwater	FRES
Seawater	SEAW
Site Location	**Location Identifier**
Amchitka Island	AI
Cannikin	CN
Long Shot	LS
Milrow	ML
Adak Island	AD
Adak, North	AN
Adak, South	AS
Sample Number	
Sample Number	1 through x
Duplicate[a]	
Duplicate	DUP (seawater samples only, not biota)

Note:
[a] In this report, duplicate results were excluded from the data analysis and corresponding graphical summaries. In general, for all species and media, there was good agreement in analytical results between the original sample and the corresponding duplicate.

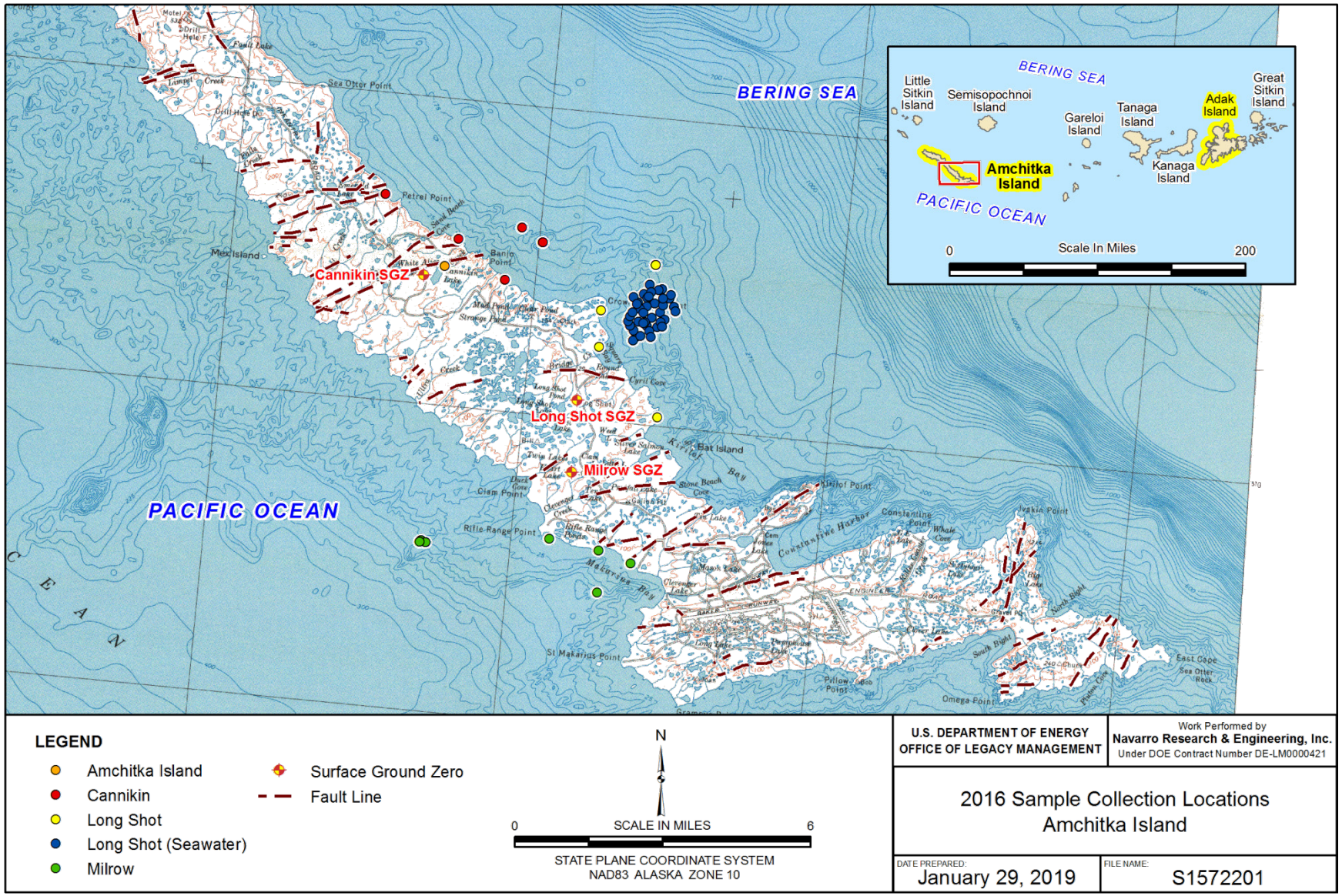


Figure 6. Amchitka Island Sample Locations

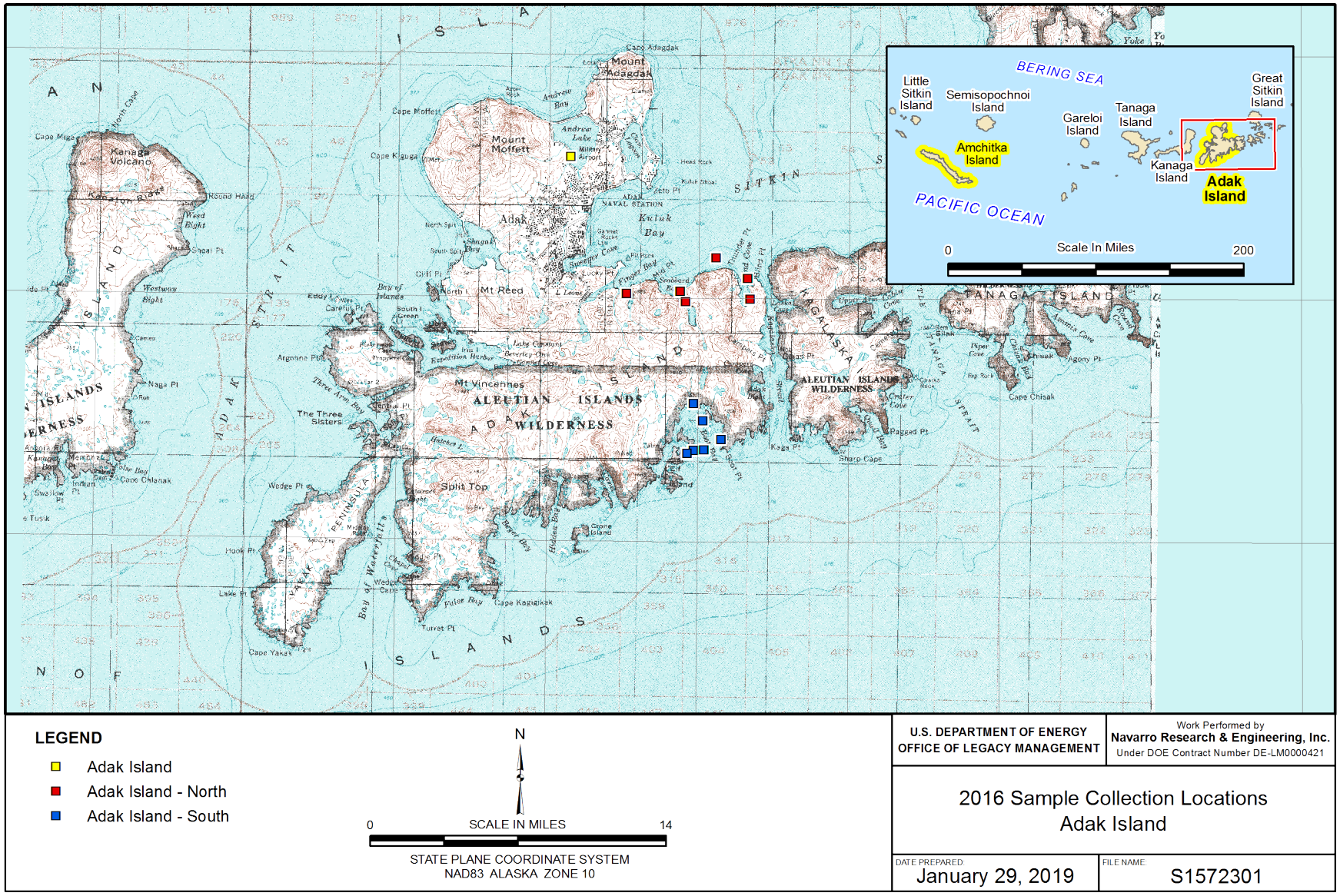


Figure 7. Adak Island Sample Locations

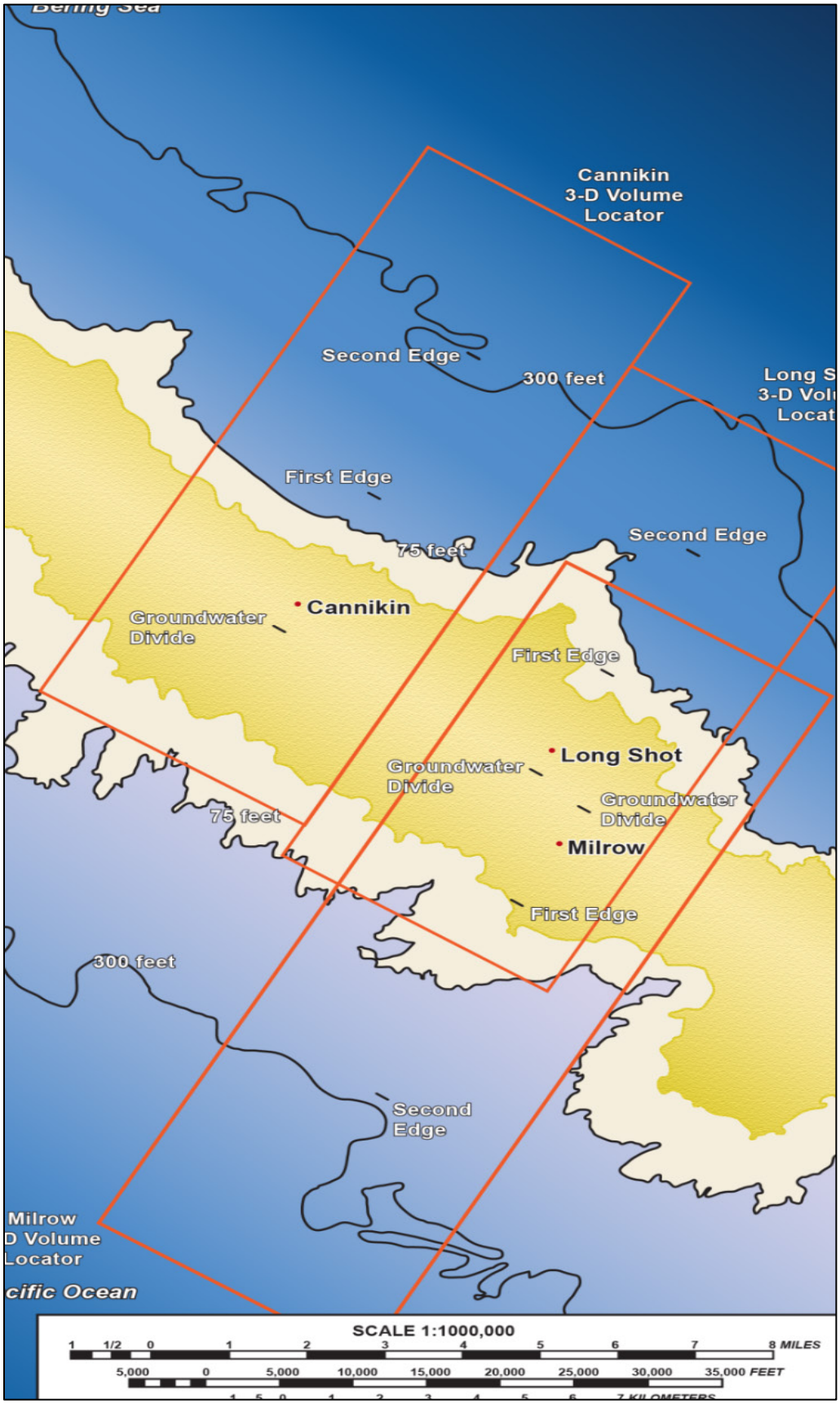


Figure 8. Locations of 3-D Volumes for the Three Areas of Potential Release

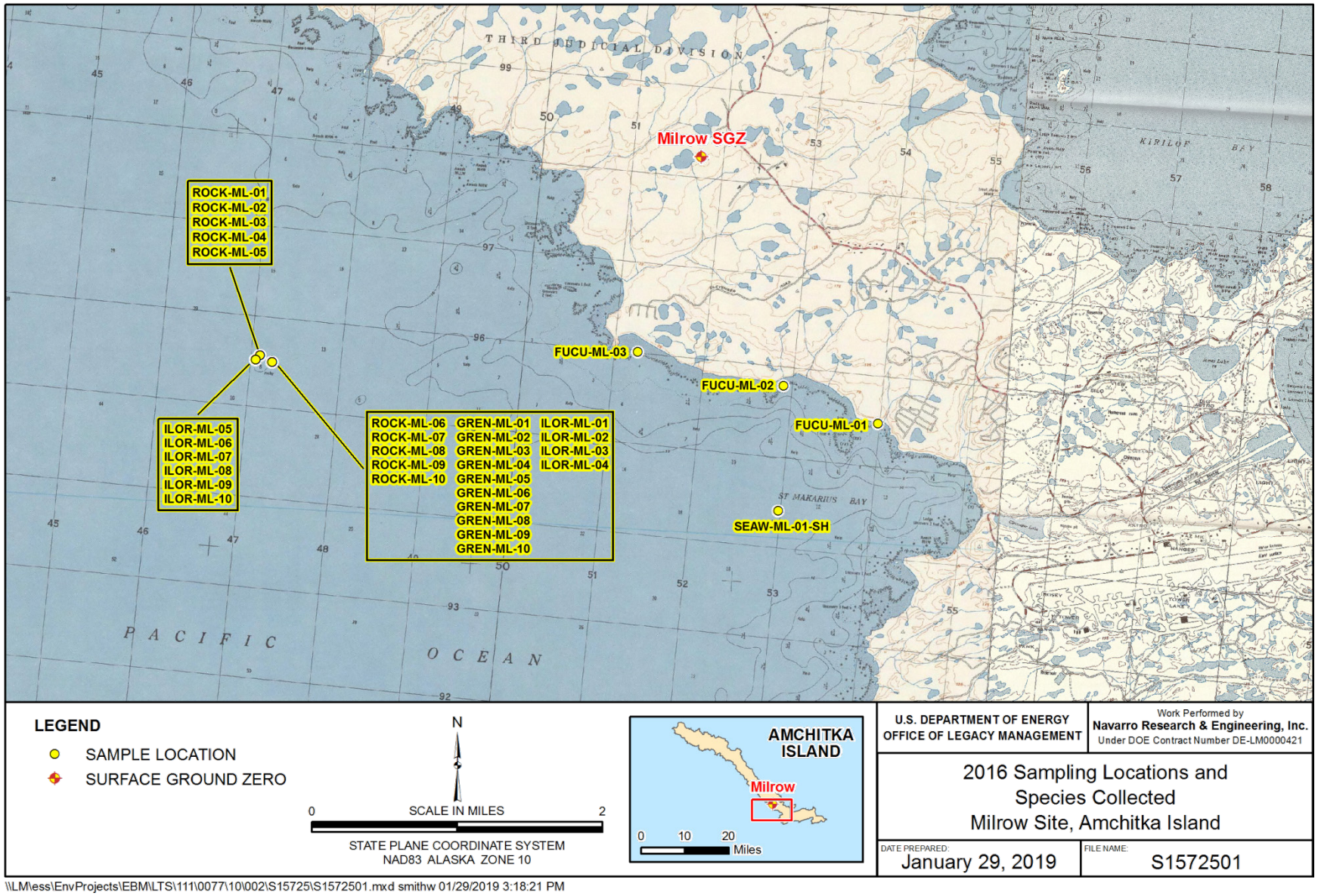


Figure 9. Milrow Sample Locations

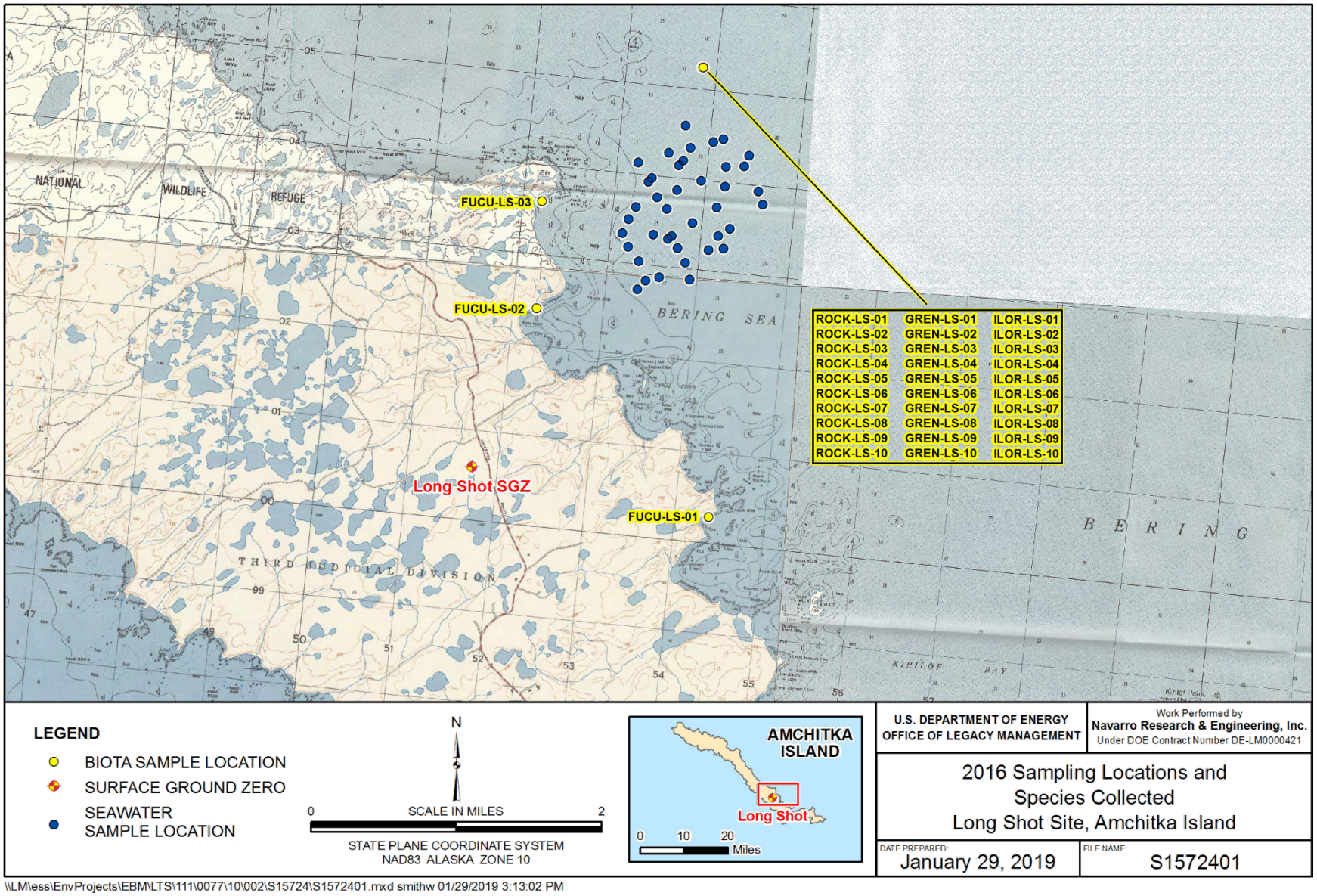


Figure 10. Long Shot Sample Locations

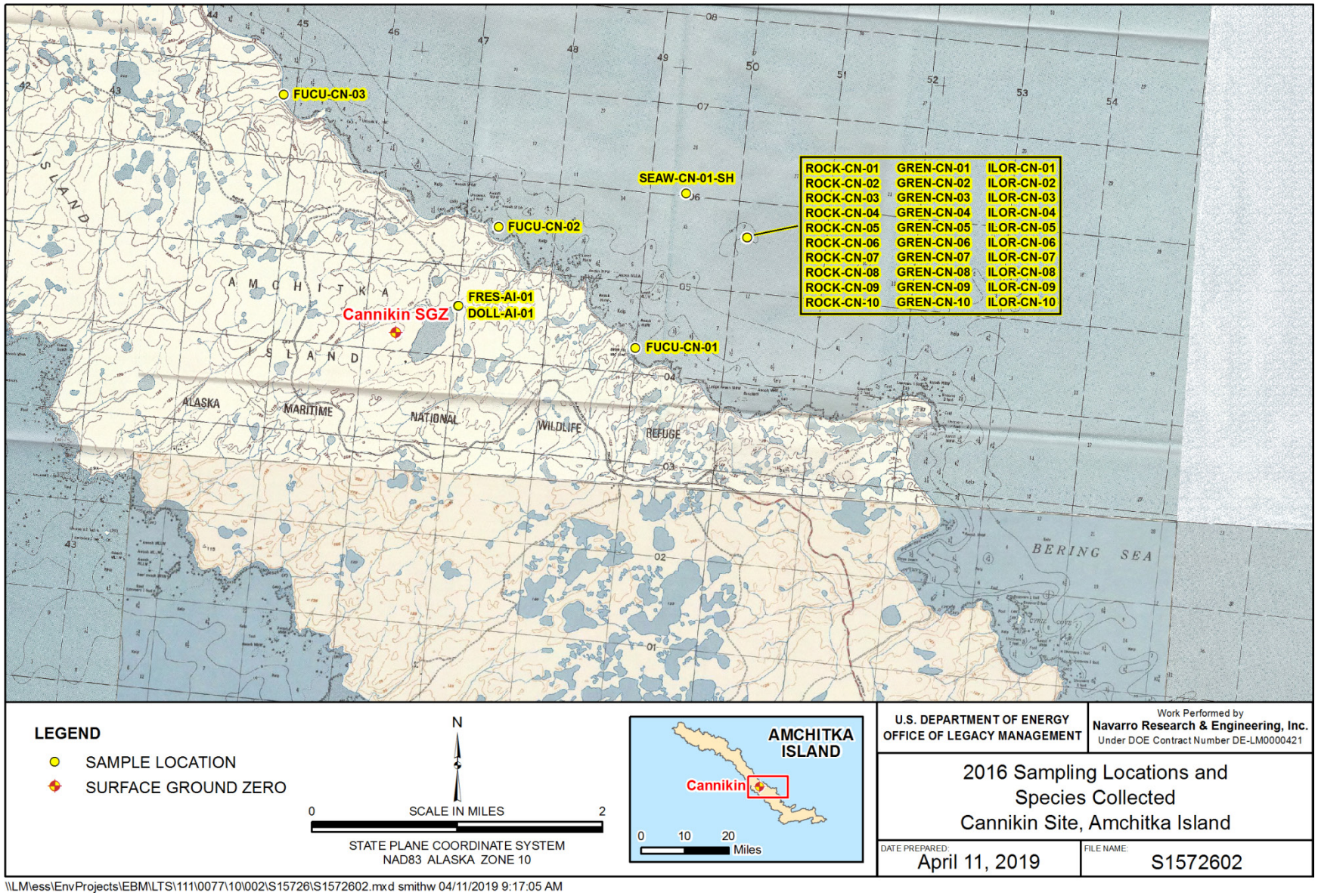


Figure 11. Cannikin Sample Locations

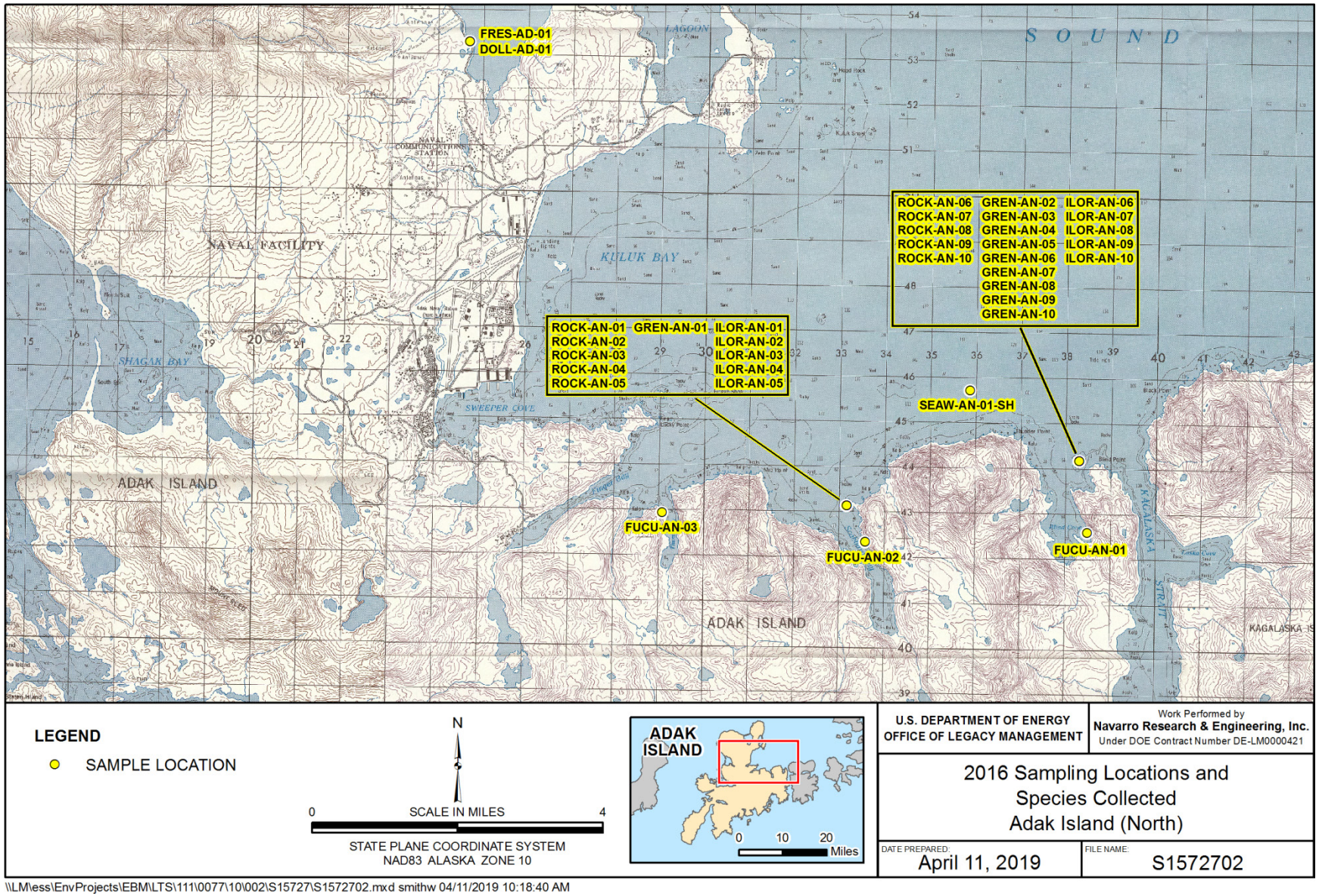


Figure 12. Adak North Sample Locations

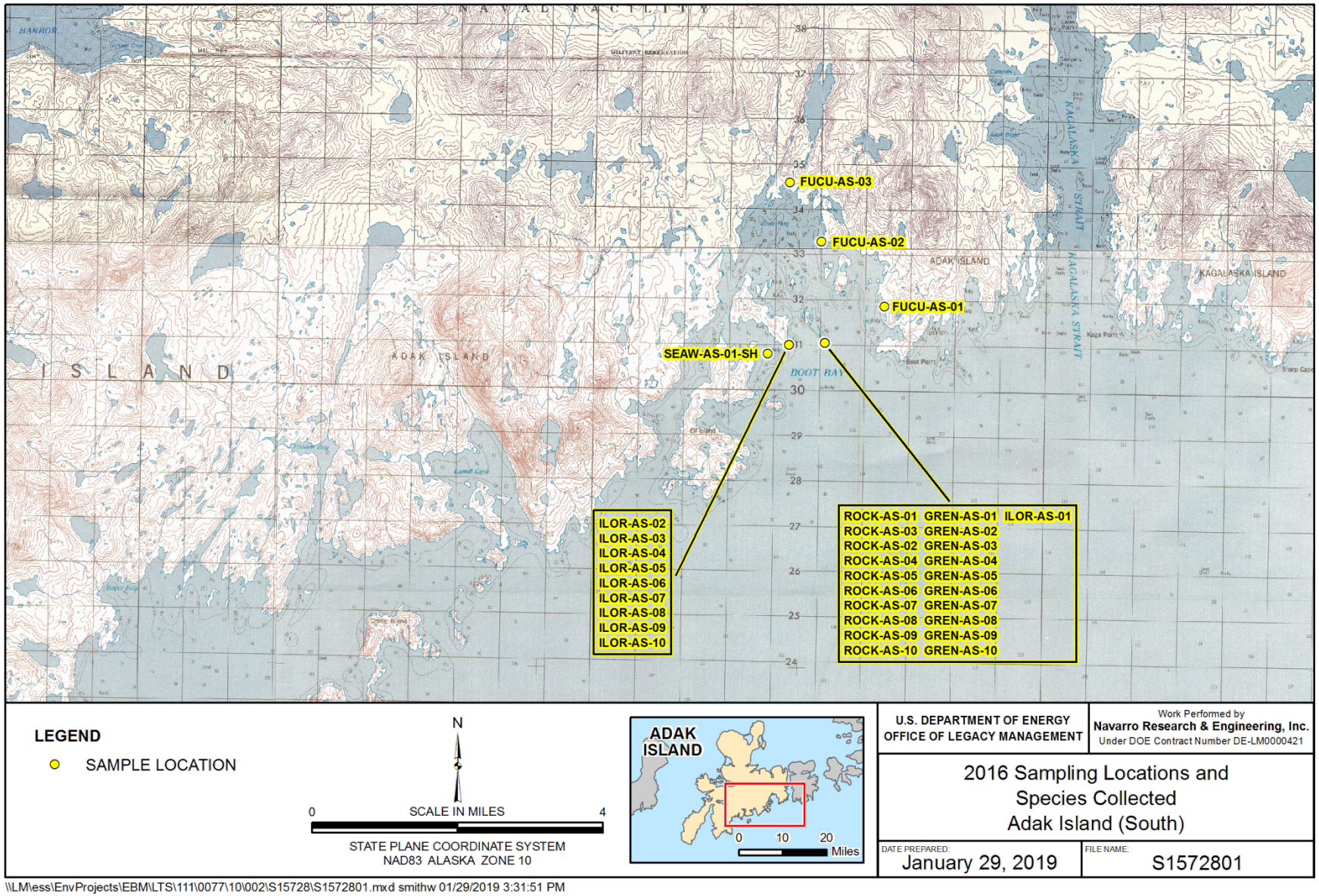
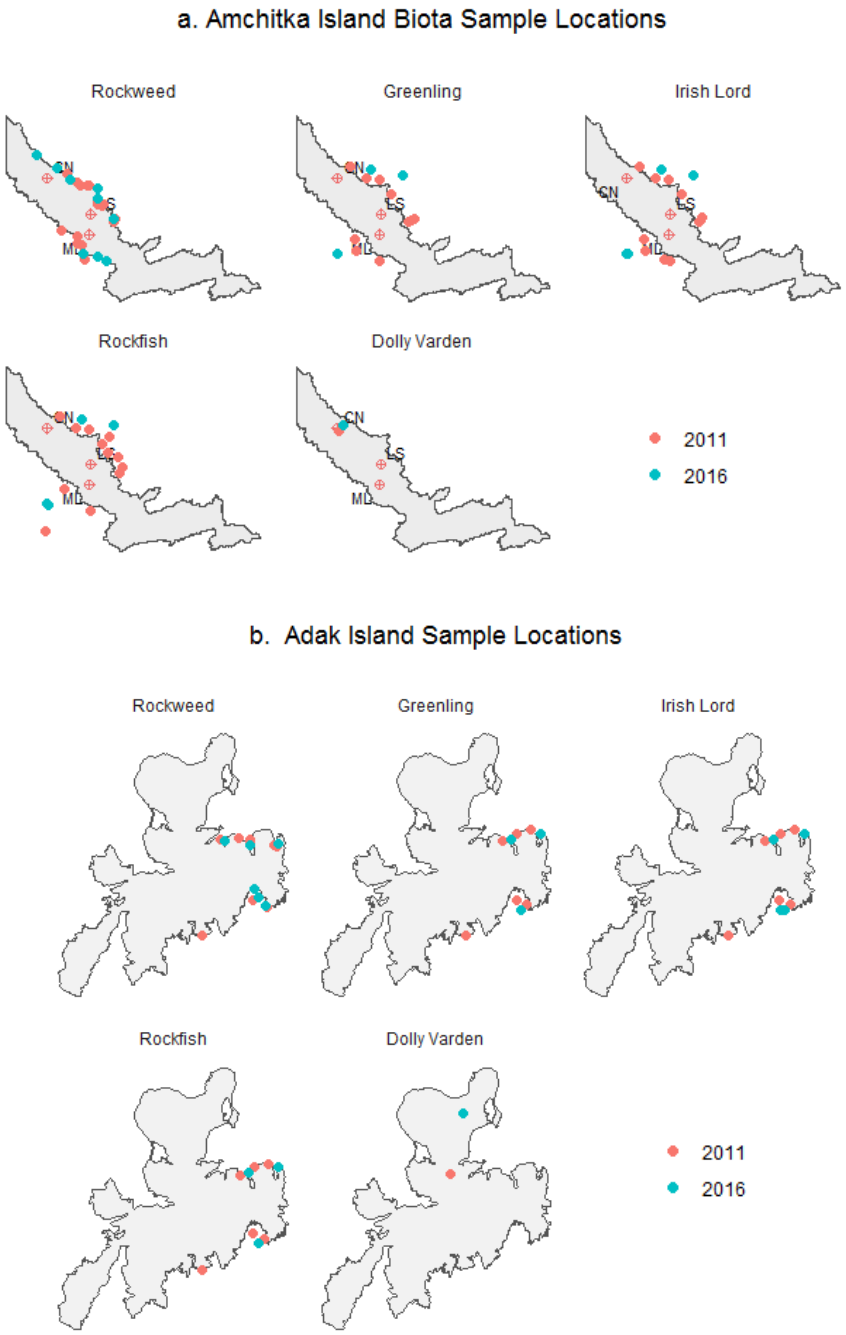


Figure 13. Adak South Sample Locations

In defining the study boundaries for the 2016 environmental sampling effort, the sampling plan (DOE 2016a) indicated that, to provide continuity and efficiency in data interpretation, the biota sampling locations at Amchitka and Adak Islands for 2016 would be the same as those sampled in 2011. As illustrated in the simplified schematic in Figure 14, although the 2011 biota sampling had more spatial diversity in locations, in general, this objective was met.



Note:
For 2011, biota sample locations are those mapped in the 2011 report (DOE 2013). Those for 2016 are shown in greater detail in the preceding figures (Figure 9 through Figure 13). Because of the relatively smaller scale in these simple schematics, there is some overlap in sample locations (thus overplotting).

Figure 14. Simplified Schematic of Biota Sample Locations Sampled in 2011 and 2016 (a) Amchitka Island; (b) Adak Island

As a follow-up to the previous figure, and to illustrate the comprehensiveness of the combined historical biological sampling efforts at and around Amchitka Island, Figure 15 is a simplified schematic of biota sample locations (across all species) by time period. Biota locations sampled in 2016 (●) correspond to those shown in Figure 9 through Figure 14.

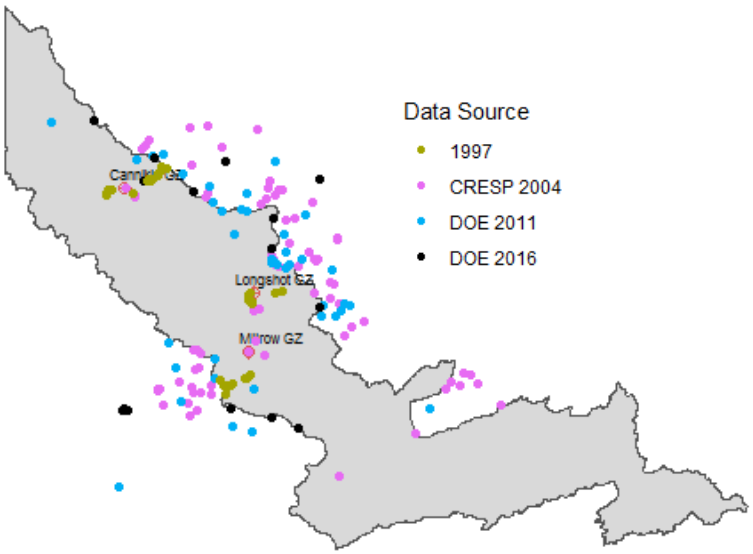


Figure 15. Historical Biota Sampling Locations at and Around Amchitka Island

3.3 Sample Collection and Preparation

Environmental sampling activities began on May 13, 2016, and continued through May 21, 2016.[13] The research vessel (R/V) chartered for the biological sampling, R/V *Qualifier 105* (Figure 16), arrived in Adak, Alaska, on May 12, 2016. The scientific team aboard the vessel included Mark Kautsky, LM's site manager at that time; Bruce Wright (APIA lead); Chase Stoudt and David Leech (UAF); Paul Darr, project manager for Navarro Research and Engineering, Inc. (Navarro); Stephen Pitton, Navarro's engineer (and current project manager); and Lauren Goodknight, Navarro's sample coordinator. Also on board were the captain of the R/V *Qualifier 105* (David Mastolier), his first mate/alternate captain (Jared Bradshaw), and additional support personnel. Biological sampling began on May 13, starting with the Milrow transect.

At each of the study transects, fish species (greenlings, Irish lords, and rockfish) were sampled from the deck of the R/V *Qualifier 105* via hook and line (fishing). Rockweed samples were collected by hand from the shoreline. At the Cannikin, Milrow, and Adak Island transects, one seawater sample was collected from each area where fish samples were collected. Freshwater samples were collected from lakes on both Amchitka and Adak Islands (Cannikin Lake and Andrew Lake, respectively).

[13] Most of the environmental sampling occurred in the May 13–21, 2016, timeframe. However, due to difficulties obtaining Dolly Varden at that time (only one was collected from Adak Island), two additional Dolly Varden samples were collected in mid-June 2016. This effort coincided with a site inspection that was ongoing at that time.

Figure 16. Research Vessel (R/V) Qualifier 105

The bulk of the seawater sampling, off the coast of the Long Shot site in Square Bay, was conducted May 15–17, 2016. UAF provided two sampling technicians and a Sea-Bird Electronics ECO water sampler with a six-bottle configuration (4 liters per bottle), enabling the scientific team to meet the volume requirement of 20 liters per sample. The sampler was deployed from the deck of the R/V *Qualifier 105* using a portable instrumentation winch (Figure 17). Water samples and corresponding real-time CTD measurements were collected at bottom depths off the coast of the Long Shot site.

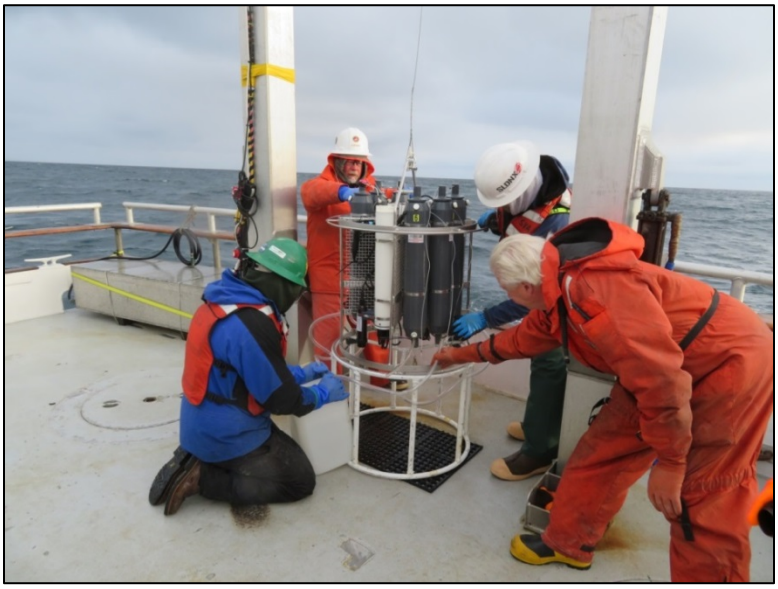


Figure 17. ECO Water Sampler

An overview of sample collection procedures used during the 2016 environmental sampling is provided in Table 5.

Table 5. Field Collection and Sample Preparation Procedures, 2016 Environmental Sampling

Species	Locations	Collection Procedure	Onboard Ship Handling
Rockweed (*Fucus distichus*)	Intertidal at all three test sites and North and South Adak	Sampling personnel from skiff. For each transect, three individual samples of the whole plants weighing approximately 5 kilograms each were collected and composited. Epibiotic growth and residual sedimentary debris were removed by shaking fronds in local seawater or onboard vessel in a large tub of seawater.	Onboard ship, composites were placed separately in plastic bags, labeled, and frozen.
<u>Marine Fish</u> Greenling (*Hexagrammos* spp.) Irish lord (*Hemilepidotus* spp.) Rockfish (*Sebastes* spp.)	Near-shore subtidal and offshore at all three test sites and North and South Adak Island	Hook-and-line, fish trap, or netting from charter vessel or skiff. For each transect, individual fish species were collected. In some cases, several fish were composited to yield the desired 1 kilogram sample size.	Once the fish were returned to the R/V, they were placed in a holding tank or cooler for processing. Each fish had its taxonomic identification checked, sex determined (if possible), length measured (total or fork length, dependent on the species) in centimeters and weight recorded in grams. Samples were placed in plastic bags and labeled accordingly as one composite sample and kept frozen.
<u>Freshwater Fish</u> Dolly Varden (*Salvelinus malma*)	*Amchitka Island*: Cannikin Lake *Adak Island*: Andrew Lake	Hook-and-line, fish trap, or netting. Limited sampling conducted; only three samples collected in May–June 2016.	
Freshwater	*Amchitka Island*: Cannikin Lake *Adak Island*: Andrew Lake	Freshwater samples collected by hand from land. Sample collection personnel used a peristaltic pump to fill two 20-liter carboys half full and a 1-liter amber glass full. Once back at the ship, the two half-full carboys were combined into one 20-liter carboy.	Container numbers and sample IDs were recorded on original field data sheets and on the sample container labels. Because samples were unfiltered, no preservatives were used. The samples were kept cool.
Seawater	Most seawater samples were collected from near the ocean bottom from the deck of the vessel off the coastline of Long Shot (Square Bay), the focus of the 2016 effort, and one from each of the five remaining transects. Remaining samples were collected offshore at each remaining transect: Cannikin, Milrow, and North and South Adak. Only one sample was collected at each of these (non-Long Shot) transects.	Sampling personnel from aboard charter vessel or skiff. Two UAF sample technicians assisted in this effort. Sample collection personnel used an ECO water sampler, or equivalent, to fill a 20-liter carboy per sample and a 1-liter amber bottle. The carboy and bottle were clean and dry, with good caps. Real-time CTD measurements were also obtained.	Sample IDs and (for Long Shot samples) CTD cast station numbers were recorded on original field data sheets and on the sample container labels. Because samples were unfiltered, no preservatives were used. The samples were kept cool.

Upon return of the R/V *Qualifier 105* to Adak on May 21, 2016, sample shipping preparations began. All samples were placed into iced coolers with a completed chain-of-custody (COC) and sample processing continued into the following day. On May 22, 2016, all of the samples were shipped from the Adak airport to LLNL and the University of Miami Rosenstiel School of Marine and Atmospheric Science via Alaska Air's Gold Streak overnight delivery.[14] Both laboratories received the samples the next day, and all of them were reported to be in good condition. Additional details, including a daily activity log, are provided in the *Summary Report on 2016 Biological Sampling at Amchitka Island, Alaska* (Navarro 2016), included as Appendix A of this report.

3.4 Laboratory Analysis

The majority of this section is based on reporting by LLNL, the laboratory that performed all analyses of biological samples collected in both 2011 and 2016, as well as the measurement of cesium isotopes in seawater and freshwater samples. LLNL received 166 biota and 50 water samples on June 14, 2016, accompanied by COC documentation. Upon arrival of the samples, LLNL performed a validation check of all samples received against the COC listing. Consistent with LM's laboratory selection in 2011, tritium analysis was conducted by the University of Miami Rosenstiel School of Marine and Atmospheric Science. Corresponding laboratory reports, including narratives and tabulations of the raw data, are provided in the appendixes to this report as follows:

- Biological Samples
  - Data Report, Part I: Processing of Biological Samples (Wet, Dry, and Ash Weights) (Appendix B)
  - Data Report, Part III: Measurement of Cs Isotopes (^{134}Cs, ^{137}Cs) in Biological Samples (Appendix C)
  - Data Report, Part IV: Measurement of Pu Isotopes (^{239}Pu, ^{240}Pu) in Biological Samples (Appendix D)
- Seawater and Freshwater Samples
  - University of Miami 2016 Tritium Sample Report (Appendix E)
  - Data Report, Part II: Measurement of Cs Isotopes (^{134}Cs, ^{137}Cs) in Seawater and Freshwater Samples (Appendix F)

3.4.1 Biota Samples

3.4.1.1 Sample Processing

LLNL received 166 biota samples on June 14, 2016. Biological samples collected in the field were sealed inside labeled plastic bags and shipped frozen; all fauna (fish) samples were received as whole animals. About one third (55) of the 153 fish samples were received with their gut cavities open: 12 greenling, 33 Irish lord, and 10 rockfish.[15] Biological samples were

[14] Half of the water samples were sent to LLNL (for analysis of cesium isotopes and a subset for ^{129}I) and the other half to the University of Miami for tritium analysis.

[15] This observation is attributed to sex determinations after collection. In some cases, gender could easily be determined based on fish coloration, but not all.

subsequently stored frozen at LLNL prior to processing (Hamilton et al. 2018a). Samples of rockweed were initially processed by allowing free liquids to drain from the samples prior to combustion in a muffle furnace. The free liquids were recombined with the dry ash prior to further processing. The dried biological material was first blended down into small size particles prior to combustion in a large volume muffle furnace. Samples of Dolly Varden, greenling, Irish lord, and rockfish were initially freeze–dried to a constant weight with an uncertainty of less than 0.1%. Table 6 lists the number of samples and the corresponding averages of wet, dry, and ash weights for each species. Dry/wet and ash/dry weight percentages are also provided.

Table 6. Average Wet, Dry, and Ash Weights of Biota Samples by Species

Species	Number of Samples	Wet Weight (g)	Dry Weight (g)	Dry/Wet %	Ash Weight (g)	Ash/Dry %
Rockweed (*Fucus distichus*)	15	5517 ± 384	1297 ± 275	24 ± 5	300 ± 41	24 ± 4
Greenling (*Hexagrammos* spp.)	50	1042 ± 199	242 ± 47	23 ± 2	53 ± 14	22 ± 6
Irish lord (*Hemilepidotus* spp.)	50	1110 ± 233	244 ± 55	22 ± 2	53 ± 10	22 ± 4
Rockfish (*Sebastes* spp.)	50	1212 ± 334	302 ± 88	25 ± 2	59 ± 17	20 ± 5
Dolly Varden[a] (*Salvelinus malma*)	3	1032 ± 304[b]	257 ± 44[b]	26 ± 3	36 ± 14	14 ± 4
Total:	**168**					

Weight and weight percent summaries are the mean ± standard deviation.

Notes:

Table adapted from Table 2 of Hamilton et al. (2018a), provided in Appendix B of this report:

> "Summary data of total sample wet, dry, and ash weights (and dry/wet and ash/dry normalization weights) grouped by biological species (Amchitka 2016)."

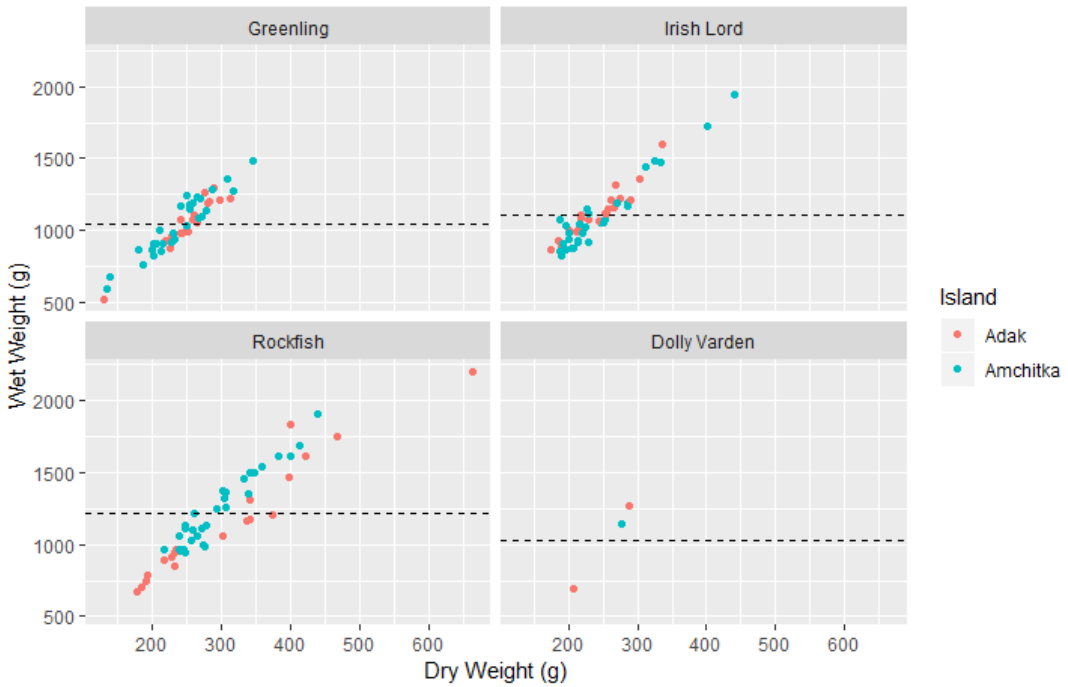
[a] Only one Dolly Varden sample was collected during the May 2016 biomonitoring event: DOLL-AD-01, from Andrew Lake on Adak Island (May 21, 2016). During a later site inspection in June, two additional Dolly Varden samples were collected: another from Andrew Lake on Adak Island (also named DOLL-AD-01, but with collection date of June 14, 2016), and one from Cannikin Lake on Amchitka Island (collection date June 21, 2016). According to LLNL (Hamilton et al. 2018a), the latter two samples were received in a later shipment without COC documentation.

[b] Wet and dry weight standard deviations reported above for Dolly Varden (304 and 44) differ from those reported by LLNL (248 and 36). This correction was based on LM's independent calculation of sample weights reported in Table 3 of LLNL's biological sample processing report ("Individual Sample Wet, Dry, and Ash Weights") (Hamilton et al. 2018a; included as Appendix B of this report).

Abbreviation:

g = grams

To evaluate whether there were any interisland differences in fish weights, Figure 18 plots wet versus dry weights for each fish species, color-coded by island. As shown in this figure, the majority of samples met the 1000-gram (g) objective for fish weights set forth in the sampling plan (DOE 2016a). The main factor driving this criterion was to ensure sufficiently low detection limits (or MDAs), which generally vary inversely with sample weight. As discussed in the following section, except for ^{240}Pu this goal was achieved; MDAs were lower in 2016 than in 2011. As evidenced by the skewness in orange points, some rockfish samples from Adak had lower moisture contents relative to those collected from Amchitka (70% versus 76%, respectively).



Notes:
Scales common in all plots to facilitate inter-species comparisons.
--- dashed line denotes average wet weight by species (Table 6).

Figure developed based on individual wet and dry weights reported in Table 3 of LLNL's biological sample processing report (Hamilton et al. 2018a), included as Appendix B of this report. Rockweed is not included in this figure because individual sample weights were not reported.

Figure 18. Distribution of Fish Sample Weights by Species

3.4.1.2 Sample Analysis

Consistent with the objectives set forth in the environmental sampling plan (DOE 2016a), in 2016 DOE selected laboratory analytical methods with low detection limits to measure activities of radionuclides in sampled biota. The detection capabilities of the analytical methodologies employed were evaluated using the MDA, a measure of method performance.[16]

[16] Historically, there has been some inconsistency in how the term "MDA," or equivalent terminology, is defined. CRESP (2005) defines MDA as "minimum detectable activity," consistent with LM's current standard terminology. This differs slightly from LLNL's definition, "minimum detection activity" (Hamilton et al. 2018a) and from the term used in the 2011 report, "minimum detectable concentration" or MDC (DOE 2013). All three terms, however, are interchangeable.

Table 7 lists the targeted radionuclides, methodologies, and both estimated and actual (achieved) limits of detection for the 2016 biological sampling program. Along with estimated MDAs documented by LLNL in their narratives, this table also shows the sample-specific MDAs by species. For biota, all references to MDAs in this report are in pCi/kg wet weight. Elaboration on laboratory methods used for cesium and plutonium isotopes follow Table 7.

Table 7. Laboratory Methods and Corresponding MDAs for Biota Samples Target Radionuclides, 2016 Environmental Sampling Program

Analyte	Laboratory Method	Estimated MDA pCi (Bq)[a]	Sample-Specific MDAs by Species (pCi/kg wet weight)[b]		
			Species	Mean	Range
^{134}Cs	Gamma spectrometry	8.1 (0.3)	Rockweed Greenling Irish lord Rockfish Dolly Varden	0.8 3.9 3.4 3.6 4.5	0.7–0.9 1.2–8.2 1.0–7.9 0.9–7.3 3.3–5.9
^{137}Cs	Gamma spectrometry[c]	8.1 (0.3)	Rockweed Greenling Irish lord Rockfish Dolly Varden	0.16 0.78 0.67 0.71 0.89	0.14–0.18 0.23–1.6 0.19–1.6 0.18–1.5 0.66–1.2
^{137}Cs	Gamma spectrometry, counted on SAGe[d]	NA	NA	0.31	0.18–0.9
^{239}Pu	Quad ICP-MS[e]	0.216 (0.008)	Rockweed Greenling Irish lord Rockfish Dolly Varden	0.0004 0.003 0.003 0.002 0.003	0.0004–0.0005 0.002–0.005 0.001–0.006 0.001–0.004 0.003–0.005
^{240}Pu	Quad ICP-MS[d]	0.54 (0.02)	Rockweed Greenling Irish lord Rockfish Dolly Varden	0.003 0.017 0.016 0.015 0.022	0.002–0.003 0.012–0.03 0.008–0.036 0.009–0.026 0.017–0.031

Notes:

[a] Estimated MDAs expressed on sample mass basis based on a 1000 kg sample, from Table 1 of Hamilton et al. (2018a), provided in Appendix B of this report.

[b] Mean MDAs and corresponding ranges are based on the sample-specific relative detection limits reported by LLNL (Hamilton et al. 2018c; 2018d) for Cs and Pu isotopes, respectively (Appendixes C and D of this report).

[c] This method differs from that used in 2011. In 2011, the majority of the ^{137}Cs samples were counted using gas proportional beta spectrometry (DOE 2013, Hamilton et al. 2012), a method that cannot differentiate between ^{137}Cs and ^{134}Cs. This factor influenced between-year comparisons of the ^{137}C biota sampling results, as discussed later in Section 4.2.

[d] About 20% of the marine biota samples contained no reportable Cs isotope activity. Many of these samples were subsequently recounted on a SAGe well detector system with improved measurement precision. Reported MDAs are not broken out by species in table above.

[e] For analysis of plutonium isotopes, LLNL anticipated using a more sensitive method—Accelerator Mass Spectrometry—but ultimately this method was not used for analysis of biota samples. Estimated MDAs using Accelerator Mass Spectrometry were 0.0003 and 0.0008 pCi/kg (0.00001 and 0.00003 Bq/kg), respectively, for 1000-g samples.

Abbreviations:

Bq = becquerels
kg = kilograms
NA = Not applicable or not reported
pCi = picocuries
Quad ICP-MS = Quadrupole Inductively Coupled Plasma Mass Spectrometry
SAGe = Small Anode Germanium (well detector)

Cesium Isotopes (^{134}Cs and ^{137}Cs)

Cesium isotopes were determined by high resolution gamma spectrometry after separation of the analytes of interest, along with added carrier, on a small quantity of micro-crystalline ammonium molybdophosphate (AMP) (Hamilton et al. 2018c). To improve quantification of cesium isotopes by gamma spectrometry and allow for a more detailed comparative assessment to be conducted between sampling events, the project reporting deadline was extended to allow for longer count times. Even with the longer count times (4–6 days), about 20% of the marine biota samples contained no reportable cesium isotope activity. These samples were subsequently recounted on a Small Anode Germanium (SAGe) well detector system with improved measurement precision.

For the subset of samples identified above, ^{134}C and ^{137}Cs sample activities were measured using a SAGe well detector system coupled to a PC-based work station operating under Canberra Apex-Gamma Lab Productivity Suite software with LabSOCS-generated efficiency calibrations for a 10-g AMP geometry. Count times usually varied between 48 and 64 hours.

Plutonium Isotopes

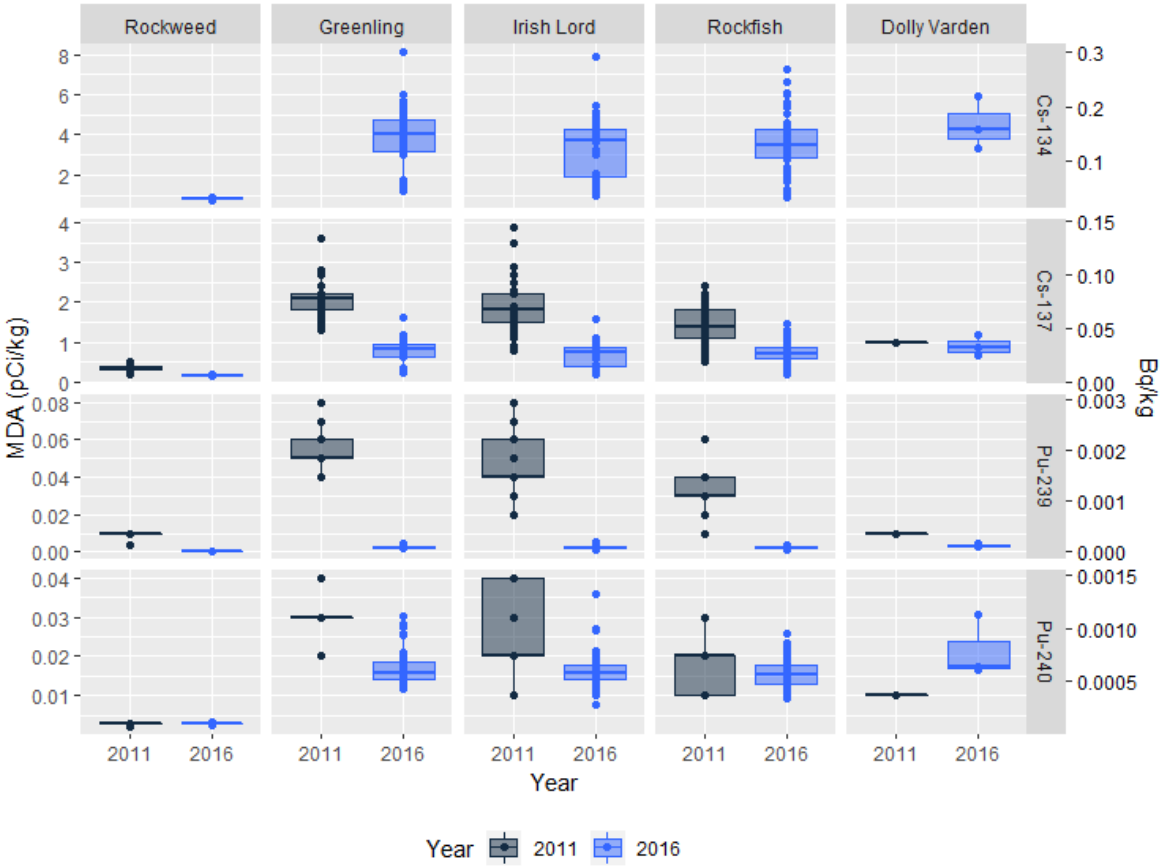
Plutonium isotopes were measured by quadrupole inductively coupled plasma mass spectrometry (ICP-MS). Although some consideration was initially given to conducting measurements of plutonium isotopes in biological samples using Accelerator Mass Spectrometry (AMS), ultimately only Quad ICP-MS was used. The acceptance criteria for plutonium isotope data was based on a sensitivity trigger rule whereby measurements were only reported when the values exceeded the relative detection limit (RDL) (Hamilton et al. 2018d).

Examination of MDAs in Light of Study DQOs

One of the DQOs established for the 2016 environmental sampling program was to have greater sensitivity in laboratory methods for biological samples (i.e., lower detection limits). As illustrated in the following figures, this objective was achieved for analysis of ^{137}Cs and ^{239}Pu in biological samples (although laboratory analyses took more than 2 years to complete, this delay did not affect data quality). However, as discussed in Section 4.0, the lower MDAs also complicated the interpretation of between-year trends for some radionuclides, in particular ^{239}Pu.

Intended as an overview, for each year/isotope grouping, Figure 19 plots the sample-specific MDAs reported by LLNL. In addition to ^{137}Cs and $^{239}Pu/^{240}Pu$, analyzed in biological samples in both 2011 and 2016, this figure also plots the MDAs for ^{134}Cs (analyzed only in 2016). Figure 20 and Figure 21 provide greater resolution on MDAs for ^{137}Cs and $^{239}Pu/^{240}Pu$, respectively. In each of these figures, data from both Amchitka and Adak are combined because no interisland difference in MDAs was found.

In general, in comparing detection limits between sampling years for a given species, MDAs were about 2 times lower for ^{137}Cs in 2016 than in 2011 (Figure 20) and an order of magnitude lower for ^{239}Pu. Exceptions include Dolly Varden, with too few samples to evaluate. The greatest difference in MDAs between years (2011 versus 2016) was found for ^{239}Pu, as shown in Figure 21. Although detected in most rockweed samples in 2011, ^{239}Pu was not detected in most marine fish samples in 2011. However, as discussed later in this report (Section 4.3), this radionuclide was detected at much higher frequencies in 2016.



● (2011) ● (2016) denote sample-specific MDAs or RDLs

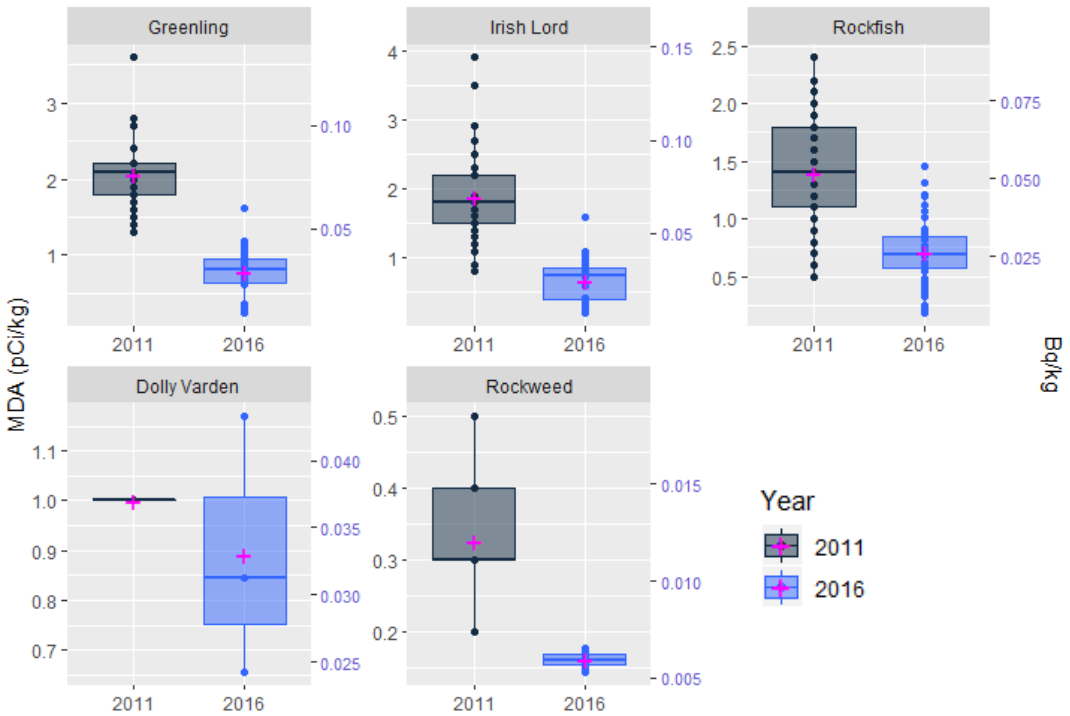
Notes:

1. MDAs in pCi/kg wet weight. Corresponding SI units, in Bq/kg, are shown on the right *y*-axis.
2. Bottom and top of boxes denote the 25th and 75th percentiles, respectively, while the center lines bisecting the boxes denote the median (presence dependent on sample number and MDA distribution).
3. For 2011, plotted values are the MDAs reported in the 2011 biological monitoring report (DOE 2013). For 2016, plotted values correspond to the sample-specific RDLs reported by LLNL (Hamilton et al. 2018c; 2018d), provided in Appendixes C and D of this report.
4. For each radionuclide, scales are common across species. As shown here, MDAs were lowest for rockweed. Additional resolution for ^{137}Cs and plutonium isotopes is provided in Figure 20 and Figure 21, respectively. Cesium-134 was not analyzed in marine vegetation or fish samples collected in 2011.

Abbreviations:

Bq/kg = becquerels per kilogram
SI = International System of Units

Figure 19. Box Plots of Biota Sample MDAs by Species and Year (2011 vs. 2016)



+ denotes mean MDA for each species/year grouping.

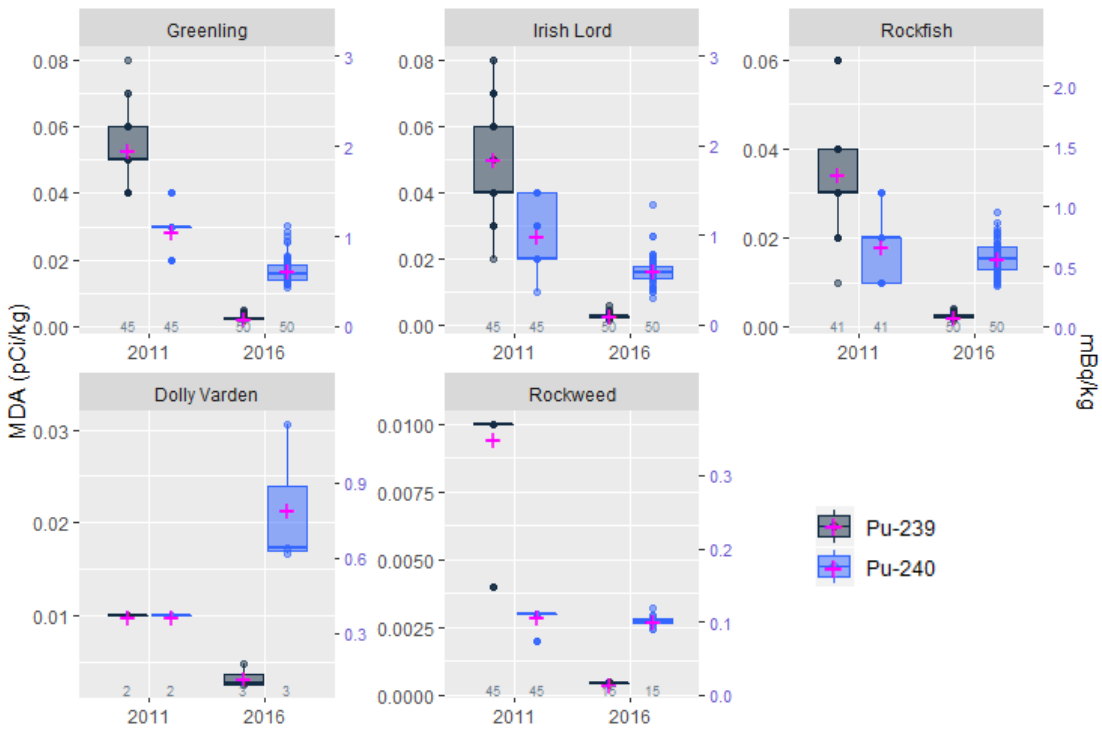
Notes:

1. MDAs in pCi/kg wet weight. Corresponding SI units, in Bq/kg, are shown on the right *y*-axis.
2. The between-year differences in MDAs likely reflect the differences in analytical methods. In 2011, the majority of ^{137}Cs samples were counted using gas proportional beta spectrometry (Hamilton et al. 2012) whereas gamma spectrometry was used in 2016.
3. For 2011, plotted values are the MDAs reported in the 2011 biological monitoring report (DOE 2013). For 2016, plotted values correspond to the sample-specific RDLs reported by LLNL (Hamilton et al. 2018c), provided in Appendix C of this report.
4. MDAs for each year reflect the combined data from both Amchitka and Adak combined, as interisland differences in MDAs were negligible.

Abbreviations:

Bq/kg = becquerels per kilogram
SI = International System of Units

Figure 20. Comparison of MDAs for ^{137}Cs in Biota Samples: 2011 vs. 2016



+ denotes mean MDA for each species/year grouping

Notes:

1. MDAs in pCi/kg wet weight. Corresponding SI units, in mBq, are shown on the right *y*-axis.
2. For 2011, plotted values are the MDAs reported in the 2011 biological monitoring report (DOE 2013). For 2016, plotted values correspond to the sample-specific RDLs reported by LLNL (Hamilton et al. 2018d), provided in Appendix D of this report.
3. MDAs for each year reflect the combined data from both Amchitka and Adak combined, as interisland differences in MDAs were negligible. Sample numbers are shown below each box plot because of overplotting (many samples having the same MDA).

Abbreviations:
mBq = millibecquerels
SI =International System of Units

Figure 21. Comparison of MDAs for Plutonium Isotopes: 2011 vs. 2016

In 2011 (DOE 2013), MDAs for measurement of ^{239}Pu ranged from 0.004–0.01 pCi/kg in rockweed and from about 0.04–0.08 pCi/kg in marine fish (greenling, Irish lord, and rockfish). This was not the case in 2016 when corresponding MDAs were about an order of magnitude lower (Figure 21). The between-year difference was less for Dolly Varden, but sample numbers were small in both years (less than 3), so any comparison may not be meaningful. Except for Dolly Varden, there is no overlap in the MDAs for ^{239}Pu between years.

While ^{239}Pu MDAs were markedly lower in 2016, this was not the case for ^{240}Pu. Relative to 2011 analyses, MDAs for ^{240}Pu in 2016 were slightly lower in the case of greenling and Irish lord, about the same for rockfish and rockweed, and higher in Dolly Varden. A related point is the fact that the ratio of MDAs—^{239}Pu/^{240}Pu—differs markedly between years. In 2011, ^{239}Pu MDAs were greater than those for ^{240}Pu; the opposite case applied in 2016, a factor that hindered identification of test-related signatures based on ^{240}Pu/^{239}Pu atom ratios. As discussed in later sections of this report, the latter finding, along with the markedly lower MDAs for some

species-isotope combinations, complicated the statistical analysis and corresponding data interpretations.

3.4.2 Seawater and Freshwater Samples

Water samples were shipped in single 20-liter (L) (5-gallon) polyethylene carboys with no preservation. Samples for analysis of cesium isotopes were received in two separate air cargo flights into San José International Airport in northern California and then immediately transported by road approximately 30 miles to LLNL. The University of Miami Rosenstiel School of Marine and Atmospheric Science provided tritium data on all seawater samples collected using the enriched method and low-level gas proportional counters. Detailed methods and raw data are provided in Appendix E (sample receipt and preparation information was not provided). Sample methods are summarized in Table 8. DQOs related to analytical sensitivity were met for the aqueous samples (i.e., MDAs were sufficiently low).

Table 8. Laboratory Methods and Corresponding MDAs for Seawater and Freshwater Samples Target Radionuclides, 2016 Environmental Sampling Program

Analyte	Laboratory	Laboratory Method	Estimated MDA pCi (Bq)	Range of MDAs[a] (pCi/L)
^{134}Cs[b]	LLNL	Gamma spectrometry (SAGe)	8.1 (0.3)[c]	0.015–0.042 (mean = 0.03)
^{137}Cs	LLNL	Gamma spectrometry (SAGe)	4.0 (0.15)[c]	0.007–0.021 (mean = 0.013)
^{3}H	University of Miami (Rosenstiel)[d]	Electrolytic enrichment followed by gas proportional counting	NA	0.29 pCi/L (all samples) (0.01 Bq/L = 0.09 TU)
^{129}I[e]	LLNL	AMS	NA	1.24×10^{-9} (all samples)

Notes:

[a] For cesium isotopes, MDAs are based on the sample-specific RDLs reported by LLNL (Hamilton et al. 2018b), provided in Appendix F of this report.

[b] According to LLNL (Hamilton et al. 2018b; Appendix F), no reportable levels of ^{134}Cs were observed in water samples. Cesium-134 was identified in the gamma software spectral output for two samples but at levels comparable to the RDL.

[c] Based on a 20-L sample (becquerels per cubic meter).

[d] Detailed report provided in Appendix E.

[e] A subset of seawater and freshwater samples (12 total) was analyzed for ^{129}I using AMS with the aim of providing information on the potential impacts of other source-terms on marine radioactivity, especially with respect to Fukushima. No other AMS measurements were conducted apart from this subset.

Abbreviations:

Bq = becquerels
Bq/L = becquerels per liter
^{3}H = tritium
NA = Not applicable or not reported
pCi = picocuries
TU = tritium units

University of Miami Analyses: Tritium

Tritium analysis was performed by the Tritium Laboratory at the University of Miami Rosenstiel School of Marine and Atmospheric Science using the enriched method and low-level gas proportional counters (additional detail provided in Appendix E).

LLNL Analyses: Cesium Isotopes and ^{129}I

Unfiltered water samples were received in 20-L polyethylene carboys with no preservation. Prior to treatment, a subsample of water (approximately 1 L) was taken for possible analysis of ^{129}I by AMS. The remaining water was subsequently acidified and then allowed to stand for a minimum period of 24-hours after addition of stable cesium carrier.

Cesium-134 and ^{137}Cs sample activities were measured using a SAGe well-detector system coupled to a PC-based work station operating under Canberra Apex-Gamma Lab Productivity Suite software with LabSOCS-generated efficiency calibrations for a 10 g AMP geometry. Count times usually varied between 48 and 64 hours. Additional information is provided in Appendix F (based on Hamilton et al. 2018b), including sample-specific results of ^{134}Cs and ^{137}Cs analyses in 2016 seawater and freshwater samples.

3.5 Data Analysis and Visualization Approaches

This section describes the generalized statistical and data visualization approaches used in this report, in particular for the subsequent discussion of biota sampling results (Section 4.0). Based on the DQOs established in the sampling plan (DOE 2016a), a major aspect of this analysis was the comparison of 2016 environmental sampling results with those from LM's first (2011) sampling event. From a statistical standpoint, this comparison was complicated by achievement of another DQO, greater laboratory analytical sensitivity in 2016 versus that achieved in 2011. These issues are elaborated upon below.

3.5.1 Statistical Approaches

In evaluating the 2016 biological data, in addition to examining the overall levels of radionuclides measured in biota, the following primary questions were addressed:

1. For a given species, in samples collected from Amchitka, did the levels of radionuclides differ between years (2016 versus 2011)?[17]
2. For a given species and year, did the levels measured differ between islands (Amchitka versus Adak)?
3. For a given species, are there differences in detection frequencies (proportions of detects versus nondetects) between islands?

These questions were addressed quantitatively using the statistical approaches described below. Differences in radionuclides among the target species (e.g., rockweed, greenling, and rockfish)

[17] Although between-year differences in radionuclide concentrations measured in species collected from the reference island, Adak, might be indicated by the statistical tests, with respect to the study DQOs (Section 1.1 and DOE 2016a), this endpoint was considered less important.

were only addressed qualitatively. Locational differences—that is, differences in biota tissue concentrations between the Amchitka test shot sites (e.g., Cannikin, Milrow, and Long Shot)—were also only qualitatively addressed, in part because of the small sample sizes in those groups.

3.5.1.1 Handling of Nondetects

Before describing the analytical approaches used to address the primary study questions noted above, the large proportion of nondetects for some radionuclides must be acknowledged. This issue was identified by CRESP (2005) as the vast majority of biota tissue results for anthropogenic radionuclides were below the MDA. This stemmed largely from the fact that most of their samples were small (100 g), versus larger (1000 g) samples, allowing greater laboratory sensitivity. Even though sample weights were larger in 2011 (on average about 1000 g), high percentages of nondetects were also reported by LM for ^{241}Am, ^{239}Pu, and ^{240}Pu based on the 2011 sampling results (DOE 2013).

The presence of nondetects in a data set, often referred to as "censored" data, can be problematic from a statistical perspective. This problem is magnified when detection limits differ between groups (e.g., years), as previously demonstrated for both ^{137}Cs and ^{239}Pu (Figure 20 and Figure 21). In this report, the term "censored" applies to results that are not quantified but known only to be less than the MDA or sample-specific RDL. In the ensuing discussion, the term "censored" is used interchangeably with "nondetect." Approaches to handling censored data have prompted much discussion, as well as debate, in the scientific community (e.g., Rouhani and van Geel 2017 and Helsel 2012). Some of these approaches include:

- Substitution—Substitute the censored or nondetect value with zero (archaic), one-half the detection limit, or the detection limit value.
- Omission—Omit the nondetect data entirely.
- Survival analysis or analogous methods—Apply more sophisticated statistical methods to avoid the drawbacks associated with substitution.
- Do not conduct any statistical analysis—An appropriate approach in cases when all or most (more than 90%) of the data are below the detection limit.

These approaches are summarized briefly below, along with a discussion of how or if they were applied in this report.

Substitution

Before the recent advent of more sophisticated analytical techniques, substitution of censored data with one-half the detection limit value has probably been the most common approach applied in environmental studies and risk assessments (e.g., Rouhani and van Geel 2017). This approach was also used by CRESP (2005) in their analysis of 2004 biological sampling results. In this analysis of 2016 biota sampling results, a more conservative variant of the latter approach was used: substitution with the detection limit or MDA (versus one-half the MDA).[18]

[18] CRESP (2005) determined that substitution of nondetects with one-half the MDA would systematically overestimate the data. This conclusion was reasonable, given that their detection limits were very high relative to those in LM's 2011 investigation and especially those achieved in the analysis of 2016 biota samples.

Examination of the distributions of MDAs in the previous section provided a glimpse of potential problems associated with substitution. That is, if the MDAs differ so markedly between years as shown in Figure 21 for ^{239}Pu, and nondetects are treated as equivalent to those MDAs, then an artificial pattern, or "invasive data" as referred to by Helsel (2012), is introduced into the data set. Despite the acknowledged drawbacks, in this report, censored data were substituted with the MDA, consistent with the approach used in 2011 (DOE 2013) in both the risk assessment and data summaries.[19] For data visualization, it was considered better to plot nondetects at the reported MDA (using distinct symbology) rather than a fraction of it. This approach is also consistent with the graphical representations used by LLNL in their analysis and interpretations of the 2011 data (Hamilton et al. 2012).

Omission

According to Helsel (2012), "the worst practice when dealing with censored data or observations is to exclude or delete them." This approach essentially entails discarding all results below the detection limit and focusing only on the higher end of the distribution, an approach that is particularly problematic for data sets with higher proportions of nondetects. Although the tables presented in the following section (e.g., Table 9) provide two sets of means and standard deviations, one for detects only and the other for all results (including censored values), nondetects were not omitted in any statistical comparisons.

Survival Analysis

Helsel (2012) cautions strongly against using both substitution and omission methods and advocates using the following alternative approaches: (1) nonparametric methods after censoring at the highest reporting limit; (2) maximum likelihood estimation (a parametric survival analysis approach); and (3) nonparametric survival analysis. These more sophisticated approaches are evolving as reflected in iterations of the Nondetects and Data Analysis for Environmental Data (NADA) package in R.[20] Although not applied in this analysis, these alternative techniques will be considered in future analyses of Amchitka site environmental sampling results.

Do not conduct any statistical analysis—This was done for radionuclides with very few detections: ^{134}Cs and ^{240}Pu, each of which was detected in only 4 of the 168 biota samples.

To illustrate some of the issues discussed above, Figure 22 presents a matrix of quantile-quantile (Q-Q) plots based on a subset of ^{239}Pu data from 2016, the 20 greenling samples collected from Adak Island. A traditional data visualization tool, Q-Q plots are simple graphical approaches used to test normality. If the data are normally distributed, then points fall in a straight or fairly straight line. In contrast, if the plot has some curvature (e.g., an S-shape), then the data are likely not normally distributed. For the example data subset, the Q-Q plots in Figure 22 show (1) data substituted with the MDA; (2) nondetects excluded; and (3) the censored data as treated using the NADA package.

[19] From a trend analysis perspective, this approach is not much different from substituting one-half the detection limit; in both cases, substitution introduces an artificial pattern into the data set. The main difference is that it yields more conservative estimates of central tendency and other statistical measures.

[20] The NADA package in R (R Core Team 2019) includes plotting and analysis techniques for censored data but, at the time of this writing, could not be used for multiple comparisons.

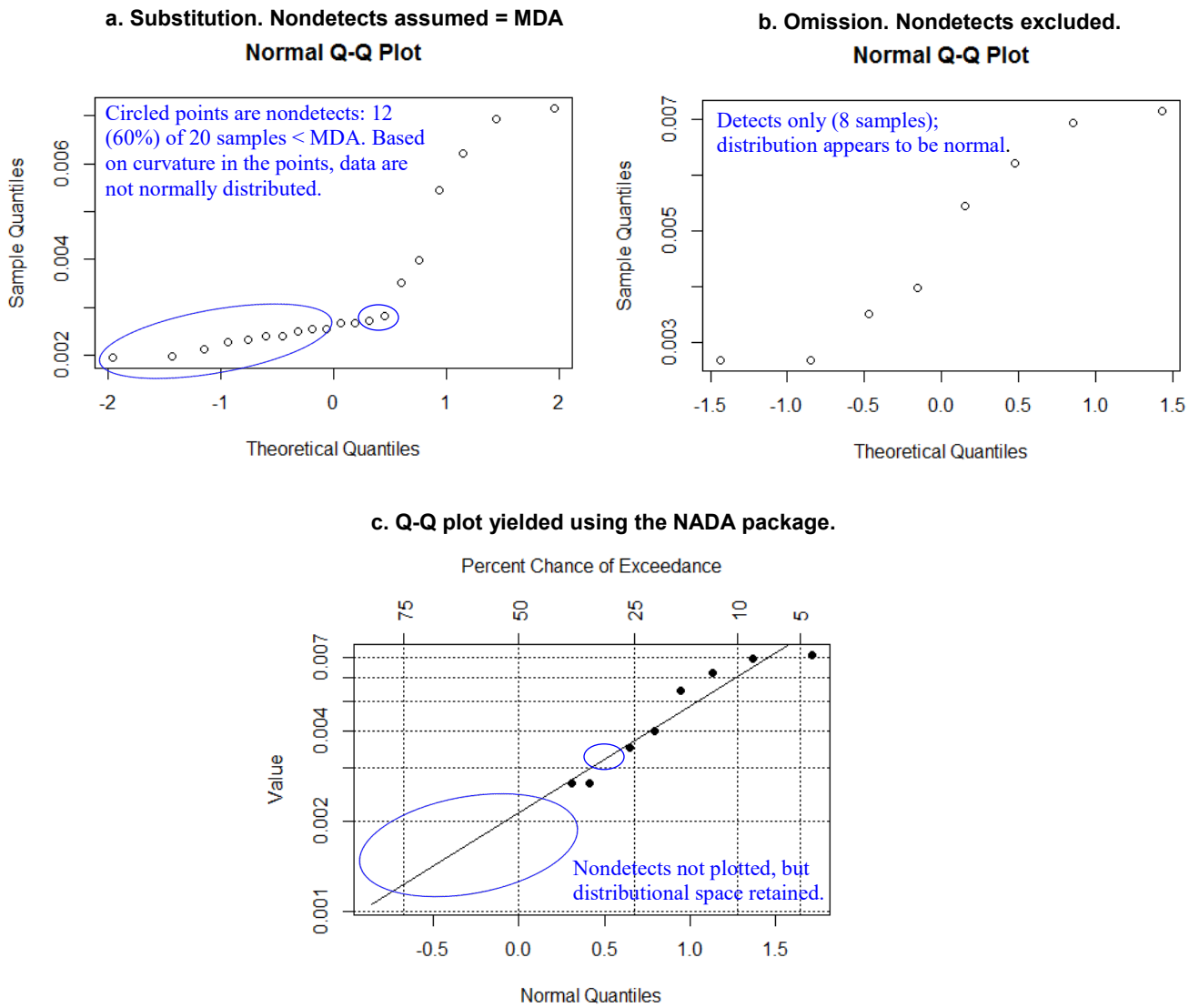


Figure 22. Illustration of Different Methods for Treating Censored Data
Example Based on ^{239}Pu Results (pCi/kg wet weight) for Greenling, Adak Island, 2016

In the example given above (Figure 22), each plot is different. The first (a) has some curvature and the slope shifts at about 0.003 pCi/kg ^{239}Pu (above which all results are detects). The second (b) shows only 40% of the data collected (given 8 of 20 detections); the distribution appears to be normal, even though it likely is not. The third plot (c) resembles the second (detects only) plot, but the *y*-axis scale is different because nondetects are accounted for. In this case, the data fall into such a small range (0.001–0.007 pCi/kg) that substitution has little effect on the mean (0.005 pCi/kg for detects only versus 0.003 pCi/kg using censored data). Problems arise, however, when comparing the distribution of this data subset with that for other groups. In contrast to Adak (with 40% detection frequency in 2016), ^{239}Pu was detected in 93% of greenling samples from Amchitka in 2016. In 2011, when MDAs ranged from 0.04–0.08 pCi/kg, ^{239}Pu was detected in only 2 of 45 samples (both from Amchitka). Again, the main purpose of this figure is to illustrate potential impacts of substitution versus omission when dealing with censored data.

In summary, for ^{137}Cs and ^{239}Pu, the radionuclides with sufficient proportions of results above the MDA in the combined (2011/2016) data set, nondetects were substituted with the MDA. Although conservative, and acknowledging the inherent drawbacks discussed above and by Helsel (2012), this approach is consistent with that used in the 2011 report for both the risk assessment and summary statistics in general (DOE 2013). As an overarching goal of LM's environmental sampling program at the site is to evaluate and ensure food safety (DOE 2013; 2016a), this approach also yields the most conservative estimates of potential risk. For ^{134}Cs and ^{240}Pu, detected in only 2% of the biological samples, apart from simple summary statistics, no statistical comparisons were made.

3.5.1.2 Between-Year and Interisland Comparisons

This section begins with the following reiteration of the decision rules specified in Section 4.1.5 of the 2016 environmental sampling plan (DOE 2016a):

> Radionuclide concentrations from rockweed and three fish species (greenling, rockfish, and Irish lord tissue) will be compared among sites and between years using analysis of variance (ANOVA), a statistical test used to test whether means (in this case, average concentrations) differ between two or more groups. Consistent with standard practice in the scientific community, a significance level of α (alpha) = 0.05 (5%) will be applied. Because two independent (or explanatory) variables will be tested, location/island (Amchitka versus Adak) and years (2016 versus 2011), a two-way ANOVA will be applied. If this analysis yields a significant result (indicating that the mean activity concentrations from at least one of the groups differ significantly from the others), a Tukey multiple comparisons test will be used to determine which group differs (e.g., 2016 ≠ 2011, Amchitka ≠ Adak, or both).

Because of the marked differences in MDAs between 2011 and 2016 for both ^{137}Cs and ^{239}Pu, two-way analysis of variance is not appropriate for testing differences in the manner described above. Any between-year differences found would likely be an artifact of the different laboratory sensitivities rather than being biologically or statistically significant. Furthermore, beta interferences identified by LLNL in the 2011 biota samples resulted in possible overestimation of ^{137}Cs content (Hamilton et al. 2012), a factor that hindered between-year comparisons. Therefore, the statistical analysis focused on interisland (versus between-year) differences. To do so, one-way analysis of variance (ANOVA) was initially considered (consistent with the 2016 sampling plan directives) but ultimately not used. Parametric ANOVA tests have the following assumptions: normal distribution (versus skewed) and equal variance. Both assumptions tend to be violated with environmental data sets, especially those with a large proportion of nondetects. In contrast, the nonparametric equivalent to the one-way ANOVA, the Kruskal-Wallis test, does not assume a distribution nor equal variance. Therefore, this test was used for interisland comparisons of radionuclide levels in biota. This approach is also consistent with that used by CRESP (2005) for analysis of the 2004 biological sampling data.

Unlike the parametric ANOVA, which tests differences in means (assuming test assumptions are met), the nonparametric Kruskal-Wallis tests differences in the cumulative distribution functions (or percentiles) of two groups. That is, does one group (the median, 75th percentile, 25th percentile) get shifted higher than the equivalent statistic in the other groups? This factor (i.e., the null hypothesis of the test) should be acknowledged when comparing group means relative to Kruskal-Wallis test results.

Interisland (Amchitka versus Adak) comparisons of detection frequencies were done using Pearson's chi square and, for verification purposes, the Fisher Exact test. Between-year differences in detection frequencies were not assessed because of the differences in detection limits discussed above.

3.5.2 Data Visualization Approaches

In the 2011 biological monitoring report, most of the graphical portrayals of results entailed box plots, a commonly used data visualization technique used to show the overall distribution of the data. To provide greater resolution, box plots presented in this report are overlain with individual measurements, distinguishing between detects (●) and results below the MDA, identified by hollow points (○). When there are many data points with similar results, points are "jittered" to address issues of overplotting. Following up on the initial presentations in Figure 19 through Figure 21, the line bisecting the box denotes the median (not shown if sample numbers small), the bottoms and tops of boxes (or "hinges") are the first and third quartiles, and the "whiskers" extend to the most extreme data point in either direction that is within a factor of 1.5 of the hinge; any points beyond the whiskers are considered outliers.

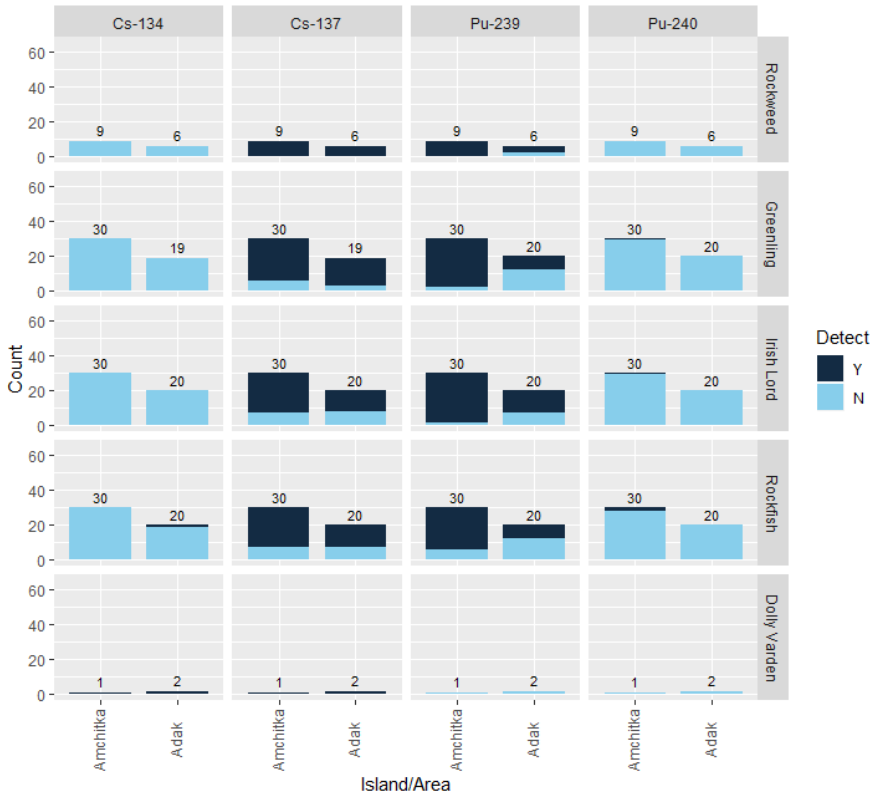
Most data plots and related graphics presented in this report were developed using R versions 3.5.2 or 3.5.3 (R Core Team 2019) and the tidyverse, version 1.2.1 (Wickham 2017). Of the numerous packages comprising the tidyverse, ggplot2 (Wickham 2009) was used most extensively (https://cran.r-project.org/web/packages/tidyverse/index.html).

4.0 Biota Sampling Results

The environmental sampling plan (DOE 2016a) specified the following DQOs related to the biomonitoring effort: (1) collect rockweed, greenling, rockfish, and Irish lords as indicator resident species; (2) collect Dolly Varden from lakes on Amchitka and Adak Islands; and (3) analyze samples for the targeted radionuclides—^{134}Cs, ^{137}Cs, ^{239}Pu, and ^{240}Pu—using adequately sensitive analytical methods and detection limits. This section documents the results of those efforts, including examination of results for both between-year (i.e., 2016 versus 2011) and interisland (i.e., Amchitka versus Adak) differences. This section also includes a renewed interpretation of the 2011 sampling results documented in the 2011 biological monitoring report (DOE 2013).

4.1 Preliminary Overview

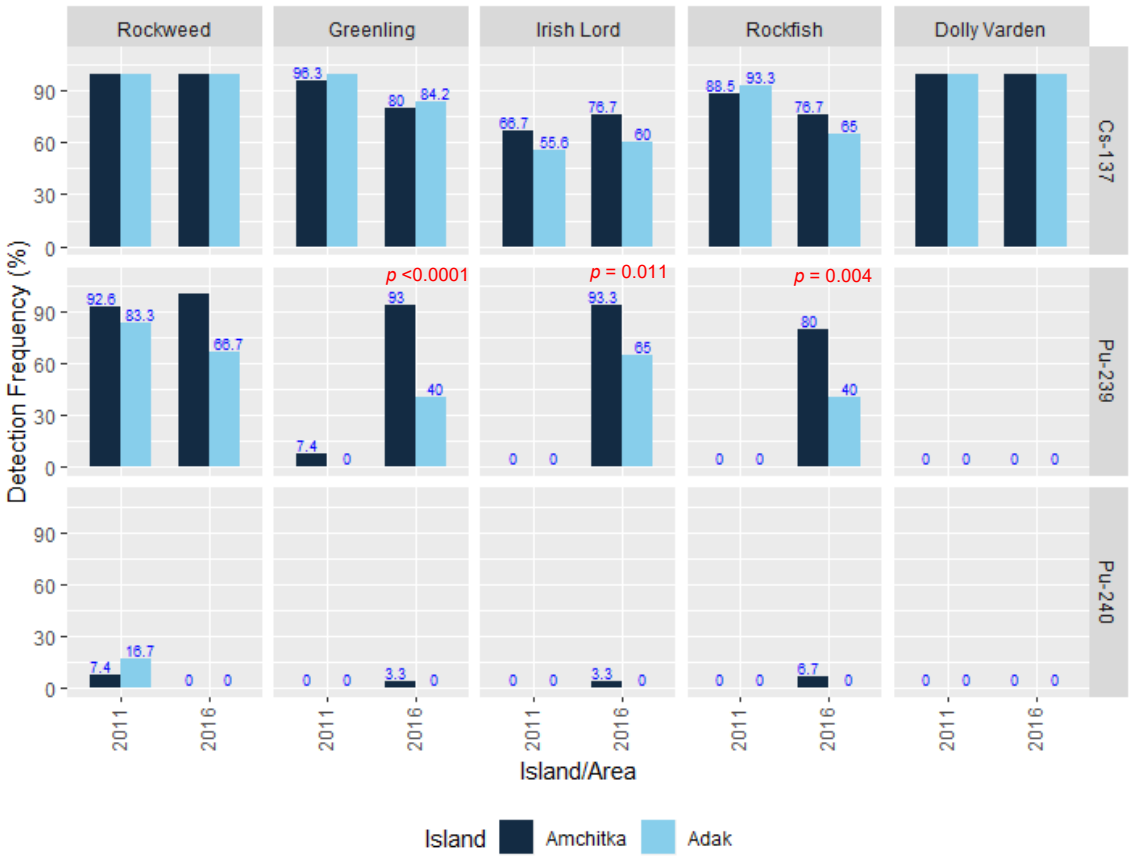
As an introduction to the data interpretation which follows, Figure 23 provides a visual overview of the relative abundance of cesium and plutonium isotopes based on the 2016 biota sampling results. As shown in this figure, detections were generally limited to ^{137}Cs and ^{239}Pu, the focus of this section. Plutonium-240 and ^{134}Cs were detected in only a few of the 168 samples and the limited ^{240}Pu detections were later deemed anomalous (Hamilton 2019).



Note:
For each species/radionuclide combination, dark blue bar segments denote the number of results with detectable levels of a given isotope (based on wet weight concentration). Pale blue bar segments denote the number of samples with results below the MDA. The corresponding number of samples collected at Amchitka and the reference site, Adak Island, is listed above the bars.

Figure 23. Detection Frequency Summary for 2016 Biota Sampling

To facilitate comparison with 2011 biomonitoring results, Figure 24 presents the same information along with corresponding detection frequencies reported in 2011 (from DOE 2013). Where measures allowed, contingency table chi square tests, comparing detection frequencies in Amchitka samples with those from the reference island, Adak, were performed for all interisland pairs. Where significant ($p < 0.05$), p values are shown in this figure. These comparisons are elaborated upon in subsequent discussions of individual isotopes and intended only as an initial overview here to allow comparisons across analytes.



$p = 0.011$ Significant interisland difference in detection frequency based on chi square test ($p < 0.05$)

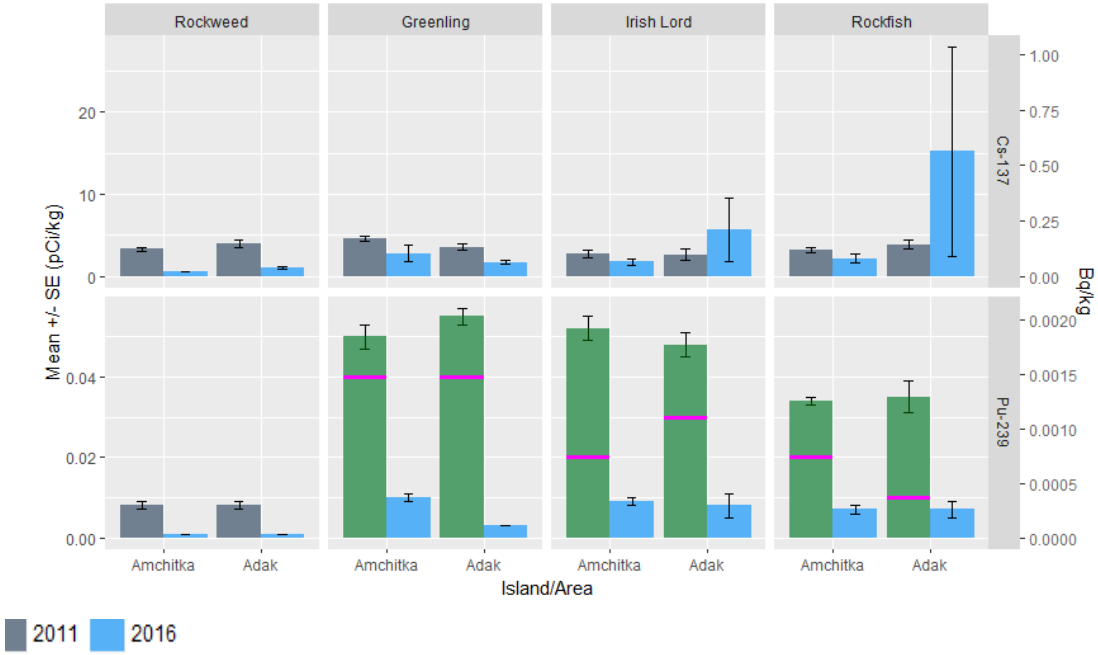
Notes:

1. Bar height represents detection frequency for Amchitka Island (dark blue bars) and the reference site, Adak Island (pale blue bars). Bars are labeled with corresponding detection frequencies except for cases when all results were above the MDA (i.e., 100% detection frequency).
2. For 2016 results, contingency table chi square tests were used to compare detection frequencies (proportion of detects versus nondetects) between islands as described in Section 3.5.1. p values are listed above only for those species/isotopes with significant differences ($p < 0.05$). Differences in detection frequencies between years were not assessed because of the differences in detection limits described previously.
3. ^{134}Cs is not shown in this figure because it was not analyzed in 2011 in fish or rockweed samples.
4. LLNL's more recent communication (Hamilton 2019) suggests that the four 2016 ^{240}Pu results initially reported as detected, although still passing quality assurance requirements, are anomalous and should not be considered as quantitative.

Figure 24. Comparison of Detection Frequencies for Biota Sampled in Both 2011 and 2016

Figure 25 plots the mean levels of ^{137}Cs and ^{239}Pu, the most frequently detected isotopes in 2016, in rockweed and the three saltwater fish. Dolly Varden (freshwater species) is excluded from this figure because of small numbers of samples and high magnitudes (49.7–447 pCi/kg) relative to marine species, thus driving the scale if plotted. The main purpose of this figure is to provide a preliminary demonstration that radionuclide levels measured in biota collected along Amchitka transects in 2016 are not higher than corresponding results reported in 2011. As such, previous determinations regarding food safety (DOE 2013) are maintained. For ^{137}Cs, detected in most biological samples in both years, in all but two cases (Irish lord and rockfish from Adak), mean concentrations measured in biota in 2016 are lower than those reported in 2011. The more prominent Fukushima signature in 2011 (versus 2016), combined with the lower MDAs in 2016 (Figure 20), may account for some, or even the majority, of the observed differences.

The interpretation is more complicated for ^{239}Pu due to the between-year differences in MDAs shown in Figure 21 and the large proportion of nondetects in 2011 (Figure 24). To account for these factors, means corresponding to largely nondetects are shaded green in Figure 25; the corresponding lowest MDAs (—) are also shown. A necessary caveat is that this figure was developed by substituting nondetects with the MDA. Despite the drawbacks associated with this approach (enumerated in Section 3.5.1), risks associated with consumption of fish at ^{239}Pu levels measured in 2016 are less than those estimated based on 2011 results. More detail regarding the distribution and range of these results is provided in the following sections for cesium and plutonium isotopes, respectively.



overlay denotes that ^{239}Pu not detected or detected at a frequency of <10% in 2011.
For fish species, — is the lowest MDA for the 2011 species/island combination; the height of the bar approximates the mean MDA.

Notes:
Units in pCi/kg wet weight; corresponding SI units (Bq/kg) shown on right *y*-axis.
Bars represent means, determined using the MDA value for nondetects; error bars are the standard error of the mean.

Abbreviations:
Bq/kg = becquerels per kilogram; SE = standard error; SI = International System of Units

Figure 25. Mean ^{137}Cs and ^{239}Pu Concentrations in Rockweed and Marine Fish: 2011 vs. 2016

4.2 Cesium Isotopes

For the 2016 environmental sampling effort, all biota samples were analyzed for both ^{134}Cs and ^{137}Cs. The decision to include ^{134}Cs (analyzed in only a few soil, sediment, and lichen samples in 2011 [Figure 3]), was based on discussions with AWG, primarily to assess the residual impact of inputs from Fukushima. This section begins with a discussion of results for ^{137}Cs in algae and marine fauna; the limited detections of ^{134}Cs are then evaluated. Detailed (sample-specific) laboratory analytical results for ^{134}Cs and ^{137}Cs collected during the Amchitka 2016 sampling event are provided in Appendix C (Hamilton et al. 2018c). Detailed results of the 2011 investigation, used here for between-year comparisons, are provided in the previous environmental sampling report (DOE 2013). Consistent with the approach used in that report, all biota sampling results are presented in units of pCi/kg wet weight. Conversions to International System of Units (SI) units, becquerels per kilogram (Bq/kg), are provided in some exhibits.

4.2.1 Cesium-137

Table 9 lists summary statistics for ^{137}Cs measured in biota samples from Amchitka and Adak islands in 2016. For each island group, this summary includes the detection frequency, mean, standard deviation (SD), range, and corresponding range of MDAs. Table 9 includes two sets of means and SDs. The first set applies to detects only (the subset of quantifiable measurements). Consistent with LM's previous approach (DOE 2013), the second set applies to all results, including nondetects substituted with the sample-specific MDA. One of the DQOs established for the 2016 sampling program was analysis of cesium and plutonium isotopes in biota samples to allow comparison with corresponding 2011 results. The corresponding decision rule was as follows:

> If the radionuclide concentrations measured in 2016 from the Amchitka Island sites are the same or lower than those measured in 2011 for rockweed, greenling, rockfish, and Irish lord, the results would support a determination that leakage from the test cavities is not indicated. In this case, the 2016 data would be used to compare against future data (DOE 2016a).

To address this objective and to facilitate between-year comparisons, Table 9 and subsequent exhibits also include results from 2011. As such, the following four data groups were evaluated: Amchitka 2011, Amchitka 2016, Adak 2011, and Adak 2016.

Before presenting these exhibits, some caveats are warranted. In the final report documenting the analytical results of the 2011 Amchitka sampling event, LLNL's data validation process indicated that Dolly Varden; rockweed; and, to a lesser exit, Irish lord contained a significant cesium isotope signature from Fukushima, the nuclear accident that occurred just 3 months before LM's 2011 sampling event. The latter was indicated by the presence of a known beta interference (^{134}Cs) in the ^{137}Cs analysis; associated measurement data were qualified accordingly (Hamilton et al. 2012). As a result, LLNL concluded that all ^{137}Cs results in 2011 samples analyzed by beta spectrometry represented conservative measures of ^{137}Cs activity in those samples. That is, summary statistics shown in Table 9 for 2011 biota samples, as well as corresponding data plotted in subsequent figures, may overestimate ^{137}Cs activity. This in turn would lessen apparent differences between the 2011 and 2016 results. As such, comparisons of 2011 results with 2016 results should be made with caution.

Table 9. Summary Statistics for ^{137}Cs in Biota: 2016 vs. 2011[a]

Species / Area	Year	No. of Detects (% > MDA)	Detects Only[b] Range	Detects Only[b] Mean ± SD	All Data[c] Mean ± SD	Range of MDAs[d]
Rockweed[e]						
Amchitka	2016	9 of 9 100%	0.5 – 0.8	0.6 ± 0.1	0.59 ± 0.1	0.1 – 0.2
Adak	2016	6 of 6 100%	0.6 – 2.0	1.0 ± 0.5	1.0 ± 0.5	0.1 – 0.2
Amchitka	2011	27 of 27 100%	1.3 – 5.8	3.3 ± 1.2	3.3 ± 1.2	0.2 – 0.5
Adak	2011	18 of 18 100%	1.0 – 7.3	4.0 ± 1.9	4.0 ± 1.9	0.3 – 0.5
Greenling						
Amchitka	2016	24 of 30 80.0%	0.5 – 31.0	3.3 ± 6.1	2.8 ± 5.5	0.2 – 1.6
Adak	2016	16 of 19 84.2%	0.7 – 3.6	1.8 ± 0.8	1.7 ± 0.8	0.2 – 1.0
Amchitka	2011	26 of 27 96.3%	1.9 – 7.8	4.6 ± 1.7	4.5 ± 1.7	1.5 – 2.8
Adak	2011	18 of 18 100%	0.9 – 7.4	3.6 ± 1.6	3.6 ± 1.6	1.3 – 3.6
Irish Lord[e]						
Amchitka	2016	23 of 30 76.7%	0.4 – 11.8	2.0 ± 2.5	1.8 ± 2.3	0.2 – 1.6
Adak	2016	12 of 20 60.0%	0.3 – 78.4	8.7 ± 22.2	5.6 ± 17.3	0.2 – 1.0
Amchitka	2011	18 of 27 66.7%	1.2 – 9.5	3.5 ± 2.2	2.8 ± 2.1	0.8 – 3.9
Adak	2011	10 of 18 55.6%	1.8 – 13.0	4.2 ± 3.2	2.8 ± 3.0	0.9 – 2.5
Rockfish						
Amchitka	2016	23 of 30 76.7%	0.6 – 14.4	2.6 ± 3.3	2.2 ± 2.9	0.2 – 0.9
Adak	2016	13 of 20 65.0%	0.6 – 257	22.5 ± 70	15.2 ± 56.9	0.3 – 1.5
Amchitka	2011	23 of 26 88.5%	1.1 – 6.4	3.6 ± 1.3	3.3 ± 1.5	0.7 – 2.2
Adak	2011	14 of 15 93.3%	1.2 – 9.4	4.0 ± 2.1	3.9 ± 2.1	0.5 – 2.4
Dolly Varden[e]						
Amchitka	2016	1 of 1 100%	102			0.8
Adak	2016	2 of 2 100%	49.7 – 69.9	59.8 ± 14.3		0.7 – 1.2
Amchitka	2011	1 of 1 100%	98.0			1.0
Adak	2011	1 of 1 100%	447			1.0

Units are in pCi/kg wet weight.
Values listed in red denote the maximum summary statistic for each species group, across years and islands.

Notes:

[a] Comparisons of 2011 results with 2016 results should be made with caution. LLNL's validation of 2011 ^{137}Cs data clearly identified the presence of Fukushima-derived ^{134}Cs in Dolly Varden and pooled samples of rockweed (Hamilton et al. 2012). Trace quantities of ^{134}Cs were also observed in pooled samples of Irish lord. Therefore, LLNL flagged all associated results with a data qualifier indicating the presence of a known beta interference. LLNL then concluded that all reported ^{137}Cs beta spectrometry measurements may be variously affected by the same data qualifier and therefore should only be used as a conservative measure of ^{137}Cs activity concentrations. That is, summary statistics shown above for 2011 biota sample results may overestimate ^{137}Cs activity, which in turn would lessen the differences between 2011 and 2016 results.

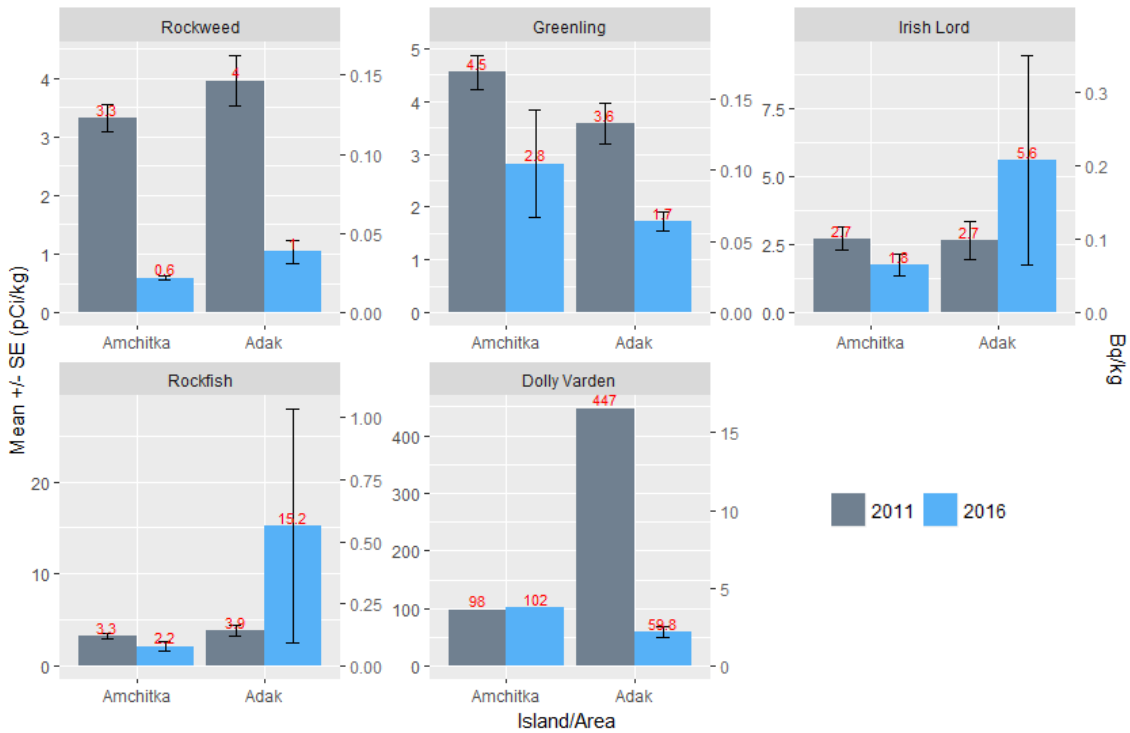
[b] Based on the range of MDAs relative to measured values, exclusion of nondetects may inflate the mean.

[c] Calculated by using the sample-specific RDL reported by LLNL for results below the MDA. In 2011, two of the reported nondetect results for Irish lord were negative: one from Adak (IRLO-AS-AST1-1, −0.1 ± 0.2 pCi/kg) and the other from Cannikin (IRLO-CN-CT2-2, −0.2 ± 0.2 pCi/kg). Although considered in determination of detection frequencies, these negative results were not used to derive the mean and SDs reported above. Also note that the summary statistics listed above may differ slightly from those reported in the previous biomonitoring report (DOE 2013) because of the different data management approaches applied to duplicate sample results.

[d] Range of MDAs for 2016 are the range of sample-specific RDLs reported by LLNL (Hamilton et al. 2018c), provided in Appendix C of this report. Those for 2011 are the range of minimum detectable concentrations reported in the 2011 biological monitoring report (DOE 2013).

[e] In 2011 samples, data for these species were flagged with a qualifier indicating the presence of a known beta interference (^{134}Cs) in the ^{137}Cs analysis (Hamilton et al. 2012). LLNL suggested that a conservative estimate of the ^{134}Cs activity in beta spectrometry counted samples could be made using the following formula: $^{134}Cs = {}^{137}Cs_{reported} * 0.59$, based in part on an assumed Fukushima fallout $^{134}Cs/^{137}Cs$ ratio of approximately 1. This correction for ^{134}Cs content corresponds to a correction factor of 0.4 for ^{137}Cs activity in the 2011 samples.

The preceding introductory figure (Figure 25) was useful in showing that mean ^{137}Cs concentrations in biota samples from Amchitka were lower in 2016 than in 2011, albeit slightly, for resident fish species. However, the scale in that figure was driven by much higher concentrations measured in rockfish from Adak Island in 2016. To provide better resolution, Figure 26 presents the same information as that shown in Figure 25, but scales are unique for each species. Results for Dolly Varden, the species with the highest ^{137}Cs concentrations historically, are also shown.

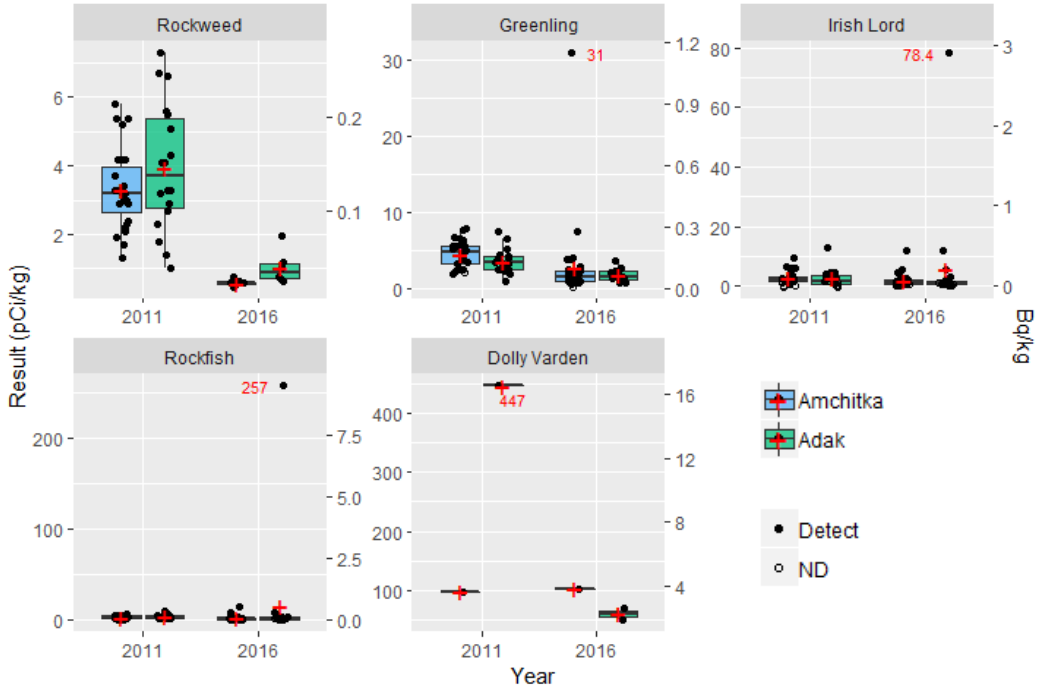


Notes:
Units are in pCi/kg wet weight; corresponding SI units (Bq/kg) shown on right *y*-axis.
Bars represent means, determined using the MDA value for nondetects. This treatment is not problematic from a statistical perspective as detection frequencies were fairly high (most >80%) for all island/year groups.
Means are labeled in red above each bar.
Error bars show the standard error of the mean, where twice the standard error roughly approximates the 95% upper confidence limit.

Abbreviation:
SE = standard error

Figure 26. Mean ± Standard Error Summary of ^{137}Cs, All Species

Figure 26 confirms the previous conclusions regarding between-year differences, but it also illustrates the large variation (indicated by the length of the standard error bars) for some species-island-year combinations. Although a data visualization approach often used in the scientific literature, mean and standard error plots can mask the true distribution of the data, particularly if the data are skewed. To provide greater resolution on the ^{137}Cs data set, the box plots in Figure 27 show the distribution of discrete measurements in the biota samples.



+ Group mean
31 Outlier for species group

Note:
Scales are unique for each species so caution is warranted when making interspecies comparisons.

Figure 27. Box Plots of ^{137}Cs in Biota Samples, 2011 vs. 2016 (All Results)

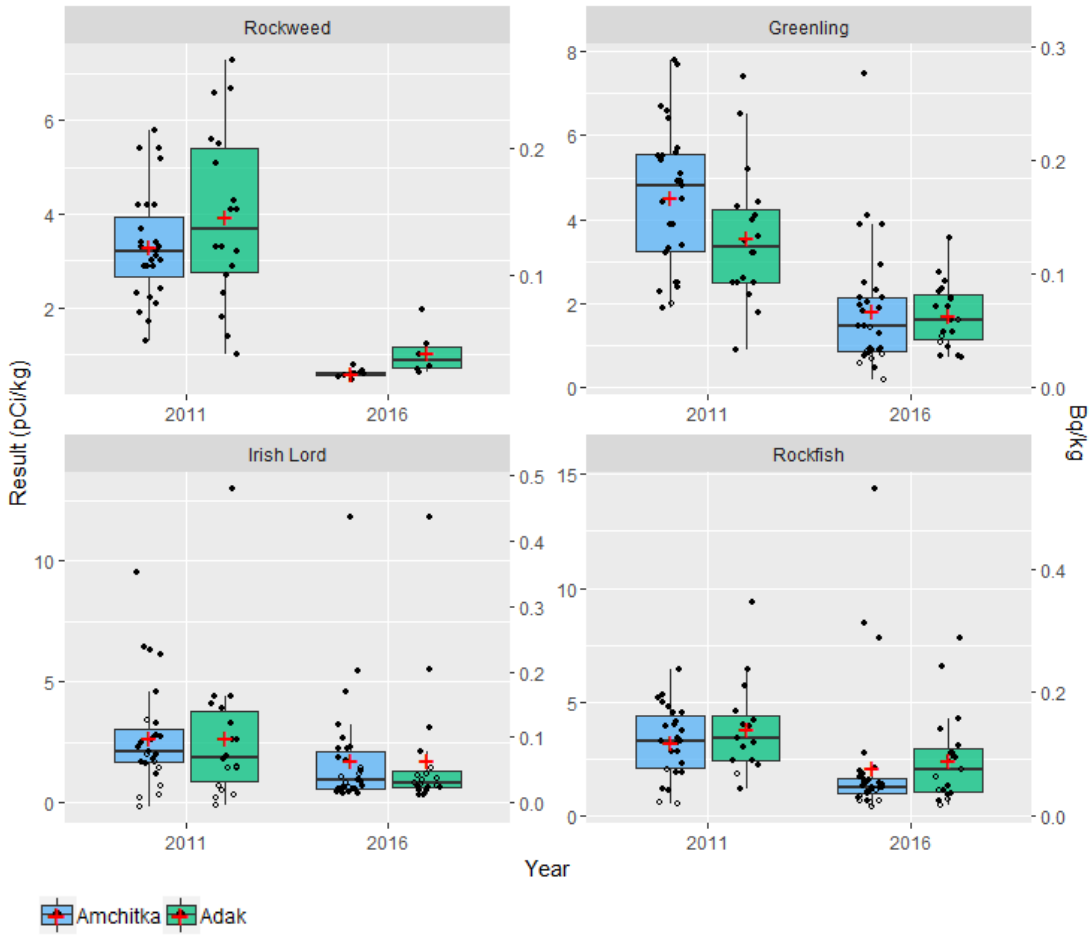
Immediately evident in Figure 26 is the presence of outliers in the data set, impeding examination of the bulk of the data. The 8 highest ^{137}Cs measurements in the combined (2011/2016) biota data set (and driving the scale in the figure above) are identified below in order of descending magnitude:

1.	Dolly Varden, Adak, 2011	DOLL-AD-XXX-1	447 pCi/kg
2.	Rockfish, Adak North, 2016	ROCK-AN-02	257 pCi/kg*
3.	Dolly Varden, Cannikin Lake, 2016	DOLL-AI-01	102 pCi/kg*
4.	Dolly Varden, Cannikin Lake, 2011	DOLL-AI-XXX-1	98 pCi/kg
5.	Irish lord, Adak North, 2016	ILOR-AN-09	78.4 pCi/kg
6.	Dolly Varden, Andrew Lake, June 2016	DOLL-AD-01	69.9 pCi/kg*
7.	Dolly Varden, Andrew Lake, May 2016	DOLL-AD-01	49.7 pCi/kg*
8.	Greenling, Amchitka, 2016	GREN-CN-07	31.0 pCi/kg

*Examined later in this section, ^{137}Cs results followed with an asterisk above also had measurable concentrations of ^{134}Cs in 2016, indicative of a Fukushima-derived signature.

The majority (five) of the eight samples with the highest ^{137}Cs concentrations (listed above) were from Adak Island. This Adak subset includes two of the three extreme outliers shown in Figure 26 for samples collected in 2016. The remaining 2016 outlier, 31 pCi/kg measured in a greenling sample from Amchitka, although high relative to other greenling measurements, is lower than maximum levels measured in fish collected from Adak Island.

Figure 28 is a similar plot of the ^{137}Cs data, but it excludes the major outliers shown in Figure 27. For the combined 2011/2016 data set, Dolly Varden characteristically has had the highest ^{137}Cs levels (49.7–447 pCi/kg) and was excluded from this figure. Figure 28 still shows the trend of lower ^{137}Cs tissue concentrations in 2016 versus 2011 for biota samples collected from Amchitka, but the resolution on results for rockweed samples collected in 2016 is poor. This poor resolution is due to the marked difference in 2016 results (0.5–2.0 pCi/kg) relative to those measured in 2011 (1.3–7.3 pCi/kg). Possible explanations for these between-year differences are the different analytical methods used in both years (beta spectrometry in 2011 versus gamma spectrometry in 2016), as well as the aforementioned beta interferences noted by LLNL in many of the 2011 biota samples (Hamilton et al. 2012).



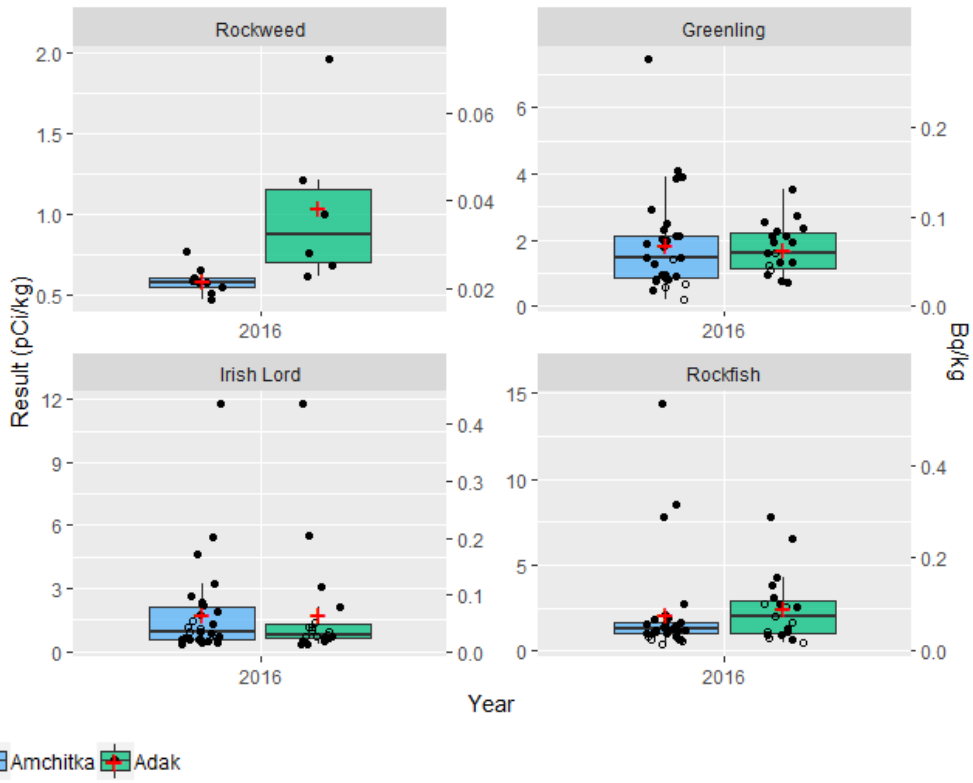
+ Group mean excluding outliers noted below
● Discrete measurement; points are "jittered" to better illustrate the distribution of the data.
○ Nondetect result (below MDA)

Notes:
Results for Dolly Varden are not shown, given high magnitudes and small sample numbers relative to other species (Figure 27). For the species shown, the following 3 outlier results were also excluded:

- greenling, Amchitka, 2016 31 pCi/kg
- Irish lord, Adak North, 2016 78.4 pCi/kg
- rockfish, Adak North, 2016 257 pCi/kg

Figure 28. Cesium-137 Distribution in Biota, 2011 vs. 2016, Excluding Extreme Outliers

The final graphical presentation of between-year and interisland distributions for ^{137}Cs presented in this section, Figure 29 plots activity concentrations for 2016 only, allowing better resolution of those results. As done in the preceding figure, Figure 29 also excludes the aforementioned outliers for greenling, Irish lord, and rockfish, as well as those for Dolly Varden, which dominates the scale across species. With respect to interisland comparisons, Figure 29 illustrates the overall similarity in results between Amchitka and Adak. This similarity is particularly evident for greenling and Irish lord which, apart from a single higher measurement in a greenling sample from Amchitka, appear almost identical.



+ Group mean excluding outliers noted below
● Discrete measurement; points are "jittered" to better illustrate the distribution of the data
○ Nondetect result (below MDA)

Notes:
Results for Dolly Varden are not shown, given high magnitudes and small sample numbers relative to other species (Figure 27). For the species shown, the following three outlier results were also excluded:

- greenling, Amchitka, 2016 31 pCi/kg
- Irish lord, Adak North, 2016 78.4 pCi/kg
- Rockfish, Adak North, 2016 257 pCi/kg

Figure 29. Cesium-137 Distribution in 2016 Biota Samples, Excluding Extreme Outliers

The preceding plots (Figure 26 through Figure 29) indicate an overall trend of lower ^{137}Cs concentrations in 2016 relative to those in 2011, especially for samples collected from Amchitka (exceptions were found in samples from Adak). To quantify these findings, Table 10 presents the results of contingency table tests, used to compare interisland detection frequencies, and the Kruskal-Wallis tests, used to compare interisland ^{137}Cs magnitudes. The considerations and caveats noted previously should be acknowledged when reviewing this table.

Table 10. Statistical Comparison Summaries for ^{137}Cs in Biota

Species/ Island[a]	Year	Detection Frequency	Test of Proportions: Pearson's Chi-squared and *p* value[b]	Mean ± SD[c]	Kruskal-Wallis Chi-squared and *p* value[d]	Between-Year Summary (Amchitka only)[e]
Rockweed						
Amchitka Adak	2016	9/9 (100%) 6/6 (100%)	--	0.6 ± 0.1 1.0 ± 0.5	7.35 *p* = 0.007	2016 ≤ 2011
Amchitka Adak	2011	27/27 (100%) 18/18 (100%)	--	3.3 ± 1.2 4.0 ± 1.9	1.14 *p* = 0.29	
Greenling						
Amchitka Adak	2016	24/30 (80.0%) 16/19 (84.2%)	0.14 *p* = 0.71*	2.8 ± 5.5 1.7 ± 0.8	0.0004 *p* = 0.98	2016 ≤ 2011
Amchitka Adak	2011	26/27 (96.3%) 18/18 (100%)	0.68 *p* = 0.41*	4.5 ± 1.7 3.6 ± 1.6	0.32 *p* = 0.57	
Irish lord						
Amchitka Adak	2016	23/30 (76.7%) 12/20 (60.0%)	1.59 *p* = 0.21	1.8 ± 2.3 5.6 ± 17.3	0.11 *p* = 0.73	2016 ≤ 2011
Amchitka Adak	2011	18/27 (66.7%) 10/18 (55.6%)	0.57 *p* = 0.45	2.7 ± 2.2 2.7 ± 3.0	3.4 *p* = 0.065	
Rockfish						
Amchitka Adak	2016	23/30 (76.7%) 13/20 (65.0%)	0.81 *p* = 0.37	2.2 ± 2.9 15.2 ± 56.9	2.4 *p* = 0.12	2016 ≤ 2011
Amchitka Adak	2011	23/ 26 (88.5%) 14/15 (93.3%)	0.26 *p* = 0.61*	3.3 ± 1.5 3.9 ± 2.1	0.32 *p* = 0.57	

-- Not applicable or not reported (e.g., when detection frequencies equivalent)
p-values < 0.05 indicate a significant interisland difference, in either detection frequency (Pearson's chi-squared) or ^{137}Cs concentration (Kruskal-Wallis test).

Notes:

[a] Dolly Varden are not listed due to limited sampling in both 2011 and 2016 (n ≤ 2 within groups).

[b] Interisland comparisons of the proportions of detects and nondetects were tested using Pearson's chi-square (contingency table) test; corresponding *p* values are listed below each chi-squared (χ^2) value. Because this test was designed for larger samples (count > 5 in each contingency table cell), the Fisher Exact test was also run for verification purposes for each interisland pairing (only chi-squared tests are listed above). * following the *p* value denotes cases when the chi-square test yielded warnings due to high (> 85%) detection frequencies. In these cases, the *p* value yielded using the Fisher Exact test was 1.

[c] Consistent with the approach in Table 9, means were calculated using the sample-specific relative detection limit reported by LLNL for results below the MDA.

[d] To assess interisland differences in ^{137}Cs levels within years, the Kruskal-Wallis rank sum test was used. Although ANOVAs were initially run, due to outliers and violation of one or more of the test assumptions (e.g., a normal distribution and equal variances), the nonparametric rank sum test was used, consistent with the statistical approach used by CRESP (2005).

[e] Although initially run[21], between-year statistical comparisons were ultimately considered not appropriate or useful given (1) the differences in analytical methods between years—beta spectrometry in 2011 versus gamma spectrometry in 2016—and (2) more importantly, the beta interferences reported by LLNL for the 2011 biota analyses (Hamilton et al. 2012). LLNL suggested that reported ^{137}Cs beta spectrometry measurements only be used as a conservative measure of ^{137}Cs activity because they likely reflected combined ^{134}Cs+^{137}Cs content. As discussed in the text and identified in Table 9 (Notes "a" and "e"), because 2011 results may represent overestimates of ^{137}Cs activity, differences between 2011 and 2016 results might be less than those indicated above. As such, the summary in the final column of this table is qualitative, intended mainly to demonstrate that associated risks in 2016 are not greater than those determined based on 2011 sample results.

[21] For all species listed above, between-year (2011 versus 2016) statistical comparisons were significant (*p* ≤ 0.01).

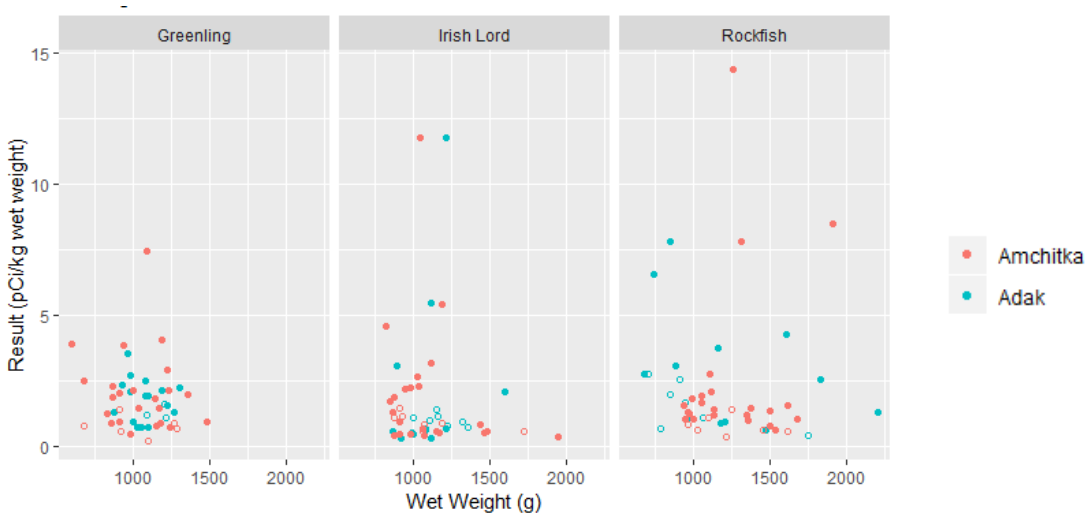
Based on the preceding figures and the results of statistical tests reported in Table 10, the following paragraphs summarize the ^{137}Cs content in samples collected in 2016 relative to corresponding 2011 results. The primary focus is on Amchitka 2016 results (by species) relative to the other island/year groups. While the ranges referenced below apply to detected results only, means and standard deviations were determined by substituting nondetects with the sample-specific MDA. All results are in pCi/kg wet weight, consistent with the presentation used throughout this report. Some, or even most, of the between-year differences noted below may reflect the aforementioned beta interferences noted by LLNL for the 2011 biota samples.

- *Rockweed*—Cesium-137 was detected in all rockweed samples collected in both 2011 (n=45) and 2016 (n=15). In 2016, mean activity concentrations of ^{137}Cs in rockweed samples from Amchitka (n=9) and Adak (n=6) were 0.6 ± 0.1 pCi/kg and 1.0 ± 0.5 pCi/kg, respectively, a difference that was statistically significant (Adak > Amchitka, $p = 0.007$). The mean ^{137}Cs concentration (0.6 pCi/kg) measured in Amchitka samples (2016) was lower than that measured in 2011 (3.3 ± 1.2 pCi/kg), as was the range (0.5–0.8 pCi/kg in 2016 versus 1.3–5.8 pCi/kg in 2011). Overall, mean ^{137}Cs concentrations in 2016 Amchitka samples were lower than those found for all other groups. This finding is not unexpected, given that 2011 ^{137}Cs results may reflect the combined presence of ^{134}Cs and ^{137}Cs.
- *Greenling*—Cesium-137 was detected in the majority of greenling samples collected in both 2011 (n=45) and 2016 (n=49). In 2016, mean activity concentrations of ^{137}Cs in greenling samples from Amchitka (n=30) and Adak (n=19) were 2.8 ± 5.5 pCi/kg and 1.7 ± 0.8 pCi/kg, respectively. The higher mean and variance for Amchitka, although not significant relative to Adak results, reflects the 31 pCi/kg outlier measurement discussed previously and plotted in Figure 27. This outlier, although higher than all other ^{137}Cs measurements in greenling (from 2011 and 2016), is lower than ^{137}Cs levels measured in other fish species from Adak (78.4–447 pCi/kg, Table 9). Even including this outlier, ^{137}Cs concentrations in 2016 samples Amchitka samples are still lower overall than those measured in 2011 (4.5 ± 1.7 pCi/kg).
- *Irish lord*—As found for other fish species, ^{137}Cs was detected in the majority of Irish lord samples collected in both 2011 (n=45) and 2016 (n=50). In 2016, mean activity concentrations of ^{137}Cs in Irish lord samples from Amchitka (n=30) and Adak (n=20) were 1.8 ± 2.3 pCi/kg and 5.6 ± 17.3 pCi/kg, respectively. The higher mean and variance for Adak, not significant relative to corresponding Amchitka results ($p = 0.57$), reflects the 78.4 pCi/kg outlier measurement (Figure 27). Cesium-137 concentrations in samples from Amchitka were also marginally lower than those measured in 2011 (2.7 ± 2.2 pCi/kg).
- *Rockfish*—Overall, results for rockfish are similar to those described above for Irish lord. Mean ^{137}Cs concentrations measured in samples collected from Amchitka in 2016 (2.2 ± 2.9 pCi/kg) are again lower than those found for all other groups: Adak 2016 (15.2 ± 56.9 pCi/kg, again the highest), Amchitka 2011 (3.3 ± 1.5 pCi/kg), and Adak 2011 (3.9 ± 2.1). The high mean yielded for Adak in 2016 reflects a 257 pCi/kg outlier result. Excluding this Adak outlier, the ^{137}Cs activity in 2016 samples from Amchitka was not significantly higher than those from Adak ($p = 0.57$), reflecting the comparable distributions shown in Figure 29.
- *Dolly Varden*—Limited conclusions can be drawn due to the small sample numbers in both the 2011 and 2016 studies: one per group except 2 collected from Adak in 2016 (Table 9), all of which were composites. Nonetheless, relative to all other species sampled, the

highest ^{137}Cs concentrations were measured in Dolly Varden, with the maximum (447 pCi/kg) collected from Adak in 2011.

In summary, for all species, the mean ^{137}Cs content measured in biota samples from Amchitka in 2016 was lower than corresponding 2011 results. Whether these differences stem from the lower MDAs in 2016 relative to 2011, the beta interferences identified for some 2011 samples, or some other factor, is not known. However, from a risk perspective, one can conclude that risks associated with ^{137}Cs in 2016 biota samples are lower than those determined based on 2011 results. For samples collected in 2016, interisland comparisons of both detection frequencies and ^{137}Cs magnitude were insignificant except for rockweed, with higher ^{137}Cs levels in samples from Adak (p=0.007).

To examine factors possibly influencing the 2016 results, the relationship between fish weight (wet weight) and corresponding wet weight ^{137}Cs concentrations was briefly examined for greenling, Irish lord, and rockfish. Based on the distribution of points in Figure 30, no pattern or relationship between sample wet weights and ^{137}Cs activity concentration is apparent. For scaling purposes, this figure excludes the three 2016 outlier results mentioned previously. No relationship was found between sample weight and magnitude in those samples.



● Solid points denote results above the MDA.
○ denote nondetect result (<MDA).

Note:
To allow comparison across species and a common scale, this plot excludes the three outliers from 2016 (≥ 31 pCi/kg) plotted in Figure 27. Wet weights for samples with 257 pCi/kg (Adak rockfish), 78.4 pCi/kg (Adak Irish lord), and 31 pCi/kg (Amchitka, greenling) were 1310, 1066, and 766 g, respectively. Some of the samples plotted in this figure represent composites.

Figure 30. Cesium-137 Activity in 2016 Marine Fish Samples vs. Sample Wet Weights

Although locational differences were not quantitatively evaluated (based on the stated DQOs, interisland differences received more focus), the mean and error plots in Figure 31 illustrate differences in mean ^{137}Cs between Adak (the reference island) and Amchitka site (Cannikin, Long Shot, and Milrow) transects. No notable differences are apparent except for higher levels at Adak for Irish lord, rockfish, and Dolly Varden. Also, mean ^{137}Cs levels in greenling appear to be higher in samples from Cannikin overall. However, in this case, 2016 mean concentrations are lower than those measured in 2011.

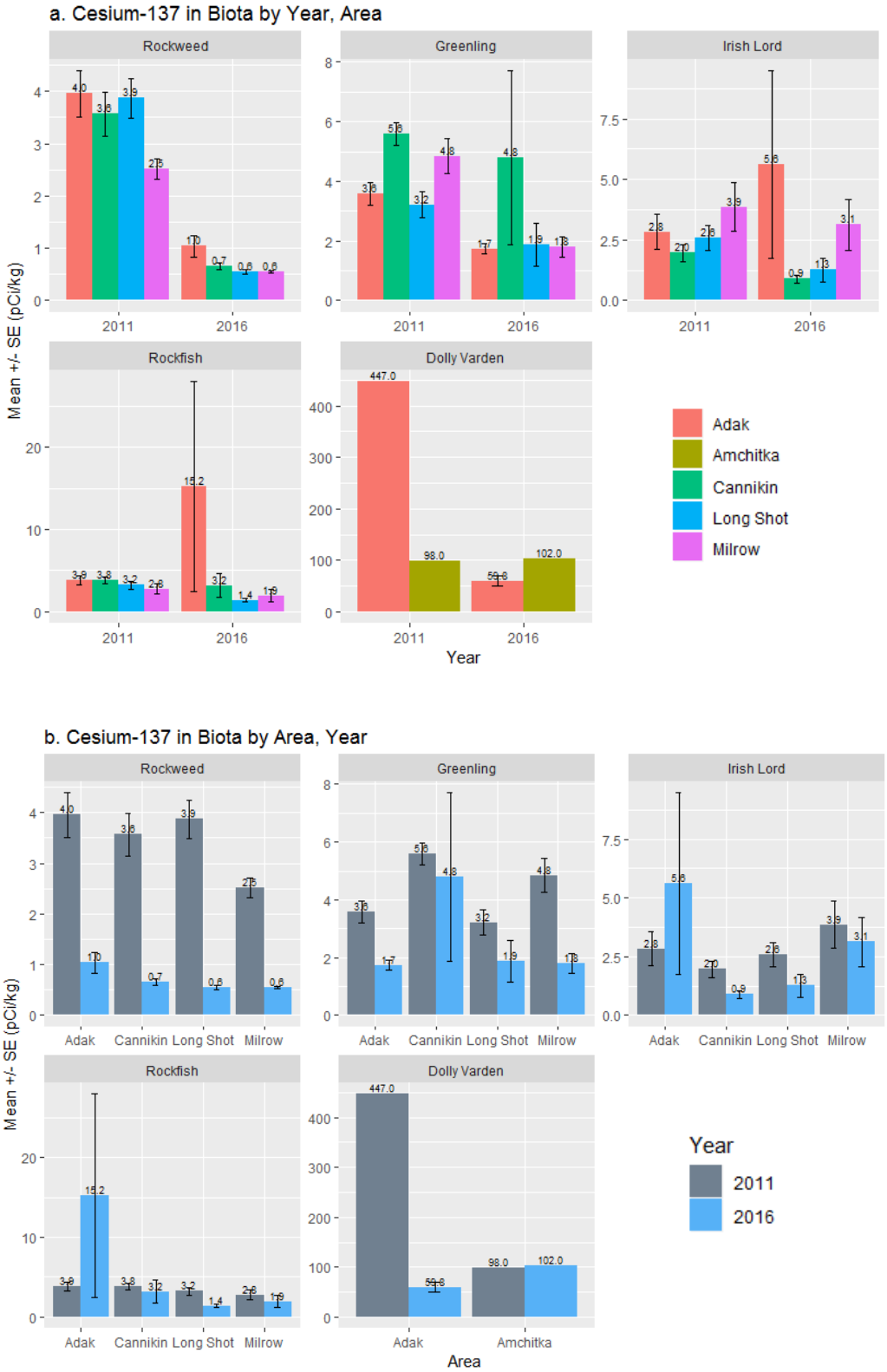


Figure 31. Cesium-137 in Biota Samples, 2011 vs. 2016 Comparisons by Location

(a) grouped by Year (x-axis variable), area (fill variable)
(b) grouped by Area (x-axis variable), year (fill variable)

This section concludes with a brief mention of ^{137}Cs results reported by CRESP based on their previous 2004 investigation (CRESP 2005; 2006a; 2006b). Ideally, these results would also be considered, even if qualitatively, in evaluating the 2016 environmental sampling results. However, these comparisons were not possible given the small number of samples analyzed by CRESP and the corresponding high MDAs mentioned previously, summarized in Table 11. The only exceptions were 1000-g samples, with lower MDAs relative to 100-g samples, but these constituted only a small portion of CRESP's overall sampling regime. As such, despite the broad sampling program and in-depth analyses conducted by CRESP in 2004–2005, because of the high MDAs (particularly for rockweed and greenling), temporal trends (i.e., 2004 versus 2011 versus 2016) cannot be evaluated, neither quantitatively nor qualitatively.

Table 11. Summary of CRESP Findings Results for ^{137}Cs, 2004–2005

Species	Number of Samples	Range pCi/kg (Bq/kg)	Mean ± SD pCi/kg (Bq/kg)	Mean MDA pCi/kg (Bq/kg)	Comment
Rockweed (*Fucus*)					
1000 g samples	2		ND	9.2 (0.34)	Highest MDAs from LM studies were 0.5 pCi/kg (2011) and 0.2 pCi/kg (2016).
100 g samples	4	--	--	164 (6.08)	
Greenling					
1000 g samples	5		ND	7.8 (0.29)	Highest MDAs from LM studies were 3.6 pCi/kg (2011) and 1.6 pCi/kg (2016).
100 g samples	23	--	--	75.9 (2.81)	
Irish lord					
1000 g samples	3	3.6 (0.132) 33% > MDA	--	--	Highest MDAs from LM studies were 3.9 pCi/kg (2011) and 1.6 pCi/kg (2016).
100 g samples	--	--	--	--	
Rockfish					
1000 g samples	3	3.0–5.1 (0.111–0.189)	3.9 ± 1.1 (0.143 ± 0.04)	2.7 (0.1)	Highest MDAs from LM studies were 2.4 pCi/kg (2011) and 1.5 pCi/kg (2016).
100 g samples	12	--	--	89.7 (3.32)	
Dolly Varden					
1000 g samples	4 (2 from 2005, 2 additional from 2006)	18.9–21.1 (0.7–0.78) Detected in 3 or 4 samples	--	3.6 (0.132)	Highest MDAs from LM studies were 1.0 pCi/kg (2011) and 1.2 pCi/kg (2016).
100 g samples	8	--	--	107.3 (3.97)	

Note:
Main units in pCi/kg consistent with this report. Bq/kg provided in parentheses consistent with CRESP's reporting (CRESP 2005; 2006a). CRESP substituted sample values below the MDA with one-half the MDA to calculate the mean and SD. Only Dolly Varden and Irish lord were addressed in the 2006 addendum (CRESP 2006a).

Abbreviations:
-- = Not reported
ND = Not Detected

4.2.2 Cesium-134

Of the 167 biota samples analyzed for cesium, no reportable ^{134}Cs was detected in fish or algae samples except for the three samples of Dolly Varden (two from Adak) and a single rockfish sample collected from Adak North. Because ^{134}Cs has a half-life of only 2 years, these results indicate a Fukushima-derived contaminant signature. Table 12 presents results for biota samples with measurable ^{134}Cs, including corresponding ^{137}Cs levels and $^{134}Cs/^{137}Cs$ activity ratios.

Table 12. Summary of 2016 Biota Samples with Measurable Levels of ^{134}Cs

Sample ID	Species	Island	Date	^{137}Cs (pCi/kg)	^{134}Cs (pCi/kg)	$^{134}Cs/^{137}Cs$ Activity Ratio
DOLL-AD-01	Dolly Varden	Adak	May 21, 2016	49.7	3.37	0.068
DOLL-AD-01	Dolly Varden	Adak	June 14, 2016	69.9	3.04	0.043
ROCK-AN-02	Rockfish	Adak (North)	May 19, 2016	257	17.0	0.066
DOLL-AI-01	Dolly Varden	Amchitka	June 21, 2016	102	4.46	0.044

All activity concentration units in pCi/kg wet weight.

As shown in Table 12, the $^{134}Cs/^{137}Cs$ activity ratios observed in these samples were tightly bounded between 4.3 and 6.8%. These ratios are about an order of magnitude lower than those reported for lichen and soil samples collected in 2011 (DOE 2013), which ranged from 30–60% and were attributed to Fukushima-derived fallout (Hamilton et al. 2012; DOE 2013).

The combined results of the 2011 and 2016 investigations indicate an overall trend of higher ^{137}Cs activity concentrations in samples from Adak relative to those from Amchitka. Dasher (2019) suggested that these results may reflect the higher fallout deposition on Adak compared to the lowland area of Amchitka. Based on oceanographic and atmospheric modeling of post-Fukushima ^{137}Cs deposition, Adak was predicted to receive more deposition from Fukushima than Amchitka, at least in the eastern region of the island where LM sampled. Differences in ocean currents affecting both regions might also account for the higher ^{137}Cs levels in some of the resident fish species collected offshore from Adak.

In summary, the ^{134}Cs detections in 2016 biota samples, albeit limited to only 4 (2%) of the 168 samples, likely indicate a Fukushima signature, a factor that complicates interpretations of ^{137}Cs levels in site environmental samples. Although used historically as a bioindicator in site evaluations (CRESP 2005; 2006a; 2006b; and DOE 2013), the extent to which ^{137}Cs activity concentrations represent a possible influence of Fukushima versus other sources (remnants of global fallout from above-ground nuclear tests or an Amchitka test-related signature) cannot be quantified. Hori et al. (2018) proposed a methodology for distinguishing between pre- and post-Fukushima-derived ^{137}Cs. However, this method is only useful if both ^{134}Cs and ^{137}Cs are measured. Given that ^{134}Cs was measured in a small percentage of 2016 environmental samples, the approach recommended by Hori et al. (2018) was not applied here.

4.3 Plutonium Isotopes

In contrast to ^{137}Cs, measured in the majority of both 2011 and 2016 samples, plutonium isotopes were only detected in a small percentage of samples collected in 2011 (DOE 2013), mostly dragon kelp (not sampled in 2016) and to a lesser extent rockweed. In their discussion of the 2011 plutonium isotopic results, LLNL commented that "it was apparent that even a small improvement in the minimum quantifiable activity of Pu may turn what appears to be a number of borderline measurements into clearly quantifiable activities" (Hamilton et al. 2012). As discussed in Section 3 and illustrated in Figure 21, substantially lower MDAs were achieved for ^{239}Pu in analysis of the 2016 samples. Detectable levels of ^{239}Pu were reported for many 2016 fish and algal samples, albeit mostly at or near the detection limits of the instrument. In contrast, only four samples contained detectable levels of ^{240}Pu. Corresponding MDAs were about 5 times higher than those for ^{239}Pu (in 2016 samples) and comparable to those achieved in 2011.

Detailed laboratory analytical results for ^{239}Pu and ^{240}Pu collected during the Amchitka 2016 sampling event are provided in Appendix D, based on Hamilton et al. (2018d). LLNL's more recent communication (Hamilton 2019) suggests that the four 2016 ^{240}Pu results initially reported as detected, although still passing quality assurance requirements, are anomalous and should not be considered as quantitative. The following discussion of plutonium results should be read with this caveat in mind.

4.3.1 Plutonium-239

Table 13 lists summary statistics for ^{239}Pu measured in biota samples from Amchitka and Adak Islands in 2016 and, to address one of the primary study objectives comparing 2016 results with 2011 to verify previous food safety conclusions, corresponding descriptive statistics for 2011. This table includes the detection frequency, mean, SD, range of detections, and corresponding range of MDAs for each of the four island/year groups. Two sets of mean and variance measures are provided, the first for detects and the second corresponding to all results (censored data).

As a prelude to the discussion of results, Figure 32 through Figure 34 illustrate the distributions of ^{239}Pu in 2016 biota samples. These figures were developed by substituting nondetects with the value of the MDA or sample-specific RDL reported by LLNL (Hamilton et al. 2018d). It is important to reiterate some of the previous interpretations that accompanied Figure 24, the initial mean and standard error plot with common scales across species presented in this section. This plot showed that, for rockweed and greenling, mean ^{239}Pu concentrations were lower in 2016 than in 2011. To provide better resolution on the scale, Figure 32 presents the same information, but scales are unique for each species. Again, interpretation of this figure is complicated given the large between-year differences in MDAs shown in Figure 21 and the large proportion of nondetects in 2011 (Figure 24). In Figure 32 (consistent with the presentation in Figure 25), means corresponding to largely nondetects are shaded green; the corresponding lowest MDAs (—) are also shown.

For both islands (Amchitka and Adak), mean ^{239}Pu levels are clearly lower in 2016 than in 2011. However, it is not clear whether those differences are a function of decreased magnitudes or, more likely, merely an artifact of the change in signal or laboratory sensitivity between the two years. The box plots in Figure 33 provide greater resolution on the distributions of ^{239}Pu in 2011 and 2016 samples, for both detects and nondetects assigned MDA values.

Figure 34 shows the same results but for 2016 only; this figure also includes an overlay of results of statistical comparisons listed in Table 14. Both figures exclude Dolly Varden, as it was not detected in any samples collected in 2016 (Table 13).

Table 13. Summary Statistics for ^{239}Pu in Biota: 2016 vs. 2011

Species / Area	Year	No. of Detects (% > MDA)	Detects Only[a] Range	Detects Only[a] Mean ± SD	All Data[b] Mean ± SD	Range of MDAs[c]
Rockweed						
Amchitka	2016	9 of 9 100%	0.0005 – 0.002	0.001 ± 0.0004	0.001 ± 0.0004	0.0004 – 0.0005
Adak	2016	4 of 6 66.7%	0.001 – 0.002	0.001 ± 0.0005	0.001 ± 0.0005	0.0004 – 0.0004
Amchitka	2011	25 of 27 92.6%	0.002 – 0.012	0.007 ± 0.003	0.008 ± 0.003	0.004 – 0.01
Adak	2011	15 of 18 83.3%	0.002 – 0.019	0.007 ± 0.004	0.008 ± 0.004	0.004 – 0.01
Greenling						
Amchitka	2016	28 of 30 93.3%	0.003 – 0.028	0.01 ± 0.006	0.01 ± 0.006	0.002 – 0.004
Adak	2016	8 of 20 40.0%	0.003 – 0.007	0.005 ± 0.002	0.003 ± 0.002	0.002 – 0.005
Amchitka	2011	2 of 27 7.4%	0.018 – 0.020	0.019 ± 0.001	0.05 ± 0.013	0.04 – 0.08
Adak	2011	0 of 18 0%				0.04 – 0.07
Irish Lord						
Amchitka	2016	28 of 30 93.3%	0.004 – 0.023	0.010 ± 0.005	0.009 ± 0.005	0.001 – 0.006
Adak	2016	13 of 20 65.0%	0.003 – 0.055	0.010 ± 0.014	0.008 ± 0.012	0.002 – 0.004
Amchitka	2011	0 of 27 0.0%				0.02 – 0.08
Adak	2011	0 of 18 0.0%				0.03 – 0.07
Rockfish						
Amchitka	2016	24 of 30 80.0%	0.003 – 0.017	0.008 ± 0.004	0.007 ± 0.004	0.0015 – 0.003
Adak	2016	8 of 20 40.0%	0.003 – 0.039	0.014 ± 0.013	0.007 ± 0.01	0.0014 – 0.004
Amchitka	2011	0 of 26 0.0%				0.02 – 0.06
Adak	2011	0 of 15 0.0%				0.01 – 0.06
Dolly Varden						
Amchitka	2016	0 of 1 0%				0.003
Adak	2016	0 of 2 0%				0.003 – 0.005
Amchitka	2011	0 of 1 0%				0.01
Adak	2011	0 of 1 0%				0.01

Units are in pCi/kg wet weight.
Values listed in red font denote the maximum summary statistic for each species group, across years and islands, except in cases where there are ties.

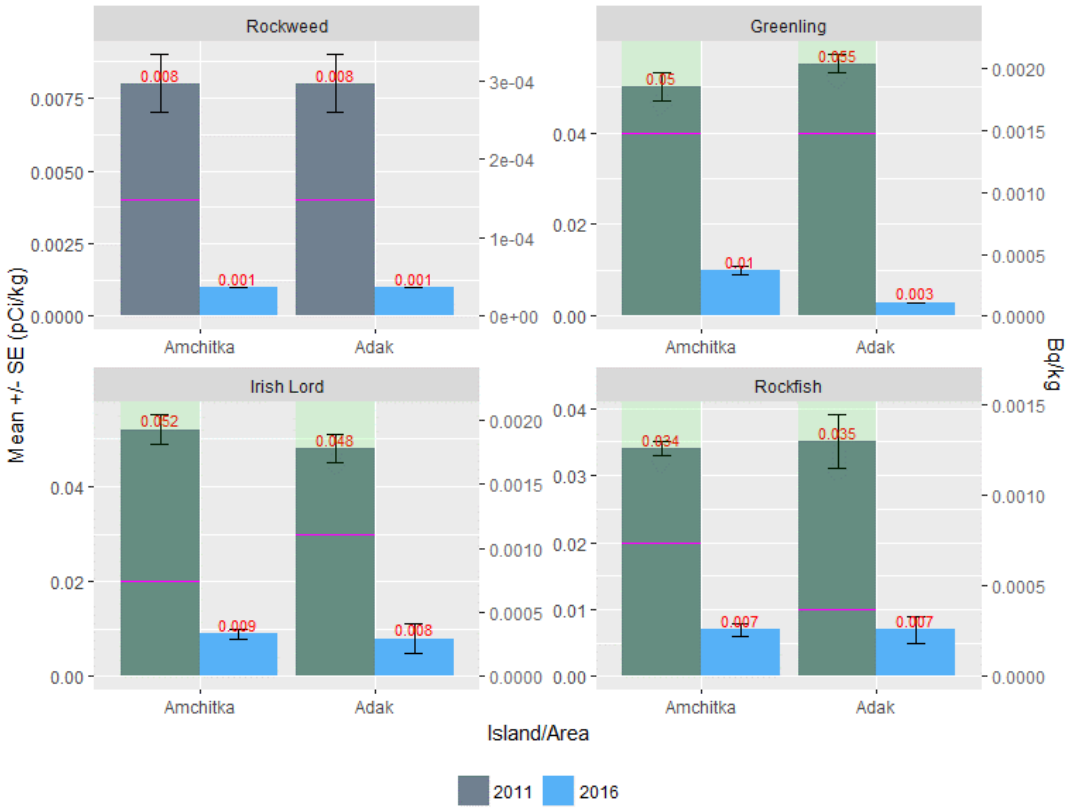
Notes:

[a] Based on the range of MDAs relative to measured values, exclusion of nondetects may inflate the mean.

[b] Calculated by using the sample-specific RDL reported by LLNL for results below the MDA. Despite problems with substitution acknowledged in Section 3.5.1, this estimator is considered more representative than the mean of detects only. However, variance is likely to be underestimated, especially for those groups with a higher proportion of nondetects.

The summary statistics listed above may differ slightly from those reported in the previous (DOE 2013) biomonitoring report. In that report, means and SDs were calculated using the maximum of duplicate results. In generating data plots for this report, however, data were filtered to exclude all 2011 duplicate results (no duplicate biota samples were collected in 2016). This approach may result in some minor discrepancies between mean ± SD estimates listed above versus those listed in the 2011 report tables (DOE 2013).

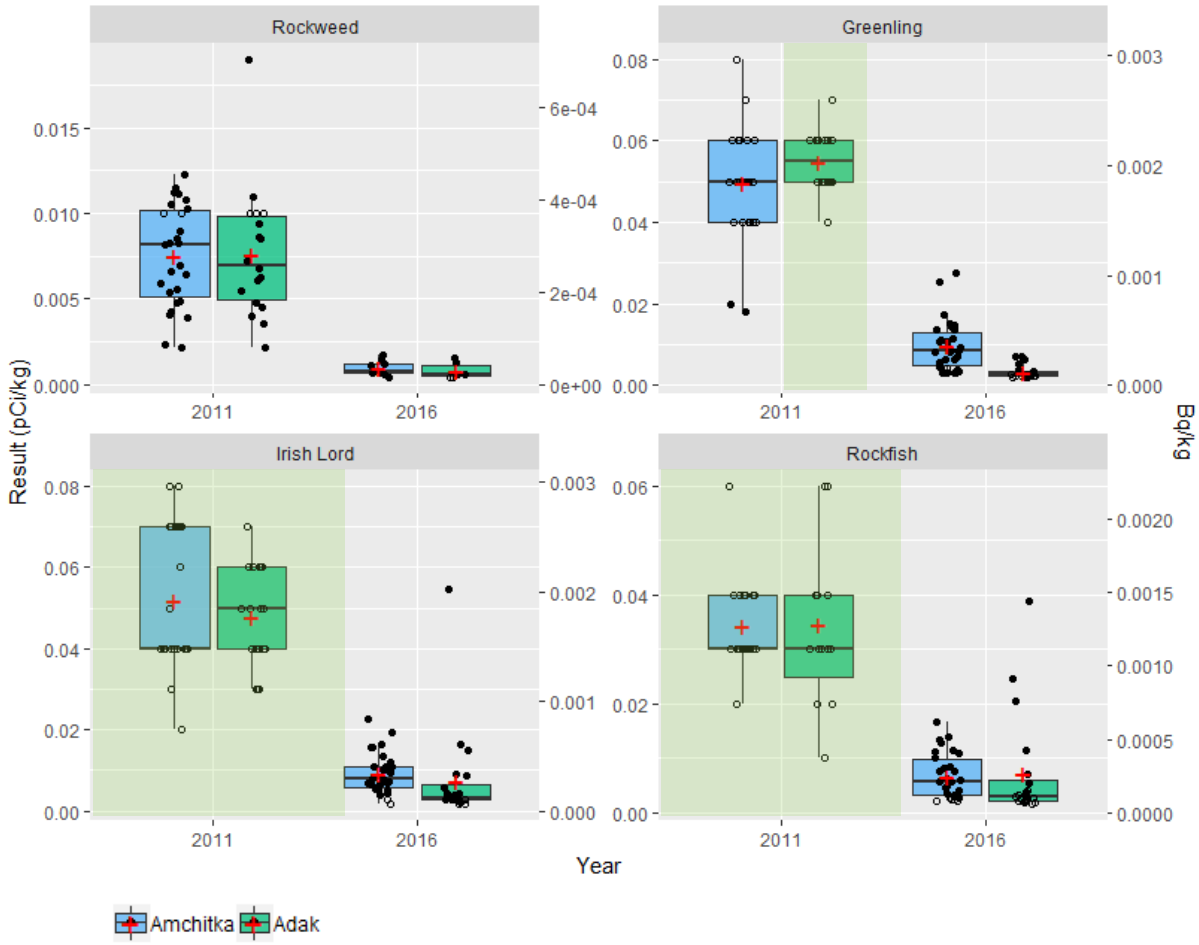
[c] Range of MDAs for 2016 are the range of sample-specific RDLs reported by LLNL (Hamilton et al. 2018d), provided in Appendix D of this report. Those for 2011 are the range of MDAs reported in the 2011 biological monitoring report (DOE 2013).



Notes:
Units in pCi/kg wet weight. Bars represent means, determined using the MDA value for nondetects.
Error bars show the standard error of the mean
overlay denotes that ^{239}Pu not detected or detected at frequency of <10% in 2011.
— is the lowest MDA for the corresponding 2011 species/island combination. Because of the very low detection frequencies for marine fish in 2011 (nondetect or <10%), the height of the bar approximates the mean MDA.

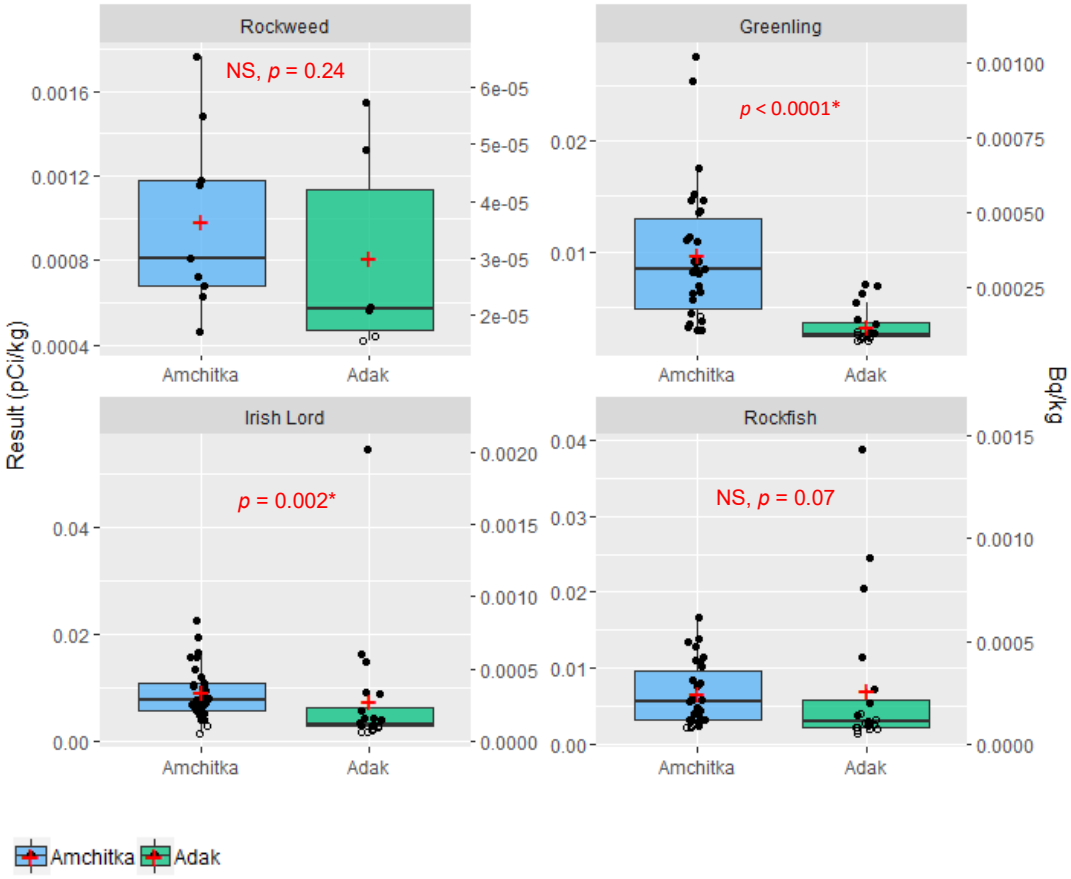
Abbreviation:
SE = standard error

Figure 32. Mean Plots of ^{239}Pu Illustrating Impacts of Between-Year MDA Differences



- ● Discrete measurement; points are "jittered" to better illustrate sample n and result distribution.
- ○ Nondetect result (below RDL).
- + Group mean excluding outliers noted below.
- Green shaded overlay denotes that all results were nondetects (applies to 2011 results for fish).

Figure 33. Plutonium-239 Distribution in Biota, 2011 vs. 2016



● Discrete measurement; points are "jittered" to better illustrate sample n and result distribution.
○ Nondetect result (below RDL).
+ Group mean excluding outliers noted below.
Kruskal-Wallis test results overlain on each plot; * denotes a significant interisland difference ($p < 0.05$) in ^{239}Pu levels. "NS" denotes non-significant result ($p > 0.05$) based on results from Table 14.

Figure 34. Plutonium-239 Distribution in Biota Samples Collected in 2016

Table 14. Statistical Comparison Summaries for ^{239}Pu in Biota

Species/ Island[a]	Year	Detection Frequency	Test of Proportions: Pearson's Chi-squared and *p* value[b]	Mean ± SD[c] (pCi/kg)	Kruskal-Wallis Chi-squared and *p* value[d]	Between-Year Summary (Amchitka only)[e]
Rockweed						
Amchitka Adak	2016	9/9 (100%) 4/6 (66.7%)	3.46 $p = 0.063$	0.001 ± 0.0004 0.001 ± 0.0005	1.39 $p = 0.24$	2016 < 2011** $2016_{AMC} = 2016_{Adak}$
Amchitka Adak	2011	25/27 (92.6%) 15/18 (83.3%)	0.94 $p = 0.33$	0.008 ± 0.003 0.008 ± 0.004	0.31 $p = 0.58$	
Greenling						
Amchitka Adak	2016	28/30 (93.3%) 8/20 (40.0%)	16.9 $p < 0.0001$*	0.01 ± 0.006 0.003 ± 0.002	24.5 $p < 0.0001$*	2016 < 2011** $2016_{AMC} > 2016_{Adak}$
Amchitka Adak	2011	2/27 (7.4%) 0/18 (0%)	NA	0.05 ± 0.013 NA (<0.07)	NA	
Irish lord						
Amchitka Adak	2016	28/30 (93.3%) 13/20 (65.0%)	6.53 $p = 0.011$*	0.009 ± 0.005 0.008 ± 0.012	9.4 $p = 0.002$*	2016 < 2011** $2016_{AMC} > 2016_{Adak}$
Amchitka Adak	2011	0/27 (0%) 0/18 (0%)	NA	NA (<0.08) NA (<0.07)	NA	
Rockfish						
Amchitka Adak	2016	24/30 (80.0%) 8/20 (40.0%)	8.33 $p = 0.004$*	0.007 ± 0.004 0.007 ± 0.01	3.3 $p = 0.07$	2016 < 2011** $2016_{AMC} = 2016_{Adak}$
Amchitka Adak	2011	0/26 (0%) 0/15 (0%)	NA	NA (<0.06) NA (<0.06)	NA	

*Significant test result ($p < 0.05$). *p*-values < 0.05 indicate a significant interisland difference, in either detection frequency (Pearson's chi-squared test) or ^{239}Pu concentration (Kruskal-Wallis test).

**Conclusion only relevant to determinations of food safety. Due to the higher MDAs in 2011 (Figure 21), and corresponding low detection frequencies found for all species except rockweed, the actual distribution of ^{239}Pu levels in most 2011 biota samples is not known.

Notes:

[a] Dolly Varden not listed as ^{239}Pu was not detected in samples collected in 2011 (n = 2) or in 2016 (n = 3).

[b] Interisland comparisons of the proportions of detects and nondetects were tested using the Pearson's chi-squared (contingency table) test; corresponding *p* values are listed below each chi-squared (χ^2) value.

[c] Means calculated using the sample-specific RDL reported by LLNL for results below the MDA.

[d] To compare interisland magnitudes within years, the Kruskal-Wallis rank sum test was used. Although ANOVAs were initially run, due to outliers and violation of one or more of the test assumptions (e.g., a normal distribution and equal variances), the nonparametric rank sum test was used, consistent with the statistical approach used by CRESP (2005).

[e] Statistical comparisons were not appropriate given the large differences in MDAs between years.

Abbreviation:

NA = not applicable (e.g., given nondetects for that species-year group)

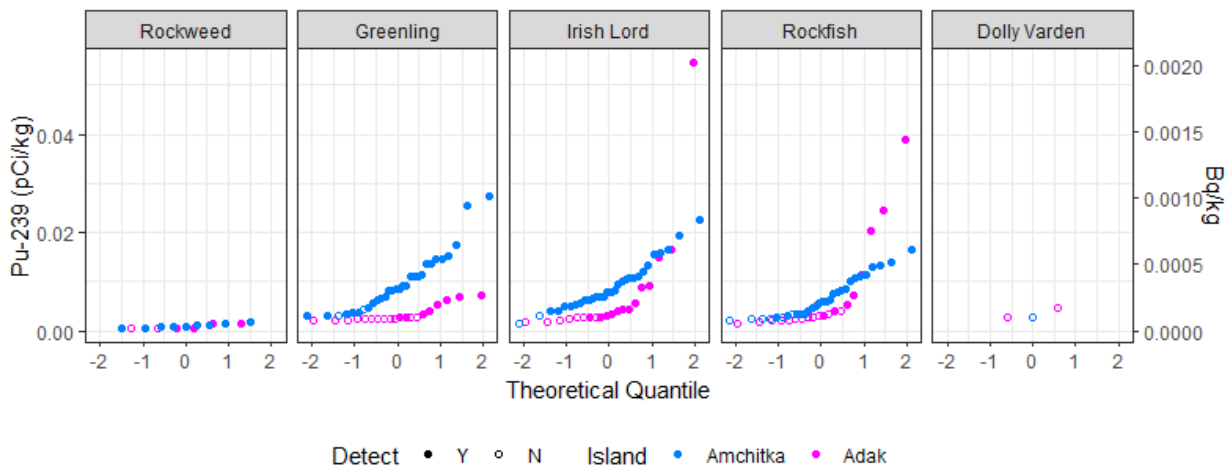
Based on the preceding figures, the data summary in Table 13 and the results of statistical tests reported in Table 14, the following paragraphs summarize the ^{239}Pu content in samples collected in 2016 relative to corresponding 2011 results. While the ranges referenced below apply to detected results only, means and standard deviations were determined by substituting nondetects with the sample-specific MDA.

- *Rockweed*—Plutonium-239 was detected in the majority of rockweed samples collected in both 2011 (n=45) and 2016 (n=15). In 2016, mean activity concentrations of ^{239}Pu in rockweed samples from Amchitka (n=9) and Adak (n=6) were both 0.001 pCi/kg with similar standard deviations (0.0004–0.0005 pCi/kg). These levels are lower than those detected in 2011 (0.008 pCi/kg in both Amchitka and Adak samples), but this finding likely reflects the fact that MDAs in 2016, ranging from 0.0004–0.0005 pCi/kg, were about an order of magnitude lower than those in 2011 (0.004–0.01 pCi/kg). For 2016 results, the interisland difference in the proportion of detects between Amchitka (100%) and Adak (66.7%) was marginally significant ($p = 0.063$, Table 14). No significant interisland difference was found in ^{239}Pu levels based on the 2016 results ($p = 0.24$, Figure 34).
- *Greenling*—Plutonium-239 was largely not detected in greenling samples from 2011: only 2/27 from Amchitka (0.018–0.02 pCi/kg) and none (0/18) from Adak (Table 13). However, ^{239}Pu was detected in the majority of greenling samples collected from Amchitka in 2016 (93.3%) at levels ranging from 0.003–0.028 pCi/kg. Significantly lower detection frequencies (40.0%) were observed for samples from Adak ($p < 0.0001$). Significant interisland differences were also found in ^{239}Pu magnitude (2016 results), with activity concentrations higher ($p < 0.0001$) in samples from Amchitka (0.01 ± 0.006 pCi/kg) relative to those from Adak (0.003 ± 0.002 pCi/kg). Differences in MDAs between years (Table 13) preclude corresponding statistical comparisons. From a food safety perspective, 2016 results are lower than 2011 results, but this conclusion is based only on what the detection capabilities were in 2016 (0.002–0.005 pCi/kg) relative to those in 2011 (0.04–0.08 pCi/kg).
- *Irish lord*—Results for Irish lord are similar to those for greenling in terms of magnitude and overall findings. Not detected in 2011 due to the higher MDAs at that time (0.02–0.08 pCi/kg), ^{239}Pu was detected in the majority (93%) of Amchitka samples in 2016. Detection frequencies were significantly lower at Adak (65%, $p = 0.011$). Significant interisland differences were also found in ^{239}Pu magnitude (2016 results), with activity concentrations higher ($p = 0.002$) in samples from Amchitka (0.009 ± 0.005 pCi/kg) relative to those from Adak (0.008 ± 0.012 pCi/kg). Although the means are similar because of the 0.055 pCi/kg outlier from Adak (Figure 33), as shown in Figure 34, the distributions are different, with Amchitka results shifted slightly higher than Adak.[22]
- *Rockfish*—Results are similar to those found for the other fish species discussed above; ^{239}Pu was not detected in 2011 due to the higher MDAs at that time (0.01–0.06 pCi/kg). MDAs achieved in 2016 were about one order of magnitude lower, ranging from 0.0014–0.004 pCi/kg. Although no interisland differences in ^{239}Pu magnitude were found (both means were 0.007 pCi/kg), there were significant differences ($p = 0.004$) in the proportion of detects between islands: 80% at Amchitka versus 40% in samples from Adak (Table 13, Table 14).
- *Dolly Varden*—Plutonium-239 (along with ^{240}Pu) was not detected in Dolly Varden samples in either 2011 (^{239}Pu < 0.01 pCi/kg) or 2016 (^{239}Pu < 0.003–0.005 pCi/kg).

[22] This example illustrates the drawbacks inherent in comparing means versus what Kruskal-Wallis actually tests, differences in percentiles.

Given the greater laboratory sensitivity achieved in 2016, ^{239}Pu was measured in the majority of samples from Amchitka in 2016 (except for Dolly Varden), and overall about half of those from Adak. Means and ranges of quantifiable measurements in 2016 were lower than MDAs achieved in 2011 by about an order of magnitude. As such, previous conclusions regarding food safety and potential risk are maintained. Based on 2016 results, significant interisland differences in detection frequency or ^{239}Pu magnitude were found for fish species (greenling, Irish lord, and rockfish). For both endpoints, measures were higher in samples from Amchitka relative to Adak.

These findings are consistent with conclusions drawn previously by CRESP (2005), who found a higher proportion of detectable values for $^{239, 240}$Pu in algae at Amchitka than at Kiska (the reference island at that time). CRESP also found significant differences in mean levels of plutonium isotopes (higher at Amchitka), although the differences were small and well below human health guidance levels. In line with CRESP's conclusions, even though statistically significant interisland differences were found in 2016 (with Amchitka higher than Adak), these differences are not considered biologically significant. To better illustrate these small differences, Figure 35 is an alternate presentation of the 2016 ^{239}Pu results shown previously (the box plots in Figure 34). In this series of Q-Q plots, scales are common across species to facilitate comparisons.



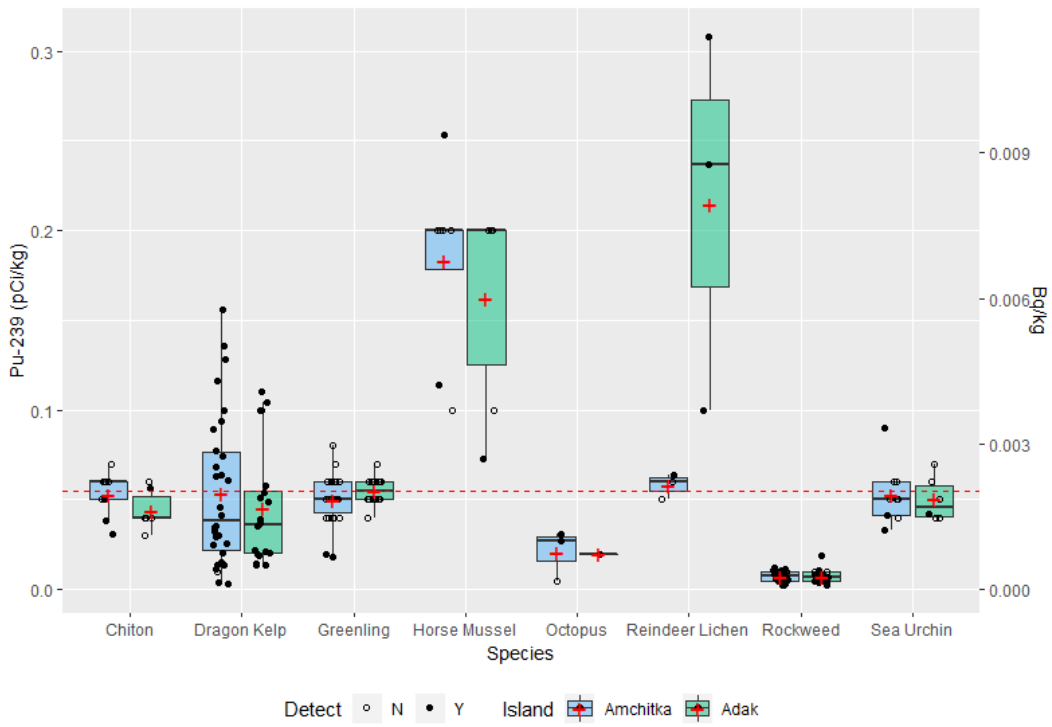
For scaling purposes, corresponding food safety guidelines (e.g., Codex guideline of 27 pCi/kg [1 Bq/kg] discussed in Section 5) are not shown because they are 2–3 orders of magnitude higher than the ^{239}Pu results plotted above.
Note:
In the quantile-quantile plots shown in this figure, the *y*-axis represents actual sample result while the *x*-axis shows the corresponding quantiles from a theoretical normal distribution.

Figure 35. Distributions of ^{239}Pu in 2016 Biota Samples: Amchitka vs. Adak

As shown in Figure 35, while ^{239}Pu results from Amchitka are shifted higher relative to Adak for greenling, Irish lord, and to a lesser extent rockfish, the shift is only on the order of about 0.01-0.02 pCi/kg (<0.001 Bq/kg). This difference is negligible relative to corresponding food safety guidelines or risk-based levels discussed in Section 4.3.2. For example, the most conservative seafood consumption/intake scenario based on the 2011 risk assessment yielded an allowable ^{239}Pu level in fish of 10.1 pCi/kg, at least two orders of magnitude higher than the levels found in 2016 samples.

Figure 35 also shows that, despite the overall higher concentrations (and detection frequencies) found in some species at Amchitka in 2016, the highest ^{239}Pu levels overall were measured in fish collected from Adak (0.055 and 0.039 pCi/kg in Irish lord and rockfish samples, respectively).

This was also the case based on 2011 results, when the highest ^{239}Pu activity concentration was measured in a reindeer lichen sample from Adak (0.308 pCi/kg). As discussed in the conclusion of Section 2.2.4, more species and analytes were addressed in the 2011 environmental monitoring event than in 2016 (Figure 2 and Figure 3). Although ^{239}Pu was not detected in rockfish or Irish lord in 2011, it was detected in other species, including: chiton, dragon kelp, horse mussel, octopus, reindeer lichen, sea urchin, and (also sampled in 2016) rockweed and greenling. In fact, both ^{239}Pu and ^{240}Pu were detected in the majority of dragon kelp samples in 2011.[23] These 2011 results are shown in Figure 36, which plots the distributions of ^{239}Pu for all species with quantifiable ^{239}Pu. For dragon kelp and rockweed, the only species with sufficient percentages of ^{239}Pu detections or sample numbers, no significant interisland differences were found in ^{239}Pu magnitude ($p = 0.71$ and $p = 0.58$, respectively).

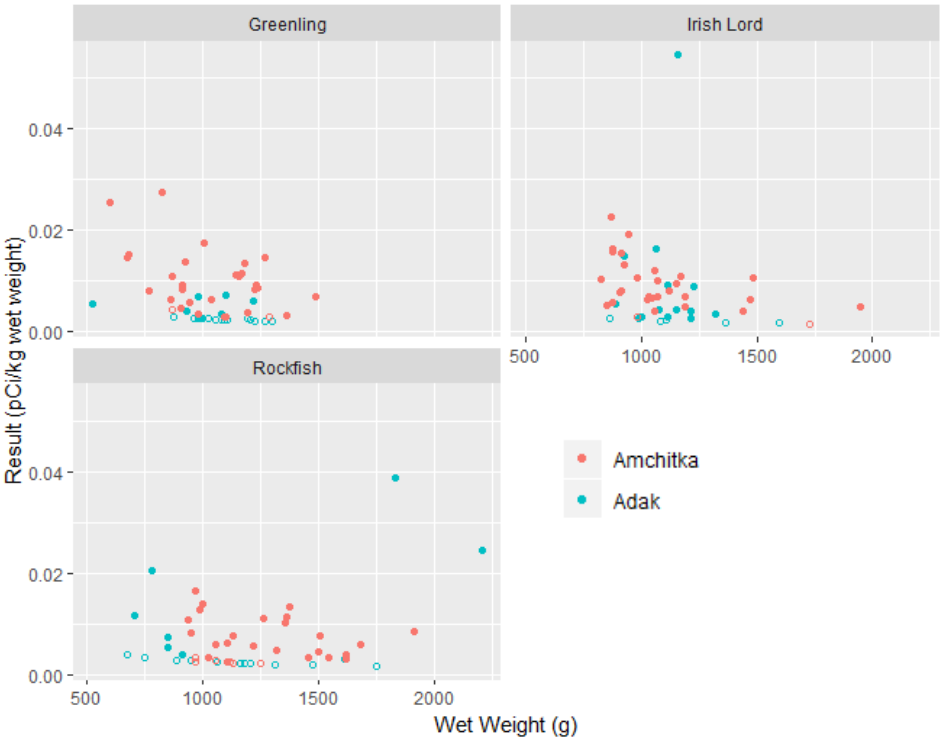


Units in pCi/kg wet weight; corresponding SI units shown on right *y*-axis.
- - - denotes the maximum ^{239}Pu activity detected in biota samples in 2016 (0.055 pCi/kg)
Note:
This plot excludes outlier nondetect datum HMUS-LS-LT3-1 and corresponding MDA (2 pCi/kg).

Figure 36. Plutonium-239 Distributions in Biota Samples Collected in 2011
Species shown are only those with quantifiable ^{239}Pu; includes species not assessed in 2016.

[23] Plutonium-239 was detected in all dragon kelp samples collected in 2011 (27 from Amchitka and 18 from Adak), while ^{240}Pu was detected in 25/27 samples from Amchitka (93% frequency) and all 18 samples from Adak.

As done for ^{137}Cs (Figure 30), this section concludes with an examination of the relationship between fish weight and corresponding ^{239}Pu concentrations for greenling, Irish lord, and rockfish. Based on the distribution of points in Figure 37, no pattern or relationship between sample wet weights and ^{239}Pu activity is apparent. A possible exception is that the two highest ^{239}Pu levels in rockfish, both from Adak Island, correspond to some of the largest (> 1750 g) fish. Also, higher ^{239}Pu levels in greenling samples from Amchitka seem to correspond to smaller fish (significance not assessed), but this relationship appears to be weak.



● Solid points denote results above the MDA.
○ denotes nondetect result (<MDA).

Notes:
Dolly Varden is not included in this figure as ^{239}Pu was not detected in the three samples collected.
Some of the samples plotted in this figure represent composites.

Figure 37. Plutonium-239 Activity in 2016 Marine Fish Samples vs. Sample Wet Weights

4.3.2 Plutonium-240

Table 15 presents summary statistics for ^{240}Pu. Given the very low frequencies of detection relative to ^{239}Pu, the main purpose of this table is to document sample numbers and the range of MDAs for each year and island grouping. Of the 168 biota samples collected in 2016, ^{240}Pu was detected in only four fish samples (two rockfish, one greenling, one Irish lord) from Amchitka. These four results should be interpreted with caution given the caveat issued in the introduction to this section, based on LLNL's recent correspondence (Hamilton 2019). Unlike cesium, the March 2011 Fukushima nuclear accident did not release measurable amounts of plutonium in far-field atmospheric fallout outside of Japan (Thakur et al. 2017), so this would not explain the unusual ^{240}Pu detections.

Table 15. Summary Statistics for ^{240}Pu in Biota: 2016 vs. 2011

Units in pCi/kg wet weight. Units in mBq/kg wet weight.

Species / Area	Year	No. of Detects (% > MDA)	Detects Only[a] Range	Range of MDAs[b]	Maximum Detected	Range of MDAs
Rockweed						
Amchitka	2016	0 of 9 0%		0.002 – 0.003		0.09 – 0.12
Adak	2016	0 of 6 0%		0.003 – 0.003		0.10 – 0.10
Amchitka	2011	2 of 27 7.4%	0.005 – 0.008	0.002 – 0.003	0.30	0.07 – 0.11
Adak	2011	3 of 18 16.7%	0.006 – 0.011	0.002 – 0.003	0.41	0.07 – 0.11
Greenling						
Amchitka	2016	1 of 30 3.3%	0.10	0.012 – 0.028	3.7	0.43 – 1.05
Adak	2016	0 of 20 0.0%		0.013 – 0.030		0.46 – 1.12
Amchitka	2011	0 of 27 0.0%		0.020 – 0.040		0.7 – 1.5
Adak	2011	0 of 18 0%		0.020 – 0.040		0.7 – 1.5
Irish Lord						
Amchitka	2016	1 of 30 3.3%	0.082	0.008 – 0.036	3.0	0.29 – 1.33
Adak	2016	0 of 20 0.0%		0.011 – 0.027		0.40 – 0.99
Amchitka	2011	0 of 27 0.0%		0.01 – 0.04		0.37 1.48
Adak	2011	0 of 18 0.0%		0.02 – 0.04		0.74 1.48
Rockfish						
Amchitka	2016	2 of 30 6.7%	0.04 – 0.046	0.009 – 0.021	1.7	0.35 – 0.77
Adak	2016	0 of 20 0.0%		0.009 – 0.026		0.34 – 0.95
Amchitka	2011	0 of 26 0.0%		0.01 – 0.03		0.37 1.1
Adak	2011	0 of 15 0.0%		0.01 – 0.03		0.37 1.1
Dolly Varden						
Amchitka	2016	0 of 1 0%		0.017		0.64
Adak	2016	0 of 2 0%		0.017 – 0.031		0.61 – 1.13
Amchitka	2011	0 of 1 0%		0.010		0.37
Adak	2011	0 of 1 0%		0.010		0.37

All units in wet weight; main portion of table uses pCi/kg; values in SI units are shown to the right.

Notes:

[a] Means and standard deviations are not shown in this table because of the limited number of ^{240}Pu detections in both 2011 and 2016. Hamilton (2019) suggests that the four 2016 ^{240}Pu results, although still passing quality assurance requirements, are anomalous and should not be considered as quantitative. No biota samples were retained so reanalysis of the samples is not feasible.[b] Range of MDAs for 2016 are the range of sample-specific RDLs reported by LLNL (Hamilton et al. 2018c), provided in Appendix D of this report. Those for 2011 are the range of MDAs reported in the 2011 biological monitoring report (DOE 2013) and in LLNL's supporting documentation (Hamilton et al. 2012).

Abbreviation:

mBq/kg = millibecquerels per kilogram

The anomalous ^{240}Pu results are listed in Table 16 along with corresponding ^{239}Pu results and MDAs for both isotopes. As shown in this table and in Appendix D, MDAs for ^{240}Pu in 2016 were consistently about 5 to 6 times higher than those for ^{239}Pu. This was not the case in 2011, when ^{240}Pu MDAs were equal to or lower than corresponding ^{239}Pu MDAs—approximately 0.02 and 0.03 pCi for ^{240}Pu and ^{2390}Pu, respectively (Hamilton et al. 2012).

Table 16. Samples with Detectable Levels of ^{240}Pu Based on LLNL Results

Sample ID	^{239}Pu (pCi/kg)	^{240}Pu[a,b] (pCi/kg)	^{239}Pu MDA (pCi/kg)[c]	^{240}Pu MDA (pCi/kg)[c]
GREN-CN-09	0.025 ± 0.004	0.100 ± 0.007	0.004	0.028
ILOR-08[d]	0.017 ± 0.002	0.082 ± 0.011	0.003	0.02
ROCK-LS-02	0.011 ± 0.002	0.046 ± 0.003	0.002	0.02
ROCK-LS-03	0.013 ± 0.001	0.040 ± 0.002	0.002	0.01

Mass units in pCi/kg wet weight.
Results in red font denote anomalous result based on Hamilton (2019).

Notes:

[a] Although reported as detected in LLNL's initial report (Hamilton et al. 2018d), the ^{240}Pu detections listed above were later identified as being possible analytical artifacts (Hamilton 2019). Although still passing quality assurance requirements, these results are anomalous and should not be considered as quantitative. No biota samples were retained so reanalysis of the samples is not feasible.

[b] ^{240}Pu/^{239}Pu atom ratios were initially calculated but are not reported here because the ^{240}Pu detections were later determined to be anomalous. Also, accurate atom ratio determinations require AMS or thermal ionization mass spectrometry, whereas ICP-MS was used for the 2016 analyses.

[c] MDAs are the sample-specific RDLs (rounded) reported in Hamilton et al. (2018d), provided in Appendix D.

[d] Sample ILOR-08 was collected from Cannikin.

As indicated in Table 15 and Table 16 above, for the fauna and fish species sampled in both 2011 and 2016, ^{240}Pu loadings were mostly below the MDA. The few detections in fish in 2016 were considered suspect (Hamilton 2019). In reporting the 2011 biota sampling results, LLNL reported an average ^{240}Pu/^{239}Pu ratio of 0.21 ± 0.02 for dragon kelp (Hamilton et al. 2012). LLNL suggested using this ratio to estimate the total $^{239+240}$Pu content of marine fauna for samples with detectable levels of ^{239}Pu but no associated quantifiable ^{240}Pu. The estimated total $^{239+240}$Pu content, essentially 20% higher than the measured ^{239}Pu, could then be applied in food safety and risk evaluations.

Despite the aforementioned caveats associated with the 2016 ^{240}Pu analyses, consistent with conclusions drawn by LLNL in their reporting of 2011 results (Hamilton et al. 2012), the quantification capabilities of ICP-MS for plutonium isotopes in 2016 still provide an adequate level of detection sensitivity to support diet-based radiological assessments with a reasonable measure of safety.

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5.0 Food Safety and Risk Analysis Update

Although Amchitka Island is uninhabited, the surrounding marine environment (the Bering Sea and North Pacific Ocean) is biologically rich and fished both commercially and for subsistence purposes by Aleut Natives living in the Aleutian and Pribilof Islands. The native populations that rely on subsistence foods live several hundred miles from Amchitka Island and include Aleut villages such as Adak, Atka, Nikolski, and Unalaska (DOE 2013). As such, any fish harvested from Amchitka would likely represent only a portion of a nearby islander's subsistence diet. Commercial fishing is another route by which human exposure is possible, although most consumers would derive only a small percentage of their diet from the Amchitka vicinity. Nonetheless, because seafood is harvested from the Amchitka region, LM's 2011 investigation and report focused on (1) sampling marine biota for test-related radionuclides and (2) evaluation of potential risks associated with seafood consumption based on those results.

In developing the risk assessment for the 2011 environmental monitoring report, LM in collaboration with ANL evaluated available subsistence diet information, including food preferences and portions consumed, for four Aleut villages: Atka, Nikolski, St. Paul, and Unalaska (DOE 2013). For all seafood species evaluated, intake rates from the four Aleut diets were averaged to develop a fifth "composite" diet scenario. Risk estimates were then derived for each radionuclide-dietary component combination using conservative intake assumptions.[24] For example, the risk assessment assumed that all subsistence- and commercial-catch seafood consumed is harvested from regions at or around Amchitka or Adak Islands (DOE 2013). For most diet scenarios, risk estimates were below 1×10^{-5} (1 in 100,000), the level used by the State of Alaska (ADEC) as the benchmark for acceptable risk.[25] Based on these results, the 2011 report concluded that seafood harvested from the Amchitka region is safe to eat (DOE 2013), confirming previous conclusions drawn by CRESP (2005). For ^{137}Cs and plutonium isotopes (^{239}Pu and ^{240}Pu), the primary radionuclides of interest addressed in this report, cancer risks estimated based on maximum concentrations in 2011 biota samples are summarized as follows:

- *^{137}Cs*—Total risks for Amchitka (summed over all seafood species) ranged from 3×10^{-7} (St. Paul diet) to 4×10^{-6} (Nikolski diet). For most species, these risks were lower than those determined for Adak, which ranged from 2×10^{-7} to 6×10^{-6} (DOE 2013).
- *^{239}Pu*—For Amchitka samples, risks ranged from 2×10^{-8} (St. Paul diet) to 8×10^{-8} (Atka diet), well below the 10^{-5} benchmark. These risks were just slightly higher than those determined for Adak, which ranged from 7×10^{-9} to 4×10^{-8} (DOE 2013).
- *^{240}Pu*—For the species sampled in 2016, most results were below the MDA; in these cases, risks were calculated using the maximum reported MDA. Corresponding risks ranged from 8×10^{-9} to 4×10^{-8} for Amchitka biota samples and 4×10^{-9} to 2×10^{-8} for Adak samples.

The previous section demonstrated that, except for some fish samples from Adak, overall, radionuclide levels measured in 2016 biota samples were lower than those measured in 2011. As such, if 2011 levels were considered safe for seafood consumption, then levels measured in 2016 would be as safe or safer.

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[24] This yielded nearly 1200 unique risk estimates for both Amchitka and Adak area groups: 7 radionuclides × 5 diet scenarios × 17 seafood species × 2 radionuclide concentrations (documented in Tables 24–33 of DOE [2013]).

[25] The only exceptions were total risks estimated for the Nikolski diet (with much higher fish consumption rates), for which maximum total risks (summed across radionuclides) for Amchitka and Adak were equivalent: 2.3×10^{-5}.

To frame the 2016 biota sampling results in terms of a risk-based perspective, risk estimates were derived for ^{137}Cs and plutonium isotopes (^{239}Pu + ^{240}Pu) using the same equations and assumptions used in the 2011 risk assessment (DOE 2013). The only difference is that, while risks were estimated for 5 distinct diet scenarios in the 2011 assessment (each with different intake rates), only maximum intake rates were used here (Table 17). Consistent with that approach, potential risks associated with subsistence- and commercial-catch seafood consumption were estimated using the following equation:

$$Risk_{i,j} = \left[SF_i \times ADI_j \times C_{i,j} \times 10^{-3} \times EF \times ED\right]$$

where:

Risk = Excess lifetime cancer risk resulting from ingestion of seafood
SF_i = Slope factor for radionuclide *i* (1/picocurie):
3.74×10^{-11} for ^{137}Cs (and daughter products)
1.74×10^{-10} for ^{239}Pu and ^{240}Pu
i = Index for radionuclides
j = Index for marine species
ADI = Average daily intake rate attributed to marine species or food group (g/day)
$C_{i,j}$ = Concentration of radionuclide *i* in marine species *j*, wet-weight based (pCi/kg)
10^{-3} = Unit conversion factor (kilograms/g)
EF = Exposure frequency (days/year) (365)
ED = Exposure duration (years) (30).

As a conservative measure, risks were calculated using maximum concentrations measured in the 2011 and 2016 biota samples.[26] For cases in which a radionuclide was not detected in a given species (e.g., ^{239}Pu in most 2011 samples), the maximum corresponding MDA was used in the risk calculations. Risks were not calculated for ^{134}Cs given the limited detections in 2016 biota samples (Table 12) and the lack of comparison data for 2011 (^{134}Cs was not analyzed in 2011 fish or seaweed samples). Plutonium-240 was not detected in 2011 marine fish samples and the few (four) detections in corresponding 2016 samples were found to be anomalous (Table 16). To yield conservative risk estimates, ^{240}Pu content was estimated based on quantifiable ^{239}Pu results using the approach recommended by LLNL (Hamilton et al. 2012). These investigators reported an average $^{240}Pu/^{239}Pu$ atom ratio of 0.21 ± 0.02 in 2011 dragon kelp samples and suggested applying this ratio to estimate the total $^{239+240}Pu$ content of marine fauna.

To frame the risk estimates in a manner allowing direct comparison with 2016 radionuclide levels, corresponding risk-based concentrations (RBCs) were derived using the following equation:

$$RBC_i = 10^{-5} \times \left[SF_i \times ADI \times 10^{-3} \times EF \times ED\right]^{-1}$$

where:

RBC_i = Risk-based concentration of radionuclide in marine species, wet-weight (pCi/kg),
10^{-5} = Acceptable excess lifetime cancer risk resulting from ingestion of seafood.

RBCs are listed along with the risk estimates in Table 17. As the RBCs are seafood item- and radionuclide-specific, their derivation does not reflect the effects of additivity (i.e., the effects from exposure to multiple radionuclides).

[26] This approach is consistent with that used in the 2011 risk assessment (DOE 2013). In that report, risks were also calculated using the 95 percent upper confidence limit of the mean, or UCL_{95}, values.

Table 17. Allowable ^{137}Cs and Plutonium Levels in Biota and Corresponding Risk Estimates 2011 and 2016 Results

Radionuclide Seafood Item or Diet Basis[a]	ADI (g/day)[b]	10^{-5} RBC (pCi/kg)[c]	Maximum Concentrations in Biota (pCi/kg wet weight)[d]				Corresponding Risk Estimates[d]			
			2011		2016		2011		2016	
			AMC	Adak	AMC	Adak	AMC	Adak	AMC	Adak
Cesium-137 (+D)										
Rockweed (seaweed)[a]	0.1	244,000	5.8	7.3	0.8	2.0	2×10^{-10}	3×10^{-10}	3×10^{-11}	8×10^{-11}
Dolly Varden	19	1280	98	450	102	70	8×10^{-7}	4×10^{-6}	8×10^{-7}	5×10^{-7}
Marine Fish (Other fish)[a]	18	1360								
Greenling			7.8	7.4	31.0	3.6	6×10^{-8}	6×10^{-8}	2×10^{-7}	3×10^{-8}
Irish lord			9.5	13.0	11.8	78.4	7×10^{-8}	1×10^{-7}	9×10^{-8}	6×10^{-7}
Rockfish			6.4	9.4	14.4	257	5×10^{-8}	7×10^{-8}	1×10^{-7}	2×10^{-6}
Total Risk			–				**9×10^{-7}**	**4×10^{-6}**	**1×10^{-6}**	**3×10^{-6}**
Fish, Total[b,c] Atka and Composite Diets Nikolski Diet	 100 520	 244 47.0	RBCs derived to provide a conservative risk context. Corresponding ADIs were not used in the 2011 risk assessment (DOE 2013).							
Food Safety Guidelines Codex Derived Intervention Level	–	 27,000 32,400	Codex and DIL food guidelines provided as alternate perspective.							
Plutonium-239 + ^{240}Pu (estimated)[e]										
Rockweed (seaweed)[a]	0.1	52,500	0.022	0.034	0.003	0.003	4×10^{-12}	6×10^{-12}	6×10^{-13}	5×10^{-13}
Dolly Varden	19	276	0.01	0.01	0.017	0.031	4×10^{-10}	4×10^{-10}	6×10^{-10}	1×10^{-9}
Marine Fish (Other fish)[a]	18	292								
Greenling			0.036	0.07	0.049	0.013	1×10^{-9}	2×10^{-9}	2×10^{-9}	4×10^{-10}
Irish lord			0.08	0.07	0.040	0.097	3×10^{-9}	2×10^{-9}	1×10^{-9}	3×10^{-9}
Rockfish			0.06	0.06	0.030	0.069	2×10^{-9}	2×10^{-9}	1×10^{-9}	2×10^{-9}
Total Risk			–				**6×10^{-9}**	**7×10^{-9}**	**5×10^{-9}**	**7×10^{-9}**
Fish, Total[b,c] Atka and Composite Diets Nikolski Diet	 100 520	 52.5 10.1	RBCs derived to provide a conservative risk context. Corresponding ADIs were not used in the 2011 risk assessment (DOE 2013).							
Food Safety Guidelines Codex DIL	–	 27.0 54.0	Codex and DIL food guidelines provided as alternate perspective.							

Values in red font denote nondetect results—the maximum reported MDAs or risks calculated using those MDAs.
– Not applicable or not reported. Alternate shading used to facilitate review and interisland comparisons.

Notes:

[a] Seafood item categories listed are consistent with those defined in the human health risk assessment developed by ANL based on the 2011 environmental sampling data (DOE 2013). Seafood items evaluated in that assessment common to the species sampled in 2016 were Dolly Varden, "other fish," and seaweed. In the 2011 assessment, the "other fish" category collectively referred to greenling, Pacific cod, and rockfish, while the seaweed category included both dragon kelp and rockweed. To facilitate direct comparison between 2011 and 2016 results, this table presents radionuclide concentrations and corresponding risk estimates for individual species. The collective approach used in the 2011 assessment (DOE 2013)—seafood item groups comprised of multiple species—was not used.

[b] ADIs listed are the most conservative (highest) of the five diet scenarios evaluated in the previous risk assessment, cited in Table 16 of the 2011 environmental monitoring report (DOE 2013). For example, the highest ADI for Dolly Varden (19 g/day) corresponds to the Nikolski diet, while ADIs for seaweed (0.1 g/day) and "other fish" (18 g/day) correspond to the Atka diet. To provide an even more conservative perspective, several ADIs previously determined for total fish consumption were also used. In the 2011 report, ADIs for "Fish, total" represented the sum of halibut, Dolly Varden, cod, salmon, and a general category of "others," where salmon, halibut, and cod were the largest portion of fish consumed. The ADIs of 100 g/day (Atka diet) and 520 g/day (Nikolski) diet, although used to calculate conservative RBCs, were not used to estimate risks because assumptions are not consistent with those used in the 2011 assessment.

[c] RBCs (rounded to 3 significant figures) were calculated using the equation provided on the previous page.

[d] As a conservative measure, risks were calculated based on maximum concentrations measured in 2011 and 2016 biota samples. For nondetects (e.g., ^{239}Pu in Dolly Varden samples), the maximum MDAs were used.

[e] Plutonium-240 was not detected in 2011 marine fish samples and the few (4) detections in corresponding 2016 samples were found to be anomalous (Table 16). Using the approach recommended by LLNL (Hamilton et al. 2012), ^{240}Pu was estimated by applying a $^{240}Pu/^{239}Pu$ atom ratio of 0.21 ± 0.02 to the quantifiable ^{239}Pu results, whereby the estimated $^{240}Pu = {}^{239}Pu \times 0.7823$. In cases where both ^{239}Pu and ^{240}Pu were below the MDA (e.g., 2011 rockfish results), the maximum reported MDA was used (^{240}Pu was not estimated).

Abbreviations: ADI = average daily intake rate of seafood item (g/day); D = daughter products; DIL = U.S. Food and Drug Administration derived intervention level.

As shown in Table 17, risk estimates calculated assuming life-long consumption of subsistence seafood, and maximum concentrations measured in 2016 biota samples, were 1×10^{-6} and 3×10^{-6} for Amchitka and Adak, respectively. These levels are consistent with those derived based on 2011 results and are lower than the 1×10^{-5} risk level (in excess of background) used by the State of Alaska as a benchmark for acceptable risk. Cesium-137 is the primary contributor to the total risk, a portion of which likely reflects a Fukushima signature. Risks calculated for plutonium (^{239}Pu + estimated ^{240}Pu) were orders of magnitude lower than those for ^{137}Cs: 5×10^{-9} and 7×10^{-9} for Amchitka and Adak, respectively. Based on these results, seafood harvested at Amchitka (and Adak) continues to be considered safe for consumption at the assumed intake levels.

For fish consumption, RBCs calculated for cesium isotopes ranged from 47 pCi/kg—the most conservative, using total fish intakes established for the Nikolski diet—to about 1400 pCi/kg. Those for plutonium isotopes ranged from 10.1–300 pCi/kg. The lower-bound RBCs for plutonium are generally consistent with established food safety standards listed below, while those for cesium are much more conservative:

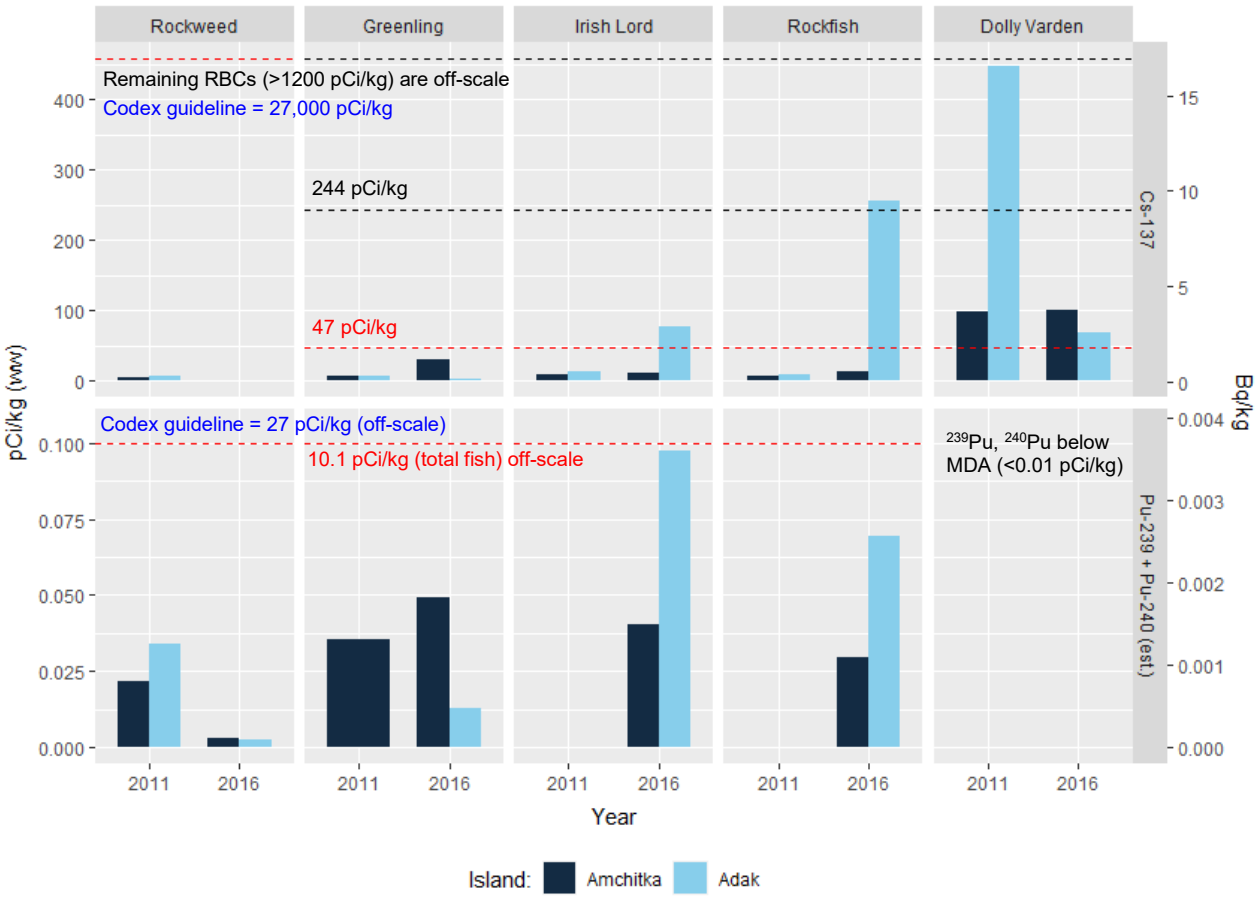
- The Codex Alimentarius Committee of the Food and Agriculture Organization (FAO) and World Health Organization (WHO) food safety values for radionuclides are intended to screen food sources as acceptable for consumption for a 1-year time frame (FAO/WHO 2004)—27,027 and 27 pCi/kg for cesium and plutonium isotopes (1000 Bq/kg and 1 Bq/kg), respectively.[27]
- The U.S. Food and Drug Administration's (FDA's) derived intervention level (DIL) is a guidance level for food that is imported into the United States (FDA 2009). DILs established for cesium and plutonium isotopes are 32,432 and 54.05 pCi/kg, respectively (1200 Bq/kg and 2 Bq/kg).

RBCs listed in Table 17 for rockweed (seaweed/kelp category) are high relative to those for fish, reflecting the lower subsistence diet average daily intake rates. As such, corresponding risks are very low for both cesium and plutonium isotopes—3×10^{-11} and 6×10^{-13}, respectively—again using maximum concentrations in 2016 Amchitka marine biota samples.

To conclude this section, Figure 38 plots the maximum detected concentrations of ^{137}Cs and estimated $^{239+240}$Pu reported for the 2016 biota samples relative to the RBCs shown in Table 17. In general, measured levels in biota are below both established food safety guidelines (e.g., Codex) and the conservative site-specific RBCs. The only exceptions are ^{137}Cs levels in some fish samples collected from Adak, which likely reflect a Fukushima-derived signature. As shown in Figure 38, the highest ^{137}Cs levels have been measured in Dolly Varden, rockfish, and Irish lord caught off Adak Island. All maximum ^{137}Cs concentrations are well below corresponding RBCs calculated using the assumptions applied in the 2011 risk assessment, listed in Table 17. Alternate RBCs, 47 pCi/kg and 244 pCi/kg, are shown to provide the most conservative risk perspective. These values were derived assuming total fish consumption intakes of 520 g/day and 100 g/day, respectively, for a subsistence diet consisting mostly of salmon, halibut, and cod.

[27] Guideline levels (converted from Bq/kg to pCi/kg) for infants and adults from ingestion of imported foods in a year. Levels shown are those derived for infant foods (the most conservative), http://www.fao.org/fao-who-codexalimentarius/home/en/. Fact sheet found at: http://www.fao.org/fileadmin/user_upload/agns/pdf/codex_guideline_for_radionuclitide_contaminated_food.pdf.

Maximum plutonium activity concentrations (^{239}Pu + estimated ^{240}Pu) are more than 2 orders of magnitude below the most conservative RBC of 10.1 pCi/kg (Figure 38), and more than 3 orders of magnitude below seafood-item specific RBCs listed in Table 17.



- - - Denotes the most conservative RBC from Table 17
- - - Alternate RBCs for other diet scenarios from Table 17

Notes:

Chart reflects only results reported above the MDA (i.e., detects only). Blank plots denote that radionuclide not measured in that species. Refer to preceding exhibits for illustrations of overall distributions of the data.

Cesium-134 results are not shown in this figure because this radionuclide was detected in only four 2016 marine biota samples and because it was not analyzed for in 2011 marine fauna samples. In 2016, ^{134}Cs activity concentrations ranged from 3.0–17.0 pCi/kg (3 of the 4 samples were from Adak), below the most conservative (47 pCi/kg) RBC for cesium listed in Table 17.

For $^{239+240}$Pu, the most conservative risk-based concentration was 10.1 pCi/kg (Table 17). For scaling purposes, the dashed line shown above is the level two orders of magnitude below that (0.1 pCi/kg).

Plutonium-240 activity concentrations—considered by LLNL as possible analytical artifacts (Hamilton 2019)—ranged from 0.04–0.1 pCi/kg, 2 orders of magnitude below the most conservative 10.1 pCi/kg RBC (Table 16). Given the anomalous ^{240}Pu results in 2016 samples, the total $^{239+240}$Pu content was estimated using the ^{240}Pu/^{239}Pu atom ratio of 0.21 ± 0.02 suggested by Hamilton et al. (2012).

Abbreviation:

ww = wet weight

Figure 38. Maximum Detected Concentrations of ^{137}Cs and $^{239+240}$Pu in Biota Samples

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6.0 Seawater and Freshwater Sampling Results

In accordance with the DQOs outlined in the sampling plan (DOE 2016a), the 2016 environmental sampling effort included the collection of seawater and freshwater samples. Figure 39 shows the Amchitka water sampling locations, including seawater samples from 40 locations in the Long Shot transect area; one each from the Cannikin and Milrow transects; and one freshwater sample collected from Cannikin Lake. Figure 40 provides greater detail on samples collected within the Long Shot transect, the focus of the 2016 seawater sampling investigation (DOE 2016a). Figure 41 shows the sampling locations at and around the reference site, Adak Island.

In each of these figures, each sample point is labelled with the corresponding tritium result in pCi/L as this analyte was the primary focus of the 2016 sampling effort. All samples were also analyzed for ^{134}Cs and ^{137}Cs and a small subset for ^{129}I. The majority of this section focuses on tritium (Section 6.1), including a comparison of the 2016 sampling results with data and literature from the North Pacific. Section 6.2 documents the results of analyses for ^{134}Cs, ^{137}Cs, and ^{129}I. Portions of this discussion and associated literature reviews were developed with the assistance of ANL.

6.1 Tritium

Tritium is produced in large amounts during nuclear tests, especially from the fusion components of the weapons, and is highly mobile in groundwater. These properties make it one of the first radionuclides likely to be detected above background if contaminant migration from the detonation zones and breakthrough to the seafloor were to occur. The initial hydrologic model developed by the DRI (Hassan et.al. 2002) indicated that the shortest arrival times would be at the Long Shot test site. However, DRI's subsequent verification model (Hassan and Chapman 2006) did not differentiate arrival times because, for all test sites, no breakthrough was predicted within the 2200-year simulation time frame.

An important factor to consider when evaluating tritium sampling results is its well-documented presence in the marine environment as a result of global fallout. The March 2011 Fukushima accident resulted in an increase in the North Pacific tritium background range, from 1.29–1.93 pCi/L (pre-Fukushima) to the current (post-Fukushima) range of 1.35–5.4 pCi/L (Dasher 2017).[28] The upper bound of the post-Fukushima range, 5.4 pCi/L, was established as the level above which AWG would discuss a path forward (DOE 2016a).

Until LM's first major sampling in 2011, tritium sampling in the marine environment around Amchitka was sporadic. Some sampling was done in the 1970s and a limited shoreline survey around the island was conducted by ADEC in 2001. No further effort to measure tritium in the marine environment was done until 2007, when ADEC undertook a fairly extensive sampling effort in the Aleutians, during which a subset of seawater samples was collected off the coast of the Cannikin site (ADEC 2012). In 2011, LM's monitoring focused on the Cannikin transect and later, in 2016, offshore from Long Shot.

[28] Numerous studies assessing transport of Fukushima-derived radionuclides have been conducted. Because Dasher (2017) has developed a comprehensive compendium of the available related literature for the North Pacific Ocean, his useful distillations are cited here.

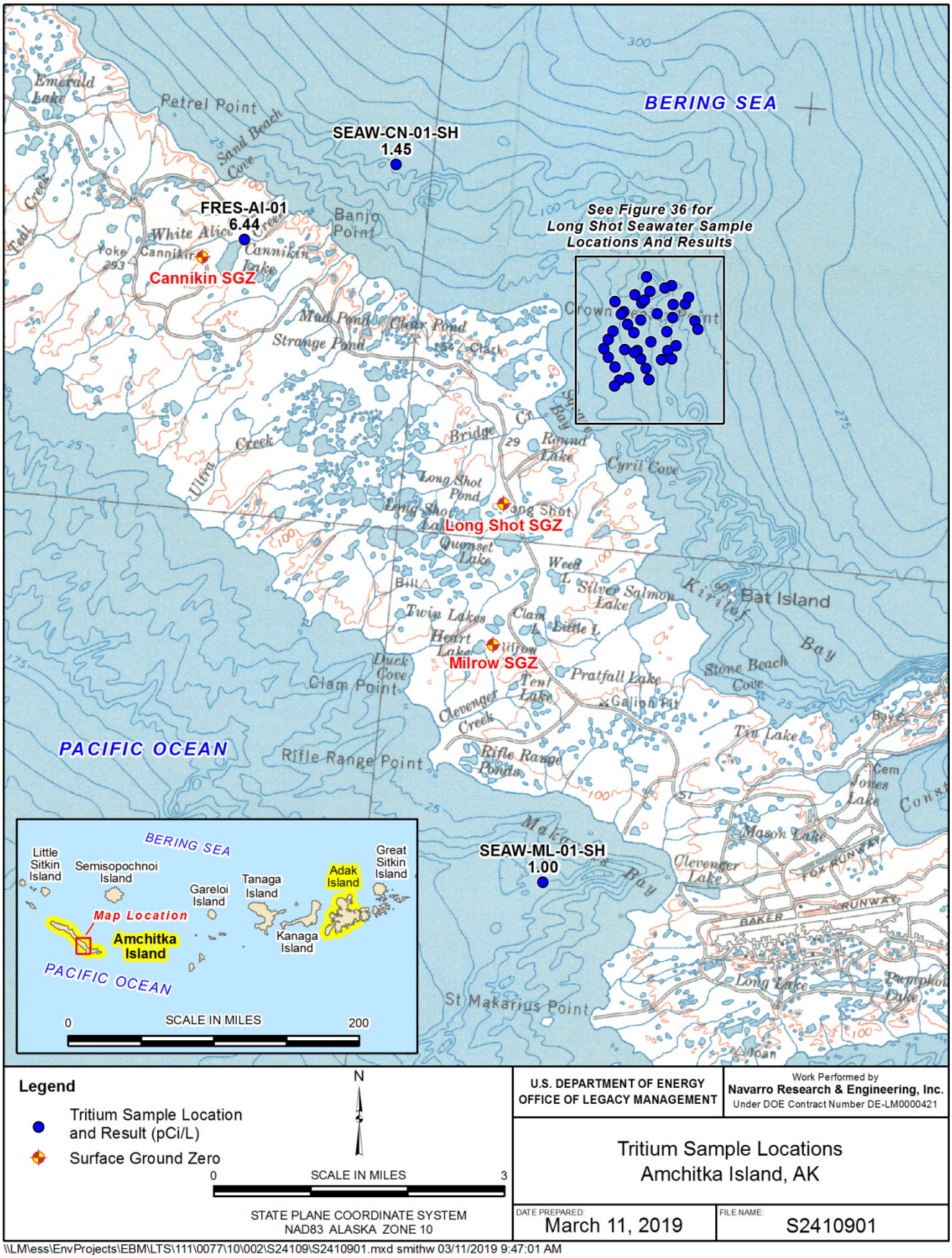


Figure 39. Seawater and Freshwater Sample Locations, Amchitka Island

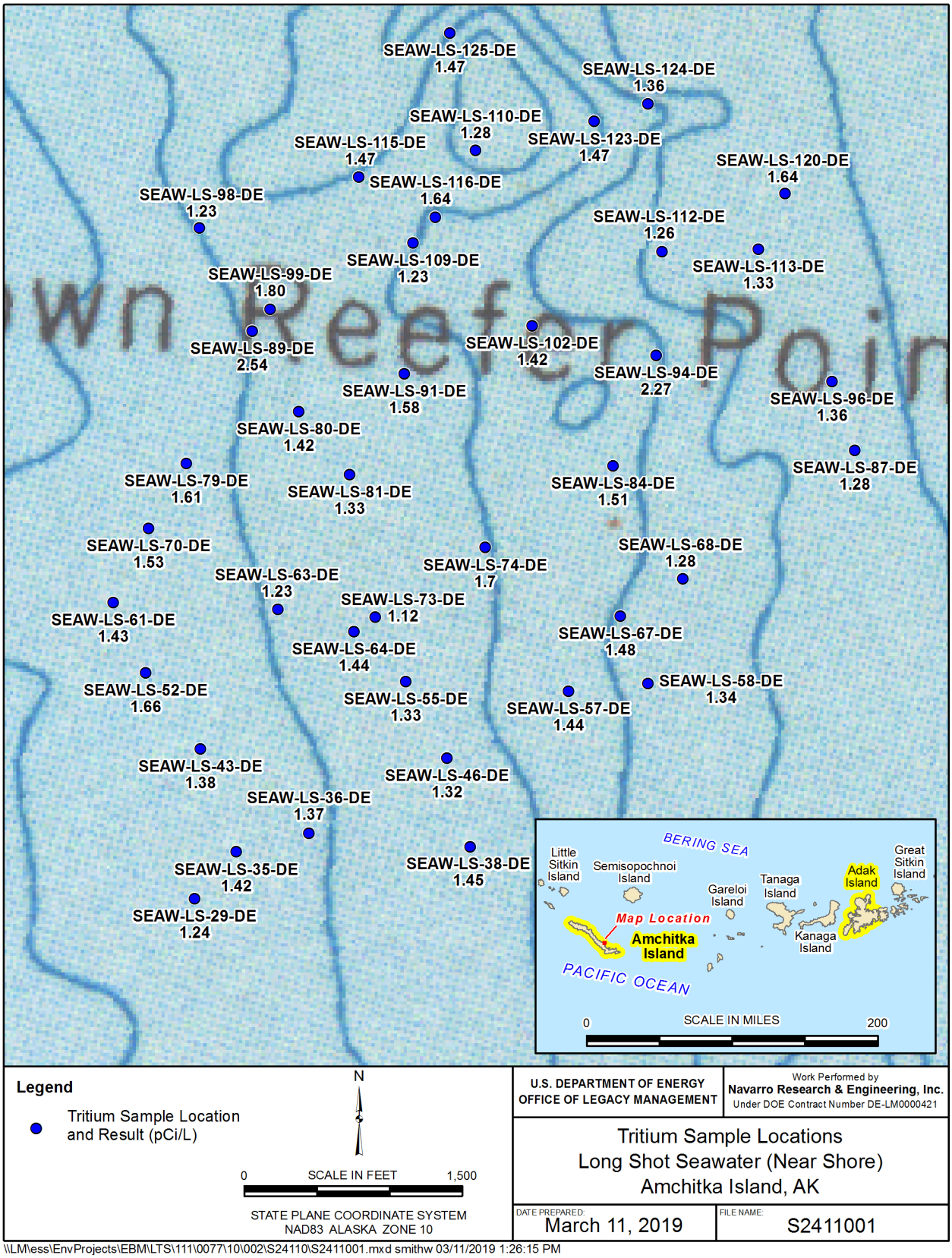


Figure 40. Seawater Sample Locations in the Long Shot Nearshore Area

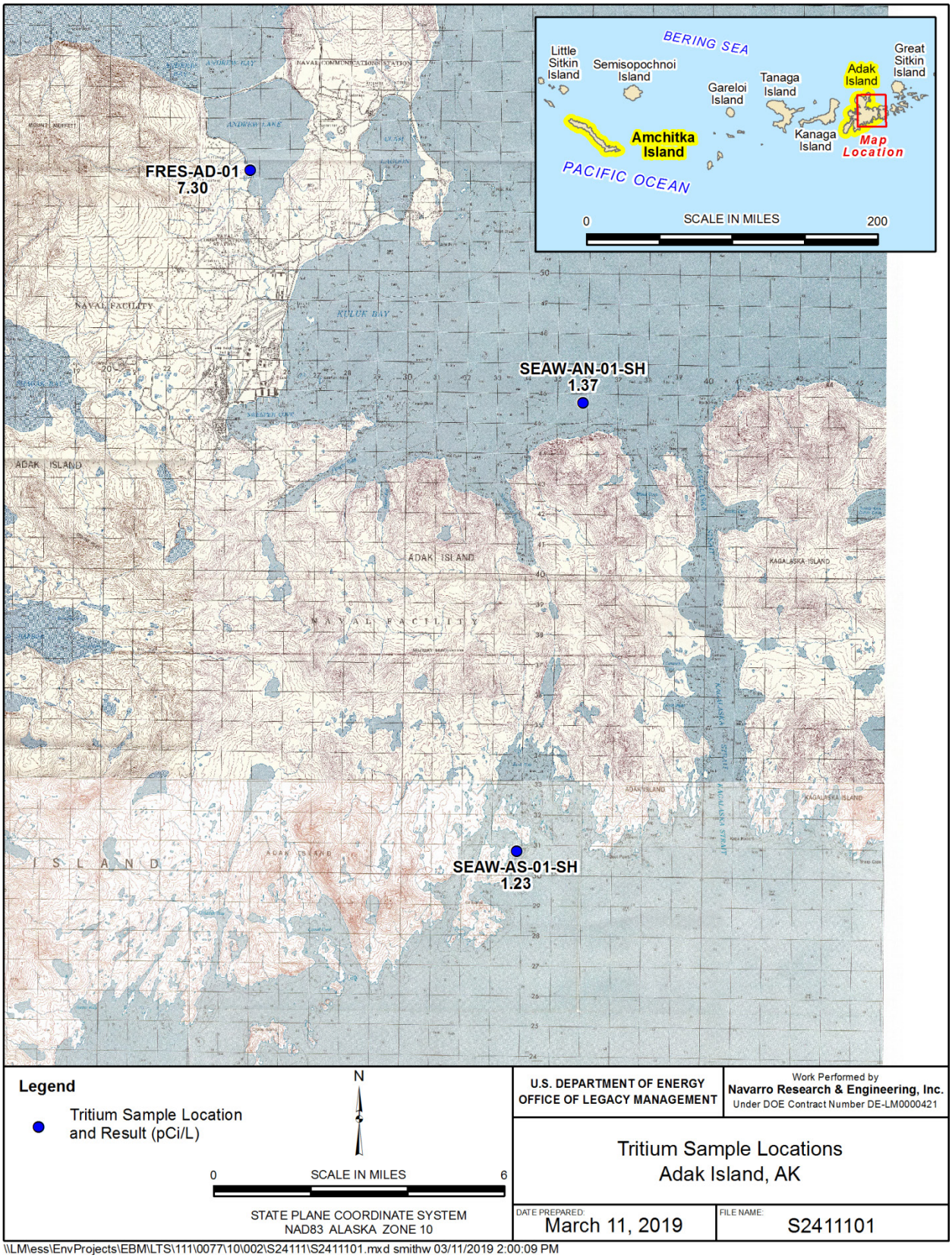


Figure 41. Seawater Sample Locations in the Adak Island Area

These locations are shown in Figure 42, a simplified schematic of historical seawater (tritium) sampling in the region around Amchitka. This figure includes locations sampled in 2007, ADEC's first major seawater effort (Dasher and Jewett 2007); 2011 locations, LM's first environmental sampling effort conducted after issuing the LTSP; and the locations sampled in 2016. The 2007 (ADEC) effort focused on the region off Cannikin; the 2011 effort was more spatially comprehensive (also focused along the Cannikin transect but with some coverage along Long Shot and Milrow transects), while the 2016 effort focused on a relatively smaller area off of Long Shot. Apparent differences in tritium concentrations over the years are discussed in the following section. Tritium results reported for the 2016 sampling effort are listed in Table 18.

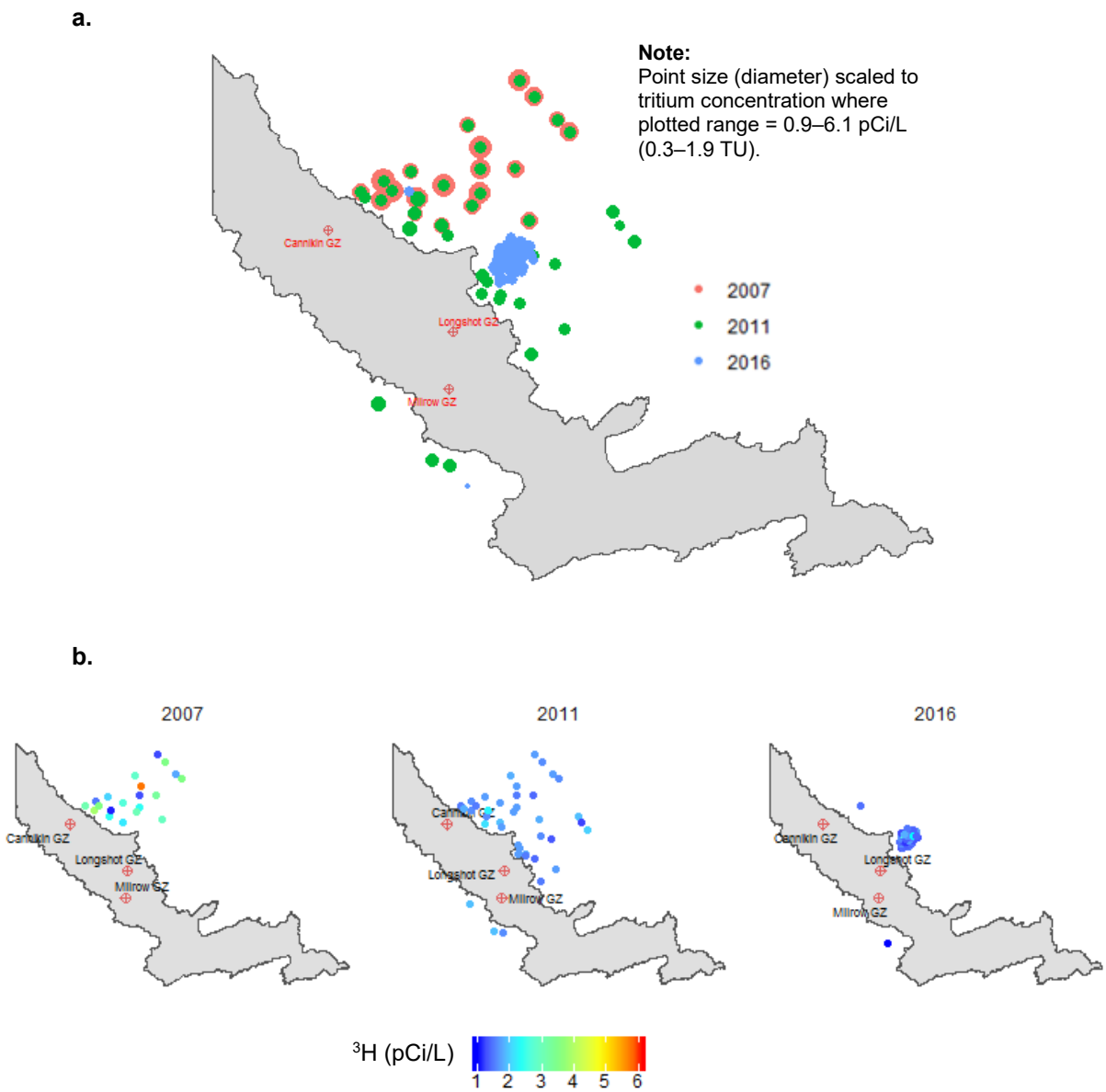


Figure 42. Tritium Seawater Sampling Locations: 2007, 2011, and 2016 Sampling Events

(a) Tritium sample locations for all three study periods. Tritium activity denoted by point size.
(b) Alternate view, separated by year. Tritium activity denoted by color scale.

Table 18. May 2016 Tritium Results, Seawater and Freshwater Samples

Sample ID[a]	Sample Date	Tritium Result[b]			CTD Cast[c] / Station No.	Latitude	Longitude	Depth (m)
		pCi/L	TU	Bq/L				
SEAW-LS-29-DE*	5/16/2016	1.24	0.385	0.046	29	51.455	179.205	29
SEAW-LS-35-DE*	5/16/2016	1.42	0.441	0.053	28	51.456	179.206	16
SEAW-LS-36-DE*[D]	5/16/2016	1.37	0.425	0.051	30, 31	51.457	179.208	18
SEAW-LS-38-DE	5/16/2016	1.45	0.450	0.054	22	51.457	179.213	25
SEAW-LS-43-DE[D]	5/16/2016	1.38	0.428	0.051	32, 33, 34	51.458	179.204	17
SEAW-LS-46-DE	5/16/2016	1.32	0.410	0.049	21	51.458	179.212	24
SEAW-LS-52-DE	5/16/2016	1.66	0.515	0.061	35	51.459	179.203	18
SEAW-LS-55-DE	5/16/2016	1.33	0.413	0.049	20	51.460	179.210	21
SEAW-LS-57-DE	5/17/2016	1.44	0.447	0.053	48	51.460	179.215	32
SEAW-LS-58-DE	5/16/2016	1.34	0.416	0.050	19	51.460	179.218	34
SEAW-LS-61-DE	5/16/2016	1.43	0.444	0.053	36	51.461	179.201	15
SEAW-LS-63-DE	5/16/2016	1.23	0.382	0.046	23	51.461	179.206	22
SEAW-LS-64-DE	5/16/2016	1.44	0.447	0.053	40	51.461	179.209	22
SEAW-LS-67-DE	5/16/2016	1.48	0.459	0.055	18	51.461	179.217	32
SEAW-LS-68-DE	5/16/2016	1.28	0.397	0.047	17	51.462	179.219	35
SEAW-LS-70-DE	5/16/2016	1.53	0.475	0.057	37	51.462	179.202	15
SEAW-LS-73-DE*	5/16/2016	1.12	0.348	0.041	24	51.461	179.209	24
SEAW-LS-74-DE	5/17/2016	1.70	0.528	0.063	47	51.462	179.213	25
SEAW-LS-79-DE	5/16/2016	1.61	0.500	0.060	38	51.463	179.203	18
SEAW-LS-80-DE[D]	5/16/2016	1.42	0.441	0.053	25, 26	51.465	179.207	21
SEAW-LS-81-DE	5/16/2016	1.33	0.413	0.049	39	51.463	179.208	25
SEAW-LS-84-DE	5/17/2016	1.51	0.469	0.056	45	51.464	179.216	34
SEAW-LS-87-DE	5/16/2016	1.28	0.397	0.047	16	51.465	179.223	46
SEAW-LS-89-DE	5/16/2016	2.54	0.788	0.094	27	51.466	179.205	22
SEAW-LS-91-DE	5/16/2016	1.58	0.490	0.058	14	51.465	179.210	25
SEAW-LS-94-DE*	5/16/2016	2.27	0.705	0.084	15	51.466	179.217	33
SEAW-LS-96-DE	5/17/2016	1.36	0.422	0.050	46	51.466	179.223	48
SEAW-LS-98-DE	5/16/2016	1.23	0.382	0.046	13	51.468	179.203	21
SEAW-LS-99-DE	5/16/2016	1.8	0.559	0.067	12	51.466	179.206	21
SEAW-LS-102-DE	5/17/2016	1.42	0.441	0.053	43	51.466	179.214	35
SEAW-LS-109-DE[D]	5/16/2016	1.23	0.382	0.046	10, 11	51.468	179.210	25
SEAW-LS-110-DE	5/16/2016	1.28	0.397	0.047	9	51.470	179.211	30
SEAW-LS-112-DE	5/15/2016	1.26	0.391	0.047	8	51.468	179.217	39
SEAW-LS-113-DE	5/17/2016	1.33	0.413	0.049	44	51.468	179.220	49
SEAW-LS-115-DE	5/17/2016	1.47	0.456	0.054	41	51.469	179.208	27
SEAW-LS-116-DE	5/15/2016	1.64	0.509	0.061	7	51.468	179.210	25
SEAW-LS-120-DE*	5/15/2016	1.64	0.509	0.061	6	51.469	179.221	47
SEAW-LS-123-DE	5/15/2016	1.47	0.456	0.054	5	51.470	179.215	25
SEAW-LS-124-DE	5/17/2016	1.36	0.422	0.050	42	51.471	179.217	38
SEAW-LS-125-DE	5/15/2016	1.47	0.456	0.054	4	51.472	179.210	25
SEAW-CN-01-SH*	5/15/2016	1.44	0.447	0.053		51.486	179.149	
SEAW-ML-01-SH*	5/14/2016	0.99	0.307	0.037		51.381	179.195	
SEAW-AN-01-SH*	5/20/2016	1.37	0.425	0.051		51.862	−176.482	
SEAW-AS-01-SH*	5/19/2016	1.23	0.382	0.046		51.728	−176.512	
FRES-AI-01*	5/18/2016	6.38	1.980	0.236		51.473	179.114	
FRES-AD-01*	5/21/2016	7.3	2.266	0.270		51.930	−176.643	

Notes:

[a] In addition to tritium, all samples listed were analyzed for ^{134}Cs and ^{137}Cs (results summarized in Figure 20).
*denotes that sample also analyzed for ^{129}I; D denotes that field duplicate sample was collected.

[b] Tritium reported in pCi/L (main reporting unit); tritium units (TU) (where 1 TU = 3.222 pCi/L); and Bq/L.

[c] Corresponding CTD cast numbers are provided to facilitate comparison with UAF field measurements.
Salinity and temperature in all seawater samples were uniform (i.e., with little variation): 33 practical salinity units and 5° C.

6.1.1 2016 Tritium Sampling Results and Discussion

As shown in Table 18, tritium concentrations measured in seawater samples collected in 2016 are fairly uniform, generally ranging from about 1–1.5 pCi/L, well below the 5.4 pCi/L trigger established by AWG. Tritium levels in the two freshwater samples were higher, 6.4 pCi/L and 7.3 pCi/L from Amchitka and Adak, respectively. These results likely reflect lower salinities and are not comparable to global fallout levels derived for the North Pacific. To facilitate review, Table 18 also includes conversions to tritium units (TU) and Bq/L and, for seawater samples, sample location and depth information. Appendix E includes the raw data report provided by the University of Miami.

To provide a context for evaluating the 2016 results, Table 19 compares the tritium concentrations measured in seawater in 2016 with corresponding sample results from 2011. Pre- and post-Fukushima background tritium concentrations reported in the literature for the North Pacific are also provided. Tritium levels measured in Amchitka seawater samples in 2016 (global mean of 1.5 pCi/L across all transects) were comparable to and slightly lower than those measured in 2011 (mean of 1.7 pCi/L). These levels are also comparable to tritium concentrations measured in seawater samples collected near Adak Island, the reference site (means were 1.8 and 1.3 pCi/L in 2011 and 2016, respectively). Measured tritium levels are also well within reported ranges of both pre-Fukushima (1.3–1.9 pCi/L) and post-Fukushima (1.4–5.4 pCi/L) background levels. These results are summarized visually in Figure 43, which plots the distributions of tritium in seawater for 2007 (ADEC sampling results), 2011, and 2016. The matrix of histograms in Figure 44 provides an alternate view of the 2011 and 2016 results.

Table 19. Tritium in Seawater Samples at Amchitka, Adak, and the North Pacific Ocean

	2011 Sampling Results[a]				2016 Sampling Results[a]				Pre-Fukushima[b]	2014–2015[b]
	Milrow	Cannikin[c]	Long Shot[c]	Adak	Milrow	Cannikin	Long Shot	Adak	North Pacific[d,e]	
No. of samples	9	69	9	18	1	1	40	2		
min.	1.6	1.2	1.5	1.4			1.12	1.23		
max.	2.2	2.2	2.0	2.8			2.54	1.37		
mean	1.89	1.64	1.73	1.84	0.99	1.44	1.47	1.3	1.29–1.93	1.35–5.4
SD	0.17	0.21	0.18	0.37			0.26	0.1		

All units in pCi/L.

Notes:

[a] Duplicate results excluded from summaries, as were results of the limited freshwater sampling conducted in 2011 and 2016. In comparison to the seawater sampling results above, tritium concentrations in freshwater (lake) samples were higher:

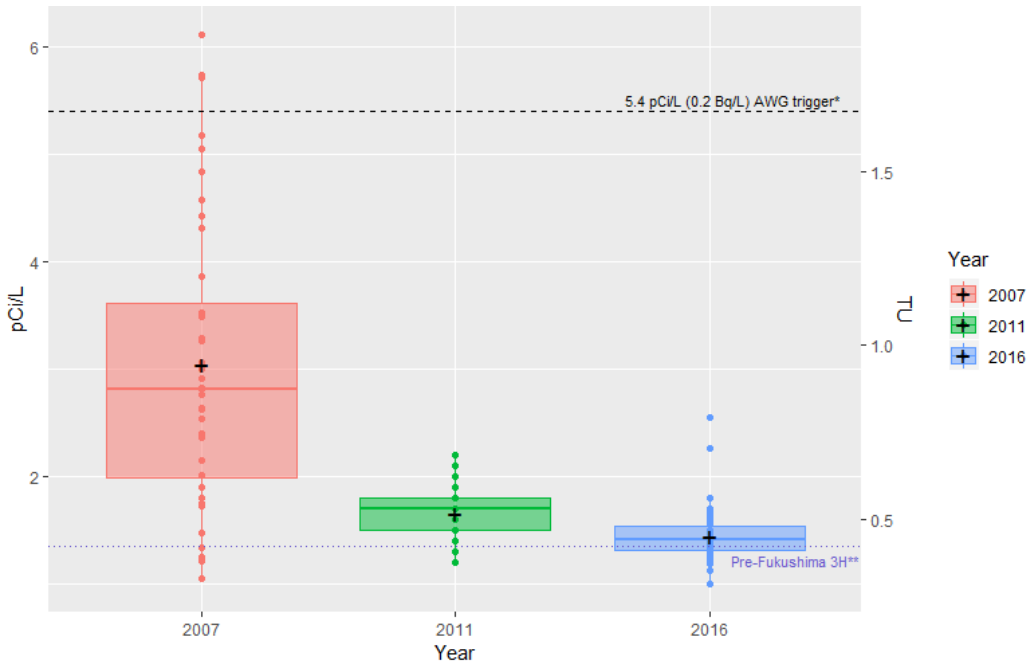
8.8–10 pCi/L from lake on Long Shot 2011
7.6–7.9 pCi/L from Cannikin Lake 2011
6.38 and 7.3 pCi/L from lakes on Amchitka and Adak, respectively, in 2016

[b] Tritium concentrations for the North Pacific Ocean reported in the literature vary, depending on the sampling locations and sampling date. The concentration listed in Table 19 shows the range summarized from different sources for 2010 and for 2014–2015.

[c] In 2011, many of the samples associated with the Cannikin transect (with "CN" sample IDs) overlapped with the Long Shot transect area (e.g., Square Bay), so the spatial distinctions may not be valid. Corresponding summary statistics were similar, however, as reflected above.

[d] Dasher 2017.

[e] Povinec et al. 2013.



+ denotes average by year, pCi/L on left y-axis; TU scaling on right *y*-axis.
Pre- and post-Fukushima levels from Dasher (2017); these differ slightly from Povinec et al. (2013).

Figure 43. Box Plot of Tritium in Seawater Relative to Pre- and Post-Fukushima Ranges 2007 (ADEC) vs. 2011 vs. 2016

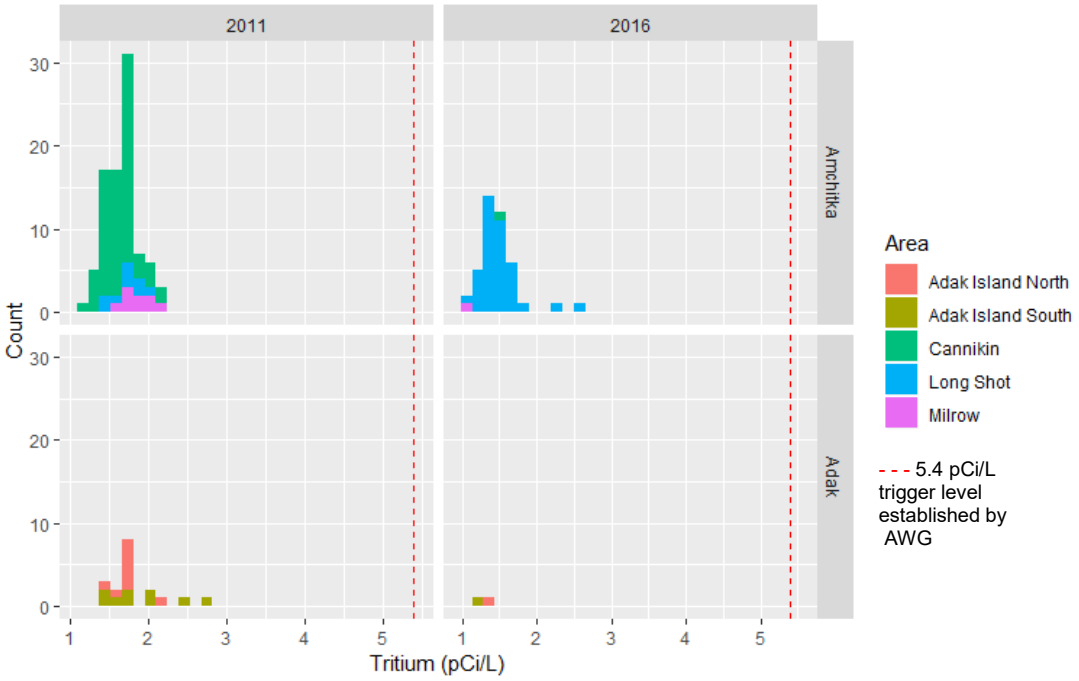


Figure 44. Histogram of Tritium in Seawater Samples, 2011 vs. 2016 Sampling

As shown in Figure 42 and Figure 43, tritium levels reported by ADEC for 2007 are notably higher (mean of 3.1 pCi/L) than 2011 and 2016 results (means of 1.7 and 1.5 pCi/L, respectively). It is not known what this difference is attributable to, but it could reflect the higher detection limits at that time (Dasher 2019). Detection limits in 2007 ranged from 2–5.3 pCi/L; data were not flagged as nondetects in the data provided to LM (i.e., all results were reported as above the MDA). In contrast, tritium detection levels for analyses in 2011 and 2016 were consistent at 0.3 pCi/L, about one order of magnitude lower than those reported in 2007.

Some discussion about the bases for pre- and post-Fukushima tritium levels listed in Table 19 is warranted. After the Fukushima nuclear accident, numerous investigators focused on studying the impact of the accident and radionuclides related to the accident in the North Pacific Ocean (Povinec et al. 2013; 2017). For these studies, pre-Fukushima radionuclide concentrations in seawater were estimated for comparison with the concentrations measured after Fukushima. The estimated pre-Fukushima concentrations were based on measurement data stored in the GLOMARD/MARIS database, which correspond to the 1997 sampling expedition of the International Atomic Energy Agency (IAEA) for the Worldwide Marine Radioactivity Studies project, and accounted for the effective decay from 1997 to 2010 or 2011 prior to Fukushima. The reported pre-Fukushima concentrations were in the range of 1.29–1.93 pCi/L (0.04–0.06 TU) for tritium, as cited in Table 19.

Various seawater sampling activities were conducted shortly and within 1–2 years after Fukushima in the North Pacific Ocean (Povinec et al. 2013 and 2017; Wu et al. 2015). However, reporting of radioactivity in the seawater after 2012 focused primarily on ^{137}Cs (Buesseler et al. 2017). Therefore, post-Fukushima tritium levels listed in Table 19 were based on reviews of the literature conducted by Dasher (2017). A range of 1.35–5.4 pCi/L (0.05–0.2 Bq/L), which is 1 to 4 times the pre-Fukushima level, was chosen to represent the post Fukushima (2014–2015) timeframe. This range is considered reasonable based on the reported concentrations of tritium in June 2011 (Povinec et al. 2013; 2017) and the effective decay of radioactivity to 2014–2015.

6.1.2 Summary

Tritium levels measured in Amchitka seawater samples in 2016 ranged from 1.1–2.5 pCi/L; the mean concentration was 1.5 pCi/L. These levels are comparable to but slightly lower than those measured in 2011 (1.1–2.2 pCi/L; mean of 1.7 pCi/L), as well as measurements from Adak, which ranged from 1.2–2.8 pCi/L. Measured tritium levels are also well within reported ranges of both pre-Fukushima (1.3-1.9 pCi/L) and post-Fukushima (1.4–5.4 pCi/L) background levels. Given low levels relative to global fallout, and similar measures at Adak and Amchitka, there is no evidence of test-related contaminant migration based on the 2016 sampling results. Rather, the activity of tritium in the marine environment surrounding both Amchitka and Adak is similar to that resulting from global fallout from nuclear testing and natural tritium levels in the northern hemisphere. All 2016 measurements were well below 5.4 pCi/L, the level agreed to by stakeholders and outlined in the sampling plan as a level above which further investigation might be warranted.

6.2 Cesium and Iodine-129 Results

As discussed in the outline of study DQOs provided in Section 1.1.2, the following decision rule was established for evaluating ^{134}Cs and ^{137}Cs seawater sampling results. If ^{134}Cs and ^{137}Cs concentrations in seawater from Long Shot are similar to North Pacific regional data, no further action would be warranted. AWG established a trigger level for ^{137}Cs of 0.216 pCi/L (0.008 Bq/L) based on the North Pacific background range reported in combined oceanographic studies cited by Dasher (2017). Because tritium is the better indicator of potential test-related contaminant migration and interpretation of cesium results (especially ^{134}Cs) complicated by post-Fukushima signatures, this section is brief, focusing only on the major findings.

Table 20 summarizes the results of sea and freshwater sampling for ^{134}Cs, ^{137}Cs, and ^{129}I and compares those results to corresponding pre- and post-Fukushima North Pacific background ranges. Analysis for ^{129}I was not scoped in the 2016 sampling plan (DOE 2016a). However, it was analyzed in a small subset of samples to provide information on the potential impacts of other source-terms on marine radioactivity (versus test-related impacts).

Table 20. 2016 Seawater and Freshwater Sample Results for ^{137}Cs, ^{134}Cs, and ^{129}I

Isotope	Mean ± SD (pCi/L)[a]	Range (pCi/L)[a]	Pre-Fukushima Range	Post-Fukushima Range	Comment
^{137}Cs	Amchitka (n=42): 0.045±0.005	Amchitka: 0.033–0.068 Adak (n=2): 0.048–0.05	0.027–0.054 pCi/L (1–2 Bq/m^3)[b]	0.027–0.27 pCi/L (1–10 Bq/m^3)[b]	Pre- and post-Fukushima ranges from Dasher (2017), reflecting a summary of numerous oceanographic studies from the North Pacific AWG trigger = 0.216 pCi/L
^{134}Cs	ND (< 0.042)	ND	ND (0)	0.027–0.054 pCi/L (1–2 Bq/m^3)[b]	
^{129}I	Amchitka (n=10): 4.5 ± 1.9 ×10^{-7}	Amchitka: 4.2–4.9 ×10^{-7} Adak (n=2): 4.7–5.0 ×10^{-7}	3.8–7.6 × 10^{-7} (1–2×10^7 atoms/L = 14–28 nBq/L)	4.4–7.1×10^{-7} pCi/L (1.2–1.9×10^7 atoms/L = 16–26 nBq/L)	Pre- and post-Fukushima ranges from Nagai et al. (2015)[c]

Notes:

[a] Duplicate seawater results excluded from summaries. Due to small numbers of freshwater samples (one each from Amchitka and Adak islands) and lack of comparability with literature values for seawater, these results are not shown. For reference, results were as follows:

^{137}Cs: <0.007 pCi/L (Amchitka) and 0.069 pCi/L (Adak)

^{129}I: 1.1 × 10^{-6} pCi/L (Amchitka) and 9.6 × 10^{-7} pCi/L (Adak)

[b] Dasher (2017). Units in pCi/L except where noted. For cesium isotopes, pre-Fukushima and post-Fukushima ranges are also listed in units of becquerels per cubic meter, consistent with the original citation.

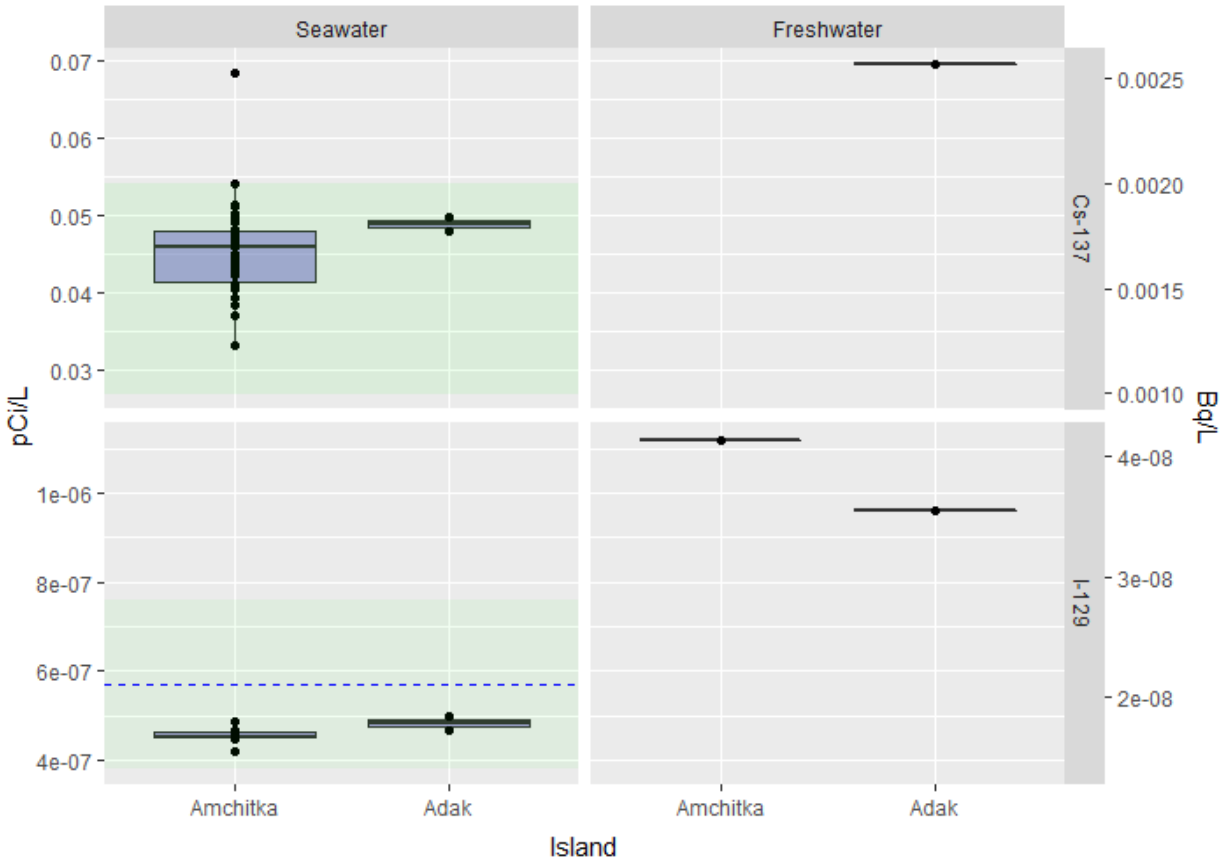
[c] Suzuki et al. (2013) reported post-Fukushima levels about an order of magnitude higher (mean of 3.6 × 10^{-6} pCi/L or 9.5 × 10^{-7} atoms/liter), but those measurements were closer to Fukushima.

Abbreviations:

Bq/m^3 = becquerels per cubic meter
nBq/L = nanobecquerels per liter
ND = Not Detected

No reportable levels of ^{134}Cs were measured in 2016 water samples (Hamilton et al. 2018b; Table 20). Cesium-137 was detected in all seawater and freshwater samples but at low levels: 0.033–0.068 pCi/L in samples from Amchitka and, tightly bracketed, 0.048–0.050 pCi/L in samples from Adak. All results are well below 0.216 pCi/L, established by AWG as a trigger level for further action (DOE 2016a). Dasher (2017) cites a slightly higher post-Fukushima background value of 0.27 pCi/L (10 becquerels per cubic meter).

Iodine-129 was detected in all seawater samples at very low levels, about 4–5 × 10^{-7} pCi/L, within established ranges of both pre- and post-Fukushima fallout. Iodine-129 measurements in freshwater samples were slightly higher, but this could be a function of differing salinity, as observed historically for tritium. Distributions of ^{137}Cs and of ^{129}I based on 2016 sampling results are plotted in Figure 45 along with corresponding background ranges.



Green shading denotes pre-Fukushima range for ^{137}Cs and ^{129}I from Table 20: 0.027–0.054 pCi/L and 4.4–7.1×10^{-7} pCi/L, respectively.

---- Pre- and post-Fukushima mean ^{129}I in the North Pacific, 5.7×10^{-7} pCi/L, midpoint of 1–2 ×10^{7} atoms/L range cited by Nagai et al. (2015).

Notes:

Based on measurements in 2012–2013, Nagai et al. (2015) found no apparent increase in ^{129}I concentrations in the North Pacific Ocean following the Fukushima accident.

For ^{137}Cs, the AWG trigger level (0.216 pCi/L) and the upper bound of the post-Fukushima range (0.27 pCi/L) from Table 20 are not shown because these levels far exceed the scale of the plot.

Figure 45. Box Plots of ^{137}Cs and ^{129}I in Seawater and Freshwater Samples

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7.0 Summary and Conclusions

The environmental monitoring conducted in 2016 had two primary objectives. The first was to provide information regarding the potential for negative health impacts associated with subsistence food consumption by sampling key indicator resident marine species (rockweed, greenling, Irish lord, rockfish, and Dolly Varden) for key anthropogenic radionuclides (cesium and plutonium isotopes). As a detailed risk assessment and concomitant food safety survey and analysis was developed for the 2011 report (DOE 2013), this objective was achieved by comparing radionuclide levels measured in 2016 with those measured in 2011 for each species. A second objective was to expand upon previous seawater sampling, this time focusing on an area off the coastline of Long Shot. Another objective was to achieve greater laboratory sensitivity (i.e., lower detection limits). As discussed below, this goal was achieved, but it also complicated analysis of between-year trends for some radionuclides, in particular ^{239}Pu.

Biota Sampling Results

- For all species, the mean ^{137}Cs content measured in biota samples from Amchitka in 2016 (0.6 pCi/kg in rockweed and 1.8–2.8 pCi/kg in marine fish) was lower than corresponding 2011 results. A possible explanation for these findings is the difference in analytical methods—beta spectrometry in 2011 and higher-resolution gamma spectrometry in 2016. Another possible explanation is the more prominent Fukushima signature in 2011, evidenced by ^{134}Cs beta interferences identified in the 2011 biota samples. For these reasons, between-year statistical comparisons were not determined. Mean ^{137}Cs levels measured in biota samples from Amchitka in 2016 were also lower than those measured in samples collected from Adak, which served as the background location. For samples collected in 2016, interisland comparisons of both detection frequencies and ^{137}Cs magnitude were insignificant except for rockweed, with higher ^{137}Cs levels in samples from Adak (p=0.007).
- Given the greater laboratory sensitivity achieved in 2016, ^{239}Pu was measured in the majority of fish and algal samples from Amchitka in 2016 and overall about half of those from Adak, albeit mostly at or near the detection limits of the instrument. This was not the case in 2011, when ^{239}Pu was measured in only a small subset of biota samples. For both islands (Amchitka and Adak) and all species, mean ^{239}Pu levels were lower in 2016 than in 2011. The between-year differences likely are an artifact of the change in measurement sensitivity between the two years rather than a true decrease in concentration.
- Based on 2016 results, significant interisland differences in detection frequency or ^{239}Pu activity concentrations were found for all resident marine fish species. For both endpoints, measures were higher in samples from Amchitka relative to Adak. However, these differences are not considered biologically significant because measured Pu levels were far below established food safety guidelines and corresponding risks below 1×10^{-8}.
- Of the 168 biota samples collected in 2016, ^{240}Pu was detected in only four fish samples from Amchitka. The levels were very low (≤ 0.1 pCi/kg) and, although passing quality assurance requirements, were later determined by LLNL to be anomalous because they were very close to the corresponding MDAs.
- Of the 167 biota samples collected in 2016, no reportable ^{134}Cs was detected in fish or algae samples except for 3 Dolly Varden (3.4–4.5 pCi/kg; two samples were from Adak) and a single rockfish sample (17 pCi/kg), also collected from Adak. As ^{134}Cs has a half-life of only 2 years, these results likely indicate a Fukushima-derived contaminant signature.

In summary, the 2016 biota sampling results continue to demonstrate that seafood harvested at Amchitka and Adak Islands is safe for consumption. Additionally, there is no indication of migration of test-related radionuclides based on the criteria defined in the sampling plan. LM's primary focus is on ensuring food safety given the significant uncertainties associated with detecting and attributing migration of radionuclides to the underground nuclear tests.

Food Safety

An overarching goal of LM's environmental sampling program at the site is to evaluate and ensure food safety (DOE 2013; 2016a). To do so, LM undertook a conservative evaluation of risks in the 2011 report (DOE 2013). For most diet scenarios, risk estimates were below 1×10^{-5}, the level used by the State of Alaska (ADEC) as the benchmark for acceptable risk. Therefore, the 2011 report concluded that seafood harvested from the Amchitka region is safe to eat (DOE 2013), confirming previous conclusions drawn by CRESP (2005). This report demonstrated that, except for some fish samples from Adak, radionuclide levels measured in 2016 biota samples were lower than those measured in 2011. As such, because 2011 levels were considered safe for seafood consumption, radionuclide levels measured in 2016 biota samples are considered as equally safe or safer. Risk estimates calculated assuming life-long consumption of subsistence seafood, and maximum concentrations measured in 2016 biota samples, were 1×10^{-6} and 3×10^{-6} for Amchitka and Adak, respectively. These levels are consistent with those derived based on 2011 results and are lower than the 1×10^{-5} risk level used by the State of Alaska as a benchmark for acceptable risk. Cesium-137 was the primary contributor to the total risk, a portion of which likely reflects a Fukushima signature.

Seawater Sampling Results

Tritium levels measured in Amchitka seawater samples in 2016 ranged from 1.1–2.5 pCi/L; the mean concentration was 1.5 pCi/L. These levels are comparable to but slightly lower than those measured in 2011, as well as measurements from Adak. Measured tritium levels are also within reported ranges of both pre- (1.3–1.9 pCi/L) and post-Fukushima (1.4–5.4 pCi/L) background levels. All results were well below the 5.4 pCi/L established by AWG. Given the low tritium levels relative to global fallout, and similar activity concentrations at Adak and Amchitka, there is no evidence of test-related radionuclide migration based on the 2016 sampling results. Cesium-137 was detected in all seawater and freshwater samples but at low levels: 0.033–0.068 pCi/L in samples from Amchitka and 0.048–0.050 pCi/L in those from Adak. All results are well below the 0.216 pCi/L criterion established in the sampling plan as a trigger level for further action. No reportable levels of ^{134}Cs were measured in 2016 water samples.

Summary

In summary, previous conclusions regarding food safety are maintained given that 2016 results are less than 2011 results. Corresponding risk estimates, calculated assuming life-long consumption of subsistence seafood and maximum concentrations measured in biota, were below 1×10^{-5}, the level considered safe by ADEC. Tritium concentrations measured in seawater samples are well within both pre- and post-Fukushima background ranges; most results were well below the 5.4 pCi/L trigger established by the working group. Future discussion should focus on how biota and seawater should be monitored over time to best meet long-term study objectives, in particular the continued evaluation of food safety.

8.0 References

ADEC (Alaska Department of Environmental Conservation), 2012. Personal communication with Terri Lomax, Alaska Monitoring & Assessment Program, Re: tritium data collected in the eastern Aleutian Islands in 2006 and in the western Aleutian Islands in 2007 with additional tritium data collected off the coast of the Cannikin site, October 22.

Buesseler, K., et al., 2017. "Fukushima Daiichi-Derived Radionuclides in the Ocean: Transport, Fate, and Impacts," *Annual Review of Marine Science* 9:173–203.

Burger, J., M. Gochfeld, D.S. Kosson, C.W. Powers, S. Jewett, B. Friedlander, H. Chenelot, C.D. Volz, and C. Jeitner, 2006. "Radionuclides in Marine Macroalgae from Amchitka and Kiska Islands in the Aleutians: Establishing a Baseline for Future Biomonitoring," *Journal of Environmental Radiochemistry* 91:27–40.

Burger, J., M. Gochfeld, and S.C. Jewett, 2007a. "Radionuclide Concentrations in Benthic Invertebrates from Amchitka and Kiska Islands in the Aleutian Chain, Alaska," *Environmental Monitoring Assessment* 128 (2007):329–341.

Burger, J., M. Gochfeld, D.S. Kosson, C.W. Powers, B. Friedlander, M. Stabin, D. Favret, S. Jewett, D. Snigaroff, T. Stamm, J. Weston, C. Jeitner, and C.D. Volz, 2007b. "Radionuclides in Marine Fishes and Birds from Amchitka and Kiska Islands in the Aleutians: Establishing a Baseline," *Health Physics* 92 (2007):265–278.

CRESP (Consortium for Risk Evaluation with Stakeholder Participation II), 2005. *Amchitka Independent Science Assessment: Biological and Geophysical Aspects of Potential Radionuclide Exposure in the Amchitka Marine Environment*, C.W. Powers, J. Burger, D.S. Kosson, M. Gochfeld, and D. Barnes, eds., Piscataway, New Jersey, August. http://www.cresp.org/projects/amchitka/amchitka-final-report/

CRESP (Consortium for Risk Evaluation with Stakeholder Participation II), 2006a. Addendum to *Amchitka Independent Science Assessment: Biological and Geophysical Aspects of Potential Radionuclide Exposure in the Amchitka Marine Environment: Selecting Radiological Data for Bioindicator Selection*, C.W. Powers, J. Burger, D.S. Kosson, and M. Gochfeld, January. http://www.cresp.org/Amchitka/FINAL_AmchitkaAddendum_1_24_06.pdf

CRESP (Consortium for Risk Evaluation with Stakeholder Participation II), 2006b. *Biomonitoring for Ecosystem and Human Health Protection at Amchitka Island*, J. Burger, M. Gochfeld, D.S. Kosson, and C.W. Powers, January. http://www.cresp.org/Amchitka/Final_BiomonitoringPlanPR_1_24_06.pdf

Dasher, D., W. Hanson, S. Read, S. Faller, D. Farmer, W. Efurd, J. Kelley, and R. Patrick, 2002. "An Assessment of the Reported Leakage of Anthropogenic Radionuclides from the Underground Nuclear Tests at Amchitka Island, Alaska, USA, to the Surface Environment," *Journal of Environmental Radioactivity* 60(2002):165–187.

Dasher, D. and S. Jewett, 2007. *Amchitka Island, Alaska Former Underground Nuclear Test Area Near-Shore Marine Water Tritium Assessment Plan For Regions Adjacent Cannikin and/or Long Shot Test Sites Summer 2007*, June.

Dasher, D., 2017, "Background Radioactivity in the North Pacific Ocean," Alaska Forum on the Environment 2017.

Dasher, D., 2019. Amchitka Working Group (AWG), personal communication during AWG meeting held February 12 in Anchorage, Alaska.

DOE (U.S. Department of Energy), 1982. *Amchitka Radiobiological Program Final Report July 1970 to December 1979,* DOE/DP00269-39, November.

DOE (U.S. Department of Energy), 2000. *Amchitka Island, Alaska, Special Sampling Project 1997*, DOE/NV-624, Rev. 1, Las Vegas, Nevada, June.

DOE (U.S. Department of Energy), 2002. *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota*. Technical Standard DOE-STD-1153-2002. Module 1-3, Washington, D.C.

DOE (U.S. Department of Energy), 2008. *Long-Term Surveillance and Maintenance Plan for the U.S. Department of Energy Amchitka, Alaska, Site*, LMS/AMC/S01980, Office of Legacy Management, Grand Junction, Colorado, September.

DOE (U.S. Department of Energy), 2013. *Amchitka Island, Alaska, Biological Monitoring Report, 2011 Sampling Results*, LMS/AMC/S08833, Office of Legacy Management, September. https://www.osti.gov/biblio/1110198-amchitka-island-alaska-biological-monitoring-report-sampling-results

DOE (U.S. Department of Energy), 2014a. *Long-Term Surveillance Plan for the Amchitka, Alaska, Site*, LMS/AMC/S01980-1.0, Office of Legacy Management, July.

DOE (U.S. Department of Energy), 2014b. *Options Analysis for Repair, Mud Pit Cap Damage, Amchitka Island, Alaska*, LMS/AMC/S12293, Office of Legacy Management, July.

DOE (U.S. Department of Energy), 2016a. *Environmental Sampling Plan for the Amchitka, Alaska, Site and Adak Island, 2016 Sampling Event*, LMS/AMC/S12630, Office of Legacy Management, April. https://www.lm.doe.gov/Amchitka/S12630_SAP.pdf

DOE (U.S. Department of Energy), 2016b. *Post-Closure Monitoring and Inspection Plan for Amchitka Island Mud Pit Release Sites, Amchitka, Alaska*, LMS/AMC/S13961, Office of Legacy Management, May.

FAO/WHO (Food and Agriculture Organization of the United Nations and the World Health Organization), 2004. Joint FAO/WHO Food Standards Programme.

FDA (U.S. Food and Drug Administration), 2009. *Compliance Policy Guide, 560.750 Radionuclides in Imported Foods—Level of Concern*, December 9.

Greenpeace, 1996. *Nuclear Flashback: The Return to Amchitka*, Washington, D.C.

Hamilton, T.F., S.K.G. Peters, R.E. Martinelli, S.R. Kehl, and M.W. Tamblin, 2012. *Analysis of ^{137}Cs, Uranium and Plutonium Isotopes, and ^{241}Am in Vegetation, Fauna, Marine Sediment, and Soil Collected During the Amchitka 2011 Sampling Event,* Final Report, Lawrence Livermore National Laboratory, LLNL-SR-585214.

Hamilton, T.F., S.R. Kehl, and R.M. Berry, 2018a. *Amchitka Project Data Report, Part I, Processing of Biological Samples (Wet, Dry and Ash Weights),* Lawrence Livermore National Laboratory, LLNL-SR-751699, March. Submitted to LM electronically on June 14, 2018.

Hamilton, T.F., S.R. Kehl, and R.M. Berry, 2018b. *Amchitka Project Data Report, Part II, Measurement of Cs Isotopes (^{134}Cs, ^{137}Cs) in Seawater and Freshwater Samples,* Lawrence Livermore National Laboratory, LLNL-SR-751691, March.

Hamilton, T.F., S.R. Kehl, and R.M. Berry, 2018c. *Amchitka Project Data Report, Part III. Measurement of Cs Isotopes (^{134}C, ^{137}Cs) in Biological Samples,* Lawrence Livermore National Laboratory, LLNL-SR-752303, May. Submitted to LM electronically on August 5, 2018.

Hamilton, T.F., S.R. Kehl, and R.M. Berry, 2018d. *Amchitka Project Data Report, Part IV. Measurement of Pu Isotopes (^{239}Pu, ^{240}Pu) in Biological Samples,* Lawrence Livermore National Laboratory, LLNL-SR-942027, June. Submitted to LM electronically on August 23, 2018.

Hamilton, T.F., 2019. Email communication from Terry Hamilton, Lawrence Livermore National Laboratory (regarding 2016 ^{240}Pu results) to J. Nguyen, U.S. Department of Energy, October 10.

Hassan, A., K. Pohlmann, and J. Chapman, 2002. *Modeling Groundwater Flow and Transport of Radionuclides at Amchitka Island's Underground Nuclear Tests: Milrow, Long Shot, and Cannikin*, DOE/NV/11 508-51, Publication No. 45172, Desert Research Institute, Las Vegas, Nevada, October.

Hassan, A., and J. Chapman, 2006. *Verification and Uncertainty Reduction of Amchitka Underground Nuclear Testing Models*, DOE/NV/13609-46, Publication No. 451216, Desert Research Institute, Las Vegas, Nevada, February.

Helsel, D.R., 2012. *Statistics for Censored Environmental Data Using Minitab® and R,* second edition, John Wiley & Sons, Inc., Hoboken, New Jersey.

Hori, M., T. Saito, and K. Shozugawa, 2018. "Source Evaluation of ^{137}Cs Foodstuffs Based on Trace ^{134}Cs Radioactivity Measurements Following the Fukushima Nuclear Accident," *Scientific Reports* 8:16806. https://www.nature.com/articles/s41598-018-35183-z.pdf

Layton, D., R. Edson, M. Varela, and B. Napier, 1997. *Radionuclides in the Arctic Seas from the Former Soviet Union: Potential Health and Ecological Risks*, Office of Naval Research, Arctic Nuclear Waste Assessment Program, November.

Merritt, M.L., and R.G. Fuller (eds), 1977. *The Environment of Amchitka Island, Alaska*, TID-26712, Technical Information Center, Energy Research and Development Administration, Washington, D.C.

Nagai, H., A. Hasegawa, T. Yamagata, Y. Kumamoto, S. Nishino, and H. Matsuzaki, 2015. "Anthropogenic ^{129}I in the North Pacific, Bering and Chukchi Seas, and Arctic Ocean in 2012-2013," *Nuclear Instruments and Methods in Physics Research B*, 361:680–684, August.

Navarro (Navarro Research and Engineering, Inc.), 2016. *Summary Report on 2016 Biological Sampling at Amchitka Island, Alaska,* LMS/S14643, August.

Povinec, P.P., et al., 2013. "Cesium, Iodine and Tritium in NW Pacific Waters – A Comparison of the Fukushima Impact with Global Fallout," *Biogeosciences* 10:5481–5496.

Povinec, P.P., et al., 2017. "Impact of the Fukushima Accident on Tritium, Radiocarbon and Radiocesium Levels in Seawater of the Western North Pacific Ocean with Pre-Fukushima Situation," *Journal of Environmental Radioactivity* 166:56–66.

R Core Team (2019). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

Rouhani, S. and A. van Geel, 2017. *Treatment of Non-Detects in the Los Alamos National Laboratory Natural Resource Damage Assessment*, Final Report, prepared for the Los Alamos National Laboratory Natural Resource Damage Assessment Trustee Council, June.

Suzuki, T., S. Otosaka, J. Juwabara, H. Kawamura, and T. Kobayashi, 2013. "Iodine-129 Concentration in Seawater Near Fukushima Before and After the Accident at the Fukushima Daiichi Nuclear Power Plant," *Biogeosciences* 10:3839–3847, June.

Thakur, P., H. Khaing, and Salminen-Paatero, 2017. "Plutonium in the Atmosphere: A Global Perspective," *Journal of Environmental Radioactivity*,175–176, 39–51.

Wickham, H., 2009. *ggplot2: Elegant Graphics for Data Analysis*, Springer-Verlag, New York.

Wickham, H., 2017. *tidyverse: Easily Install and Load the "Tidyverse"*. R package version 1.2.1. https://CRAN.R-project.org/package=tidyverse

Wu, M., et al., 2015. "Radioactive Status of Seawater in the Northwest Pacific More Than One Year after the Fukushima Nuclear Accident," *Scientific Reports* 5, article number: 7757.

Appendix A

Summary Report on 2016 Biological Sampling at Amchitka Island, Alaska

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LMS/S14643

Summary Report on 2016 Biological Sampling at Amchitka Island, Alaska

Work performed under DOE contract number DE-LM0000421
for the U.S. Department of Energy Office of Legacy Management.

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Appendix

Appendix A Daily Log of the Environmental Sampling Project on Amchitka and Adak Islands, May 10–23, 2016

Abbreviations

AWG	Amchitka Working Group
CTD	conductivity, temperature, and depth
ft	feet
LLNL	Lawrence Livermore National Laboratory
LM	Office of Legacy Management
LMS	Legacy Management Support
Navarro	Navarro Research and Engineering, Inc.
NEPA	National Environmental Policy Act
USFWS	U.S. Fish and Wildlife Service

1.0 Introduction

In the 1960s and early 1970s, the U.S. Department of Defense conducted three underground nuclear tests in conjunction with the U.S. Atomic Energy Commission on Amchitka Island, Alaska. The *Long-Term Surveillance Plan for the Amchitka, Alaska, Site*, dated July 2014, details how the U.S. Department of Energy Office of Legacy Management (LM) intends to fulfill its mission to maintain protection of human health and the environment at and around the Amchitka Island site. The Long-Term Surveillance Plan directs monitoring to be performed every 5 years, at least in the initial phase of the project. The most recent monitoring event was conducted in May 2016. The purpose of the monitoring is to develop a baseline of activity concentrations for selected radionuclides in biota, water, and soil, both on Amchitka Island and at the reference location on Adak Island, which is approximately 322 kilometers (200 miles) northeast.

This report documents the actions taken by Navarro Research and Engineering, Inc. (Navarro) to ensure the May 2016 sampling event was conducted efficiently and in accordance with the established requirements. This report fulfils Performance Objective 1, Performance Item 1, "Amchitka – Conduct Biological Sampling," as specified in the Legacy Management Support (LMS) contractor's Performance Evaluation Measurement Plan, dated May 24, 2016.

2.0 Background

Navarro performed biological sampling of the environment on and around Amchitka and Adak Islands beginning on May 12, 2016, and ending on May 23, 2016. Planning for this event began in the winter of 2014, when LMS personnel began developing the *Environmental Sampling Plan for the Amchitka, Alaska, Site and Adak Island 2016 Sampling Event*. The 2-year lag time between the time the plan was written and the time the work was performed was necessary so that Navarro could procure an ocean-going vessel that was appropriately sized for successful completion of the sampling activities.

Initially, Navarro personnel worked with the Amchitka Working Group (AWG) to conceptually define the data quality objectives for the environmental sampling activities. Once the data quality objectives were agreed upon, Navarro personnel began to concurrently prepare the Environmental Sampling Plan and procure a charter vessel that could accommodate the scientific team and their equipment.

The AWG meets infrequently, either in person in Anchorage, Alaska, or via teleconference, so development of the Environmental Sampling Plan was a lengthy process. Even though the plan had not been finalized, Navarro personnel could proceed with procurement of the charter vessel because the AWG had agreed to the overall concept of how sample collection would be performed. For example, the 2011 Environmental Sampling Plan called for 13 species of marine and terrestrial samples to be collected. Of the marine samples, three of the species lived on, or grew from, the bottom of the ocean and required the assistance of divers to collect the samples. The 2016 Environmental Sampling Plan called for only four species of marine life to be collected (three species of fish and one species of algae), and all of the samples could be collected without the assistance of divers.

The following sections of this report document how the May 2016 sampling event was conducted efficiently and in accordance with the established requirements.

3.0 Charter Vessel Procurement

Appropriately-sized charter vessels available for work in the western Aleutian Islands are at a premium and must be chartered a full year in advance. Before a vessel can be chartered, the scope of work must be adequately defined so that the charter vessel matches the need (e.g., the vessel must accommodate the number of scientists needed to perform the work, and the vessel's capabilities must be adequate to undertake the scientific mission).

The charter vessel contract value for the 2011 sampling event was just under $500,000. Navarro's in-house estimate for the 2016 sampling event was $425,000.00. This contract value necessitates a procurement process that seeks bids from three or more companies which can provide competitively priced bids.

Navarro sent the solicitation to charter vessel providers that were identified in previous solicitations and recommended by the LMS project manager. A total of seven vendors were provided with solicitation packages. Three vendors submitted proposals for a total of four vessels. The vendors that submitted proposals and the bid amounts are provided in Table 1.

Table 1. Vendor Proposals Received and Bid Amounts

No.	Vendor	Bid Amount
1	Alaska Charter Boats LLC	$367,980.00
2	Norseman Maritime Charters	$413,144.00
3	Ocean Services, LLC (*Ocean Star*)	$676,456.00
4	Ocean Services, LLC (*Pacstar*)	$793,522.00

The Technical Evaluation Team members were Chairperson Paul Darr, Rick Findlay, and Rick Hutton. The team evaluated the technical proposals against the criteria set forth in the solicitation. Norseman Maritime Charters received the highest score at 95, Alaska Charter Boats LLC scored 89, and Ocean Service, LLC (both the *Ocean Star* and *Pacstar*) scored 85.

The highest technical score was awarded the maximum number of technical points, which was 100 in this case. The technical points for the remaining proposals were calculated by dividing each offeror's technical score by the highest technical score and multiplying the result by the maximum technical points available. This calculation allowed the Technical Evaluation Team to compare the cost and the resulting technical point scores with the correct weighting on each score. The technical points assigned to each vendor when the technical scores were normalized on the basis of 100 points for the highest-rated vendor are listed in Table 2 on the following page.

Table 2. Technical Points Assigned to Vendor Proposals

No.	Vendor	Technical Points
1	Norseman Maritime Charters	100.00
2	Alaska Charter Boats LLC	93.68
3	Ocean Services, LLC (*Ocean Star*)	89.47
4	Ocean Services, LLC (*Pacstar*)	89.47

Navarro's evaluation was based on a pre-established weighting percentage for technical merit versus cost. The maximum technical points (perfect score) was a pre-established number. The maximum technical points and the weighting percentage determined the number of cost points available. As defined in the solicitation, technical consideration was weighted at 60%, and cost was weighted at 40%. The proposal offering the lowest total cost was awarded the maximum number of cost points available, which was 66.67 points in this case. The cost points for the remaining proposals were calculated by dividing the lowest total cost by each offeror's total cost and multiplying the result by the maximum cost points available. Table 3 lists the points awarded to each vendor.

Table 3. Technical Points, Cost Points, and Total Points Awarded to Each Vendor

No.	Vendor	Technical Points	Cost Points	Total Points
1	Alaska Charter Boats LLC	93.68	66.67	160.35
2	Norseman Maritime Charter	100.00	59.38	159.38
3	Ocean Services, LLC (*Pacstar*)	89.47	46.37	135.85
4	Ocean Services, LLC (*Ocean Star*)	89.47	36.27	124.74

Navarro selected Alaska Charter Boats LLC as the subcontractor offering the best value to Navarro and LM based on the selection criteria in the solicitation. Navarro checked the Excluded Parties Listing System at www.sam.gov/portal/public/SAM/ on December 9, 2015, and the proposed awardee was not on the list. Navarro checked the references that Alaska Charter Boats LLC listed in their proposal. The vendor's other clients had projects that were very similar in size and scope to Navarro's current project. Navarro determined that the selected vendor was responsive and responsible, and they had the necessary Representations and Certifications on file. Alaska Charter Boats LLC is a small, women-owned business operating out of Juneau, Alaska, and the charter vessel they provided was the *Qualifier 105*, which is shown in Figure 1 on the following page.

4.0 Environmental Sampling

Once the charter vessel has been procured, Navarro could begin evaluating the environmental compliance items that needed to be in place for this project to begin. A Special Use Permit from the U.S. Fish and Wildlife Service (USFWS) is required to access the island. A Fish Resource Permit is required by the Alaska Department of Fish and Game that identifies the species of fish to be caught, how many will be caught, and the purpose of the sampling program. LM required a Determination of National Environmental Policy Act (NEPA) Adequacy to ensure the existing

NEPA documentation fully covered the proposed action and to determine whether an additional NEPA review was warranted. The Alaska Department of Fish and Game approved the Fish Resource Permit on April 6, 2016; LM approved the Determination of NEPA Adequacy on May 3, 2016; and the USFWS approved the Special Use Permit on May 25, 2016.

Figure 1. Qualifier 105

Navarro finalized the Environmental Sampling Plan for the 2016 Amchitka site and Adak Island sampling event in April 2016. The primary objective of the sampling event was consistent with the Long-Term Surveillance Plan and subsequent discussions with the various stakeholders, including the Alaska Department of Environmental Conservation, USFWS, and the Aleutian Pribilof Islands Association. The primary objective included collecting water and tissue data to determine leakage from the test site cavities, with a specific focus on seawater sampling of the area of potential leakage off the Long Shot test site, as defined in the Amchitka site groundwater model. The hydrologic model indicated that the shortest leakage arrival times could occur at the Long Shot site.

In addition, the results of the leakage assessment provided information on food safety. Prior assessment results have demonstrated that the subsistence foods available on and around Amchitka Island have not been adversely impacted by radionuclides associated with the underground nuclear tests. If sufficient monitoring is conducted and does not identify radionuclide seepage from the nuclear test sites, then it can be concluded that the subsistence foods remain safe with respect to test-related radionuclides.

The Environmental Sampling Plan directed collection of four species of fish and one species of algae:

- Yellow or red Irish lords (*Hemilepidotus jordani or H. hemilepidotus)* (see Figure 2)
- Kelp or rock greenling (*Hexagrammos decagrammus or H. lagocephalus*) (see Figure 3)
- Black or dusky rockfish (*Sebastes melanops or S. cilatus*) (see Figure 4)
- Dolly Varden (*Salvelinus malma*) (see Figure 5)
- Rockweed (*Fucus distichus*), a species of brown algae (see Figure 6)

The scientific team sampled the fish species via hook and line (fishing) and collected the rockweed by hand from the shoreline. In addition, seawater was sampled in each area where fish were caught and in a specified area off the coastline of the Long Shot site. The team collected freshwater samples from lakes on both Amchitka and Adak Islands.

Figure 2. Irish Lord

Figure 3. Greenling

Figure 4. Rockfish

Figure 5. Dolly Varden

Figure 6. Rockweed

On May 12, 2016, the scientific team met the *Qualifier 105* in Adak, Alaska. The scientific team included the following personnel:

- Mark Kautsky, LM site manager
- Bruce Wright, Aleutian Pribilof Islands Association lead
- Chase Stoudt, University of Alaska Fairbanks
- David Leech, University of Alaska Fairbanks
- Paul Darr, Navarro site lead
- Stephen Pitton, Navarro engineer
- Lauren Goodknight, Navarro sample coordinator

Once aboard the *Qualifier 105*, introductions were made, and the scientific crew moved their gear onboard and into their respective staterooms. The captain of the *Qualifier 105* is David Mastolier, and his first mate/alternate captain is Jared Bradshaw. The crew of the *Qualifier 105* is comprised of two additional deck hands, the vessel's engineer, and a cook. David Mastolier also brought along two additional personnel that provided assistance with the fishing activities to collect samples.

Once introductions had been made the captain provided a safety briefing that detailed the ship's safety features, the ship's working routine, and what to do in case of an emergency. During the portion of the briefing on emergencies, each member of the scientific team was required to don and doff an immersion suit. Once these activities were concluded, the *Qualifier 105* pulled away from the pier and began the 20-hour transit to Amchitka Island.

The day-to-day activities of this 2016 sampling event are provided in Appendix A. Based on a review of the daily log of sampling activities, the actual time it took to fish for the four species of fish from each of the five sampling locations was as follows:

- Adak South site, 1.5 hours
- Adak North site, 1.75 hours
- Milrow site, 3.0 hours
- Long Shot site, 3.0 hours
- Cannikin site, 4.5 hours

5.0 Seawater Sampling

Seawater sampling off the coastline of the Long Shot site took 1 full day and part of 2 days. The University of Alaska Fairbanks provided two sampling technicians and a Sea-Bird Electronics ECO water sampler with a six-bottle configuration (4 liters per bottle). This ECO water sampler enabled the scientific team to meet the volume requirement of 20-liters per sample for the Long Shot site seawater samples. The ECO seawater sampler was deployed from the deck of the *Qualifier 105* to the desired depth. The ECO water sampler and a portable instrumentation winch were utilized to optimize real-time conductivity, temperature, and depth (CTD) measurements and water-sample profiling at the desired depths off the coast of the Long Shot site. The ECO

water sampler is shown in Figure 7. The scientific team also conducted transect seawater sampling at each of the five sampling areas where biological samples were collected.

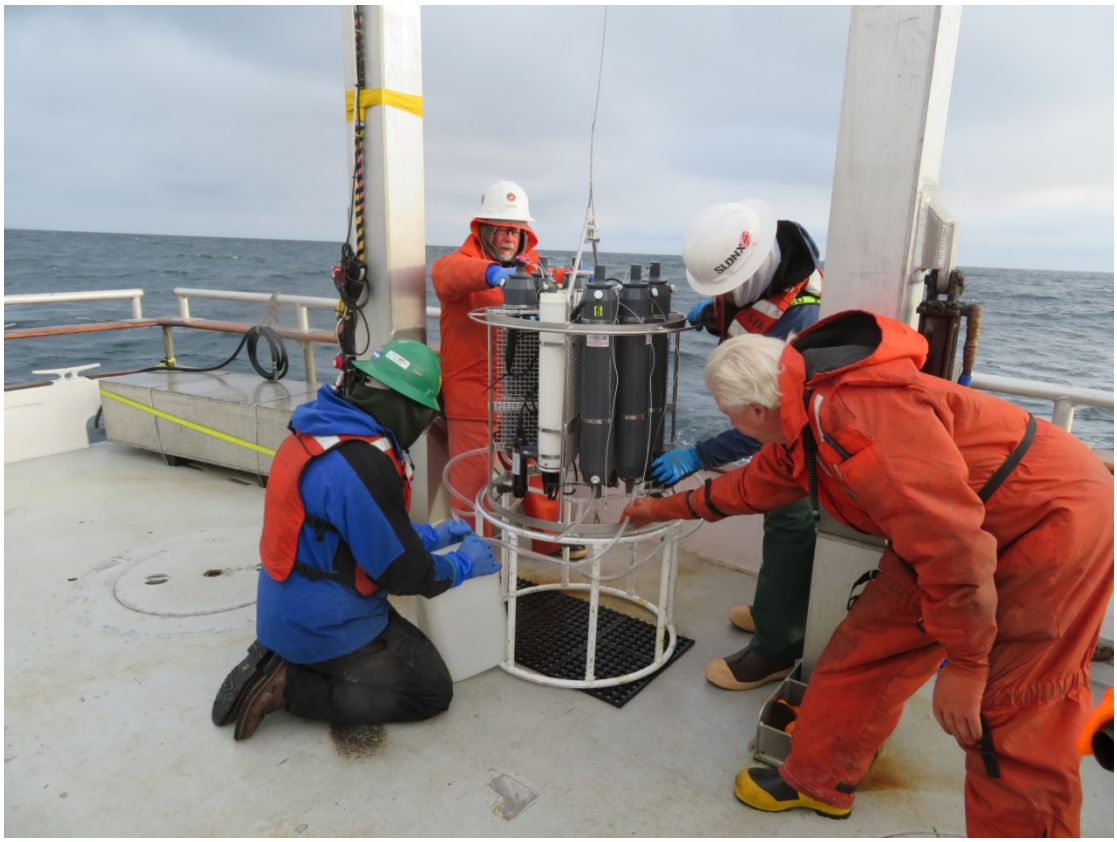

Figure 7. ECO Water Sampler

6.0 Laboratory Analyses

The two laboratories that the AWG agreed on to perform the environmental sample analyses were Lawrence Livermore National Laboratory (LLNL) in Livermore, California, and the University of Miami's Tritium Laboratory. Overall, the scientific team collected 268 environmental samples at Amchitka and Adak Islands, duplicates included, which were comprised of the following:

- Greenling: 50 samples (10 at each of the following sites: Long Shot, Milrow, Cannikin, Adak North, and Adak South) sent to LLNL
- Irish Lords: 50 samples (10 at each of the following sites: Long Shot, Milrow, Cannikin, Adak North, and Adak South) sent to LLNL
- Rockfish: 50 samples (10 at each of the following sites: Long Shot, Milrow, Cannikin, Adak North, and Adak South) sent to LLNL
- Dolly Varden: 3 samples (2 at Adak Island and 1 at Amchitka Island), which were sent to LLNL
- Rockweed: 15 samples (3 at each of the following sites: Long Shot, Milrow, Cannikin, Adak North, and Adak South) sent to LLNL

- Seawater: 96 samples (88 at the Long Shot site and 2 each at the Milrow, Cannikin, Adak North, and Adak South sites); half of the samples were 20-liters each and sent to LLNL; the other half of the samples were 1-liter each and sent to the University of Miami
- Freshwater: 4 samples (2 at Adak Island and 2 at Amchitka Island); one set of samples sent to each laboratory

On May 22, 2016, all of the samples were shipped from the Adak airport to LLNL and the University of Miami via Alaska Air's Gold Streak overnight delivery. Both laboratories received the samples the next day, and all of them were in good condition.

7.0 Conclusions

Navarro conducted the May 2016 sampling event at the Amchitka site efficiently and in accordance with the established requirements. The 2016 environmental sampling project was well planned and safely executed. The scientific team was well prepared, mentally and physically, to perform all aspects of this project. To successfully complete the environmental sampling event, teamwork and logistical support were necessary from all of the parties involved, from the LMS personnel involved in scheduling and planning to the various vendors supporting the project to the ship's crew and the scientific team.

All of the environmental, seawater, and freshwater samples specified in the Environmental Sampling Plan were collected, as required. All of the samples were delivered to the laboratories on time, without any shipping incidents, and they met all of the holding-time requirements.

Financially, Navarro completed the 2016 environmental sampling effort 2 months ahead of schedule and approximately $300,000 under budget.

Appendix A

Daily Log of the Environmental Sampling Project
Amchitka and Adak Islands
May 10–23, 2016

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Tuesday, May 10, 2016

Navarro scientific crew members (Paul Darr, Stephen Pitton, and Lauren Goodknight) depart Grand Junction, Colorado, for Anchorage, Alaska.

Arrive Anchorage 1540.

Wednesday, May 11, 2016

Anchorage all day.

Collecting miscellaneous items for the Amchitka environmental sampling project.

Pick Mark Kautsky up at the airport in the afternoon.

Thursday, May 12, 2016

Depart Anchorage for Adak mid-afternoon.

Arrive Adak late afternoon.

David Mastolier, Captain of the *Qualifier 105*, meets the Amchitka site scientific crew at the Adak airport and transports everyone to Sweeper Cove Pier to board the vessel.

Once onboard the *Qualifier 105*, David provides a safety briefing for everyone, and afterwards, dinner is served.

Qualifier 105 departs Adak at 1915 for Amchitka Island.

Friday, May 13, 2016

Weather is partly sunny to partly cloudy; winds are 15 knots from the north.

Temperature is in the upper 30s, with wind chill in the upper 20s.

Seas are running 8–12 feet (ft).

1530: *Qualifier 105* arrives offshore the Milrow site (North Pacific Ocean). Fishing for black and dusky rockfish, rock and kelp greenling, and red and yellow Irish lords begins immediately.

1830: The fishermen have collected all the samples required for the Milrow site sampling transect.

1845: Overnight anchorage off Milrow site coastline.

1945: Begin processing fish samples.

2100: Complete processing fish samples.

Saturday, May 14, 2016

Weather is partly cloudy to cloudy; winds are 15–20 knots from the north.

Temperature is in the upper 30s, with wind chill in the upper 20s.

Seas are running 8–10 ft.

0730: Skiff departs for shore to collect three samples of rockweed.

0900: Skiff is back at Q10 with three rockweed samples.

1015: Collect seawater sample.

1030: *Qualifier 105* departs Milrow site for Long Shot site.

1230: *Qualifier 105* arrives Long Shot sampling transect area, and the fishermen immediately begin to fish.

1530: The fishermen have collected all the samples required for the Long Shot site sampling transect.

1600: Collect Long Shot site seawater sample using the CDT sampling tool.

1630: *Qualifier 105* transits to Constantine Harbor for overnight anchorage.

1715: Arrive Constantine Harbor anchorage.

1945: Begin processing fish samples.

2045: Complete processing fish samples.

Sunday, May 15, 2016

Weather is cloudy; winds are 15–20 knots from the north.

Temperature is in the upper 30s, with wind chill in the upper 20s.

Seas are running 8–12 ft.

0730: *Qualifier 105* departs Constantine Harbor for Cannikin site sampling transect.

0900: *Qualifier 105* arrives Cannikin site sampling transect area, and the fishermen immediately begin to fish.

1330: The fishermen have collected all the samples required for the Cannikin site sampling transect.

1500: Collect Cannikin site seawater sample using the CDT sampling tool.

1530: *Qualifier 105* transits to Long Shot site to begin CTD seawater sampling.

1630: Six CTD seawater samples.

1635: *Qualifier 105* transits back to Constantine Harbor for overnight anchorage.

1715: Arrive Constantine Harbor anchorage.

1945: Begin processing fish samples.

2045: Complete processing fish samples.

Monday, May 16, 2016

Weather is cloudy; winds are 10–15 knots from the north.

Temperature is in the upper 30s, with wind chill in the upper 20s.

Seas are running 8–12 ft.

0745: *Qualifier 105* departs Constantine Harbor for Long Shot site sampling transect.

0900: *Qualifier 105* arrives Long Shot site sampling transect to begin seawater sampling using the CDT sampling tool.

1715: 27 CTD seawater samples collected.

1720: *Qualifier 105* transits back to Constantine Harbor for overnight anchorage.

1800: Arrive Constantine Harbor anchorage.

Tuesday, May 17, 2016

Weather is cloudy; winds are 8–10 knots from the northwest.

Temperature is in the upper 30s, with wind chill in the upper 20s.

Seas are running 8–12 ft.

0730: *Qualifier 105* departs Constantine Harbor for Long Shot site sampling transect.

0845: *Qualifier 105* arrives Long Shot site sampling transect to begin seawater sampling using the CDT sampling tool.

1015: 8 CTD seawater samples collected.

1220: *Qualifier 105* transits to southeast side of Amchitka Island, and fishermen begin to fish for fish with the intention of catching halibut.

1630: *Qualifier 105* transits back to Constantine Harbor for overnight anchorage.

1745: *Qualifier 105* arrives Constantine Harbor anchorage.

Wednesday, May 18, 2016

Weather is cloudy; winds are 6–10 knots from the northwest.

Temperature is in the upper 30s, with wind chill in the upper 20s.

Seas are running 4–8 ft.

0715: *Qualifier 105* departs Constantine Harbor for Long Shot site and Cannikin Lake sampling transects for rockweed collection.

0845: *Qualifier 105* arrives Cannikin Lake sampling transect to drop off personnel (Bruce, Jeff, and Cort) hiking into Cannikin Lake for Dolly Varden fishing.

0900: Skiff away transporting fishermen to shore.

0915: Skiff returns and *Qualifier 105* transits back to Long Shot site transect area to begin collection of rockweed.

1000: *Qualifier 105* off Long Shot site and rockweed collection personnel (Mark, Paul, and Stephen) depart in skiff for collection of rockweed at three separate locations along the shoreline of Long Shot site.

1100: Collection of rockweed along Long Shot site coastline completed.

1200: Collection of rockweed along Cannikin site coastline completed.

1300: Mark, Paul, Stephen, Lauren, and Chase dropped off at Cannikin site shoreline to hike into Cannikin Lake and collect water sample.

1345: Arrive Cannikin Lake and collect water sample. Meet up with Cannikin Lake fishermen.

1415: Everyone begins hike back to Cannikin site shoreline for pickup.

1510: Everyone back at shoreline and transported back to *Qualifier 105*.

1600: *Qualifier 105* departs Amchitka Island for Adak Island.

Thursday, May 19, 2016

Weather is cloudy; winds are 4–6 knots from the west northwest.

Temperature is in the upper 30s, with wind chill in the upper 20s.

Seas are running 2–4 ft.

0530: *Qualifier 105* arrives south side of Adak Island.

0745: *Qualifier 105* arrives Boot Bay, and fishermen begin to fish.

0915: All fish have been collected.

1000: Skiff in water to take Mark, Bruce, Stephen, and Paul to three locations along north side of Boot Bay. CTD seawater sample collected.

1130: Skiff returns with three rockweed samples.

1300: *Qualifier 105* transits through Kagalaska Strait to north side of Adak Island.

1500: *Qualifier 105* following coastline between Blind Bay and Scabard Bay with fishermen collecting samples. Begin processing samples.

1715: Fishing ceased for the day, and sample processing completed.

1800: *Qualifier 105* at anchorage in Blind Cove.

Friday, May 20, 2016

Weather is cloudy; winds are 2–4 knots from the west.

Temperature is in the low 40s, with wind chill in the mid-30s.

Seas are running 0–2 ft.

0715: *Qualifier 105* departs Blind Cove to fish off coastline adjacent to Kagalaska Straight.

0800: Fishermen begin to collect samples.

0945: Fishermen collect all samples.

1000: Collect CDT seawater sample, and skiff away with Mark, Bruce, Stephen, and Paul in it to collect rockweed.

1130: Skiff back at *Qualifier 105*.

1300: *Qualifier 105* heads out to Kuluk Bay; fishing for halibut and processing samples.

1430: Complete processing samples.

1700: *Qualifier 105* anchors in Kuluk Bay.

Saturday, May 21, 2016

Weather is cloudy; winds are 2–4 knots from the west.

Temperature is in the low 40s, with wind chill in the mid-30s.

Seas are running 0–2 ft.

0730: *Qualifier 105* departs Kuluk Bay anchorage.

1000: *Qualifier 105* ties up at pier in Adak, Alaska. Sample shipping preparations begin.

1500: Sample preparations end for the day.

Sunday, May 22, 2016

0830: Sample preparations continue. Transport samples to airport and clear airport security.

1430: Samples at airport and in Alaska Air's possession.

1800: Alaska Air flight departs Adak for Anchorage, Alaska.

2145: Alaska Air flight arrives Anchorage, Alaska.

Monday, May 23, 2016

0130: United Airlines departs for Denver, Colorado.

0650: United Airlines arrives Denver, Colorado.

0950: United Airlines departs for Grand Junction, Colorado.

1100: United Airlines arrives Grand Junction, Colorado.

Appendix B

Lawrence Livermore National Laboratory

Data Report, Part I: Processing of Biological Samples (Wet, Dry, and Ash Weights)

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LLNL-SR-751699

AMCHITKA PROJECT

Data Report, Part I

Processing of Biological Samples (Wet, Dry and Ash Weights)

T.F. Hamilton
S.R. Kehl
R.M. Berry

March 2018

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LAWRENCE LIVERMORE NATIONAL LABORATORY
GLOBAL SECURITY PRINCIPAL DIRECTORATE

AMCHITKA PROJECT
WFO Proposal D201231

Data Report, Part I

Processing of Biological Samples (Wet, Dry and Ash Weights)

T.F. Hamilton, S.R. Kehl, and R.M. Berry

March 2018

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Appendix 1. COC Sample Receipt and Variance Reports

Appendix 2. Table 3. Individual Sample Wet, Dry and Ash Weights

[CD copies of this report along with excel data listings are available upon request].

TABLES and FIGURES

Table 1. List of targeted radionuclides, laboratory methods and estimated detection limits (2016 Amchitka Sampling Event) (after DOE, 2016).

Table 2. Summary data of total sample wet, dry and ash weight (and dry/wet and ash/dry normalization weights) grouped by biological species (Amchitka 2016).

Fig. 1. NorthStar freeze dryer (Amchitka 2016).

Fig. 2. Algae containment bin for collecting free liquor prior to sample drying and combustion.

1.0 Prologue

The following data report was prepared under contract with the U.S. Department of Energy (DOE), Office of Legacy Management (LM), Grand Junction, Colorado, in support of the Long-Term Surveillance Plan (LTSP) for the Aleutian Islands nuclear site test on Amchitka Island (DOE, 2014). Following the 2016 sampling event, the Lawrence Livermore National Laboratory (LLNL) received a collection of seawater, freshwater and biological samples for analysis of targeted radionuclides. The sampling activities implemented in 2016 for Amchitka Island and its reference site of Adak, Alaska, were similar in purpose to those conducted previously (USDOE, 2013; 2014). Added emphasis was placed on seawater sampling near an area of potential leakage off the Long Shot test detonation site. There was also an interest in conducting analyses of targeted radionuclides with lower limits of detection for the expressed purpose of directing future trending analysis (DOE, 2016). The targeted radionuclides of interest included tritium(^{3}H), cesium-134 (^{134}Cs), cesium-137 (^{137}Cs), plutonium-239 (^{239}Pu), and plutonium-240 (^{240}Pu). ^{134}Cs was presumably included to assess the residual impact of inputs from Fukushima.

The systematics and specific objectives of the 2016 sampling event and associated analytical program were formulated by LM in partnership with the Alaska Department of Environmental Conservation (ADEC), the *Aleutian Pribilof Islands Association, Inc.* (APIA) (a federally recognized tribal organization of the Alet people in Alaska), and the Argonne National Laboratory (ANL). A specific project goal for the 2016 sampling event was to attest to the possibility that selected residual radionuclides from underground nuclear tests conducted on Amchitka Island may enter the marine food chain, and result in potential ecological and human health effects.

LLNL was tasked to provide analytical support for the project with electronic data reporting. Samples of seawater (unfiltered) (N=25)$^{\#}$ and freshwater (unfiltered) (N=2) were received for analysis of ^{134}Cs and ^{137}Cs. A larger subset of marine biota and algae samples were received for analysis of ^{134}Cs-^{137}Cs and ^{239}Pu-^{240}Pu isotopes. The biological sample collection included Dolly Varden (*Salvelinus malma*) (N=3), Greenling (*Hexagrammos spp*) (N=50), Irish Lord (*Hemilepidotus spp*) (N=50), Rockfish (*Sebastes spp*) (N=50) and Rockweed (*Fucus distichus*) (N=15). Cs isotopes were determined by high resolution gamma-spectrometry after separation of the analytes of interest, along with added carrier, on a small quantity of micro-crystalline ammonium molybdophosphate (AMP). Pu isotopes were measured by quadrupole

Inductively Coupled Plasma Mass Spectrometry (ICP-MS). During early discussion with the sponsor, some consideration was to be given to conducting measurements of Pu isotopes in waters and biological samples by Accelerator Mass Spectrometry (AMS).

The scope of work as outlined in the sampling plan covered specific Quality Assurance Objectives (QAOs) with respect to achievable limits of detection for each of the targeted radionuclides. Livermore scientists found that the agreed-to limits of detection contained in the 2016 sampling plan were not necessarily supportive of the overall program goals to provide quantitative data and information for future trending analysis. To improve quantification of Cs isotopes by gamma-spectrometry and allow for a more detailed comparative assessment to be conducted between sampling events, the project reporting deadline was extended to allow for longer counting times. Even with the longer count times (up to 5 days), about 20% of the marine biota samples contained no reportable Cs isotope activity. Many of these samples were subsequently recounted on a Small Anode Germanium (SAGe) well detector system with improved measurement precision. Also, with agreement from the sponsor, a subset of seawater and freshwater samples were analyzed for iodine-129 (^{129}I) using AMS with the aim of providing information on the potential impacts of other source-terms on marine radioactivity, especially with respect to Fukushima. No other AMS measurements were subsequently conducted under the terms of the contract award to LLNL.

[#] N = number of individual samples received for analysis

2.0 Scope of Analytical Project at LLNL

2.1 Objective

Provide analytical measurement data and reporting under the 2016 Amchitka sampling event.

2.2 Statement of Work

1. Measure the ^{137}Cs, ^{134}Cs, ^{239}Pu and ^{240}Pu content of marine biota and algae samples as supplied under the 2016 Amchitka Sampling Event using a combination of high-resolution gamma-spectrometry (Cs isotopes) and Inductively Coupled Plasma Mass Spectrometry (Pu isotopes).
2. Measure the ^{137}Cs and ^{134}Cs content of freshwater and seawater as supplied under the 2016 Amchitka Sampling Event using a SAGe well gamma detector system.
3. Provide EDD and hard copy reporting of analytical data with a description of methodologies and supporting quality assurance measures.

2.2 Target Radionuclides and Selection Criteria for Methods of Analysis

Previous studies conducted by CRESP (Consortium for Risk Evaluation with Stakeholder Participation) (CRESP, 2015) and LM under the LTSP for the Aleutian Islands nuclear site test on Amchitka Island show that reported levels of anthropogenic radionuclides contained in marine biota from the site were at or below the acceptable consumption risk range of 10^{-4} to 10^{-6} excess risk of cancer. The aim of the current sampling event was to optimize the design of the sampling and analytical program. This was done not only to provide additional confirmatory measurement of the possible health risk posed by consumption of marine foods from the region but to yield high quality data for trending analyses. Under a formal strategic planning process, pre-determined sample locations and DQOs were devised to reduce uncertainties in assessing food safety and provide adequate detection sensitivity to support future statistical trending analyses. This included placing minimum requirements on the quantity of biological materials to be collected (based on practical limitations) based on estimated limits of detection for prescribed measurement techniques.

A listing of targeted radionuclides, methodologies and estimated limits of detection for the 2016 Amchitka sampling event is contained in Table 1.

2.3 Sample Delivery/COC Documentation

Biological samples collected in the field were sealed inside labeled plastic bags and shipped frozen. All biological fauna samples were received as whole animals. It should be noted; however, several fish samples were received with their gut cavities open (refer Appendix 1). Water samples were shipped in single 20-L (5-gallon) polyethylene carboys with no preservation. The samples were shipped out in two (2) separate overnight air cargo flights into San José International Airport in northern California, and then immediately transported by road (app. 30 miles) to LLNL. Biological samples were subsequently stored frozen at LLNL prior to processing. Each sample shipment was accompanied by Change-of-Custody (COC) documentation listing the task code, COC ID, sample ID, location code, matrix type (biota or water), date and time of sampling, collection code (grab or composite), number of sample containers (typically 1 ea.), and the type of sample analysis to be performed. Upon arrival of the samples at LLNL, a validation check was performed of sample received against the COC listing and any variances identified (Appendix 1).

All COC listed samples were accounted for. Sample AMC01.1-16060002-001 (DOLL-AI-01) and AMC13.1-16060002-003 (DOLL-AD-01) were received in a later shipment without COC documentation.

The report shown here gives a brief description of the initial laboratory methods (and the associated wet/dry/ash data) used to prepare biological samples for radiometric analysis. All samples were analyzed as received. Reporting of wet, dry and ash weights is expected to allow for more accurate comparisons to made with data obtained from the open scientific literature.

Table 1. List of targeted radionuclides, laboratory methods and estimated detection limits (2016 Amchitka Sampling Event) (after DOE, 2016).

Analyte	Laboratory Method	Estimated MDA (Bq)	A Priori MDA ($Bq\ kg^{-1}$ - wet weight)[a]		
			Based on 100 g sample	Based on 1000 g sample	Based on 5000 g sample
Biological samples					
^{134}Cs	Gamma-spectrometry	0.3	3	0.3	0.06
^{137}Cs	Gamma-spectrometry	0.3	3	0.3	0.06
^{239}Pu	Quad ICP-MS	0.008	0.08	0.008	0.0016
^{240}Pu	Quad ICP-MS	0.02	0.2	0.02	0.004
^{239}Pu	AMS	0.00001	0.0001	0.00001	0.000002
^{240}Pu	AMS	0.00003	0.0003	0.00003	0.000006
Seawater and freshwater Samples					
^{134}Cs	Gamma-spectrometry (SAGe)	0.006	0.3[b]		
^{137}Cs	Gamma-spectrometry (SAGe)	0.003	0.15[b]		
^{3}H	Electrolytic enrichment followed by gas proportional counting	0.01184[c]			

[a] MDA expressed on sample mass basis [represents the Relative Detection Limit (RDL)].

[b] Based on a 20-liter sample ($Bq\ m^{-3}$).

[c] $Bq\ L^{-1}$ (Tritium Laboratory, Rosenstiel School of Marine and Atmospheric Science, Miami, FL).

Abbreviations:

MDA = Minimum Detection Activity

AMS = Accelerator Mass Spectrometry

ICP-MS = Inductively Coupled Palsma Mass Spectrometry

g = grams

SAGe = Single Anode Germanium

3.0 Sample Processing Procedures

3.1 Sample Drying

The laboratory sample handling and processing procedures were identical to those previously described for Amchitka 2011 (Hamilton *et al*., 2012). Dolly Varden, Greenling, Irish Lord, and Rockfish were dried by lyophilization in an industrial size freeze dryer (Northstar, model 3666, ~1.1 m^3 capacity). The unit uses a modified condenser system (-50 °C) and a liquid nitrogen (LN) trap coupled to two large capacity Sargent-Welch vacuum pumps running in series. The condenser and LN trap collect sublimed sample tissue water and require regular servicing to remove ice. Towards the end of the drying cycle, the freeze dryer chamber was opened, and tissue samples allowed to thaw over a period of several hours. This partial thawing process allows residual tissue bound water to migrate to the more porous outer (dry) surface of the sample material and helps accelerate the drying process. The freeze dryer was otherwise operated continuously for a 16-week period with drying times for each load of samples varying between 3 to 6 weeks. Samples were

Fig 1. Large Capacity NorthStar Freeze Dryer (Amchitka 2016).

considered dry after two or more consecutive weighs showed little or no change based on self-imposed laboratory DQOs (< 0.1% uncertainty) in reported normalization (dry/wet) weights.

For Rock Weed, experience has shown that it advantageous to collect the free liquid (sample liquor containing a complex mixture of polysaccharides) as a separate subsample before attempting to dry ash (combust) large volume marine algae samples (> 1-2 kg). This was accomplished by placing the algae samples in large plastic funnels and allowing the sample to thaw so liquor can drain out into 2-L glass beakers placed inside a covered containment bin (Fig. 2). The liquor samples and the residual biological material were then dried to constant weight in a fan-forced drying oven at 60° C, and the results summed to give a measure of the total dry weight.

2.2 Sample Combustion

Under Amchitka 2011 (Hamilton *et al.*, 2012), emphasis was placed on collecting larger size samples to yield more quantifiable data and information. A similar strategy was employed during 2016 (DOE, 2016). These large size environment samples require some

Fig 2. Algae containment bin for collecting free liquor prior to sample drying and combustion.

form of sample volume reduction step prior to conducting any wet chemistry. This is easily and most effectively accomplished by incorporating a dry combustion step into the analytical scheme. In this instance, the dried biological material was first blended down into small size particles prior to combustion in a large volume Lindberg (*General Signal*) Muffle Furnace. The biological samples were all combusted in pre-weighted 2-L glass beakers at 450-500 °C for approximately 7 days. It is sometimes difficult to destroy all the organic matter contained in large biological samples, but experience has shown that residual trace quantities of carbon could be rendered down by addition of H_2O_2 during the subsequent wet chemistry dissolution step (Hamilton *et al*., 2014).

This interim report provides a full listing of sample wet, dry and ash weights along with dry/wet and ash/dry normalization weights to support comparative assessments as units of specific activity for environmental measurements are not always reported in a consistent manner.

4.0 Summary Results

4.1 Sample Wet, Dry and Ash Weights

A full listing of individual wet, dry and ash sample weights is given in Appendix 2. Table 2 contains the average wet, dry and ash weights and associated dry/wet and ash/dry normalization weights for each species. The average wet weight of Dolly Varden, Greenling, Irish Lord, Rockfish and Rockweed received was 1032, 1042, 1110, 1212, and 5517 gram, respectively. Similarly, the average dry weight for each species was 257, 242, 244, 302 and 1297 gram, respectively. The average ash weights were 36, 53, 53, 59 and 300 gram, respectively. The dry/wet normalization weights for fish species ranged between 22 and 26 %. The dry/wet normalization weight for rockweed was 26 %. The associated ash/dry normalization weights for fish and rockweed were 14 to 22 %, and 24%, respectively.

In general, sample dry and ash weights are relatively consistent with previous findings (Hamilton *et a*l., 2012) and should not lead to any bias in reported radiometric measurements.

5.0 References

CRESP (Consortium for Risk Evaluation with Stakeholder Participation II), 2005. Amchitka Independent Science Assessment: Biological and Geophysical Aspects of Potential Radionuclide Exposure in the Amchitka Marine Environment, C.W. Powers, J. Burger, D. Kosson, M. Gochfeld, and D. Barnes, eds., Piscataway, New Jersey, August.

Hamilton, T.F., S.K.G. Peters, R.E. Martinelli, S.R. Kehl, and M.W. Tamblin (2012). Initial Sample Processing (Wet, Dry and Ash Weights), Interim Report, AMCHITKA PROJECT, WFO Project D13386, Lawrence Livermore National Laboratory, LLNL-SR-535833.

Hamilton, T.F., S.R. Kehl, and R.W Berry (2014). Measurement of Cs isotopes in Biological Samples. Data Report, Part III, AMCHITKA PROJECT, WFO Project D201231, Lawrence Livermore National Laboratory (in preparation).

U.S Department of Energy (2016). Environmental Sampling Plan for the Amchitka, Alaska, Site and Adak Island 2016 Sampling Event, Office of Legacy Management (LM), USDOE, Colorado, LMS/AMC/S12630 (not for public release).

DOE (U.S. Department of Energy), 2014. Long-Term Surveillance Plan for the U.S. Department of Energy Amchitka, Alaska, Site, Office of Legacy Management (LM), USDOE, Colorado, LMS/AMC/S01980.

U.S Department of Energy (2013). Amchitka Island, Alaska, Biological Monitoring Report 2011 Sampling Results, Office of Legacy Management (LM), USDOE, Colorado, LMS/AMC/SO8833.

Table 2. Summary data of total sample wet, dry and ash weight (and dry/wet and ash/dry normalization weights) grouped by biological species (Amchitka 2016).

Species	Number of Samples	Wet Weight (g)		Dry Weight (g)		Dry/Wet %		Ash Weight (g)		Ash/Dry %	
Dolly Varden (*Salvelinus malma*)	3	1032	± 248	257	± 36	26	± 3	36	± 14	14	± 4
Greenling (*Hexagrammos spp*)	50	1042	± 199	242	± 47	23	± 2	53	± 14	22	± 6
Irish Lord (*Hemilepidotus spp*)	50	1110	± 233	244	± 55	22	± 2	53	± 10	22	± 4
Rockfish (*Sebastes spp*)	50	1212	± 334	302	± 88	25	± 2	59	± 17	20	± 5
Rockweed (Fucus distichus)	15	5517	± 384	1297	± 275	24	± 5	300	± 41	24	± 4
Total Samples = 168											

Appendix 1

COC Sample Receipt and Variance Reports

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Chain of Custody / Sample Submittal Form

Print COC
Ver 6.4.2.1

Task Code:	AMC01.1-16050001	COC ID:	AMC01.1-16050001-COC.1	TURNAROUND TIME:		Page 1 of 1

PROJECT INFORMATION		LABORATORY		SAMPLING / SHIPPING	
Facility Name	Amchitka Site	Lab Name:	Lawrence Livermore National Laboratory	Shipping Company:	
Project Number	1.104.1.04.611.2.01	Address:	700 East Avenue	Tracking Number:	
Project Name:	Amchitka Site (Amchitka Island)	City:	Livermore State: CA	Cooler Count:	
		Postal Code:	84550	Date Shipped:	
		Phone Number:	925-424-2619	Sampled by (Print, Sign):	
		PO Number:			
				Sampler 2:	

SAMPLE DETAILS — ANALYSIS REQUESTED — Filtered - F: Field, L: Lab, FL: Field & Lab, N: None

Sample ID	Location	Matrix	Date	Time (24hr)	G=Grab C=Comp	# of Cont	Cs Iso, Biota	Pu Iso	Cs Iso, Water									
Container								PLASTIC BAG	HDPE 20 L									
Filtered																		
Preserv.								4 C	None									
~~AMC01.1-16050001-001~~	~~DOLL-AI-01~~	~~BIOTA~~			~~C~~	~~1~~	~~X~~	~~1~~										
AMC01.1-16050001-002	FRES-AI-01	WATER	5/18/2016	1400	C	1			1									

X = shared container

ADDITIONAL COMMENTS/SPECIAL INSTRUCTIONS	RELINQUISHED BY	DATE/TIME	ACCEPTED BY	DATE/TIME
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Chain of Custody / Sample Submittal Form

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Task Code:	AMC02.1-16050001	COC ID:	AMC02.1-16050001-COC.1	TURNAROUND TIME:		Page 1 of 7

PROJECT INFORMATION		LABORATORY		SAMPLING / SHIPPING	
Facility Name	Amchitka Site (Long Shot)	Lab Name:	Lawrence Livermore National Laboratory	Shipping Company:	
Project Number	1.104.1.04.611.2.01	Address:	700 East Avenue	Tracking Number:	
Project Name:	Amchitka Site (Long Shot)	City:	Livermore State: CA	Cooler Count:	
		Postal Code:	84550	Date Shipped:	
		Phone Number:	925-424-2619	Sampled by (Print, Sign):	
		PO Number:			
				Sampler 2:	

SAMPLE DETAILS — ANALYSIS REQUESTED — Filtered - F: Field, L: Lab, FL: Field & Lab, N: None

Sample ID	Location	Matrix	Date	Time (24hr)	G=Grab C=Comp	# of Cont	Container		PLASTIC BAG										
							Filtered												
							Preserv.		4 C	None									
							ANALYSIS	Cs Iso, Biota	Pu Iso	Cs Iso, Water									
AMC02.1-16050001-001	FUCU-LS-01	BIOTA	5/18/2016	945	C	1		X	1										
AMC02.1-16050001-002	FUCU-LS-02	BIOTA	5/18/2016	1015	C	1		X	1										
AMC02.1-16050001-003	FUCU-LS-03	BIOTA	5/18/2016	1100	C	1		X	1										
~~AMC02.1-16050001-004~~	~~FUCU-LS-04~~	~~BIOTA~~			~~C~~	~~1~~	X = shared container	~~X~~	~~1~~										
~~AMC02.1-16050001-005~~	~~FUCU-LS-05~~	~~BIOTA~~			~~C~~	~~1~~		~~X~~	~~1~~										
~~AMC02.1-16050001-006~~	~~FUCU-LS-06~~	~~BIOTA~~			~~C~~	~~1~~		~~X~~	~~1~~										
~~AMC02.1-16050001-007~~	~~FUCU-LS-07~~	~~BIOTA~~			~~C~~	~~1~~		~~X~~	~~1~~										
~~AMC02.1-16050001-008~~	~~FUCU-LS-08~~	~~BIOTA~~			~~C~~	~~1~~		~~X~~	~~1~~										
~~AMC02.1-16050001-009~~	~~FUCU-LS-09~~	~~BIOTA~~			~~C~~	~~1~~		~~X~~	~~1~~										
~~AMC02.1-16050001-010~~	~~FUCU-LS-10~~	~~BIOTA~~			~~C~~	~~1~~		~~X~~	~~1~~										
AMC02.1-16050001-011	GREN-LS-01	BIOTA	5/14/2016	2000	C	1		X	1										
AMC02.1-16050001-012	GREN-LS-02	BIOTA	5/14/2016	2005	C	1		X	1										
AMC02.1-16050001-013	GREN-LS-03	BIOTA	5/14/2016	2005	C	1		X	1										
AMC02.1-16050001-014	GREN-LS-04	BIOTA	5/14/2016	2010	C	1		X	1										

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Task Code:	AMC02.1-16050001	COC ID:	AMC02.1-16050001-COC.2	TURNAROUND TIME:		Page 2 of 7

PROJECT INFORMATION		LABORATORY		SAMPLING / SHIPPING	
Facility Name	Amchitka Site (Long Shot)	Lab Name:	Lawrence Livermore National Laboratory	Shipping Company:	
Project Number	1.104.1.04.611.2.01	Address:	700 East Avenue	Tracking Number:	
Project Name:	Amchitka Site (Long Shot)	City:	Livermore State: CA	Cooler Count:	
		Postal Code:	84550	Date Shipped:	
		Phone Number:	925-424-2619	Sampled by (Print, Sign):	
		PO Number:			
				Sampler 2:	

SAMPLE DETAILS — ANALYSIS REQUESTED — Filtered - F: Field, L: Lab, FL: Field & Lab, N: None

Sample ID	Location	Matrix	Date	Time (24hr)	G=Grab C=Comp	# of Cont	Cs Iso, Biota	Pu Iso	Cs Iso, Water									
Container								PLASTIC BAG										
Filtered																		
Preserv.								4 C	None									
ANALYSIS							Cs Iso, Biota	Pu Iso	Cs Iso, Water									
AMC02.1-16050001-015	GREN-LS-05	BIOTA	5/14/2016	2010	C	1	X	1										
AMC02.1-16050001-016	GREN-LS-06	BIOTA	5/14/2016	2015	C	1	X	1										
AMC02.1-16050001-017	GREN-LS-07	BIOTA	5/14/2016	2015	C	1	X	1										
AMC02.1-16050001-018	GREN-LS-08	BIOTA	5/14/2016	2020	C	1	X	1										
AMC02.1-16050001-019	GREN-LS-09	BIOTA	5/14/2016	2025	C	1	X	1										
AMC02.1-16050001-020	GREN-LS-10	BIOTA	5/14/2016	2025	C	1	X	1										
AMC02.1-16050001-021	ILOR-LS-01	BIOTA	5/14/2016	2055	C	1	X	1										
AMC02.1-16050001-022	ILOR-LS-02	BIOTA	5/14/2016	2100	C	1	X	1										
AMC02.1-16050001-023	ILOR-LS-03	BIOTA	5/14/2016	2100	C	1	X	1										
AMC02.1-16050001-024	ILOR-LS-04	BIOTA	5/14/2016	2100	C	1	X	1										
AMC02.1-16050001-025	ILOR-LS-05	BIOTA	5/14/2016	2105	C	1	X	1										
AMC02.1-16050001-026	ILOR-LS-06	BIOTA	5/14/2016	2105	C	1	X	1										
AMC02.1-16050001-027	ILOR-LS-07	BIOTA	5/14/2016	2110	C	1	X	1										
AMC02.1-16050001-028	ILOR-LS-08	BIOTA	5/14/2016	2110	C	1	X	1										

X = shared container

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Task Code: AMC02.1-16050001 | COC ID: AMC02.1-16050001-COC.3 | TURNAROUND TIME: | Page 3 of 7

PROJECT INFORMATION		LABORATORY		SAMPLING / SHIPPING	
Facility Name:	Amchitka Site (Long Shot)	Lab Name:	Lawrence Livermore National Laboratory	Shipping Company:	
Project Number:	1.104.1.04.611.2.01	Address:	700 East Avenue	Tracking Number:	
Project Name:	Amchitka Site (Long Shot)	City:	Livermore	Cooler Count:	
		State:	CA	Date Shipped:	
		Postal Code:	84550		
		Phone Number:	925-424-2619	Sampled by (Print, Sign):	
		PO Number:			
				Sampler 2:	

SAMPLE DETAILS | ANALYSIS REQUESTED | Filtered - F: Field, L: Lab, FL: Field & Lab, N: None

Sample ID	Location	Matrix	Date	Time (24hr)	G=Grab C=Comp	# of Cont	Gamma, Biota	Pu 239	Gamma, Water									
Preservative								PLASTIC BAG	NONE 500 L									
Filtered																		
Preservative								4 C	None									
Analysis							Gamma, Biota	Pu 239	Gamma, Water									
AMC02.1-16050001-029	ILOR-LS-09	BIOTA	5/14/2016	2115	C	1	x	1										
AMC02.1-16050001-030	ILOR-LS-10	BIOTA	5/14/2016	2115	C	1	x	1										
AMC02.1-16050001-031	ROCK-LS-01	BIOTA	5/14/2016	1545	C	1	x	1										
AMC02.1-16050001-032	ROCK-LS-02	BIOTA	5/14/2016	1450	C	1	x	1										
AMC02.1-16050001-033	ROCK-LS-03	BIOTA	5/14/2016	1455	C	1	x	1										
AMC02.1-16050001-034	ROCK-LS-04	BIOTA	5/14/2016	1525	C	1	x	1										
AMC02.1-16050001-035	ROCK-LS-05	BIOTA	5/14/2016	1530	C	1	x	1										
AMC02.1-16050001-036	ROCK-LS-06	BIOTA	5/14/2016	1535	C	1	x	1										
AMC02.1-16050001-037	ROCK-LS-07	BIOTA	5/14/2016	1540	C	1	x	1										
AMC02.1-16050001-038	ROCK-LS-08	BIOTA	5/14/2016	1550	C	1	x	1										
AMC02.1-16050001-039	ROCK-LS-09	BIOTA	5/14/2016	1550	C	1	x	1										
AMC02.1-16050001-040	ROCK-LS-10	BIOTA	5/14/2016	1605	C	1	x	1										
AMC02.1-16050001-041	SEAW-LS-64-DE	WATER	5/16/2016	1655	C	1			1									
AMC02.1-16050001-042	SEAW-LS-115-DE	WATER	5/17/2016	855	C	1			1	Evidence of leakage								

ADDITIONAL COMMENTS/SPECIAL INSTRUCTIONS	RELINQUISHED BY	DATE/TIME	ACCEPTED BY	DATE/TIME
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Task Code: AMC02.1-16050001 | COC ID: AMC02.1-16050001-COC.4 | TURNAROUND TIME: | Page 4 of 7

PROJECT INFORMATION		LABORATORY		SAMPLING / SHIPPING	
Facility Name	Amchitka Site (Long Shot)	Lab Name:	Lawrence Livermore National Laboratory	Shipping Company:	
Project Number	1.104.1.04.611.2.01	Address:	700 East Avenue	Tracking Number:	
Project Name:	Amchitka Site (Long Shot)	City:	Livermore	State: CA	Cooler Count:
		Postal Code:	84550		Date Shipped:
		Phone Number:	925-424-2619		
		PO Number:			Sampled by (Print, Sign):
					Sampler 2:

SAMPLE DETAILS | ANALYSIS REQUESTED | Filtered - F: Field, L: Lab, FL: Field & Lab, N: None

Sample ID	Location	Matrix	Date	Time (24hr)	G-Grab C-Comp	# of Cont	Cs 137, Birch	Pu 239	Cs 137, Water									
Preservative									NOTE 10 L									
Filtered																		
Temp.								4 C	None									
AMC02.1-16050001-043	SEAW-LS-124-DE	WATER	5/17/2016	905	C	1			1									
AMC02.1-16050001-044	SEAW-LS-109-DE	WATER	5/16/2016	940	C	1			1									
AMC02.1-16050001-045	SEAW-LS-110-DE	WATER	5/16/2016	930	C	1			1									
AMC02.1-16050001-046	SEAW-LS-112-DE	WATER	5/15/2016	1715	C	1			1									
AMC02.1-16050001-047	SEAW-LS-116-DE	WATER	5/15/2016	1715	C	1			1									
AMC02.1-16050001-048	SEAW-LS-102-DE	WATER	5/17/2016	915	C	1			1									
AMC02.1-16050001-049	SEAW-LS-120-DE	WATER	5/15/2016	1645	C	1			1									
AMC02.1-16050001-050	SEAW-LS-123-DE	WATER	5/15/2016	1620	C	1			1									
AMC02.1-16050001-051	SEAW-LS-125-DE	WATER	5/15/2016	1605	C	1			1									
AMC02.1-16050001-052	SEAW-LS-113-DE	WATER	5/17/2016	925	C	1			1									
AMC02.1-16050001-053	SEAW-LS-84-DE	WATER	5/17/2016	935	C	1			1									
AMC02.1-16050001-054	SEAW-LS-96-DE	WATER	5/17/2016	945	C	1			1									
AMC02.1-16050001-055	SEAW-LS-74-DE	WATER	5/17/2016	955	C	1			1	Evidence of leakage								
AMC02.1-16050001-056	SEAW-LS-43-DE	WATER	5/16/2016	1530	C	1			1									

ADDITIONAL COMMENTS/SPECIAL INSTRUCTIONS	RELINQUISHED BY	DATE/TIME	ACCEPTED BY	DATE/TIME
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Task Code:	AMC02.1-16050001	COC ID:	AMC02.1-16050001-COC.5	TURNAROUND TIME:		Page 5 of 7

PROJECT INFORMATION		LABORATORY		SAMPLING / SHIPPING	
Facility Name	Amchitka Site (Long Shot)	Lab Name:	Lawrence Livermore National Laboratory	Shipping Company:	
Project Number	1.104.1.04.611.2.01	Address:	700 East Avenue	Tracking Number:	
Project Name:	Amchitka Site (Long Shot)	City:	Livermore State: CA	Cooler Count:	
		Postal Code:	84550	Date Shipped:	
		Phone Number:	925-424-2619	Sampled by (Print, Sign):	
		PO Number:			
				Sampler 2:	

SAMPLE DETAILS — ANALYSIS REQUESTED — Filtered - F: Field, L: Lab, FL: Field & Lab, N: None

Sample ID	Location	Matrix	Date	Time (24hr)	G=Grab C=Comp	# of Cont	Cs Iso, Biota	Pu Iso	Cs Iso, Water									
						Container			HDPE 20 L									
						Filtered												
						Preserv.		4 C	None									
						ANALYSIS	Cs Iso, Biota	Pu Iso	Cs Iso, Water									
AMC02.1-16050001-057	SEAW-LS-29-DE	WATER	5/16/2016	1445	C	1			1									
AMC02.1-16050001-058	SEAW-LS-35-DE	WATER	5/16/2016	1440	C	1			1									
AMC02.1-16050001-059	SEAW-LS-38-DE	WATER	5/16/2016	1150	C	1			1									
AMC02.1-16050001-060	SEAW-LS-46-DE	WATER	5/16/2016	1140	C	1			1									
AMC02.1-16050001-061	SEAW-LS-36-DE	WATER	5/16/2016	1505	C	1			1									
AMC02.1-16050001-062	SEAW-LS-52-DE	WATER	5/16/2016	1555	C	1			1									
AMC02.1-16050001-063	SEAW-LS-55-DE	WATER	5/16/2016	1130	C	1			1									
AMC02.1-16050001-064	SEAW-LS-58-DE	WATER	5/16/2016	1120	C	1			1									
AMC02.1-16050001-065	SEAW-LS-57-DE	WATER	5/17/2016	1000	C	1			1									
AMC02.1-16050001-066	SEAW-LS-61-DE	WATER	5/16/2016	1605	C	1			1									
AMC02.1-16050001-067	SEAW-LS-63-DE	WATER	5/16/2016	1205	C	1			1									
AMC02.1-16050001-068	SEAW-LS-67-DE	WATER	5/16/2016	1105	C	1			1									
AMC02.1-16050001-069	SEAW-LS-68-DE	WATER	5/16/2016	1055	C	1			1									
AMC02.1-16050001-070	SEAW-LS-70-DE	WATER	5/16/2016	1620	C	1			1									

X = shared container

ADDITIONAL COMMENTS/SPECIAL INSTRUCTIONS	RELINQUISHED BY	DATE/TIME	ACCEPTED BY	DATE/TIME
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Task Code:	AMC02.1-16050001	COC ID:	AMC02.1-16050001-COC.6	TURNAROUND TIME:		Page 6 of 7

PROJECT INFORMATION		LABORATORY		SAMPLING / SHIPPING	
Facility Name	Amchitka Site (Long Shot)	Lab Name:	Lawrence Livermore National Laboratory	Shipping Company:	
Project Number	1.104.1.04.611.2.01	Address:	700 East Avenue	Tracking Number:	
Project Name:	Amchitka Site (Long Shot)	City:	Livermore State: CA	Cooler Count:	
		Postal Code:	84550	Date Shipped:	
		Phone Number:	925-424-2619	Sampled by (Print, Sign):	
		PO Number:			
				Sampler 2:	

SAMPLE DETAILS / ANALYSIS REQUESTED — Filtered - F: Field, L: Lab, FL: Field & Lab, N: None

Sample ID	Location	Matrix	Date	Time (24hr)	G=Grab C=Comp	# of Cont	Cs Iso, Biota	Pu Iso	Cs Iso, Water									
Container									HDPE 20 L									
Filtered																		
Preserv.								4 C	None									
ANALYSIS																		
AMC02.1-16050001-071	SEAW-LS-73-DE	WATER	5/16/2016	1340	C	1			1									
AMC02.1-16050001-072	SEAW-LS-81-DE	WATER	5/16/2016	1645	C	1			1									
AMC02.1-16050001-073	SEAW-LS-79-DE	WATER	5/16/2016	1635	C	1			1									
AMC02.1-16050001-074	SEAW-LS-80-DE	WATER	5/16/2016	1350	C	1			1									
AMC02.1-16050001-075	SEAW-LS-87-DE	WATER	5/16/2016	1045	C	1			1									
AMC02.1-16050001-076	SEAW-LS-89-DE	WATER	5/16/2016	1410	C	1			1									
AMC02.1-16050001-077	SEAW-LS-91-DE	WATER	5/16/2016	1020	C	1			1									
AMC02.1-16050001-078	SEAW-LS-94-DE	WATER	5/16/2016	1035	C	1			1									
AMC02.1-16050001-079	SEAW-LS-98-DE	WATER	5/16/2016	1015	C	1			1									
AMC02.1-16050001-080	SEAW-LS-99-DE	WATER	5/16/2016	1005	C	1			1									
~~AMC02.1-16050001-081~~	~~SEAW-LS-201.SH~~	~~WATER~~			~~C~~	~~5~~			~~5~~									
~~AMC02.1-16050001-082~~	~~SEAW-LS-202.SH~~	~~WATER~~			~~C~~	~~5~~			~~5~~									
~~AMC02.1-16050001-083~~	~~SEAW-LS-203.SH~~	~~WATER~~			~~C~~	~~5~~			~~5~~									
AMC02.1-16050001-084	SEAW-LS-109-DE-DUP	WATER	5/16/2016	940	C	1			1									

X = shared container

ADDITIONAL COMMENTS/SPECIAL INSTRUCTIONS	RELINQUISHED BY	DATE/TIME	ACCEPTED BY	DATE/TIME
			T.F. Hamilton	6/14/16

Chain of Custody / Sample Submittal Form

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Task Code:	AMC02.1-16050001	COC ID:	AMC02.1-16050001-COC.7	TURNAROUND TIME:	Page 7 of 7

PROJECT INFORMATION		LABORATORY		SAMPLING / SHIPPING	
Facility Name	Amchitka Site (Long Shot)	Lab Name:	Lawrence Livermore National Laboratory	Shipping Company:	
Project Number	1.104.1.04.611.2.01	Address:	700 East Avenue	Tracking Number:	
Project Name:	Amchitka Site (Long Shot)	City:	Livermore State: CA	Cooler Count:	
		Postal Code:	84550	Date Shipped:	
		Phone Number:	925-424-2619	Sampled by (Print, Sign):	
		PO Number:			
				Sampler 2:	

SAMPLE DETAILS — ANALYSIS REQUESTED — Filtered - F: Field, L: Lab, FL: Field & Lab, N: None

Sample ID	Location	Matrix	Date	Time (24hr)	G=Grab C=Comp	# of Cont	Cs Iso, Biota	Pu Iso	Cs Iso, Water									
Container									HDPE 20 L									
Filtered																		
Preserv.								4 C	None									
ANALYSIS							Cs Iso, Biota	Pu Iso	Cs Iso, Water									
AMC02.1-16050001-085	SEAW-LS-43-DE-DUP	WATER	5/16/2016	1530	C	1			1									
AMC02.1-16050001-086	SEAW-LS-36-DE-DUP	WATER	5/16/2016	1505	C	1			1									
AMC02.1-16050001-087	SEAW-LS-80-DE-DUP	WATER	5/16/2016	1350	C	1			1									

X = shared container

ADDITIONAL COMMENTS/SPECIAL INSTRUCTIONS	RELINQUISHED BY	DATE/TIME	ACCEPTED BY	DATE/TIME
			T.F. Hamilton	6/14/16

Chain of Custody / Sample Submittal Form

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Task Code:	AMC03.1-16050001	COC ID:	AMC03.1-16050001-COC.1	TURNAROUND TIME:		Page 1 of 4

PROJECT INFORMATION		LABORATORY		SAMPLING / SHIPPING	
Facility Name	Amchitka Site (Milrow)	Lab Name:	Lawrence Livermore National Laboratory	Shipping Company:	
Project Number	1.104.1.04.611.2.01	Address:	700 East Avenue	Tracking Number:	
Project Name:	Amchitka Site (Milrow)	City:	Livermore State: CA	Cooler Count:	
		Postal Code:	84550	Date Shipped:	
		Phone Number:	925-424-2619	Sampled by (Print, Sign):	
		PO Number:			
				Sampler 2:	

SAMPLE DETAILS — ANALYSIS REQUESTED — Filtered - F: Field, L: Lab, FL: Field & Lab, N: None

Sample ID	Location	Matrix	Date	Time (24hr)	G=Grab C=Comp	# of Cont	Container		PLASTIC BAG										
							Filtered												
							Preserv.		4 C	None									
							ANALYSIS	Cs Iso, Biota	Pu Iso	Cs Iso, Water									
AMC03.1-16050001-001	FUCU-ML-01	BIOTA	5/14/2016	755	C	1	X = shared container	X	1										
AMC03.1-16050001-002	FUCU-ML-02	BIOTA	5/14/2016	815	C	1		X	1										
AMC03.1-16050001-003	FUCU-ML-03	BIOTA	5/14/2016	835	C	1		X	1										
~~AMC03.1-16050001-004~~	~~FUCU-ML-04~~	~~BIOTA~~			~~C~~	~~1~~		~~X~~	~~1~~										
~~AMC03.1-16050001-005~~	~~FUCU-ML-05~~	~~BIOTA~~			~~C~~	~~1~~		~~X~~	~~1~~										
~~AMC03.1-16050001-006~~	~~FUCU-ML-06~~	~~BIOTA~~			~~C~~	~~1~~		~~X~~	~~1~~										
~~AMC03.1-16050001-007~~	~~FUCU-ML-07~~	~~BIOTA~~			~~C~~	~~1~~		~~X~~	~~1~~										
~~AMC03.1-16050001-008~~	~~FUCU-ML-08~~	~~BIOTA~~			~~C~~	~~1~~		~~X~~	~~1~~										
~~AMC03.1-16050001-009~~	~~FUCU-ML-09~~	~~BIOTA~~			~~C~~	~~1~~		~~X~~	~~1~~										
~~AMC03.1-16050001-010~~	~~FUCU-ML-10~~	~~BIOTA~~			~~C~~	~~1~~		~~X~~	~~1~~										
AMC03.1-16050001-011	GREN-ML-01	BIOTA	5/13/2016	1605	C	1		X	1										
AMC03.1-16050001-012	GREN-ML-02	BIOTA	5/13/2016	1615	C	1		X	1										
AMC03.1-16050001-013	GREN-ML-03	BIOTA	5/13/2016	1620	C	1		X	1										
AMC03.1-16050001-014	GREN-ML-04	BIOTA	5/13/2016	1630	C	1		X	1										

ADDITIONAL COMMENTS/SPECIAL INSTRUCTIONS	RELINQUISHED BY	DATE/TIME	ACCEPTED BY	DATE/TIME
			T.F. Hamilton	6/14/16

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Chain of Custody / Sample Submittal Form

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Task Code:	AMC03.1-16050001	COC ID:	AMC03.1-16050001-COC.2	TURNAROUND TIME:		Page 2 of 4

PROJECT INFORMATION		LABORATORY		SAMPLING / SHIPPING	
Facility Name	Amchitka Site (Milrow)	Lab Name:	Lawrence Livermore National Laboratory	Shipping Company:	
Project Number	1.104.1.04.611.2.01	Address:	700 East Avenue	Tracking Number:	
Project Name:	Amchitka Site (Milrow)	City:	Livermore State: CA	Cooler Count:	
		Postal Code:	84550	Date Shipped:	
		Phone Number:	925-424-2619	Sampled by (Print, Sign):	
		PO Number:			
				Sampler 2:	

SAMPLE DETAILS — ANALYSIS REQUESTED — Filtered - F: Field, L: Lab, FL: Field & Lab, N: None

Sample ID	Location	Matrix	Date	Time (24hr)	G=Grab C=Comp	# of Cont	Container		PLASTIC BAG										
							Filtered												
							Preserv.		4 C	None									
							ANALYSIS	Cs Iso, Biota	Pu Iso	Cs Iso, Water									
AMC03.1-16050001-015	GREN-ML-05	BIOTA	5/13/2016	1640	C	1	X = shared container	X	1										
AMC03.1-16050001-016	GREN-ML-06	BIOTA	5/13/2016	1645	C	1		X	1										
AMC03.1-16050001-017	GREN-ML-07	BIOTA	5/13/2016	1705	C	1		X	1										
AMC03.1-16050001-018	GREN-ML-08	BIOTA	5/13/2016	1750	C	1		X	1										
AMC03.1-16050001-019	GREN-ML-09	BIOTA	5/13/2016	1730	C	1		X	1										
AMC03.1-16050001-020	GREN-ML-10	BIOTA	5/13/2016	1850	C	1		X	1										
AMC03.1-16050001-021	ILOR-ML-01	BIOTA	5/13/2016	1740	C	1		X	1										
AMC03.1-16050001-022	ILOR-ML-02	BIOTA	5/13/2016	1750	C	1		X	1										
AMC03.1-16050001-023	ILOR-ML-03	BIOTA	5/13/2016	1755	C	1		X	1										
AMC03.1-16050001-024	ILOR-ML-04	BIOTA	5/13/2016	1805	C	1		X	1										
AMC03.1-16050001-025	ILOR-ML-05	BIOTA	5/13/2016	1815	C	1		X	1										
AMC03.1-16050001-026	ILOR-ML-06	BIOTA	5/13/2016	1825	C	1		X	1										
AMC03.1-16050001-027	ILOR-ML-07	BIOTA	5/13/2016	1835	C	1		X	1										
AMC03.1-16050001-028	ILOR-ML-08	BIOTA	5/13/2016	1840	C	1		X	1										

ADDITIONAL COMMENTS/SPECIAL INSTRUCTIONS	RELINQUISHED BY	DATE/TIME	ACCEPTED BY	DATE/TIME
			T.F. Hamilton	6/14/16

Chain of Custody / Sample Submittal Form

Print COC
Ver 6.4.2.1

Task Code:	AMC03.1-16050001	COC ID:	AMC03.1-16050001-COC.3	TURNAROUND TIME:		Page 3 of 4

PROJECT INFORMATION		LABORATORY		SAMPLING / SHIPPING	
Facility Name	Amchitka Site (Milrow)	Lab Name:	Lawrence Livermore National Laboratory	Shipping Company:	
Project Number	1.104.1.04.611.2.01	Address:	700 East Avenue	Tracking Number:	
Project Name:	Amchitka Site (Milrow)	City:	Livermore State: CA	Cooler Count:	
		Postal Code:	84550	Date Shipped:	
		Phone Number:	925-424-2619	Sampled by (Print, Sign):	
		PO Number:			
				Sampler 2:	

SAMPLE DETAILS — ANALYSIS REQUESTED — Filtered - F: Field, L: Lab, FL: Field & Lab, N: None

Sample ID	Location	Matrix	Date	Time (24hr)	G=Grab C=Comp	# of Cont	Cs Iso, Biota	Pu Iso	Cs Iso, Water									
						Container		PLASTIC BAG	HDPE 20 L									
						Filtered												
						Preserv.		4 C	None									
						ANALYSIS	Cs Iso, Biota	Pu Iso	Cs Iso, Water									
AMC03.1-16050001-029	ILOR-ML-09	BIOTA	5/13/2016	1850	C	1	X	1										
AMC03.1-16050001-030	ILOR-ML-10	BIOTA	5/13/2016	1900	C	1	X	1										
AMC03.1-16050001-031	ROCK-ML-01	BIOTA	5/13/2016	1545	C	1	X	1										
AMC03.1-16050001-032	ROCK-ML-02	BIOTA	5/13/2016	1545	C	1	X	1										
AMC03.1-16050001-033	ROCK-ML-03	BIOTA	5/13/2016	1550	C	1	X	1										
AMC03.1-16050001-034	ROCK-ML-04	BIOTA	5/13/2016	1550	C	1	X	1										
AMC03.1-16050001-035	ROCK-ML-05	BIOTA	5/13/2016	1555	C	1	X	1										
AMC03.1-16050001-036	ROCK-ML-06	BIOTA	5/13/2016	1602	C	1	X	1										
AMC03.1-16050001-037	ROCK-ML-07	BIOTA	5/13/2016	1615	C	1	X	1										
AMC03.1-16050001-038	ROCK-ML-08	BIOTA	5/13/2016	1620	C	1	X	1										
AMC03.1-16050001-039	ROCK-ML-09	BIOTA	5/13/2016	1630	C	1	X	1										
AMC03.1-16050001-040	ROCK-ML-10	BIOTA	5/13/2016	1640	C	1	X	1										
AMC03.1-16050001-041	SEAW-ML-01-SH	WATER	5/14/2016	955	C	1			1									
~~AMC03.1-16050001-042~~	~~SEAW-ML-02-SH~~	~~WATER~~			~~C~~	~~5~~			~~5~~									

X = shared container

ADDITIONAL COMMENTS/SPECIAL INSTRUCTIONS	RELINQUISHED BY	DATE/TIME	ACCEPTED BY	DATE/TIME
			T.F. Hamilton	6/14/16

Chain of Custody / Sample Submittal Form

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Task Code:	AMC03.1-16050001	COC ID:	AMC03.1-16050001-COC.4	TURNAROUND TIME:		Page 4 of 4

PROJECT INFORMATION		LABORATORY		SAMPLING / SHIPPING	
Facility Name	Amchitka Site (Milrow)	Lab Name:	Lawrence Livermore National Laboratory	Shipping Company:	
Project Number	1.104.1.04.611.2.01	Address:	700 East Avenue	Tracking Number:	
Project Name:	Amchitka Site (Milrow)	City:	Livermore State: CA	Cooler Count:	
		Postal Code:	84550	Date Shipped:	
		Phone Number:	925-424-2619	Sampled by (Print, Sign):	
		PO Number:			
				Sampler 2:	

SAMPLE DETAILS — ANALYSIS REQUESTED — Filtered - F: Field, L: Lab, FL: Field & Lab, N: None

Sample ID	Location	Matrix	Date	Time (24hr)	G=Grab C=Comp	# of Cont	Container			HDPE 20 L								
							Filtered											
							Preserv.		4 C	None								
							ANALYSIS	Cs Iso, Biota	Pu Iso	Cs Iso, Water								
~~AMC03.1-16050001-043~~	~~SEAW-ML-03-SH~~	~~WATER~~			~~C~~	~~5~~				~~5~~								
							X = shared container											

ADDITIONAL COMMENTS/SPECIAL INSTRUCTIONS	RELINQUISHED BY	DATE/TIME	ACCEPTED BY	DATE/TIME
			T.F. Hamilton	6/14/16

Chain of Custody / Sample Submittal Form

Print COC
Ver 6.4.2.1

Task Code:	AMC05.1-16050001	COC ID:	AMC5.1-16050001-COC.1	TURNAROUND TIME:		Page 1 of 4

PROJECT INFORMATION		LABORATORY		SAMPLING / SHIPPING	
Facility Name	Amchitka Site (Cannikin)	Lab Name:	Lawrence Livermore National Laboratory	Shipping Company:	
Project Number	1.104.1.04.611.2.01	Address:	700 East Avenue	Tracking Number:	
Project Name:	Amchitka Site (Cannikin)	City:	Livermore State: CA	Cooler Count:	
		Postal Code:	84550	Date Shipped:	
		Phone Number:	925-424-2619	Sampled by (Print, Sign):	
		PO Number:			
				Sampler 2:	

SAMPLE DETAILS — ANALYSIS REQUESTED — Filtered - F: Field, L: Lab, FL: Field & Lab, N: None

Sample ID	Location	Matrix	Date	Time (24hr)	G=Grab C=Comp	# of Cont	Container		PLASTIC BAG										
							Filtered												
							Preserv.		4 C	None									
							ANALYSIS	Cs Iso, Biota	Pu Iso	Cs Iso, Water									
AMC05.1-16050001-001	FUCU-CN-01	BIOTA	5/18/2016	1130	C	#NAME?	X = shared container	X	1										
AMC05.1-16050001-002	FUCU-CN-02	BIOTA	5/18/2016	1300	C	#NAME?		X	1										
AMC05.1-16050001-003	FUCU-CN-03	BIOTA	5/18/2016	1200	C	#NAME?		X	1										
~~AMC05.1-16050001-004~~	~~FUCU-CN-04~~	~~BIOTA~~			~~C~~	~~#NAME?~~		~~X~~	~~1~~										
~~AMC05.1-16050001-005~~	~~FUCU-CN-05~~	~~BIOTA~~			~~C~~	~~#NAME?~~		~~X~~	~~1~~										
~~AMC05.1-16050001-006~~	~~FUCU-CN-06~~	~~BIOTA~~			~~C~~	~~#NAME?~~		~~X~~	~~1~~										
~~AMC05.1-16050001-007~~	~~FUCU-CN-07~~	~~BIOTA~~			~~C~~	~~#NAME?~~		~~X~~	~~1~~										
~~AMC05.1-16050001-008~~	~~FUCU-CN-08~~	~~BIOTA~~			~~C~~	~~#NAME?~~		~~X~~	~~1~~										
~~AMC05.1-16050001-009~~	~~FUCU-CN-09~~	~~BIOTA~~			~~C~~	~~#NAME?~~		~~X~~	~~1~~										
~~AMC05.1-16050001-010~~	~~FUCU-CN-10~~	~~BIOTA~~			~~C~~	~~#NAME?~~		~~X~~	~~1~~										
AMC05.1-16050001-011	GREN-CN-01	BIOTA	5/15/2016	1610	C	#NAME?		X	1										
AMC05.1-16050001-012	GREN-CN-02	BIOTA	5/15/2016	1615	C	#NAME?		X	1										
AMC05.1-16050001-013	GREN-CN-03	BIOTA	5/15/2016	1615	C	#NAME?		X	1										
AMC05.1-16050001-014	GREN-CN-04	BIOTA	5/15/2016	1620	C	#NAME?		X	1										

ADDITIONAL COMMENTS/SPECIAL INSTRUCTIONS	RELINQUISHED BY	DATE/TIME	ACCEPTED BY	DATE/TIME
			T.F. Hamilton	6/14/16

Chain of Custody / Sample Submittal Form

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Ver 6.4.2.1

Task Code:	AMC05.1-16050001	COC ID:	AMC5.1-16050001-COC.2	TURNAROUND TIME:		Page 2 of 4

PROJECT INFORMATION		LABORATORY		SAMPLING / SHIPPING	
Facility Name	Amchitka Site (Cannikin)	Lab Name:	Lawrence Livermore National Laboratory	Shipping Company:	
Project Number	1.104.1.04.611.2.01	Address:	700 East Avenue	Tracking Number:	
Project Name:	Amchitka Site (Cannikin)	City:	Livermore State: CA	Cooler Count:	
		Postal Code:	84550	Date Shipped:	
		Phone Number:	925-424-2619	Sampled by (Print, Sign):	
		PO Number:			
				Sampler 2:	

SAMPLE DETAILS — ANALYSIS REQUESTED — Filtered - F: Field, L: Lab, FL: Field & Lab, N: None

Sample ID	Location	Matrix	Date	Time (24hr)	G=Grab C=Comp	# of Cont	Cs Iso, Biota	Pu Iso	Cs Iso, Water									
						Container		PLASTIC BAG										
						Filtered												
						Preserv.		4 C	None									
						ANALYSIS	Cs Iso, Biota	Pu Iso	Cs Iso, Water									
AMC05.1-16050001-015	GREN-CN-05	BIOTA	5/15/2016	1620	C	#NAME?	X	1										
AMC05.1-16050001-016	GREN-CN-06	BIOTA	5/15/2016	1625	C	#NAME?	X	1										
AMC05.1-16050001-017	GREN-CN-07	BIOTA	5/15/2016	1625	C	#NAME?	X	1										
AMC05.1-16050001-018	GREN-CN-08	BIOTA	5/15/2016	1635	C	#NAME?	X	1										
AMC05.1-16050001-019	GREN-CN-09	BIOTA	5/15/2016	1635	C	#NAME?	X	1										
AMC05.1-16050001-020	GREN-CN-10	BIOTA	5/15/2016	1640	C	#NAME?	X	1										
AMC05.1-16050001-021	ILOR-01	BIOTA	5/15/2016	1935	C	#NAME?	X	1										
AMC05.1-16050001-022	ILOR-02	BIOTA	5/15/2016	1940	C	#NAME?	X	1										
AMC05.1-16050001-023	ILOR-03	BIOTA	5/15/2016	1940	C	#NAME?	X	1										
AMC05.1-16050001-024	ILOR-04	BIOTA	5/15/2016	1940	C	#NAME?	X	1										
AMC05.1-16050001-025	ILOR-05	BIOTA	5/15/2016	1945	C	#NAME?	X	1										
AMC05.1-16050001-026	ILOR-06	BIOTA	5/15/2016	1945	C	#NAME?	X	1										
AMC05.1-16050001-027	ILOR-07	BIOTA	5/15/2016	1950	C	#NAME?	X	1										
AMC05.1-16050001-028	ILOR-08	BIOTA	5/15/2016	1950	C	#NAME?	X	1										

X = shared container

ADDITIONAL COMMENTS/SPECIAL INSTRUCTIONS	RELINQUISHED BY	DATE/TIME	ACCEPTED BY	DATE/TIME
			T.F. Hamilton	6/14/16

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Chain of Custody / Sample Submittal Form

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Ver 6.4.2.1

Task Code: AMC05.1-16050001 | COC ID: AMC5.1-16050001-COC.3 | TURNAROUND TIME: | Page 3 of 4

PROJECT INFORMATION		LABORATORY		SAMPLING / SHIPPING	
Facility Name:	Amchitka Site (Cannikin)	Lab Name:	Lawrence Livermore National Laboratory	Shipping Company:	
Project Number:	1.104.1.04.611.2.01	Address:	700 East Avenue	Tracking Number:	
Project Name:	Amchitka Site (Cannikin)	City:	Livermore	Cooler Count:	
		State:	CA	Date Shipped:	
		Postal Code:	84550		
		Phone Number:	925-424-2619	Sampled by (Print, Sign):	
		PO Number:			
				Sampler 2:	

SAMPLE DETAILS | ANALYSIS REQUESTED | Filtered - F: Field, L: Lab, FL: Field & Lab, N: None

Sample ID	Location	Matrix	Date	Time (24hr)	G=Grab C=Comp	# of Cont	Gamma, Biota	Pu 239	Gamma, Water									
Preservative																		
Container								PLASTIC BAG	HDPE 250 L									
Filtered																		
Preserv.								4 C	None									
AMC05.1-16050001-029	ILOR-09	BIOTA	5/15/2016	1955	C	#NAME?	X	1										
AMC05.1-16050001-030	ILOR-10	BIOTA	5/15/2016	1955	C	#NAME?	X	1										
AMC05.1-16050001-031	ROCK-CN-01	BIOTA	5/15/2016	1100	C	#NAME?	X	1										
AMC05.1-16050001-032	ROCK-CN-02	BIOTA	5/15/2016	1100	C	#NAME?	X	1										
AMC05.1-16050001-033	ROCK-CN-03	BIOTA	5/15/2016	1105	C	#NAME?	X	1										
AMC05.1-16050001-034	ROCK-CN-04	BIOTA	5/15/2016	1105	C	#NAME?	X	1										
AMC05.1-16050001-035	ROCK-CN-05	BIOTA	5/15/2016	1110	C	#NAME?	X	1										
AMC05.1-16050001-036	ROCK-CN-06	BIOTA	5/15/2016	1110	C	#NAME?	X	1										
AMC05.1-16050001-037	ROCK-CN-07	BIOTA	5/15/2016	1115	C	#NAME?	X	1										
AMC05.1-16050001-038	ROCK-CN-08	BIOTA	5/15/2016	1115	C	#NAME?	X	1										
AMC05.1-16050001-039	ROCK-CN-09	BIOTA	5/15/2016	1120	C	#NAME?	X	1										
AMC05.1-16050001-040	ROCK-CN-10	BIOTA	5/15/2016	1130	C	#NAME?	X	1										
AMC05.1-16050001-041	SEAW-CN-01-SH	WATER	5/15/2016	1450	C	1			1	Evidence of leakage								
~~AMC05.1-16050001-042~~	~~SEAW-CN-02-SH~~	~~WATER~~			~~C~~	~~#NAME? 2~~			~~1~~									

ADDITIONAL COMMENTS/SPECIAL INSTRUCTIONS	RELINQUISHED BY	DATE/TIME	ACCEPTED BY	DATE/TIME
			T.F. Hamilton	6/14/16

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Chain of Custody / Sample Submittal Form

Print COC
Ver 6.4.2.1

Task Code:	AMC05.1-16050001	COC ID:	AMC5.1-16050001-COC.4	TURNAROUND TIME:		Page 4 of 4

PROJECT INFORMATION		LABORATORY		SAMPLING / SHIPPING	
Facility Name	Amchitka Site (Cannikin)	Lab Name:	Lawrence Livermore National Laboratory	Shipping Company:	
Project Number	1.104.1.04.611.2.01	Address:	700 East Avenue	Tracking Number:	
Project Name:	Amchitka Site (Cannikin)	City:	Livermore State: CA	Cooler Count:	
		Postal Code:	84550	Date Shipped:	
		Phone Number:	925-424-2619	Sampled by (Print, Sign):	
		PO Number:			
				Sampler 2:	

SAMPLE DETAILS — ANALYSIS REQUESTED — Filtered - F: Field, L: Lab, FL: Field & Lab, N: None

Sample ID	Location	Matrix	Date	Time (24hr)	G=Grab C=Comp	# of Cont	Container			HDPE 20 L								
							Filtered											
							Preserv.		4 C	None								
							ANALYSIS	Cs Iso, Biota	Pu Iso	Cs Iso, Water								
~~AMC05.1-16050001-043~~	~~SEAW-CN-03-SH~~	~~WATER~~			~~C~~	~~#NAME?~~				~~5~~								
						#NAME?												
						#NAME?												
						#NAME?												
						#NAME?												
						#NAME?												
						#NAME?												
						#NAME?												
						#NAME?												
						#NAME?												
						#NAME?												
						#NAME?												
						#NAME?												
						#NAME?												
						#NAME?												
						#NAME?												

X = shared container

ADDITIONAL COMMENTS/SPECIAL INSTRUCTIONS	RELINQUISHED BY	DATE/TIME	ACCEPTED BY	DATE/TIME
			T.F. Hamilton	6/14/16

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Chain of Custody / Sample Submittal Form

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Ver 6.4.2.1

Task Code:	AMC13.1-16050001	COC ID:	AMC13.1-16050001-COC.1	TURNAROUND TIME:	Page 1 of 1

PROJECT INFORMATION		LABORATORY		SAMPLING / SHIPPING	
Facility Name	Amchitka Site (Adak Island)	Lab Name:	Lawrence Livermore National Laboratory	Shipping Company:	
Project Number	1.104.1.04.611.2.01	Address:	700 East Avenue	Tracking Number:	
Project Name:	Amchitka Site (Adak Island)	City:	Livermore State: CA	Cooler Count:	
		Postal Code:	84550	Date Shipped:	
		Phone Number:	925-424-2619	Sampled by (Print, Sign):	
		PO Number:			
				Sampler 2:	

SAMPLE DETAILS — ANALYSIS REQUESTED — Filtered - F: Field, L: Lab, FL: Field & Lab, N: None

Sample ID	Location	Matrix	Date	Time (24hr)	G=Grab C=Comp	# of Cont	Container		PLASTIC BAG	HDPE 20 L									
							Filtered												
							Preserv.		4 C	None									
							ANALYSIS	Cs Iso, Biota	Pu Iso	Cs Iso, Water									
AMC13.1-16050001-001	DOLL-AD-01	BIOTA	5/21/2016	1200	C	#NAME?		X	1										
AMC13.1-16050001-002	FRES-AD-01	WATER	5/21/2016	1130	C	1				1									
						#NAME?													
						#NAME?													
						#NAME?													
						#NAME?													
						#NAME?													
						#NAME?													
						#NAME?													
						#NAME?													
						#NAME?													
						#NAME?													
						#NAME?													
						#NAME?													

X = shared container

ADDITIONAL COMMENTS/SPECIAL INSTRUCTIONS	RELINQUISHED BY	DATE/TIME	ACCEPTED BY	DATE/TIME
			T.F. Hamilton	6/14/16

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Chain of Custody / Sample Submittal Form

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Task Code:	AMC14.1-16050001	COC ID:	AMC14.1-16050001-COC.1	TURNAROUND TIME:		Page 1 of 4

PROJECT INFORMATION		LABORATORY		SAMPLING / SHIPPING	
Facility Name	Amchitka Site (Adak Island North)	Lab Name:	Lawrence Livermore National Laboratory	Shipping Company:	
Project Number	1.104.1.04.611.2.01	Address:	700 East Avenue	Tracking Number:	
Project Name:	Amchitka Site (Adak Island North)	City:	Livermore State: CA	Cooler Count:	
		Postal Code:	84550	Date Shipped:	
		Phone Number:	925-424-2619	Sampled by (Print, Sign):	
		PO Number:			
				Sampler 2:	

SAMPLE DETAILS — ANALYSIS REQUESTED — Filtered - F: Field, L: Lab, FL: Field & Lab, N: None

Sample ID	Location	Matrix	Date	Time (24hr)	G=Grab C=Comp	# of Cont	Cs Iso, Biota	Pu Iso	Cs Iso, Water									
						Container		PLASTIC BAG										
						Filtered												
						Preserv.		4 C	None									
						ANALYSIS	Cs Iso, Biota	Pu Iso	Cs Iso, Water									
AMC14.1-16050001-001	FUCU-AN-01	BIOTA	5/20/2106	930	C	#NAME?	X	1										
AMC14.1-16050001-002	FUCU-AN-02	BIOTA	5/20/2106	1015	C	#NAME?	X	1										
AMC14.1-16050001-003	FUCU-AN-03	BIOTA	5/20/2106	1100	C	#NAME?	X	1										
~~AMC14.1-16050001-004~~	~~FUCU-AN-04~~	~~BIOTA~~			~~C~~	~~#NAME?~~	~~X~~	~~1~~										
~~AMC14.1-16050001-005~~	~~FUCU-AN-05~~	~~BIOTA~~			~~C~~	~~#NAME?~~	~~X~~	~~1~~										
~~AMC14.1-16050001-006~~	~~FUCU-AN-06~~	~~BIOTA~~			~~C~~	~~#NAME?~~	~~X~~	~~1~~										
~~AMC14.1-16050001-007~~	~~FUCU-AN-07~~	~~BIOTA~~			~~C~~	~~#NAME?~~	~~X~~	~~1~~										
~~AMC14.1-16050001-008~~	~~FUCU-AN-08~~	~~BIOTA~~			~~C~~	~~#NAME?~~	~~X~~	~~1~~										
~~AMC14.1-16050001-009~~	~~FUCU-AN-09~~	~~BIOTA~~			~~C~~	~~#NAME?~~	~~X~~	~~1~~										
~~AMC14.1-16050001-010~~	~~FUCU-AN-10~~	~~BIOTA~~			~~C~~	~~#NAME?~~	~~X~~	~~1~~										
AMC14.1-16050001-011	GREN-AN-01	BIOTA	5/19/2016	1615	C	#NAME?	X	1										
AMC14.1-16050001-012	GREN-AN-02	BIOTA	5/20/2106	1100	C	#NAME?	X	1										
AMC14.1-16050001-013	GREN-AN-03	BIOTA	5/20/2106	1105	C	#NAME?	X	1										
AMC14.1-16050001-014	GREN-AN-04	BIOTA	5/20/2106	1110	C	#NAME?	X	1										

X = shared container

ADDITIONAL COMMENTS/SPECIAL INSTRUCTIONS	RELINQUISHED BY	DATE/TIME	ACCEPTED BY	DATE/TIME
			T.F. Hamilton	6/14/16

Chain of Custody / Sample Submittal Form

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Task Code:	AMC14.1-16050001	COC ID:	AMC14.1-16050001-COC.2	TURNAROUND TIME:	Page 2 of 4

PROJECT INFORMATION		LABORATORY		SAMPLING / SHIPPING	
Facility Name	Amchitka Site (Adak Island North)	Lab Name:	Lawrence Livermore National Laboratory	Shipping Company:	
Project Number	1.104.1.04.611.2.01	Address:	700 East Avenue	Tracking Number:	
Project Name:	Amchitka Site (Adak Island North)	City:	Livermore State: CA	Cooler Count:	
		Postal Code:	84550	Date Shipped:	
		Phone Number:	925-424-2619	Sampled by (Print, Sign):	
		PO Number:			
				Sampler 2:	

SAMPLE DETAILS — ANALYSIS REQUESTED — Filtered - F: Field, L: Lab, FL: Field & Lab, N: None

Sample ID	Location	Matrix	Date	Time (24hr)	G=Grab C=Comp	# of Cont	Cs Iso, Biota	Pu Iso	Cs Iso, Water									
Container								PLASTIC BAG										
Filtered																		
Preserv.								4 C	None									
ANALYSIS							Cs Iso, Biota	Pu Iso	Cs Iso, Water									
AMC14.1-16050001-015	GREN-AN-05	BIOTA	5/20/2016	1115	C	#NAME?	X	1										
AMC14.1-16050001-016	GREN-AN-06	BIOTA	5/20/2016	1120	C	#NAME?	X	1										
AMC14.1-16050001-017	GREN-AN-07	BIOTA	5/20/2016	1125	C	#NAME?	X	1										
AMC14.1-16050001-018	GREN-AN-08	BIOTA	5/20/2016	1130	C	#NAME?	X	1										
AMC14.1-16050001-019	GREN-AN-09	BIOTA	5/20/2016	1135	C	#NAME?	X	1										
AMC14.1-16050001-020	GREN-AN-10	BIOTA	5/20/2016	1200	C	#NAME?	X	1										
AMC14.1-16050001-021	ILOR-AN-01	BIOTA	5/19/2016	1610	C	#NAME?	X	1										
AMC14.1-16050001-022	ILOR-AN-02	BIOTA	5/19/2016	1615	C	#NAME?	X	1										
AMC14.1-16050001-023	ILOR-AN-03	BIOTA	5/19/2016	1620	C	#NAME?	X	1										
AMC14.1-16050001-024	ILOR-AN-04	BIOTA	5/19/2016	1625	C	#NAME?	X	1										
AMC14.1-16050001-025	ILOR-AN-05	BIOTA	5/19/2016	1630	C	#NAME?	X	1										
AMC14.1-16050001-026	ILOR-AN-06	BIOTA	5/20/2016	1000	C	#NAME?	X	1										
AMC14.1-16050001-027	ILOR-AN-07	BIOTA	5/20/2016	1005	C	#NAME?	X	1										
AMC14.1-16050001-028	ILOR-AN-08	BIOTA	5/20/2016	1010	C	#NAME?	X	1										

X = shared container

ADDITIONAL COMMENTS/SPECIAL INSTRUCTIONS	RELINQUISHED BY	DATE/TIME	ACCEPTED BY	DATE/TIME
			T.F. Hamilton	6/14/16

Chain of Custody / Sample Submittal Form

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Task Code:	AMC14.1-16050001	COC ID:	AMC14.1-16050001-COC.3	TURNAROUND TIME:		Page 3 of 4

PROJECT INFORMATION		LABORATORY		SAMPLING / SHIPPING	
Facility Name	Amchitka Site (Adak Island North)	Lab Name:	Lawrence Livermore National Laboratory	Shipping Company:	
Project Number	1.104.1.04.611.2.01	Address:	700 East Avenue	Tracking Number:	
Project Name:	Amchitka Site (Adak Island North)	City:	Livermore State: CA	Cooler Count:	
		Postal Code:	84550	Date Shipped:	
		Phone Number:	925-424-2619	Sampled by (Print, Sign):	
		PO Number:			
				Sampler 2:	

SAMPLE DETAILS — ANALYSIS REQUESTED — Filtered - F: Field, L: Lab, FL: Field & Lab, N: None

Sample ID	Location	Matrix	Date	Time (24hr)	G=Grab C=Comp	# of Cont	Cs Iso, Biota	Pu Iso	Cs Iso, Water									
Container								PLASTIC BAG	HDPE 20 L									
Filtered																		
Preserv.								4 C	None									
ANALYSIS							Cs Iso, Biota	Pu Iso	Cs Iso, Water									
AMC14.1-16050001-029	ILOR-AN-09	BIOTA	5/20/2016	1015	C	#NAME?	X	1										
AMC14.1-16050001-030	ILOR-AN-10	BIOTA	5/20/2016	1020	C	#NAME?	X	1										
AMC14.1-16050001-031	ROCK-AN-01	BIOTA	5/19/2016	1600	C	#NAME?	X	1										
AMC14.1-16050001-032	ROCK-AN-02	BIOTA	5/19/2016	1605	C	#NAME?	X	1										
AMC14.1-16050001-033	ROCK-AN-03	BIOTA	5/19/2016	1610	C	#NAME?	X	1										
AMC14.1-16050001-034	ROCK-AN-04	BIOTA	5/19/2016	1615	C	#NAME?	X	1										
AMC14.1-16050001-035	ROCK-AN-05	BIOTA	5/19/2016	1620	C	#NAME?	X	1										
AMC14.1-16050001-036	ROCK-AN-06	BIOTA	5/20/2016	1100	C	#NAME?	X	1										
AMC14.1-16050001-037	ROCK-AN-07	BIOTA	5/20/2016	1105	C	#NAME?	X	1										
AMC14.1-16050001-038	ROCK-AN-08	BIOTA	5/20/2016	1110	C	#NAME?	X	1										
AMC14.1-16050001-039	ROCK-AN-09	BIOTA	5/20/2016	1115	C	#NAME?	X	1										
AMC14.1-16050001-040	ROCK-AN-10	BIOTA	5/20/2016	1130	C	#NAME?	X	1										
AMC14.1-16050001-041	SEAW-AN-01-SH	WATER	5/20/2016	945	C	1			1									
~~AMC14.1-16050001-042~~	~~SEAW-AN-02-SH~~	~~WATER~~	~~5/20/2016~~		~~C~~	~~#NAME?~~			~~5~~									

X = shared container

ADDITIONAL COMMENTS/SPECIAL INSTRUCTIONS	RELINQUISHED BY	DATE/TIME	ACCEPTED BY	DATE/TIME
			T.F. Hamilton	6/14/16

Chain of Custody / Sample Submittal Form

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Task Code:	AMC14.1-16050001	COC ID:	AMC14.1-16050001-COC.4	TURNAROUND TIME:		Page 4 of 4

PROJECT INFORMATION		LABORATORY		SAMPLING / SHIPPING	
Facility Name	Amchitka Site (Adak Island North)	Lab Name:	Lawrence Livermore National Laboratory	Shipping Company:	
Project Number	1.104.1.04.611.2.01	Address:	700 East Avenue	Tracking Number:	
Project Name:	Amchitka Site (Adak Island North)	City:	Livermore State: CA	Cooler Count:	
		Postal Code:	84550	Date Shipped:	
		Phone Number:	925-424-2619	Sampled by (Print, Sign):	
		PO Number:			
				Sampler 2:	

SAMPLE DETAILS / ANALYSIS REQUESTED — Filtered - F: Field, L: Lab, FL: Field & Lab, N: None

Sample ID	Location	Matrix	Date	Time (24hr)	G=Grab C=Comp	# of Cont	Cs Iso, Biota	Pu Iso	Cs Iso, Water									
Container									HDPE 20 L									
Filtered																		
Preserv.								4 C	None									
~~AMC14.1-16050001-043~~	~~SEAW-AN-03-SH~~	~~WATER~~			~~C~~	~~#NAME?~~			~~S~~									
						#NAME?												
						#NAME?												
						#NAME?												
						#NAME?												
						#NAME?												
						#NAME?												
						#NAME?												
						#NAME?												
						#NAME?												
						#NAME?												
						#NAME?												
						#NAME?												
						#NAME?												

X = shared container

ADDITIONAL COMMENTS/SPECIAL INSTRUCTIONS	RELINQUISHED BY	DATE/TIME	ACCEPTED BY	DATE/TIME
			T.F. Hamilton	6/14/16

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Chain of Custody / Sample Submittal Form

Print COC
Ver 6.4.2.1

Task Code:	AMC15.1-16050001	COC ID:	AMC15.1-16050001-COC.1	TURNAROUND TIME:		Page 1 of 4

PROJECT INFORMATION		LABORATORY		SAMPLING / SHIPPING	
Facility Name	Amchitka Site (Adak Island South)	Lab Name:	Lawrence Livermore National Laboratory	Shipping Company:	
Project Number	1.104.1.04.611.2.01	Address:	700 East Avenue	Tracking Number:	
Project Name:	Amchitka Site (Adak Island South)	City:	Livermore State: CA	Cooler Count:	
		Postal Code:	84550	Date Shipped:	
		Phone Number:	925-424-2619	Sampled by (Print, Sign):	
		PO Number:			
				Sampler 2:	

SAMPLE DETAILS — ANALYSIS REQUESTED — Filtered - F: Field, L: Lab, FL: Field & Lab, N: None

Sample ID	Location	Matrix	Date	Time (24hr)	G=Grab C=Comp	# of Cont	Cs Iso, Biota	Pu Iso	Cs Iso, Water									
						Container		PLASTIC BAG										
						Filtered												
						Preserv.		4 C	None									
						ANALYSIS	Cs Iso, Biota	Pu Iso	Cs Iso, Water									
AMC15.1-16050001-001	FUCU-AS-01	BIOTA	5/19/2016	1300	C	#NAME?	X	1										
AMC15.1-16050001-002	FUCU-AS-02	BIOTA	5/19/2016	1310	C	#NAME?	X	1										
AMC15.1-16050001-003	FUCU-AS-03	BIOTA	5/19/2016	1320	C	#NAME?	X	1										
~~AMC15.1-16050001-004~~	~~FUCU-AS-04~~	~~BIOTA~~			~~C~~	~~#NAME?~~	~~X~~	~~1~~										
~~AMC15.1-16050001-005~~	~~FUCU-AS-05~~	~~BIOTA~~			~~C~~	~~#NAME?~~	~~X~~	~~1~~										
~~AMC15.1-16050001-006~~	~~FUCU-AS-06~~	~~BIOTA~~			~~C~~	~~#NAME?~~	~~X~~	~~1~~										
~~AMC15.1-16050001-007~~	~~FUCU-AS-07~~	~~BIOTA~~			~~C~~	~~#NAME?~~	~~X~~	~~1~~										
~~AMC15.1-16050001-008~~	~~FUCU-AS-08~~	~~BIOTA~~			~~C~~	~~#NAME?~~	~~X~~	~~1~~										
~~AMC15.1-16050001-009~~	~~FUCU-AS-09~~	~~BIOTA~~			~~C~~	~~#NAME?~~	~~X~~	~~1~~										
~~AMC15.1-16050001-010~~	~~FUCU-AS-10~~	~~BIOTA~~			~~C~~	~~#NAME?~~	~~X~~	~~1~~										
AMC15.1-16050001-011	GREN-AS-01	BIOTA	5/19/2016	1100	C	#NAME?	X	1										
AMC15.1-16050001-012	GREN-AS-02	BIOTA	5/19/2016	1105	C	#NAME?	X	1										
AMC15.1-16050001-013	GREN-AS-03	BIOTA	5/19/2016	1110	C	#NAME?	X	1										
AMC15.1-16050001-014	GREN-AS-04	BIOTA	5/19/2016	1115	C	#NAME?	X	1										

X = shared container

ADDITIONAL COMMENTS/SPECIAL INSTRUCTIONS	RELINQUISHED BY	DATE/TIME	ACCEPTED BY	DATE/TIME
			T.F. Hamilton	6/14/16

Chain of Custody / Sample Submittal Form

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Task Code:	AMC15.1-16050001	COC ID:	AMC15.1-16050001-COC.2	TURNAROUND TIME:	Page 2 of 4

PROJECT INFORMATION		LABORATORY		SAMPLING / SHIPPING	
Facility Name	Amchitka Site (Adak Island South)	Lab Name:	Lawrence Livermore National Laboratory	Shipping Company:	
Project Number	1.104.1.04.611.2.01	Address:	700 East Avenue	Tracking Number:	
Project Name:	Amchitka Site (Adak Island South)	City:	Livermore State: CA	Cooler Count:	
		Postal Code:	84550	Date Shipped:	
		Phone Number:	925-424-2619	Sampled by (Print, Sign):	
		PO Number:			
				Sampler 2:	

SAMPLE DETAILS — ANALYSIS REQUESTED — Filtered - F: Field, L: Lab, FL: Field & Lab, N: None

Sample ID	Location	Matrix	Date	Time (24hr)	G=Grab C=Comp	# of Cont	Container		PLASTIC BAG										
							Filtered												
							Preserv.		4 C	None									
							ANALYSIS	Cs Iso, Biota	Pu Iso	Cs Iso, Water									
AMC15.1-16050001-015	GREN-AS-05	BIOTA	5/19/2016	1120	C	#NAME?	X = shared container	X	1										
AMC15.1-16050001-016	GREN-AS-06	BIOTA	5/19/2016	1125	C	#NAME?		X	1										
AMC15.1-16050001-017	GREN-AS-07	BIOTA	5/19/2016	1130	C	#NAME?		X	1										
AMC15.1-16050001-018	GREN-AS-08	BIOTA	5/19/2016	1135	C	#NAME?		X	1										
AMC15.1-16050001-019	GREN-AS-09	BIOTA	5/19/2016	1140	C	#NAME?		X	1										
AMC15.1-16050001-020	GREN-AS-10	BIOTA	5/19/2016	1145	C	#NAME?		X	1										
AMC15.1-16050001-021	ILOR-AS-01	BIOTA	5/19/2016	1120	C	#NAME?		X	1										
AMC15.1-16050001-022	ILOR-AS-02	BIOTA	5/19/2016	1125	C	#NAME?		X	1										
AMC15.1-16050001-023	ILOR-AS-03	BIOTA	5/19/2016	1130	C	#NAME?		X	1										
AMC15.1-16050001-024	ILOR-AS-04	BIOTA	5/19/2016	1135	C	#NAME?		X	1										
AMC15.1-16050001-025	ILOR-AS-05	BIOTA	5/19/2016	1140	C	#NAME?		X	1										
AMC15.1-16050001-026	ILOR-AS-06	BIOTA	5/19/2016	1145	C	#NAME?		X	1										
AMC15.1-16050001-027	ILOR-AS-07	BIOTA	5/19/2016	1150	C	#NAME?		X	1										
AMC15.1-16050001-028	ILOR-AS-08	BIOTA	5/19/2016	1155	C	#NAME?		X	1										

ADDITIONAL COMMENTS/SPECIAL INSTRUCTIONS	RELINQUISHED BY	DATE/TIME	ACCEPTED BY	DATE/TIME
			T.F. Hamilton	6/14/16

Chain of Custody / Sample Submittal Form

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Task Code:	AMC15.1-16050001	COC ID:	AMC15.1-16050001-COC.3	TURNAROUND TIME:	Page 3 of 4

PROJECT INFORMATION		LABORATORY		SAMPLING / SHIPPING	
Facility Name	Amchitka Site (Adak Island South)	Lab Name:	Lawrence Livermore National Laboratory	Shipping Company:	
Project Number	1.104.1.04.611.2.01	Address:	700 East Avenue	Tracking Number:	
Project Name:	Amchitka Site (Adak Island South)	City:	Livermore State: CA	Cooler Count:	
		Postal Code:	84550	Date Shipped:	
		Phone Number:	925-424-2619	Sampled by (Print, Sign):	
		PO Number:			
				Sampler 2:	

SAMPLE DETAILS — ANALYSIS REQUESTED — Filtered - F: Field, L: Lab, FL: Field & Lab, N: None

Sample ID	Location	Matrix	Date	Time (24hr)	G=Grab C=Comp	# of Cont	Cs Iso, Biota	Pu Iso	Cs Iso, Water									
Container								PLASTIC BAG	HDPE 20 L									
Filtered																		
Preserv.								4 C	None									
ANALYSIS							Cs Iso, Biota	Pu Iso	Cs Iso, Water									
AMC15.1-16050001-029	ILOR-AS-09	BIOTA	5/19/2016	1200	C	#NAME?	X	1										
AMC15.1-16050001-030	ILOR-AS-10	BIOTA	5/19/2016	1205	C	#NAME?	X	1										
AMC15.1-16050001-031	ROCK-AS-01	BIOTA	5/19/2016	945	C	#NAME?	X	1										
AMC15.1-16050001-032	ROCK-AS-02	BIOTA	5/19/2016	950	C	#NAME?	X	1										
AMC15.1-16050001-033	ROCK-AS-03	BIOTA	5/19/2016	950	C	#NAME?	X	1										
AMC15.1-16050001-034	ROCK-AS-04	BIOTA	5/19/2016	955	C	#NAME?	X	1										
AMC15.1-16050001-035	ROCK-AS-05	BIOTA	5/19/2016	1000	C	#NAME?	X	1										
AMC15.1-16050001-036	ROCK-AS-06	BIOTA	5/19/2016	1005	C	#NAME?	X	1										
AMC15.1-16050001-037	ROCK-AS-07	BIOTA	5/19/2016	1005	C	#NAME?	X	1										
AMC15.1-16050001-038	ROCK-AS-08	BIOTA	5/19/2016	1010	C	#NAME?	X	1										
AMC15.1-16050001-039	ROCK-AS-09	BIOTA	5/19/2016	1015	C	#NAME?	X	1										
AMC15.1-16050001-040	ROCK-AS-10	BIOTA	5/19/2016	1020	C	#NAME?	X	1										
AMC15.1-16050001-041	SEAW-AS-01-SH	WATER	5/19/2016	1300	C	1			1									
~~AMC15.1-16050001-042~~	~~SEAW-AS-02-SH~~	~~WATER~~	~~5/19/2016~~		~~C~~	~~#NAME?~~			~~5~~									

X = shared container

ADDITIONAL COMMENTS/SPECIAL INSTRUCTIONS	RELINQUISHED BY	DATE/TIME	ACCEPTED BY	DATE/TIME
			T.F. Hamilton	6/14/16

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Task Code:	AMC15.1-16050001	COC ID:	AMC15.1-16050001-COC.4	TURNAROUND TIME:		Page 4 of 4

PROJECT INFORMATION		LABORATORY			SAMPLING / SHIPPING	
Facility Name	Amchitka Site (Adak Island South)	Lab Name:	Lawrence Livermore National Laboratory		Shipping Company:	
Project Number	1.104.1.04.611.2.01	Address:	700 East Avenue		Tracking Number:	
Project Name:	Amchitka Site (Adak Island South)	City:	Livermore	State: CA	Cooler Count:	
		Postal Code:	84550		Date Shipped:	
		Phone Number:	925-424-2619		Sampled by (Print, Sign):	
		PO Number:				
					Sampler 2:	

SAMPLE DETAILS — ANALYSIS REQUESTED — Filtered - F: Field, L: Lab, FL: Field & Lab, N: None

Sample ID	Location	Matrix	Date	Time (24hr)	G=Grab C=Comp	# of Cont	Container	Filtered	Preserv.	Cs Iso, Biota	Pu Iso	Cs Iso, Water
									HDPE 20 L			
									4 C		None	
~~AMC15.1-16050001-043~~	~~SEAW-AS-03-SH~~	~~WATER~~			~~C~~	~~#NAME?~~						~~5~~
						#NAME?						
						#NAME?						
						#NAME?						
						#NAME?						
						#NAME?						
						#NAME?						
						#NAME?						
						#NAME?						
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X = shared container

ADDITIONAL COMMENTS/SPECIAL INSTRUCTIONS	RELINQUISHED BY	DATE/TIME	ACCEPTED BY	DATE/TIME
			T.F. Hamilton	6/14/16

Appendix 2

Individual Sample Wet, Dry and Ash Weigh

Table 3. Individual Sample Wet, Dry, and Ash Weights.

Sample ID#	Location	Date of Collection	Wet Weight (g)	Dry Weight (g)	Dry/Wet %	Ash Weight (g)	Ash/Dry %	Flags
AMC01.1-16060002-001	DOLL-AI-01	6/21/16	1138.99	276.72	24%	55.02	20%	A
AMC02.1-16050001-011	GREN-LS-01	5/14/16	1269.82	317.23	25%	61.54	19%	
AMC02.1-16050001-012	GREN-LS-02	5/14/16	1360.34	308.66	23%	57.86	19%	
AMC02.1-16050001-013	GREN-LS-03	5/14/16	858.66	212.64	25%	32.52	15%	
AMC02.1-16050001-014	GREN-LS-04	5/14/16	1039.18	250.09	24%	41.92	17%	
AMC02.1-16050001-015	GREN-LS-05	5/14/16	982.97	230.31	23%	53.30	23%	
AMC02.1-16050001-016	GREN-LS-06	5/14/16	1089.78	267.87	25%	41.10	15%	
AMC02.1-16050001-017	GREN-LS-07	5/14/16	923.72	228.66	25%	40.34	18%	
AMC02.1-16050001-018	GREN-LS-08	5/14/16	942.39	231.30	25%	42.05	18%	
AMC02.1-16050001-019	GREN-LS-09	5/14/16	1486.04	345.68	23%	50.99	15%	
AMC02.1-16050001-020	GREN-LS-10	5/14/16	1099.42	272.27	25%	53.35	20%	
AMC02.1-16050001-021	ILOR-LS-01	5/14/16	983.58	200.63	20%	39.71	20%	
AMC02.1-16050001-022	ILOR-LS-02	5/14/16	1187.36	271.33	23%	50.37	19%	
AMC02.1-16050001-023	ILOR-LS-03	5/14/16	877.63	205.78	23%	34.81	17%	
AMC02.1-16050001-024	ILOR-LS-04	5/14/16	1171.47	285.27	24%	54.46	19%	
AMC02.1-16050001-025	ILOR-LS-05	5/14/16	1484.09	324.36	22%	60.94	19%	
AMC02.1-16050001-026	ILOR-LS-06	5/14/16	1469.95	332.54	23%	66.63	20%	
AMC02.1-16050001-027	ILOR-LS-07	5/14/16	1443.36	312.41	22%	61.24	20%	
AMC02.1-16050001-028	ILOR-LS-08	5/14/16	911.49	192.76	21%	36.19	19%	
AMC02.1-16050001-029	ILOR-LS-09	5/14/16	1059.23	251.40	24%	38.96	15%	
AMC02.1-16050001-030	ILOR-LS-10	5/14/16	984.10	219.25	22%	42.97	20%	GCO
AMC02.1-16050001-031	ROCK-LS-01	5/14/16	1501.38	341.93	23%	69.30	20%	
AMC02.1-16050001-032	ROCK-LS-02	5/14/16	1363.00	307.32	23%	73.62	24%	
AMC02.1-16050001-033	ROCK-LS-03	5/14/16	1373.63	301.81	22%	70.04	23%	
AMC02.1-16050001-034	ROCK-LS-04	5/14/16	1057.58	264.72	25%	44.47	17%	
AMC02.1-16050001-035	ROCK-LS-05	5/14/16	951.90	240.27	25%	51.46	21%	
AMC02.1-16050001-036	ROCK-LS-06	5/14/16	967.96	217.23	22%	41.53	19%	

Sample ID#	Location	Date of Collection	Wet Weight (g)	Dry Weight (g)	Dry/Wet %	Ash Weight (g)	Ash/Dry %	Flags
AMC02.1-16050001-037	ROCK-LS-07	5/14/16	1131.27	278.11	25%	45.33	16%	
AMC02.1-16050001-038	ROCK-LS-08	5/14/16	1115.30	246.35	22%	46.21	19%	
AMC02.1-16050001-039	ROCK-LS-09	5/14/16	1107.70	270.34	24%	44.15	16%	
AMC02.1-16050001-040	ROCK-LS-10	5/14/16	1452.71	332.88	23%	96.91	29%	
AMC03.1-16050001-011	GREN-ML-01	5/13/16	1225.35	269.62	22%	62.40	23%	GCO
AMC03.1-16050001-012	GREN-ML-02	5/13/16	1229.63	265.51	22%	57.53	22%	
AMC03.1-16050001-013	GREN-ML-03	5/13/16	1153.39	253.48	22%	60.77	24%	
AMC03.1-16050001-014	GREN-ML-04	5/13/16	1180.22	254.87	22%	59.61	23%	
AMC03.1-16050001-015	GREN-ML-05	5/13/16	1289.73	286.76	22%	63.77	22%	
AMC03.1-16050001-016	GREN-ML-06	5/13/16	1190.76	258.58	22%	50.29	19%	
AMC03.1-16050001-017	GREN-ML-07	5/13/16	1170.28	241.93	21%	58.56	24%	
AMC03.1-16050001-018	GREN-ML-08	5/13/16	1239.34	248.94	20%	55.30	22%	
AMC03.1-16050001-019	GREN-ML-09	5/13/16	907.47	205.03	23%	43.86	21%	
AMC03.1-16050001-020	GREN-ML-10	5/13/16	1002.67	209.73	21%	42.80	20%	
AMC03.1-16050001-021	ILOR-ML-01	5/13/16	870.83	197.41	23%	44.68	23%	GCO
AMC03.1-16050001-022	ILOR-ML-02	5/13/16	944.90	200.36	21%	37.50	19%	BIS
AMC03.1-16050001-023	ILOR-ML-03	5/13/16	1035.96	196.17	19%	46.09	23%	GCO
AMC03.1-16050001-024	ILOR-ML-04	5/13/16	1044.17	216.09	21%	53.11	25%	
AMC03.1-16050001-025	ILOR-ML-05	5/13/16	1072.86	188.24	18%	41.89	22%	
AMC03.1-16050001-026	ILOR-ML-06	5/13/16	1149.51	227.84	20%	54.77	24%	GCO
AMC03.1-16050001-027	ILOR-ML-07	5/13/16	824.65	190.27	23%	35.95	19%	GCO
AMC03.1-16050001-028	ILOR-ML-08	5/13/16	1024.68	224.04	22%	55.09	25%	GCO
AMC03.1-16050001-029	ILOR-ML-09	5/13/16	1121.02	229.21	20%	46.24	20%	GCO
AMC03.1-16050001-030	ILOR-ML-10	5/13/16	852.29	188.69	22%	39.48	21%	GCO
AMC03.1-16050001-031	ROCK-ML-01	5/13/16	1911.64	438.12	23%	57.23	13%	
AMC03.1-16050001-032	ROCK-ML-02	5/13/16	1056.32	238.11	23%	51.51	22%	GCO
AMC03.1-16050001-033	ROCK-ML-03	5/13/16	1502.63	347.23	23%	47.05	14%	

Sample ID#	Location	Date of Collection	Wet Weight (g)	Dry Weight (g)	Dry/Wet %	Ash Weight (g)	Ash/Dry %	Flags
AMC03.1-16050001-034	ROCK-ML-04	5/13/16	970.28	238.08	25%	53.10	22%	
AMC03.1-16050001-035	ROCK-ML-05	5/13/16	1352.38	338.17	25%	85.43	25%	
AMC03.1-16050001-036	ROCK-ML-06	5/13/16	1682.87	413.07	25%	83.64	20%	
AMC03.1-16050001-037	ROCK-ML-07	5/13/16	1218.14	260.76	21%	60.00	23%	
AMC03.1-16050001-038	ROCK-ML-08	5/13/16	1131.58	247.02	22%	45.95	19%	
AMC03.1-16050001-039	ROCK-ML-09	5/13/16	1541.31	358.33	23%	88.54	25%	
AMC03.1-16050001-040	ROCK-ML-10	5/13/16	1617.07	382.43	24%	102.62	27%	
AMC05.1-16050001-011	GREN-CN-01	5/15/16	865.92	198.50	23%	34.45	17%	GCO
AMC05.1-16050001-012	GREN-CN-02	5/15/16	1140.30	278.45	24%	40.25	14%	GCO
AMC05.1-16050001-013	GREN-CN-03	5/15/16	909.60	213.69	23%	44.72	21%	GCO
AMC05.1-16050001-014	GREN-CN-04	5/15/16	912.20	202.56	22%	42.54	21%	GCO
AMC05.1-16050001-015	GREN-CN-05	5/15/16	867.00	180.23	21%	35.19	20%	GCO
AMC05.1-16050001-016	GREN-CN-06	5/15/16	826.42	201.16	24%	33.63	17%	GCO
AMC05.1-16050001-017	GREN-CN-07	5/15/16	766.85	186.46	24%	29.55	16%	GCO
AMC05.1-16050001-018	GREN-CN-08	5/15/16	679.40	137.86	20%	29.27	21%	GCO
AMC05.1-16050001-019	GREN-CN-09	5/15/16	598.61	133.87	22%	27.69	21%	GCO
AMC05.1-16050001-020	GREN-CN-10	5/15/16	676.38	138.82	21%	31.03	22%	GCO
AMC05.1-16050001-021	ILOR-01	5/15/16	1945.99	440.49	23%	86.69	20%	GCO
AMC05.1-16050001-022	ILOR-02	5/15/16	875.56	208.08	24%	43.69	21%	GCO
AMC05.1-16050001-023	ILOR-03	5/15/16	914.23	214.57	23%	68.59	32%	GCO
AMC05.1-16050001-024	ILOR-04	5/15/16	1725.10	400.74	23%	67.99	17%	GCO
AMC05.1-16050001-025	ILOR-05	5/15/16	1059.26	246.31	23%	48.77	20%	GCO
AMC05.1-16050001-026	ILOR-06	5/15/16	1188.92	285.84	24%	61.33	21%	GCO
AMC05.1-16050001-027	ILOR-07	5/15/16	1071.40	252.18	24%	59.54	24%	GCO
AMC05.1-16050001-028	ILOR-08	5/15/16	875.21	208.05	24%	52.82	25%	GCO
AMC05.1-16050001-029	ILOR-09	5/15/16	913.90	228.57	25%	51.64	23%	GCO

Sample ID#	Location	Date of Collection	Wet Weight (g)	Dry Weight (g)	Dry/Wet %	Ash Weight (g)	Ash/Dry %	Flags
AMC05.1-16050001-030	ILOR-10	5/15/16	925.46	214.32	23%	51.79	24%	GCO
AMC05.1-16050001-031	ROCK-CN-01	5/15/16	939.08	248.05	26%	56.88	23%	GCO
AMC05.1-16050001-032	ROCK-CN-02	5/15/16	1250.56	293.17	23%	77.52	26%	GCO
AMC05.1-16050001-033	ROCK-CN-03	5/15/16	967.19	246.17	25%	58.61	24%	GCO
AMC05.1-16050001-034	ROCK-CN-04	5/15/16	1260.92	305.34	24%	60.28	20%	
AMC05.1-16050001-035	ROCK-CN-05	5/15/16	1318.16	304.07	23%	50.02	16%	
AMC05.1-16050001-036	ROCK-CN-06	5/15/16	988.09	275.69	28%	73.65	27%	GCO
AMC05.1-16050001-037	ROCK-CN-07	5/15/16	999.41	273.30	27%	56.73	21%	GCO
AMC05.1-16050001-038	ROCK-CN-08	5/15/16	1616.18	398.97	25%	84.36	21%	GCO
AMC05.1-16050001-039	ROCK-CN-09	5/15/16	1102.21	259.24	24%	63.35	24%	
AMC05.1-16050001-040	ROCK-CN-10	5/15/16	1025.58	255.84	25%	68.72	27%	
AMC13.1-16050001-001	DOLL-AD-01	5/21/16	689.31	206.80	30%	21.29	10%	
AMC13.1-16060002-003	DOLL-AD-01	6/14/16	1267.87	288.76	23%	31.50	11%	A
AMC14.1-16050001-011	GREN-AN-01	5/19/16	1057.58	264.69	25%	55.56	21%	
AMC14.1-16050001-012	GREN-AN-02	5/20/06	983.08	244.06	25%	78.67	32%	
AMC14.1-16050001-013	GREN-AN-03	5/20/06	1215.35	297.51	24%	88.12	30%	
AMC14.1-16050001-014	GREN-AN-04	5/20/06	997.22	252.44	25%	51.23	20%	
AMC14.1-16050001-015	GREN-AN-05	5/20/16	982.47	240.48	24%	88.88	37%	
AMC14.1-16050001-016	GREN-AN-06	5/20/16	526.24	130.37	25%	58.82	45%	
AMC14.1-16050001-017	GREN-AN-07	5/20/16	872.91	225.82	26%	51.06	23%	
AMC14.1-16050001-018	GREN-AN-08	5/20/16	928.57	220.08	24%	53.98	25%	
AMC14.1-16050001-019	GREN-AN-09	5/20/16	1227.11	313.79	26%	63.58	20%	
AMC14.1-16050001-020	GREN-AN-10	5/20/16	1103.05	261.50	24%	63.08	24%	
AMC14.1-16050001-021	ILOR-AN-01	5/19/16	999.87	213.83	21%	59.74	28%	GCO
AMC14.1-16050001-022	ILOR-AN-02	5/19/16	1217.09	260.80	21%	69.99	27%	GCO
AMC14.1-16050001-023	ILOR-AN-03	5/19/16	1116.41	255.15	23%	49.08	19%	GCO

Sample ID#	Location	Date of Collection	Wet Weight (g)	Dry Weight (g)	Dry/Wet %	Ash Weight (g)	Ash/Dry %	Flags
AMC14.1-16050001-024	ILOR-AN-04	5/19/16	988.54	212.62	22%	61.32	29%	
AMC14.1-16050001-025	ILOR-AN-05	5/19/16	1116.50	252.94	23%	49.76	20%	
AMC14.1-16050001-026	ILOR-AN-06	5/20/16	1321.39	267.68	20%	51.06	19%	
AMC14.1-16050001-027	ILOR-AN-07	5/20/16	1597.63	335.85	21%	51.41	15%	
AMC14.1-16050001-028	ILOR-AN-08	5/20/16	1214.54	289.36	24%	50.57	17%	GCO
AMC14.1-16050001-029	ILOR-AN-09	5/20/16	1066.02	245.01	23%	63.89	26%	GCO
AMC14.1-16050001-030	ILOR-AN-10	5/20/16	1077.84	228.17	21%	59.12	26%	GCO
AMC14.1-16050001-031	ROCK-AN-01	5/19/16	2204.77	663.43	30%	105.58	16%	GCO
AMC14.1-16050001-032	ROCK-AN-02	5/19/16	1310.82	340.14	26%	53.55	16%	GCO
AMC14.1-16050001-033	ROCK-AN-03	5/19/16	1829.90	400.54	22%	52.54	13%	
AMC14.1-16050001-034	ROCK-AN-04	5/19/16	849.19	232.84	27%	55.47	24%	
AMC14.1-16050001-035	ROCK-AN-05	5/19/16	1062.69	302.25	28%	51.06	17%	GCO
AMC14.1-16050001-036	ROCK-AN-06	5/20/16	1162.42	336.07	29%	55.53	17%	
AMC14.1-16050001-037	ROCK-AN-07	5/20/16	1471.98	398.54	27%	55.95	14%	
AMC14.1-16050001-038	ROCK-AN-08	5/20/16	1749.52	467.89	27%	54.40	12%	
AMC14.1-16050001-039	ROCK-AN-09	5/20/16	1178.90	341.54	29%	64.84	19%	
AMC14.1-16050001-040	ROCK-AN-10	5/20/16	1207.28	373.68	31%	61.87	17%	
AMC15.1-16050001-011	GREN-AS-01	5/19/16	1025.74	248.89	24%	63.75	26%	
AMC15.1-16050001-012	GREN-AS-02	5/19/16	1079.51	240.29	22%	60.47	25%	
AMC15.1-16050001-013	GREN-AS-03	5/19/16	1267.67	275.09	22%	59.64	22%	
AMC15.1-16050001-014	GREN-AS-04	5/19/16	1100.41	260.46	24%	66.51	26%	
AMC15.1-16050001-015	GREN-AS-05	5/19/16	1205.35	281.90	23%	63.81	23%	
AMC15.1-16050001-016	GREN-AS-06	5/19/16	964.11	226.80	24%	66.89	29%	
AMC15.1-16050001-017	GREN-AS-07	5/19/16	1081.02	257.82	24%	67.68	26%	
AMC15.1-16050001-018	GREN-AS-08	5/19/16	1089.95	262.82	24%	56.18	21%	
AMC15.1-16050001-019	GREN-AS-09	5/19/16	1300.18	289.02	22%	56.38	20%	

Sample ID#	Location	Date of Collection	Wet Weight (g)	Dry Weight (g)	Dry/Wet %	Ash Weight (g)	Ash/Dry %	Flags
AMC15.1-16050001-020	GREN-AS-10	5/19/16	1189.71	279.11	23%	47.79	17%	GCO
AMC15.1-16050001-021	ILOR-AS-01	5/19/16	1085.70	219.13	20%	53.75	25%	GCO
AMC15.1-16050001-022	ILOR-AS-02	5/19/16	1226.22	274.43	22%	46.32	17%	GCO
AMC15.1-16050001-023	ILOR-AS-03	5/19/16	1151.38	258.20	22%	67.75	26%	GCO
AMC15.1-16050001-024	ILOR-AS-04	5/19/16	1160.41	265.50	23%	53.93	20%	GCO
AMC15.1-16050001-025	ILOR-AS-05	5/19/16	1108.30	219.03	20%	48.15	22%	GCO
AMC15.1-16050001-026	ILOR-AS-06	5/19/16	866.98	174.25	20%	46.42	27%	
AMC15.1-16050001-027	ILOR-AS-07	5/19/16	924.86	184.81	20%	54.21	29%	GCO
AMC15.1-16050001-028	ILOR-AS-08	5/19/16	1362.40	302.69	22%	66.66	22%	GCO
AMC15.1-16050001-029	ILOR-AS-09	5/19/16	997.98	200.92	20%	56.71	28%	GCO
AMC15.1-16050001-030	ILOR-AS-10	5/19/16	889.31	190.76	21%	56.77	30%	GCO
AMC15.1-16050001-031	ROCK-AS-01	5/19/16	967.18	234.97	24%	44.72	19%	
AMC15.1-16050001-032	ROCK-AS-02	5/19/16	746.20	191.45	26%	48.33	25%	
AMC15.1-16050001-033	ROCK-AS-03	5/19/16	675.93	178.22	26%	48.27	27%	
AMC15.1-16050001-034	ROCK-AS-04	5/19/16	886.73	217.63	25%	40.20	18%	
AMC15.1-16050001-035	ROCK-AS-05	5/19/16	850.80	231.97	27%	45.41	20%	
AMC15.1-16050001-036	ROCK-AS-06	5/19/16	948.20	233.11	25%	49.40	21%	
AMC15.1-16050001-037	ROCK-AS-07	5/19/16	703.16	183.66	26%	43.99	24%	
AMC15.1-16050001-038	ROCK-AS-08	5/19/16	782.67	193.58	25%	45.88	24%	
AMC15.1-16050001-039	ROCK-AS-09	5/19/16	1611.25	421.32	26%	34.23	8%	
AMC15.1-16050001-040	ROCK-AS-10	5/19/16	912.36	226.97	25%	36.62	16%	

A = not contained in COC listing; GCO = fish received with gut cavity open; BIS = Bait remaining inside stomach of fish

Lawrence Livermore National Laboratory
Technical Information Department
Livermore, CA 94551

Appendix C

Lawrence Livermore National Laboratory

Data Report, Part III: Measurement of Cs isotopes (^{134}Cs, ^{137}Cs) in Biological Samples

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AMCHITKA PROJECT

Data Report, Part III

Measurement of Cs isotopes (^{134}Cs, ^{137}Cs) in biological samples

T.F. Hamilton
S.R. Kehl
R.M. Berry

May 2018

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LAWRENCE LIVERMORE NATIONAL LABORATORY
GLOBAL SECURITY PRINCIPAL DIRECTORATE

AMCHITKA PROJECT
WFO Proposal D201231

Data Report, Part III

Measurement of Cs isotopes (^{134}Cs, ^{137}Cs) in biological samples

T.F. Hamilton, S.R. Kehl, and R.M. Berry

May 2018

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APPENDIX 1. ^{134}Cs and ^{137}Cs in Biological Samples

[CD copies of this report along with excel data listings are available upon request].

TABLES and FIGURES

Table 1. List of targeted radionuclides, laboratory methods and estimated detection limits (2016 Amchitka Sampling Event) (after USDOE, 2016).

Table 2. Coefficient of Variation (CV) between replicate ^{137}Cs sample counts.

1.0 Prologue

The following data report was prepared under contract with the U.S. Department of Energy (DOE), Office of Legacy Management (LM), Grand Junction, Colorado, in support of the LongTerm Surveillance Plan (LTSP) for the Aleutian Islands nuclear site test on Amchitka Island (USDOE, 2014). Following the 2016 sampling event, the Lawrence Livermore National Laboratory (LLNL) received a collection of seawater, freshwater and biological samples for analysis of targeted radionuclides. The sampling activities implemented in 2016 for Amchitka Island and its reference site of Adak, Alaska, were similar in purpose to those conducted previously (USDOE, 2013; 2014). Added emphasis was placed on seawater sampling near an area of potential leakage off the Long Shot test detonation site. There was also an interest in conducting analyses of targeted radionuclides with lower limits of detection for the expressed purpose of directing future trending analysis (USDOE, 2016). The targeted radionuclides of interest included tritium(^{3}H), cesium-134 (^{134}Cs), cesium-137 (^{137}Cs), plutonium-239 (^{239}Pu), and plutonium-240 (^{240}Pu). ^{134}Cs was presumably included to assess the residual impact of inputs from Fukushima.

The systematics and specific objectives of the 2016 sampling event and the associated analytical program were formulated by LM in partnership with the Alaska Department of Environmental Conservation (ADEC), the *Aleutian Pribilof Islands Association, Inc.* (APIA) (a federally recognized tribal organization of the Alet people in Alaska), and the Argonne National Laboratory (ANL). A specific project goal for the 2016 sampling event was to attest to the possibility that selected residual radionuclides from underground nuclear tests conducted on Amchitka Island may enter the marine food chain and result in potential ecological and human health effects.

LLNL was tasked to provide analytical support for the project with electronic data reporting. Samples of seawater (unfiltered) (N=25) and freshwater (unfiltered) (N=2) were received for analysis of ^{134}Cs and ^{137}Cs. A larger subset of marine biota and algae samples were received for analysis of ^{134}Cs-^{137}Cs and ^{239}Pu-^{240}Pu isotopes. The biological sample collection included Dolly Varden (*Salvelinus malma*) (N=3), Greenling (*Hexagrammos spp*.) (N=50), Irish Lord (*Hemilepidotus spp*.) (N=50), Rockfish (*Sebastes spp*.) (N=50) and Rockweed (*Fucus distichus*) (N=15). Cs isotopes were determined by high resolution gamma-spectrometry after separation of the analytes of interest, along with added carrier, on a small quantity of microcrystalline ammonium molybdophosphate (AMP). Pu isotopes were measured by

quadrupole Inductively Coupled Plasma Mass Spectrometry (ICP-MS). During early discussion with the sponsor, some consideration was to be given to conducting measurements of Pu isotopes in waters and biological samples by Accelerator Mass Spectrometry (AMS).

The scope of work as outlined in the sampling plan covered specific Quality Assurance Objectives (QAOs) with respect to achievable limits of detection for each of the targeted radionuclides. Livermore scientists found that the agreed-to limits of detection contained in the 2016 sampling plan were not necessarily supportive of overall program goals to provide quantitative data and information for future trending analysis. To improve quantification of Cs isotopes by gamma-spectrometry and allow for a more detailed comparative assessment to be conducted between sampling events, the project reporting deadline was extended to allow for longer count times. Even with the longer count times (4-6 days), about 20% of the marine biota samples contained no reportable Cs isotope activity. These samples were subsequently recounted on a Small Anode Germanium (SAGe) well detector system with improved measurement precision. Also, with agreement from the sponsor, a subset of seawater and freshwater samples were analyzed for iodine-129 (^{129}I) using AMS with the aim of providing information on the potential impacts of other source-terms on marine radioactivity, especially with respect to Fukushima. No other AMS measurements were subsequently conducted under the terms of the contract award to LLNL.

N = number of individual samples received for analysis.

2.0 Scope of Analytical Project at LLNL

2.1 Objective

Provide analytical measurement data and reporting under the 2016 Amchitka sampling event.

2.2 Statement of Work

1. Measure the ^{137}Cs, ^{134}Cs, ^{239}Pu and ^{240}Pu content of marine biota and algae samples as supplied under the 2016 Amchitka Sampling Event using a combination of high-resolution gamma spectrometry (Cs isotopes) and Inductively Coupled Plasma Mass Spectrometry (Pu isotopes).
2. Measure the ^{137}Cs and ^{134}Cs content of freshwater and seawater as supplied under the 2016 Amchitka Sampling Event using a SAGe well gamma detector system.

3. Provide EDD and hard copy reporting of analytical data with a description of methodologies and supporting quality assurance measures.

2.2 Target Radionuclides and Selection Criteria for Methods of Analysis

Previous studies conducted by CRESP (Consortium for Risk Evaluation with Stakeholder Participation) (CRESP, 2015) and LM under the LTSP for the Aleutian Islands nuclear site test on Amchitka Island show that reported levels of anthropogenic radionuclides contained in marine biota from the site were at or below the acceptable consumption risk range of 10^{-4} to 10^{-6} excess risk of cancer. The aim of the current sampling event was to optimize the design of the sampling and analytical program. This was done not only to provide additional confirmatory measurements of the possible health risk posed by consumption of marine foods from the region but to yield high quality data for trending analyses. Under a formal strategic planning process, pre-determined sample locations and DQOs were devised to reduce uncertainties in assessing food safety and provide adequate detection sensitivity to support future statistical trending analyses. This included placing minimum requirements on the quantity of biological materials to be collected (within practical limitations) based on estimated limits of detection for prescribed measurement techniques.

A listing of targeted radionuclides, methodologies and estimated limits of detection for the 2016 Amchitka sampling event is contained in Table 1 (after USDOE, 2016).

2.3 Sample Delivery/COC Documentation

Biological samples collected in the field were sealed inside labeled plastic bags and shipped frozen. All biological fauna samples were received as whole animals. It should be noted, however, that several fish samples were received with their gut cavities open (Hamilton et al., 2018a). Water samples were shipped in single 20-L (5-gallon) polyethylene carboys with no preservation. Samples were received in two (2) separate air cargo flights into San José International Airport in northern California, and then immediately transported by road (app. 30 miles) to LLNL. Biological samples were subsequently stored frozen at LLNL prior to processing. Each sample shipment was accompanied by Change-of-Custody (COC) documentation listing the task code, COC ID, sample ID, location code, matrix type (biota or water), date and time of sampling, collection code (grab or composite), number of sample containers (typically 1 ea.), and

the type of sample analysis to be performed. Upon arrival of the samples at LLNL, a validation check was performed of samples received against the COC listing and any variances identified (see Hamilton *et al*., 2018a). All COC listed samples were accounted for. Sample AMC01.116060002-001 (DOLL-AI-01) and AMC13.1-16060002-003 (DOLL-AD-01) were received in the 2nd sample shipment without accompanying COC documentation.

Table 1. List of targeted radionuclides, laboratory methods and estimated detection limits (2016 Amchitka Sampling Event) (after USDOE, 2016).

Analyte	Laboratory Method	Estimated MDA (Bq)	A Priori MDA (Bq kg^{-1} - wet weight)[a]		
			Based on 100 g sample	Based on 1000 g sample	Based on 5000 g sample
Biological samples					
^{134}Cs	Gamma-spectrometry	0.3	3	0.3	0.06
^{137}Cs	Gamma-spectrometry	0.3	3	0.3	0.06
^{239}Pu	Quad ICP-MS	0.008	0.08	0.008	0.0016
^{240}Pu	Quad ICP-MS	0.02	0.2	0.02	0.004
^{239}Pu	AMS	0.00001	0.0001	0.00001	0.000002
^{240}Pu	AMS	0.00003	0.0003	0.00003	0.000006
Seawater and freshwater Samples					
^{134}Cs	Gamma-spectrometry (SAGe)	0.006	0.3[b]		
^{137}Cs	Gamma-spectrometry (SAGe)	0.003	0.15[b]		
^{3}H	Electrolytic enrichment followed by gas proportional counting	0.01184[c]			

[a] MDA expressed on sample mass basis [represents the Relative Detection Limit (RDL)].

[b] Based on a 20-liter sample (Bq m^{-3}).

[c] Bq L^{-1} (Tritium Laboratory, Rosenstiel School of Marine and Atmospheric Science, Miami, FL).

Abbreviations:

MDA = Minimum Detection Activity

AMS = Accelerator Mass Spectrometry

ICP-MS = Inductively Coupled Palsma Mass Spectrometry

g = grams

SAGe = Single Anode Germanium

3.0 Cs Isotope Measurements in Biological Samples

3.1 Sample Preparation

The biological samples collected during the 2016 Amchitka planning event were dried to a constant weight, spiked with 10 mg of stable Cs carrier, and then reduced to an ash in a muffle furnace at 450-500 °C (after Hamilton *et al*., 2018a). The residual sample material was then treated with concentrated $HN0_3$ and heated on a hotplate with periodic additions of H_2O_2 to destroy any remaining C (charcoal). The sample solution was then filtered to remove insoluble materials and evaporated to near dryness. The residue was then dissolved in dilute HCl and the solution adjusted to pH 2-3 with NH_4OH solution. Cs isotopes were extracted onto 4 g of microcrystalline cation exchanger, Ammonium Molybdophosphate (AMP) (AlfaAesar, Thermo Fisher Scientific), by mixing in the product as a slurry and allowing the material to settle out overnight. The Cs-AMP was then recovered by centrifugation in a 250 mL plastic bottle, dried in an oven at 60 °C, and the bottles containing the dried Cs-AMP counted by high-resolution gamma-spectrometry. For those samples where no Cs isotope activity was found, the Cs-AMP was quantitively transferred to a scintillation vial and re-counted on a SAGe well detector system.

3.2 Detection and Measurement

The Marshall Islands Program Low-Level Radiometric Laboratory houses 23 gamma detectors (20-75 % relative efficiency) coupled to a PC-based work station operating Canberra Apex-Gamma Lab Productivity Suite software. Detector and AMP pellet Cs isotope geometry specific calibrations were performed by counting matched spike standards containing known quantities of ^{134}Cs and ^{137}Cs. The ^{134}Cs and ^{137}Cs tracer solutions were acquired from Isotope Products Laboratories *Inc*. (IPL), and are indirectly traceable to the National Institute of Standards and Technology (NIST). The recovery of Cs was measured X-ray Fluorescence (XRF) (Ametek, 200T) based external calibration using powered AMP samples containing known quantities of stable Cs.

The estimated Minimum Detectable Activity (MDA) for detection of ^{137}Cs by gamma-spectrometry based on our standard detector configuration was given as 0.3 Bq (refer Table 1). However, it became clear during the initial phase of this project that the prescribed MDA given in the sampling plan would not allow for quantitation of ^{137}Cs (or ^{134}Cs) in biological samples collected during the sampling campaign. Moreover, the MDA given here is not by definition the

same as the minimum quantifiable amount needed to assay the activity in a sample with a predetermined degree of confidence to allow for future trending analysis. As such, to improve quantification, much longer counting times were employed and/or samples were recounted on a more sensitive SAGe well detector system.

Biological samples were processed in parallel with a series of reagent blanks (N=20), and Reference Materials (RMs) obtained from the International Atomic Energy Agency (namely Baltic Seaweed, IAEA-446; and Mixed Fish from the Irish Sea, IAEA-414) containing certified activity concentrations of ^{137}Cs. The performance test RMs were prepared as subaliquots containing comparable levels of ^{137}Cs as the Amchitka biota samples. Count times usually varied between 4 and 6 days for samples counted on our standard gamma configuration or 1 and 3 days using a SAGe well detector.

3.3 Quality Assurance

The estimated MDA for detection of Cs isotopes under our standard detector configuration was assessed for a subset of gamma detectors by a method of standard additions (after Hubaux and Vos, 1970). The average calculated MDA for detection of ^{137}Cs was around 0.028 Bq. For those samples counted on the SAGe well detector (approximately 20% of all biological samples measured), the average reported MDA for ^{137}Cs was around 0.01 Bq. The mean Cs isotope recovery for fish samples was estimated to be around 83 ± 13 %.

The average measurement bias for detection of ^{137}Cs based on the analysis of IAEA RMs was -6% (N=6) with an individual sample bias ranging from -22 to +13%. This compares with the average one sigma measurement uncertainty of ±5%. Replicate counts were performed on a subset of samples taken across a range of sample activity concentrations (Table 2). The average Coefficient of Variation (CV) between replicate counts was 15.9%. Facility wide systems data quality performance and accountability checks are also performed routinely by voluntary participation in periodic blind performance tests and interlaboratory comparison exercises conducted by the International Atomic Energy Agency (IAEA) and the U.S. Department of Energy (DOE) Mixed Analyte Performance Evaluation Program (MAPEP) (see Hamilton *et al*., 2000).

The LM specified reporting units were given as pCi kg^{-1}, wet weight. It was decided to include more conventional SI units (in Bq kg^{-1}, wet weight) in this hardcopy data report.

Table 2. Coefficient of Variation (CV) Between Replicate ^{137}Cs Sample Counts.

Sample ID	Sample Location	^{137}Cs, Bq kg^{-1}, wet		CV (%)
		Measure #1	Measure #2	
AMC02.1-16050001-016	GREN-LS-06	0.28 ±0.01	0.30 ±0.02	6
AMC02.1-16050001-025	ILOR-LS-05	0.02 ±0.01	0.03 ±0.01	28
AMC13.1-16050001-001	DOLL-AD-01	2.59 ±0.03	1.9 ±0.03	21
AMC03.1-16050001-011	GREN-ML-01	0.11 ±0.01	0.13 ±0.02	13
AMC03.1-16050001-020	GREN-ML-10	0.08 ±0.01	0.08 ±0.01	4
AMC03.1-16050001-026	ILOR-ML-06	0.021 ±0.003	0.005 ±0.009	87
AMC03.1-16050001-031	ROCK-ML-01	0.31 ±0.01	0.32 ±0.01	2
AMC03.1-16050001-033	ROCK-ML-03	0.05 ±0.01	0.06 ±0.01	5
AMC05.1-16050001-033	ROCK-CN-03	0.05 ±0.01	0.06 ±0.01	18
AMC14.1-16050001-029	ILOR-AN-09	2.90 ±0.03	2.5 ±0.03	10
AMC05.1-16050001-017	GREN-CN-07	1.15 ±0.03	1.1 ±0.03	3
AMC14.1-16050001-032	ROCK-AN-02	9.51 ±0.05	10.3 ±0.03	6
AMC14.1-16050001-040	ROCK-AN-10	0.04 ±0.01	0.04 ±0.01	16
AMC15.1-16050001-017	GREN-AS-07	0.09 ±0.02	0.10 ±0.02	4
AMC15.1-16050001-025	ILOR-AS-05	0.04 ±0.02	0.05 ±0.02	17
			average =	**15.9%**

4.0 Results & Discussion

The individual sample results of analyses of ^{134}Cs and ^{137}Cs in biological samples collected during the 2016 Amchitka sampling event are shown in Appendix I. No reportable ^{134}Cs or ^{137}Cs was detected in the combined average sample reagent blanks (N=20).

No reportable ^{134}Cs was detected in fish or algae samples with exception of the 3 samples of Dolly Varden, and a single Rockfish sample collected from the Adak North control site. The ^{134}Cs/ ^{137}Cs activity ratio observed in these samples were tightly bounded between 4.3 to 6.8 %, providing some level of internal confidence in the quality of the measurements. The source of ^{134}Cs in the freshwater lakes where the Dolly Varden were collected is most likely direct atmospheric deposition from Fukushima. We have no clear explanation for the measurable quantity of ^{134}Cs observed in the single sample of Rockfish.

The weighted average activity concentration of ^{137}Cs in Greenling, Irish Lord, Rockfish and Rockweed from the Long Shot (LS) site was 0.19 (N=10; 95% CI, 0.10–0.28), 0.02 (N=10;

95% CI, 0.01–0.03), 0.037 (N=10; 95% CI, 0.027–0.046) and 0.02 (N=3; 95% CI, 0.012–0.027), Bq kg^{-1} (wet weight), respectively.

The weighted average activity concentration of ^{137}Cs in Greenling, Irish Lord, Rockfish and Rockweed from the Milrow (ML) shot site was 0.039 (N=10; 95% CI, 0.020–0.058), 0.13 (N=10; 95% CI, 0.047–0.22), 0.032 (N=10; 95% CI, 0.003–0.059) and 0.021 (N=3; 95% CI, 0.017–0.024), Bq kg^{-1} (wet weight), respectively.

The weighted average activity concentration of ^{137}Cs in Greenling, Irish Lord, Rockfish and Rockweed from the Cannikin (CN) shot site was 0.052 (N=10; 95% CI, -0.03–0.13), 0.015 (N=10; 95% CI, 0.011–0.019), 0.10 (N=10; 95% CI, -0.01–0.21) and 0.023 (N=3; 95% CI, 0.013–0.035), Bq kg^{-1} (wet weight), respectively.

The weighted average activity concentration of ^{137}Cs in Greenling, Irish Lord, Rockfish and Rockweed from the Adak North control site was 0.031 (N=9; 95% CI, 0.024–0.038) with one sample lost during processing, 0.021 (N=10; 95% CI, -0.04–0.078) with one significant outlier, 0.035 (N=10; 95% CI, -0.12–0.19) with one significant outlier, and 0.029 (N=3; 95% CI, 0.010–0.047), Bq kg^{-1} (wet weight), respectively.

The weighted average activity concentration of ^{137}Cs in Greenling, Irish Lord, Rockfish and Rockweed from the Adak South control site was 0.038 (N=10; 95% CI, 0.025–0.051), 0.022 (N=10; 95% CI, 0.013–0.030), 0.039 (N=10; 95% CI, 0.021–0.058) and 0.043 (N=3; 95% CI, -0.010–0.098, Bq kg^{-1} (wet weight), respectively.

These data can be compared with combined weighted average concentration of ^{137}Cs in Dolly Varden collected from the Cannikin Lake and on Adak Island of 2.7 (N=3; 95% CI, 0.4–5.0), Bq kg^{-1} (wet weight).

It should be noted that fish were processed as received so some level of added variability might be expected from fish ingesting different amounts of detrital material.

5.0 Conclusion

The activity concentration of ^{137}Cs was successfully measured in all available biological samples collected during the 2016 Amchitka sampling event. Detectable levels of ^{134}Cs were also found in Dolly Varden collected from Cannikin Lake and from a freshwater lake on Adak Island, and in a single Rockfish sample collected from the Adak North control site. All data appears to

satisfy internal and external quality assurance measures within the uncertainty of the measurements.

5.0 References

CRESP (2005). Amchitka Independent Science Assessment: Biological and Geophysical Aspects of Potential Radionuclide Exposure in the Amchitka Marine Environment, Consortium for Risk Evaluation with Stakeholder Participation (CRESP), C.W. Powers, J. Burger, D. Kosson, M. Gochfeld, and D. Barnes, eds., Piscataway, New Jersey.

Hamilton, T.F., S. R. Kehl, and R. M. Berry (2018a). Processing of Biological Samples (Wet, Dry and Ash Weights), Data Report, Part I, AMCHITKA PROJECT, WFO Project D201231, Lawrence Livermore National Laboratory, LLNL-SR-751699.

Hamilton, T., W. Robison, S. Kehl, A. Stoker, C. Conrado (2000). The Marshall Islands Radioassay Quality Assurance Program: An Overview, J. Radioanal. Nucl. Chem., 243 (2), 415-422.

USDOE (2016). Environmental Sampling Plan for the Amchitka, Alaska, Site and Adak Island 2016 Sampling Event, Office of Legacy Management (LM), U.S Department of Energy (USDOE), Colorado, LMS/AMC/S12630 (not for public release).

USDOE (2014). Long-Term Surveillance Plan for the U.S. Department of Energy Amchitka, Alaska, Site, Office of Legacy Management (LM), U.S Department of Energy (USDOE), Colorado, LMS/AMC/S01980.

USDOE (2013). Amchitka Island, Alaska, Biological Monitoring Report 2011 Sampling Results, Office of Legacy Management (LM), U.S Department of Energy (USDOE), Colorado, LMS/AMC/SO8833.

IAEA (2004). Report of the Worldwide Intercomparison, IAEA-414, Radionuclides in Mixed Fish from Irish Sea and the North Sea, IAEA/AL/145 (IAEA/MEL/73), IAEA, Vienna.

IAEA (2013). Worldwide Laboratory Comparison on the Determination Radionuclides in IAEA-443 Baltic Seaweed (*Fucus vesiculosus*), IAEA Analytical Quality in Nuclear Applications Series No. 25 (IAEA/AQ/25), IAEA, Vienna.

Hubaux, A., and G Vos (1970). Decision and detection limits for linear calibration curves. *Anal. Chem.*, *42*, 849−855.

Appendix 1

^{134}Cs and ^{137}Cs in Biological Samples

Sample ID	Sample Location	Sample MDA				^{134}Cs				^{137}Cs				Flags
		^{134}Cs		^{137}Cs		Bq kg^{-1}, wet		pCi kg^{-1}, wet		Bq kg^{-1},wet		pCi kg^{-1}, wet		
		Bq	pCi	Bq	pCi	Value	RDL	Value	RDL	Value	RDL	Value	RDL	
AMC01.1-16060002-001	DOLL-AI-01	0.1	3.7	0.03	0.7	0.17 ± 0.01	0.2	4.5 ± 0.4	4	3.79 ± 0.03	0.03	102 ± 1	0.8	
AMC02.1-16050001-011	GREN-LS-01	0.1	3.7	0.03	0.7	–	0.1	–	3	0.03 ± 0.02	0.02	0.9 ± 0.5	0.6	
AMC02.1-16050001-012	GREN-LS-02	0.1	3.7	0.03	0.7	–	0.1	–	4	0.07 ± 0.02	0.03	2.0 ± 0.5	0.8	
AMC02.1-16050001-013	GREN-LS-03	0.1	3.7	0.03	0.7	–	0.2	–	4	0.03 ± 0.01	0.03	0.9 ± 0.3	0.8	
AMC02.1-16050001-014	GREN-LS-04	0.1	3.7	0.03	0.7	–	0.1	–	4	0.05 ± 0.02	0.03	1.5 ± 0.4	0.7	
AMC02.1-16050001-015	GREN-LS-05	0.05	1.3	0.01	0.2	–	0.05	–	1	0.02 ± 0.00	0.01	0.5 ± 0.04	0.2	NS
AMC02.1-16050001-016	GREN-LS-06	0.1	3.7	0.03	0.7	–	0.1	–	4	0.28 ± 0.01	0.03	7.5 ± 0.4	0.8	
AMC02.1-16050001-017	GREN-LS-07	0.1	3.7	0.03	0.7	–	0.2	–	5	0.02 ± 0.01	0.03	0.6 ± 0.3	0.9	
AMC02.1-16050001-018	GREN-LS-08	0.1	3.7	0.03	0.7	–	0.1	–	4	0.14 ± 0.01	0.03	3.9 ± 0.3	0.7	
AMC02.1-16050001-019	GREN-LS-09	0.05	1.3	0.01	0.2	–	0.1	–	1	0.035 ± 0.002	0.01	0.9 ± 0.1	0.3	NS
AMC02.1-16050001-020	GREN-LS-10	0.1	3.7	0.03	0.7	–	0.1	–	3	0.01 ± 0.01	0.02	0.2 ± 0.3	0.7	
AMC02.1-16050001-021	ILOR-LS-01	0.1	3.7	0.03	0.7	–	0.1	–	4	0.08 ± 0.02	0.03	2.2 ± 0.6	0.7	
AMC02.1-16050001-022	ILOR-LS-02	0.1	3.7	0.03	0.7	–	0.1	–	4	0.20 ± 0.02	0.03	5.4 ± 0.5	0.7	
AMC02.1-16050001-023	ILOR-LS-03	0.05	1.3	0.01	0.2	–	0.1	–	1	0.015 ± 0.003	0.01	0.4 ± 0.1	0.3	NS
AMC02.1-16050001-024	ILOR-LS-04	0.05	1.3	0.01	0.2	–	0.04	–	1	0.020 ± 0.002	0.01	0.5 ± 0.1	0.2	NS
AMC02.1-16050001-025	ILOR-LS-05	0.1	3.7	0.03	0.7	–	0.1	–	2	0.02 ± 0.01	0.01	0.6 ± 0.2	0.4	
AMC02.1-16050001-026	ILOR-LS-06	0.05	1.3	0.01	0.2	–	0.04	–	1	0.020 ± 0.003	0.01	0.5 ± 0.1	0.2	NS
AMC02.1-16050001-027	ILOR-LS-07	0.1	3.7	0.03	0.7	–	0.1	–	3	0.03 ± 0.01	0.02	0.8 ± 0.2	0.6	
AMC02.1-16050001-028	ILOR-LS-08	0.1	3.7	0.03	0.7	–	0.2	–	5	0.03 ± 0.01	0.04	0.9 ± 0.3	1.0	
AMC02.1-16050001-029	ILOR-LS-09	0.1	3.7	0.03	0.7	–	0.1	–	3	0.03 ± 0.01	0.02	0.7 ± 0.2	0.6	
AMC02.1-16050001-030	ILOR-LS-10	0.1	3.7	0.03	0.7	–	0.2	–	4	0.02 ± 0.01	0.03	0.5 ± 0.3	0.8	
AMC02.1-16050001-031	ROCK-LS-01	0.05	1.3	0.01	0.2	–	0.04	–	1	0.029 ± 0.002	0.01	0.8 ± 0.1	0.2	NS

Sample ID	Sample Location	Sample MDA				^{134}Cs				^{137}Cs				Flags
		^{134}Cs		^{137}Cs		Bq kg^{-1}, wet		pCi kg^{-1}, wet		Bq kg^{-1},wet		pCi kg^{-1}, wet		
		Bq	pCi	Bq	pCi	Value	RDL	Value	RDL	Value	RDL	Value	RDL	
AMC02.1-16050001-032	ROCK-LS-02	0.1	3.7	0.03	0.7	–	0.1	–	3	0.04 ± 0.01	0.02	1.0 ± 0.3	0.6	
AMC02.1-16050001-033	ROCK-LS-03	0.1	3.7	0.03	0.7	–	0.1	–	3	0.05 ± 0.01	0.02	1.4 ± 0.3	0.6	
AMC02.1-16050001-034	ROCK-LS-04	0.1	3.7	0.03	0.7	–	0.1	–	4	0.06 ± 0.02	0.03	1.7 ± 0.5	0.7	
AMC02.1-16050001-035	ROCK-LS-05	0.1	3.7	0.03	0.7	–	0.2	–	4	0.04 ± 0.01	0.03	1.0 ± 0.3	0.8	
AMC02.1-16050001-036	ROCK-LS-06	0.1	3.7	0.03	0.7	–	0.2	–	4	0.03 ± 0.01	0.03	0.8 ± 0.3	0.8	
AMC02.1-16050001-037	ROCK-LS-07	0.05	1.3	0.01	0.2	–	0.1	–	2	0.053 ± 0.005	0.01	1.4 ± 0.1	0.4	NS
AMC02.1-16050001-038	ROCK-LS-08	0.1	3.7	0.03	0.7	–	0.1	–	3	0.08 ± 0.02	0.03	2.1 ± 0.5	0.7	
AMC02.1-16050001-039	ROCK-LS-09	0.1	3.7	0.03	0.7	–	0.2	–	4	0.10 ± 0.02	0.03	2.8 ± 0.5	0.8	
AMC02.1-16050001-040	ROCK-LS-10	0.1	3.7	0.03	0.7	–	0.1	–	4	0.02 ± 0.01	0.03	0.7 ± 0.4	0.7	
AMC03.1-16050001-011	GREN-ML-01	0.1	3.7	0.03	0.7	–	0.2	–	4	0.11 ± 0.01	0.03	2.9 ± 0.4	0.9	
AMC03.1-16050001-012	GREN-ML-02	0.1	3.7	0.03	0.7	–	0.1	–	3	0.08 ± 0.02	0.02	2.1 ± 0.5	0.6	
AMC03.1-16050001-013	GREN-ML-03	0.05	1.3	0.01	0.2	–	0.04	–	1	0.030 ± 0.003	0.01	0.8 ± 0.1	0.2	NS
AMC03.1-16050001-014	GREN-ML-04	0.05	1.3	0.01	0.2	–	0.1	–	2	0.034 ± 0.004	0.01	0.9 ± 0.1	0.4	NS
AMC03.1-16050001-015	GREN-ML-05	0.1	3.7	0.03	0.7	–	0.2	–	4	0.02 ± 0.01	0.03	0.7 ± 0.4	0.8	
AMC03.1-16050001-016	GREN-ML-06	0.1	3.7	0.03	0.7	–	0.1	–	3	0.15 ± 0.01	0.02	4.1 ± 0.3	0.6	
AMC03.1-16050001-017	GREN-ML-07	0.1	3.7	0.03	0.7	–	0.1	–	3	0.05 ± 0.02	0.02	1.5 ± 0.4	0.6	
AMC03.1-16050001-018	GREN-ML-08	0.1	3.7	0.03	0.7	–	0.1	–	3	0.03 ± 0.01	0.02	0.8 ± 0.3	0.6	
AMC03.1-16050001-019	GREN-ML-09	0.1	3.7	0.03	0.7	–	0.2	–	6	0.08 ± 0.02	0.04	2.1 ± 0.5	1.1	
AMC03.1-16050001-020	GREN-ML-10	0.1	3.7	0.03	0.7	–	0.1	–	4	0.08 ± 0.01	0.03	2.1 ± 0.3	0.8	
AMC03.1-16050001-021	ILOR-ML-01	0.1	3.7	0.03	0.7	–	0.2	–	4	0.05 ± 0.01	0.03	1.3 ± 0.3	0.8	
AMC03.1-16050001-022	ILOR-ML-02	0.1	3.7	0.03	0.7	–	0.2	–	5	0.08 ± 0.02	0.04	2.2 ± 0.5	1.0	
AMC03.1-16050001-023	ILOR-ML-03	0.1	3.7	0.03	0.7	–	0.1	–	4	0.09 ± 0.02	0.03	2.3 ± 0.6	0.7	
AMC03.1-16050001-024	ILOR-ML-04	0.1	3.7	0.03	0.7	–	0.2	–	5	0.44 ± 0.02	0.04	11.8 ± 0.5	1.1	
AMC03.1-16050001-025	ILOR-ML-05	0.1	3.7	0.03	0.7	–	0.1	–	4	0.03 ± 0.01	0.03	0.8 ± 0.3	0.8	
AMC03.1-16050001-026	ILOR-ML-06	0.05	1.3	0.01	0.2	–	0.04	–	1	0.021 ± 0.003	0.01	0.6 ± 0.1	0.2	NS
AMC03.1-16050001-027	ILOR-ML-07	0.1	3.7	0.03	0.7	–	0.2	–	5	0.17 ± 0.02	0.04	4.6 ± 0.6	0.9	
AMC03.1-16050001-028	ILOR-ML-08	0.1	3.7	0.03	0.7	–	0.3	–	8	0.10 ± 0.03	0.06	2.7 ± 0.9	1.6	
AMC03.1-16050001-029	ILOR-ML-09	0.1	3.7	0.03	0.7	–	0.2	–	4	0.12 ± 0.03	0.03	3.2 ± 0.7	0.9	
AMC03.1-16050001-030	ILOR-ML-10	0.1	3.7	0.03	0.7	–	0.2	–	4	0.06 ± 0.02	0.03	1.7 ± 0.5	0.9	
AMC03.1-16050001-031	ROCK-ML-01	0.1	3.7	0.03	0.7	–	0.1	–	2	0.31 ± 0.01	0.01	8.5 ± 0.3	0.4	
AMC03.1-16050001-032	ROCK-ML-02	0.1	3.7	0.03	0.7	–	0.2	–	4	0.07 ± 0.02	0.03	1.9 ± 0.4	0.8	
AMC03.1-16050001-033	ROCK-ML-03	0.1	3.7	0.03	0.7	–	0.1	–	3	0.05 ± 0.01	0.02	1.4 ± 0.3	0.6	

Sample ID	Sample Location	Sample MDA				^{134}Cs				^{137}Cs				Flags
		^{134}Cs		^{137}Cs		Bq kg^{-1}, wet		pCi kg^{-1}, wet		Bq kg^{-1},wet		pCi kg^{-1}, wet		
		Bq	pCi	Bq	pCi	Value	RDL	Value	RDL	Value	RDL	Value	RDL	
AMC03.1-16050001-034	ROCK-ML-04	0.05	1.3	0.01	0.2	–	0.1	–	2	0.046 ± 0.004	0.02	1.2 ± 0.1	0.4	NS
AMC03.1-16050001-035	ROCK-ML-05	0.1	3.7	0.03	0.7	–	0.1	–	3	0.05 ± 0.01	0.02	1.2 ± 0.4	0.6	
AMC03.1-16050001-036	ROCK-ML-06	0.1	3.7	0.03	0.7	–	0.1	–	3	0.04 ± 0.01	0.02	1.0 ± 0.3	0.6	
AMC03.1-16050001-037	ROCK-ML-07	0.1	3.7	0.03	0.7	–	0.1	–	3	0.01 ± 0.01	0.02	0.4 ± 0.2	0.6	
AMC03.1-16050001-038	ROCK-ML-08	0.1	3.7	0.03	0.7	–	0.1	–	4	0.05 ± 0.01	0.03	1.2 ± 0.4	0.7	
AMC03.1-16050001-039	ROCK-ML-09	0.05	1.3	0.01	0.2	–	0.03	–	1	0.024 ± 0.001	0.01	0.6 ± 0.0	0.2	NS
AMC03.1-16050001-040	ROCK-ML-10	0.1	3.7	0.03	0.7	–	0.1	–	3	0.06 ± 0.01	0.02	1.6 ± 0.4	0.6	
AMC05.1-16050001-011	GREN-CN-01	0.1	3.7	0.03	0.7	–	0.2	–	4	0.07 ± 0.02	0.03	1.9 ± 0.6	0.9	
AMC05.1-16050001-012	GREN-CN-02	0.1	3.7	0.03	0.7	–	0.2	–	5	0.07 ± 0.02	0.03	1.8 ± 0.4	0.9	
AMC05.1-16050001-013	GREN-CN-03	0.1	3.7	0.03	0.7	–	0.2	–	6	0.05 ± 0.02	0.04	1.4 ± 0.6	1.1	
AMC05.1-16050001-014	GREN-CN-04	0.05	1.3	0.01	0.2	–	0.1	–	2	0.035 ± 0.004	0.01	0.9 ± 0.1	0.3	NS
AMC05.1-16050001-015	GREN-CN-05	0.1	3.7	0.03	0.7	–	0.3	–	8	0.09 ± 0.03	0.06	2.3 ± 0.7	1.6	
AMC05.1-16050001-016	GREN-CN-06	0.1	3.7	0.03	0.7	–	0.2	–	5	0.05 ± 0.01	0.04	1.3 ± 0.4	1.0	
AMC05.1-16050001-017	GREN-CN-07	0.1	3.7	0.03	0.7	–	0.2	–	5	1.15 ± 0.03	0.04	31.0 ± 0.9	1.1	
AMC05.1-16050001-018	GREN-CN-08	0.1	3.7	0.03	0.7	–	0.2	–	5	0.09 ± 0.02	0.04	2.5 ± 0.5	1.0	
AMC05.1-16050001-019	GREN-CN-09	0.1	3.7	0.03	0.7	–	0.2	–	6	0.14 ± 0.04	0.04	3.9 ± 1.0	1.2	
AMC05.1-16050001-020	GREN-CN-10	0.1	3.7	0.03	0.7	–	0.3	–	8	0.03 ± 0.02	0.06	0.8 ± 0.5	1.6	
AMC05.1-16050001-021	ILOR-01	0.05	1.3	0.01	0.2	–	0.04	–	1	0.013 ± 0.002	0.01	0.4 ± 0.0	0.2	NS
AMC05.1-16050001-022	ILOR-02	0.1	3.7	0.03	0.7	–	0.2	–	5	0.04 ± 0.02	0.04	1.1 ± 0.4	1.0	
AMC05.1-16050001-023	ILOR-03	0.05	1.3	0.01	0.2	–	0.1	–	1	0.017 ± 0.003	0.01	0.5 ± 0.1	0.3	NS
AMC05.1-16050001-024	ILOR-04	0.1	3.7	0.03	0.7	–	0.1	–	3	0.02 ± 0.01	0.02	0.6 ± 0.3	0.6	

Sample ID	Sample Location	Sample MDA				^{134}Cs				^{137}Cs				Flags
		^{134}Cs		^{137}Cs		Bq kg^{-1}, wet		pCi kg^{-1}, wet		Bq kg^{-1},wet		pCi kg^{-1}, wet		
		Bq	pCi	Bq	pCi	Value	RDL	Value	RDL	Value	RDL	Value	RDL	
AMC05.1-16050001-025	ILOR-05	0.1	3.7	0.03	0.7	–	0.2	–	4	0.02 ± 0.01	0.03	0.6 ± 0.3	0.8	
AMC05.1-16050001-026	ILOR-06	0.1	3.7	0.03	0.7	–	0.1	–	4	0.03 ± 0.02	0.03	0.9 ± 0.5	0.8	
AMC05.1-16050001-027	ILOR-07	0.05	1.3	0.01	0.2	–	0.05	–	1	0.015 ± 0.001	0.01	0.4 ± 0.0	0.3	NS
AMC05.1-16050001-028	ILOR-08	0.05	1.3	0.01	0.2	–	0.2	–	5	0.07 ± 0.01	0.03	1.9 ± 0.3	0.9	NS
AMC05.1-16050001-029	ILOR-09	0.1	3.7	0.03	0.7	–	0.2	–	4	0.05 ± 0.02	0.03	1.4 ± 0.6	0.8	
AMC05.1-16050001-030	ILOR-10	0.1	3.7	0.03	0.7	–	0.2	–	4	0.04 ± 0.02	0.03	1.2 ± 0.6	0.8	
AMC05.1-16050001-031	ROCK-CN-01	0.1	3.7	0.03	0.7	–	0.2	–	5	0.06 ± 0.02	0.03	1.6 ± 0.5	0.9	
AMC05.1-16050001-032	ROCK-CN-02	0.1	3.7	0.03	0.7	–	0.2	–	4	0.05 ± 0.02	0.03	1.4 ± 0.5	0.9	
AMC05.1-16050001-033	ROCK-CN-03	0.1	3.7	0.03	0.7	–	0.1	–	4	0.05 ± 0.01	0.03	1.3 ± 0.3	0.8	
AMC05.1-16050001-034	ROCK-CN-04	0.1	3.7	0.03	0.7	–	0.1	–	3	0.53 ± 0.01	0.03	14.4 ± 0.4	0.7	
AMC05.1-16050001-035	ROCK-CN-05	0.1	3.7	0.03	0.7	–	0.1	–	3	0.29 ± 0.02	0.02	7.8 ± 0.5	0.6	
AMC05.1-16050001-036	ROCK-CN-06	0.1	3.7	0.03	0.7	–	0.2	–	4	0.07 ± 0.02	0.03	1.8 ± 0.5	0.8	
AMC05.1-16050001-037	ROCK-CN-07	0.1	3.7	0.03	0.7	–	0.2	–	5	0.04 ± 0.01	0.03	1.1 ± 0.3	0.9	
AMC05.1-16050001-038	ROCK-CN-08	0.1	3.7	0.03	0.7	–	0.1	–	2	0.02 ± 0.01	0.02	0.6 ± 0.3	0.5	
AMC05.1-16050001-039	ROCK-CN-09	0.1	3.7	0.03	0.7	–	0.1	–	4	0.04 ± 0.02	0.03	1.1 ± 0.6	0.8	
AMC05.1-16050001-040	ROCK-CN-10	0.1	3.7	0.03	0.7	–	0.1	–	4	0.02 ± 0.01	0.03	0.6 ± 0.3	0.7	
AMC13.1-16050001-001	DOLL-AD-01	0.1	3.7	0.03	0.7	0.12 ± 0.01	0.2	3.4 ± 0.3	6	1.84 ± 0.03	0.04	49.7 ± 0.9	1.2	
AMC13.1-16060002-003	DOLL-AD-01	0.1	3.7	0.03	0.7	0.11 ± 0.01	0.1	3.0 ± 0.2	3	2.59 ± 0.03	0.02	69.9 ± 0.7	0.7	
AMC14.1-16050001-011	GREN-AN-01	0.05	1.3	0.01	0.2	–	0.04	–	1	0.027 ± 0.002	0.01	0.7 ± 0.0	0.2	NS
AMC14.1-16050001-012	GREN-AN-02	0.1	3.7	0.03	0.7	–	0.2	–	5	0.10 ± 0.03	0.04	2.7 ± 0.7	1.0	
AMC14.1-16050001-013	GREN-AN-03	0.1	3.7	0.03	0.7	–	0.1	–	4	0.04 ± 0.01	0.03	1.1 ± 0.4	0.7	

Sample ID	Sample Location	Sample MDA				^{134}Cs				^{137}Cs				Flags
		^{134}Cs		^{137}Cs		Bq kg^{-1}, wet		pCi kg^{-1}, wet		Bq kg^{-1},wet		pCi kg^{-1}, wet		
		Bq	pCi	Bq	pCi	Value	RDL	Value	RDL	Value	RDL	Value	RDL	
AMC14.1-16050001-014	GREN-AN-04	0.05	1.3	0.01	0.2	–	0.0	–	1	0.04 ± 0.00	0.01	1.0 ± 0.1	0.3	NS
AMC14.1-16050001-015	GREN-AN-05	0.1	3.7	0.03	0.7	–	0.2	–	4	0.08 ± 0.01	0.03	2.1 ± 0.4	0.8	
AMC14.1-16050001-016	GREN-AN-06	–		–		–	–	–	–	–	–	–	–	L
AMC14.1-16050001-017	GREN-AN-07	0.1	3.7	0.03	0.7	–	0.2	–	5	0.05 ± 0.01	0.04	1.3 ± 0.3	1.0	
AMC14.1-16050001-018	GREN-AN-08	0.1	3.7	0.03	0.7	–	0.2	–	5	0.09 ± 0.02	0.03	2.3 ± 0.5	0.9	
AMC14.1-16050001-019	GREN-AN-09	0.1	3.7	0.03	0.7	–	0.1	–	3	0.06 ± 0.02	0.03	1.6 ± 0.4	0.7	
AMC14.1-16050001-020	GREN-AN-10	0.1	3.7	0.03	0.7	–	0.1	–	4	0.03 ± 0.01	0.03	0.7 ± 0.3	0.7	
AMC14.1-16050001-021	ILOR-AN-01	0.05	1.3	0.01	0.2	–	0.05	–	1	0.02 ± 0.002	0.01	0.5 ± 0.1	0.3	NS
AMC14.1-16050001-022	ILOR-AN-02	0.05	1.3	0.01	0.2	–	0.1	–	2	0.03 ± 0.002	0.01	0.7 ± 0.1	0.3	NS
AMC14.1-16050001-023	ILOR-AN-03	0.05	1.3	0.01	0.2	–	0.04	–	1	0.01 ± 0.001	0.01	0.3 ± 0.0	0.2	NS
AMC14.1-16050001-024	ILOR-AN-04	0.05	1.3	0.01	0.2	–	0.05	–	1	0.02 ± 0.001	0.01	0.5 ± 0.0	0.3	NS
AMC14.1-16050001-025	ILOR-AN-05	0.1	3.7	0.03	0.7	–	0.1	–	4	0.20 ± 0.02	0.03	5.5 ± 0.5	0.7	
AMC14.1-16050001-026	ILOR-AN-06	0.1	3.7	0.03	0.7	–	0.1	–	3	0.03 ± 0.01	0.02	0.9 ± 0.4	0.6	
AMC14.1-16050001-027	ILOR-AN-07	0.1	3.7	0.03	0.7	–	0.1	–	4	0.08 ± 0.02	0.03	2.1 ± 0.5	0.8	
AMC14.1-16050001-028	ILOR-AN-08	0.1	3.7	0.03	0.7	–	0.1	–	4	0.44 ± 0.01	0.03	11.8 ± 0.4	0.8	
AMC14.1-16050001-029	ILOR-AN-09	0.1	3.7	0.03	0.7	–	0.1	–	4	2.90 ± 0.03	0.03	78.4 ± 0.9	0.7	
AMC14.1-16050001-030	ILOR-AN-10	0.1	3.7	0.03	0.7	–	0.2	–	4	0.03 ± 0.02	0.03	0.7 ± 0.4	0.8	
AMC14.1-16050001-031	ROCK-AN-01	0.1	3.7	0.03	0.7	–	0.1	–	3	0.05 ± 0.01	0.02	1.3 ± 0.4	0.6	
AMC14.1-16050001-032	ROCK-AN-02	0.1	3.7	0.03	0.7	0.63 ± 0.02	0.1	17.0 ± 0.4	3	9.51 ± 0.05	0.03	256.9 ± 1.4	0.7	
AMC14.1-16050001-033	ROCK-AN-03	0.1	3.7	0.03	0.7	–	0.1	–	3	0.10 ± 0.02	0.03	2.6 ± 0.4	0.7	
AMC14.1-16050001-034	ROCK-AN-04	0.1	3.7	0.03	0.7	–	0.2	–	5	0.29 ± 0.01	0.03	7.8 ± 0.3	0.9	
AMC14.1-16050001-035	ROCK-AN-05	0.1	3.7	0.03	0.7	–	0.2	–	4	0.04 ± 0.02	0.03	1.1 ± 0.4	0.8	

Sample ID	Sample Location	Sample MDA				^{134}Cs				^{137}Cs				Flags
		^{134}Cs		^{137}Cs		Bq kg^{-1}, wet		pCi kg^{-1}, wet		Bq kg^{-1},wet		pCi kg^{-1}, wet		
		Bq	pCi	Bq	pCi	Value	RDL	Value	RDL	Value	RDL	Value	RDL	
AMC14.1-16050001-036	ROCK-AN-06	0.1	3.7	0.03	0.7	–	0.2	–	4	0.14 ± 0.03	0.03	3.8 ± 0.9	0.9	
AMC14.1-16050001-037	ROCK-AN-07	0.05	1.3	0.01	0.2	–	0.04	–	1	0.023 ± 0.002	0.01	0.6 ± 0.0	0.2	NS
AMC14.1-16050001-038	ROCK-AN-08	0.1	3.7	0.03	0.7	–	0.1	–	2	0.02 ± 0.01	0.02	0.4 ± 0.2	0.5	
AMC14.1-16050001-039	ROCK-AN-09	0.05	1.3	0.01	0.2	–	0.05	–	1	0.033 ± 0.002	0.01	0.9 ± 0.0	0.3	NS
AMC14.1-16050001-040	ROCK-AN-10	0.1	3.7	0.03	0.7	–	0.1	–	3	0.04 ± 0.01	0.03	1.0 ± 0.3	0.7	
AMC15.1-16050001-011	GREN-AS-01	0.05	1.3	0.01	0.2	–	0.1	–	2	0.026 ± 0.003	0.01	0.7 ± 0.1	0.3	NS
AMC15.1-16050001-012	GREN-AS-02	0.1	3.7	0.03	0.7	–	0.1	–	4	0.07 ± 0.020	0.03	1.9 ± 0.5	0.8	
AMC15.1-16050001-013	GREN-AS-03	0.05	1.3	0.01	0.2	–	0.1	–	1	0.049 ± 0.004	0.01	1.3 ± 0.1	0.3	NS
AMC15.1-16050001-014	GREN-AS-04	0.1	3.7	0.03	0.7	–	0.2	–	4	0.07 ± 0.02	0.03	1.9 ± 0.4	0.9	
AMC15.1-16050001-015	GREN-AS-05	0.1	3.7	0.03	0.7	–	0.2	–	5	0.06 ± 0.02	0.03	1.6 ± 0.6	0.9	
AMC15.1-16050001-016	GREN-AS-06	0.1	3.7	0.03	0.7	–	0.2	–	5	0.13 ± 0.03	0.04	3.6 ± 0.9	1.0	
AMC15.1-16050001-017	GREN-AS-07	0.1	3.7	0.03	0.7	–	0.2	–	4	0.09 ± 0.02	0.03	2.5 ± 0.4	0.9	
AMC15.1-16050001-018	GREN-AS-08	0.1	3.7	0.03	0.7	–	0.2	–	4	0.05 ± 0.02	0.03	1.2 ± 0.4	0.9	
AMC15.1-16050001-019	GREN-AS-09	0.1	3.7	0.03	0.7	–	0.2	–	4	0.08 ± 0.02	0.03	2.3 ± 0.4	0.9	
AMC15.1-16050001-020	GREN-AS-10	0.1	3.7	0.03	0.7	–	0.2	–	5	0.08 ± 0.02	0.04	2.1 ± 0.6	1.0	
AMC15.1-16050001-021	ILOR-AS-01	0.05	1.3	0.01	0.2	–	0.1	–	2	0.023 ± 0.002	0.02	0.6 ± 0.1	0.4	NS
AMC15.1-16050001-022	ILOR-AS-02	0.1	3.7	0.03	0.7	–	0.1	–	4	0.03 ± 0.01	0.03	0.8 ± 0.4	0.8	
AMC15.1-16050001-023	ILOR-AS-03	0.1	3.7	0.03	0.7	–	0.2	–	4	0.05 ± 0.02	0.03	1.4 ± 0.6	0.9	
AMC15.1-16050001-024	ILOR-AS-04	0.1	3.7	0.03	0.7	–	0.1	–	4	0.04 ± 0.02	0.03	1.2 ± 0.4	0.7	
AMC15.1-16050001-025	ILOR-AS-05	0.1	3.7	0.03	0.7	–	0.2	–	4	0.04 ± 0.02	0.03	1.0 ± 0.6	0.9	
AMC15.1-16050001-026	ILOR-AS-06	0.05	1.3	0.01	0.2	–	0.1	–	2	0.022 ± 0.003	0.01	0.6 ± 0.1	0.4	NS

Sample ID	Sample Location	Sample MDA				^{134}Cs				^{137}Cs				Flags
		^{134}Cs		^{137}Cs		Bq kg^{-1}, wet		pCi kg^{-1}, wet		Bq kg^{-1},wet		pCi kg^{-1}, wet		
		Bq	pCi	Bq	pCi	Value	RDL	Value	RDL	Value	RDL	Value	RDL	
AMC15.1-16050001-027	ILOR-AS-07	0.05	1.3	0.01	0.2	–	0.1	–	2	0.012 ± 0.003	0.01	0.3 ± 0.1	0.4	NS
AMC15.1-16050001-028	ILOR-AS-08	0.1	3.7	0.03	0.7	–	0.1	–	3	0.03 ± 0.01	0.02	0.7 ± 0.3	0.6	
AMC15.1-16050001-029	ILOR-AS-09	0.1	3.7	0.03	0.7	–	0.2	–	5	0.04 ± 0.01	0.04	1.1 ± 0.4	1.0	
AMC15.1-16050001-030	ILOR-AS-10	0.1	3.7	0.03	0.7	–	0.2	–	5	0.11 ± 0.01	0.03	3.1 ± 0.4	0.9	
AMC15.1-16050001-031	ROCK-AS-01	0.05	1.3	0.01	0.2	–	0.1	–	2	0.042 ± 0.002	0.01	1.1 ± 0.1	0.3	NS
AMC15.1-16050001-032	ROCK-AS-02	0.1	3.7	0.03	0.7	–	0.2	–	5	0.24 ± 0.02	0.04	6.6 ± 0.6	1.1	
AMC15.1-16050001-033	ROCK-AS-03	0.1	3.7	0.03	0.7	–	0.3	–	7	0.10 ± 0.03	0.05	2.8 ± 0.8	1.5	
AMC15.1-16050001-034	ROCK-AS-04	0.1	3.7	0.03	0.7	–	0.2	–	5	0.11 ± 0.02	0.04	3.1 ± 0.5	1.0	
AMC15.1-16050001-035	ROCK-AS-05	0.1	3.7	0.03	0.7	–	0.2	–	6	0.07 ± 0.04	0.04	2.0 ± 1.0	1.1	
AMC15.1-16050001-036	ROCK-AS-06	0.1	3.7	0.03	0.7	–	0.2	–	6	0.06 ± 0.03	0.04	1.7 ± 0.8	1.2	
AMC15.1-16050001-037	ROCK-AS-07	0.1	3.7	0.03	0.7	–	0.2	–	7	0.10 ± 0.03	0.05	2.8 ± 0.8	1.3	
AMC15.1-16050001-038	ROCK-AS-08	0.05	1.3	0.01	0.2	–	0.1	–	2	0.026 ± 0.003	0.01	0.7 ± 0.1	0.4	NS
AMC15.1-16050001-039	ROCK-AS-09	0.1	3.7	0.03	0.7	–	0.1	–	3	0.16 ± 0.01	0.02	4.3 ± 0.3	0.7	
AMC15.1-16050001-040	ROCK-AS-10	0.1	3.7	0.03	0.7	–	0.2	–	6	0.10 ± 0.03	0.04	2.6 ± 0.9	1.2	
AMC02.1-16050001-001	FUCU-LS-01	0.1	3.7	0.03	0.7	–	0.03	–	0.8	0.022 ± 0.004	0.01	0.6 ± 0.1	0.2	
AMC02.1-16050001-002	FUCU-LS-02	0.1	3.7	0.03	0.7	–	0.03	–	0.7	0.023 ± 0.003	0.01	0.6 ± 0.1	0.1	
AMC02.1-16050001-003	FUCU-LS-03	0.1	3.7	0.03	0.7	–	0.03	–	0.8	0.017 ± 0.002	0.01	0.5 ± 0.1	0.2	
AMC03.1-16050001-001	FUCU-ML-01	0.1	3.7	0.03	0.7	–	0.03	–	0.9	0.021 ± 0.004	0.01	0.6 ± 0.1	0.2	
AMC03.1-16050001-002	FUCU-ML-02	0.1	3.7	0.03	0.7	–	0.03	–	0.9	0.019 ± 0.004	0.01	0.5 ± 0.1	0.2	
AMC03.1-16050001-003	FUCU-ML-03	0.1	3.7	0.03	0.7	–	0.03	–	0.8	0.021 ± 0.004	0.01	0.6 ± 0.1	0.2	
AMC05.1-16050001-001	FUCU-CN-01	0.1	3.7	0.03	0.7	–	0.03	–	0.8	0.020 ± 0.003	0.01	0.5 ± 0.1	0.2	

Sample	ID	Sample Location	Sample MDA				^{134}Cs				^{137}Cs				Flags
			^{134}Cs		^{137}Cs		Bq kg^{-1}, wet		pCi kg^{-1}, wet		Bq kg^{-1},wet		pCi kg^{-1}, wet		
			Bq	pCi	Bq	pCi	Value	RDL	Value	RDL	Value	RDL	Value	RDL	
AMC05.1-16050001-002		FUCU-CN-02	0.1	3.7	0.03	0.7	–	0.03	–	0.9	0.024 ± 0.004	0.01	0.7 ± 0.1	0.2	
AMC05.1-16050001-003		FUCU-CN-03	0.1	3.7	0.03	0.7	–	0.03	–	0.7	0.029 ± 0.004	0.01	0.8 ± 0.1	0.1	
AMC14.1-16050001-001		FUCU-AN-01	0.1	3.7	0.03	0.7	–	0.03	–	0.8	0.037 ± 0.004	0.01	1.0 ± 0.1	0.2	
AMC14.1-16050001-002		FUCU-AN-02	0.1	3.7	0.03	0.7	–	0.03	–	0.8	0.025 ± 0.004	0.01	0.7 ± 0.1	0.2	
AMC14.1-16050001-003		FUCU-AN-03	0.1	3.7	0.03	0.7	–	0.03	–	0.8	0.023 ± 0.004	0.01	0.6 ± 0.1	0.2	
AMC15.1-16050001-001		FUCU-AS-01	0.1	3.7	0.03	0.7	–	0.03	–	0.8	0.045 ± 0.003	0.01	1.2 ± 0.1	0.2	
AMC15.1-16050001-002		FUCU-AS-02	0.1	3.7	0.03	0.7	–	0.03	–	0.7	0.028 ± 0.002	0.01	0.8 ± 0.1	0.1	
AMC15.1-16050001-003		FUCU-AS-03	0.1	3.7	0.03	0.7	–	0.03	–	0.9	0.072 ± 0.003	0.01	2.0 ± 0.1	0.2	

NS = Below Routine Gamma Limit of Detection, Recounted by SAGe; L = Gamma Sample Lost in Processing

Appendix D

Lawrence Livermore National Laboratory
Data Report, Part IV: Measurement of Pu isotopes (^{239}Pu, ^{240}Pu) in Biological Samples

NOTE:

LLNL's more recent communication (Hamilton 2019) suggests that the four 2016 ^{240}Pu results initially reported as detected, although still passing quality assurance requirements, are anomalous and should not be considered as quantitative. The following appendix, duplicated from Hamilton et al. (2018c), should be interpreted with this caveat in mind. No biota samples were retained so reanalysis of the samples is not feasible.

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AMCHITKA PROJECT

Data Report, Part IV

Measurement of Pu isotopes (^{239}Pu, ^{240}Pu) in biological samples

T.F. Hamilton
S.R. Kehl
R.M. Berry

June 2018

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GLOBAL SECURITY PRINCIPAL DIRECTORATE

AMCHITKA PROJECT
WFO Proposal D201231

Data Report, Part IV

Measurement of Pu isotopes (^{239}Pu, ^{240}Pu) in biological samples

T.F. Hamilton, S.R. Kehl, and R.M. Berry

June 2018

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APPENDIX 2. Measurement of Pu isotopes (^{239}Pu, ^{240}Pu) in biological samples (mBq kg^{-1}, wet weight)

[CD copies of this report along with excel data listings are available upon request].

TABLES and FIGURES

Table 1. List of targeted radionuclides, laboratory methods and estimated detection limits (2016 Amchitka Sampling Event) (after USDOE, 2016).

1.0 Prologue

The following data report was prepared under contract with the U.S. Department of Energy (DOE), Office of Legacy Management (LM), Grand Junction, Colorado, in support of the LongTerm Surveillance Plan (LTSP) for the Aleutian Islands nuclear site test on Amchitka Island (USDOE, 2014). Following the 2016 sampling event, the Lawrence Livermore National Laboratory (LLNL) received a collection of seawater, freshwater and biological samples for analysis of targeted radionuclides. The sampling activities implemented in 2016 for Amchitka Island and its reference site of Adak, Alaska, were similar in purpose to those conducted previously (USDOE, 2013; 2014). Added emphasis was placed on seawater sampling near an area of potential leakage off the Long Shot test detonation site. There was also an interest in conducting analyses of targeted radionuclides with lower limits of detection for the expressed purpose of directing future trending analysis (USDOE, 2016). The targeted radionuclides of interest included tritium(^{3}H), cesium-134 (^{134}Cs), cesium-137 (^{137}Cs), plutonium-239 (^{239}Pu), and plutonium-240 (^{240}Pu). ^{134}Cs was presumably included to assess the residual impact of inputs from Fukushima.

The systematics and specific objectives of the 2016 sampling event and the associated analytical program were formulated by LM in partnership with the Alaska Department of Environmental Conservation (ADEC), the *Aleutian Pribilof Islands Association, Inc.* (APIA) (a federally recognized tribal organization of the Alet people in Alaska), and the Argonne National Laboratory (ANL). A specific project goal for the 2016 sampling event was to attest to the possibility that selected residual radionuclides from underground nuclear tests conducted on Amchitka Island may enter the marine food chain and result in potential ecological and human health effects.

LLNL was tasked to provide analytical support for the project with electronic data reporting. Samples of seawater (unfiltered) (N=25) and freshwater (unfiltered) (N=2) were received for analysis of ^{134}Cs and ^{137}Cs. A larger subset of marine biota and algae samples were received for analysis of ^{134}Cs-^{137}Cs and ^{239}Pu-^{240}Pu isotopes. The biological sample collection included Dolly Varden (*Salvelinus malma*) (N=3), Greenling (*Hexagrammos spp*.) (N=50), Irish Lord (*Hemilepidotus spp*.) (N=50), Rockfish (*Sebastes spp*.) (N=50) and Rockweed (*Fucus distichus*) (N=15). Cs isotopes were determined by high resolution gamma-spectrometry after separation of the analytes of interest, along with added carrier, on a small quantity of microcrystalline ammonium molybdophosphate (AMP). Pu isotopes were measured by

quadrupole Inductively Coupled Plasma Mass Spectrometry (ICP-MS). During early discussion with the sponsor, some consideration was to be given to conducting measurements of Pu isotopes in waters and biological samples by Accelerator Mass Spectrometry (AMS).

The scope of work as outlined in the sampling plan covered specific Quality Assurance Objectives (QAOs) with respect to achievable limits of detection for each of the targeted radionuclides. Livermore scientists found that the agreed-to limits of detection contained in the 2016 sampling plan were not necessarily supportive of overall program goals to provide quantitative data and information for future trending analysis. To improve quantification of Cs isotopes by gamma-spectrometry and allow for a more detailed comparative assessment to be conducted between sampling events, the project reporting deadline was extended to allow for longer count times. Even with the longer count times (4-6 days), about 20% of the marine biota samples contained no reportable Cs isotope activity. These samples were subsequently recounted on a Small Anode Germanium (SAGe) well detector system with improved measurement precision. Also, with agreement from the sponsor, a subset of seawater and freshwater samples were analyzed for iodine-129 (^{129}I) using AMS with the aim of providing information on the potential impacts of other source-terms on marine radioactivity, especially with respect to Fukushima. No other AMS measurements were subsequently conducted under the terms of the contract award to LLNL.

N = number of individual samples received for analysis.

2.0 Scope of Analytical Project at LLNL

2.1 Objective

Provide analytical measurement data and reporting under the 2016 Amchitka sampling event.

2.2 Statement of Work

1. Measure the ^{137}Cs, ^{134}Cs, ^{239}Pu and ^{240}Pu content of marine biota and algae samples as supplied under the 2016 Amchitka Sampling Event using a combination of high-resolution gamma spectrometry (Cs isotopes) and Inductively Coupled Plasma Mass Spectrometry (Pu isotopes).
2. Measure the ^{137}Cs and ^{134}Cs content of freshwater and seawater as supplied under the 2016 Amchitka Sampling Event using a SAGe well gamma detector system.

3. Provide EDD and hard copy reporting of analytical data with a description of methodologies and supporting quality assurance measures.

2.2 Target Radionuclides and Selection Criteria for Methods of Analysis

Previous studies conducted by CRESP (Consortium for Risk Evaluation with Stakeholder Participation) (CRESP, 2015) and LM under the LTSP for the Aleutian Islands nuclear site test on Amchitka Island show that reported levels of anthropogenic radionuclides contained in marine biota from the site were at or below the acceptable consumption risk range of 10^{-4} to 10^{-6} excess risk of cancer. The aim of the current sampling event was to optimize the design of the sampling and analytical program. This was done not only to provide additional confirmatory measurements of the possible health risk posed by consumption of marine foods from the region but to yield high quality data for trending analyses. Under a formal strategic planning process, pre-determined sample locations and DQOs were devised to reduce uncertainties in assessing food safety and provide adequate detection sensitivity to support future statistical trending analyses. This included placing minimum requirements on the quantity of biological materials to be collected (within practical limitations) based on estimated limits of detection for prescribed measurement techniques.

A listing of targeted radionuclides, methodologies and estimated limits of detection for the 2016 Amchitka sampling event is contained in Table 1 (after USDOE, 2016).

2.3 Sample Delivery/COC Documentation

Biological samples collected in the field were sealed inside labeled plastic bags and shipped frozen. All biological fauna samples were received as whole animals. It should be noted, however, that several fish samples were received with their gut cavities open (Hamilton et al., 2018a). Water samples were shipped in single 20-L (5-gallon) polyethylene carboys with no preservation. Samples were received in two (2) separate air cargo flights into San José International Airport in northern California, and then immediately transported by road (app. 30 miles) to LLNL. Biological samples were subsequently stored frozen at LLNL prior to processing. Each sample shipment was accompanied by Change-of-Custody (COC) documentation listing the task code, COC ID, sample ID, location code, matrix type (biota or water), date and time of sampling, collection code (grab or composite), number of sample containers (typically 1 ea.), and

the type of sample analysis to be performed. Upon arrival of the samples at LLNL, a validation check was performed of samples received against the COC listing and any variances identified (see Hamilton *et al*., 2018a). All COC listed samples were accounted for. Sample AMC01.116060002-001 (DOLL-AI-01) and AMC13.1-16060002-003 (DOLL-AD-01) were received in the 2nd sample shipment without accompanying COC documentation.

Table 1. List of targeted radionuclides, laboratory methods and estimated detection limits (2016 Amchitka Sampling Event) (after USDOE, 2016).

Analyte	Laboratory Method	Estimated MDA (Bq)	A Priori MDA (Bq kg^{-1} - wet weight)[a]		
			Based on 100 g sample	Based on 1000 g sample	Based on 5000 g sample
Biological samples					
^{134}Cs	Gamma-spectrometry	0.3	3	0.3	0.06
^{137}Cs	Gamma-spectrometry	0.3	3	0.3	0.06
^{239}Pu	Quad ICP-MS	0.008	0.08	0.008	0.0016
^{240}Pu	Quad ICP-MS	0.02	0.2	0.02	0.004
^{239}Pu	AMS	0.00001	0.0001	0.00001	0.000002
^{240}Pu	AMS	0.00003	0.0003	0.00003	0.000006
Seawater and freshwater Samples					
^{134}Cs	Gamma-spectrometry (SAGe)	0.006	0.3[b]		
^{137}Cs	Gamma-spectrometry (SAGe)	0.003	0.15[b]		
^{3}H	Electrolytic enrichment followed by gas proportional counting	0.01184[c]			

[a] MDA expressed on sample mass basis [represents the Relative Detection Limit (RDL)].

[b] Based on a 20-liter sample (Bq m^{-3}).

[c] Bq L^{-1} (Tritium Laboratory, Rosenstiel School of Marine and Atmospheric Science, Miami, FL).

Abbreviations:

MDA = Minimum Detection Activity

AMS = Accelerator Mass Spectrometry

ICP-MS = Inductively Coupled Palsma Mass Spectrometry

g = grams

SAGe = Single Anode Germanium

3.0 Pu Isotope Measurements in Biological Samples

3.1 Sample Preparation

The biological samples collected during the 2016 Amchitka planning event were dried to a constant weight, spiked with stable Cs and $1x10^{12}$ atoms of ^{242}Pu tracer solution, and then reduced to an ash in a muffle furnace at 450-500 °C (after Hamilton *et al*., 2018a). The residual sample material was then treated with concentrated $HN0_3$ and heated on a hotplate with periodic additions of H_2O_2 to destroy any remaining C (charcoal). The sample solution was then filtered to remove insoluble materials and evaporated to near dryness. After rehydrating the sample in dilute HCl and extraction of Cs isotopes on AMP, Pu isotopes were separated from the bulk matrix by precipitation on Al phosphate after slowly raising the pH to 5.5-6.0 with addition of NH_4OH. The Al phosphate was then recovered by centrifugation and plutonium isotopes isolated and purified by ion-exchange chromatography (Martinelli, *et al*., 2009). The purified sample was evaporated to dryness and the residue taken up in 10 ml of 2% Ultra-Pure $HN0_3$ (Sigma-Aldrich) for analysis of Pu isotopes using an iCap Q ICP-MS system (ThermoFisher Scientific). Samples were processed and analyzed in parallel with a series of reagent blanks.

3.2 Detection and Measurement

ICP-MS analyses of Pu isotopes were performed in KED (Kinetic Energy Discrimination) mode with use of a He collision cell and a CETEC ASX-520 Autosampler. System performance (stability and sensitivity) were routinely monitored and optimized prior to each analytical run. Sample quantification was based on external calibration of intensities (cpm) in the range of pg g^{-1} for individual Pu isotope solution prepared from a reference standard indirectly traceable to the NIST (National Institute of Standards and Technology). The average estimated sample recovery was 84.6%.

3.3 Quality Assurance

The estimated MDA for detection of ^{239}Pu and ^{240}Pu isotopes was assessed across a series of analytical runs by a method of standard additions (after Hubaux and Vos, 1970). The average calculated MDA for detection of ^{239}Pu and ^{240}Pu was around 0.1 and 0.5 mBq (0.002 and 0.01 pCi), respectively. Analytical sample data was typically computed from the average of 3 internal runs with each run composed of 50 to 100 sweeps across each of the targeted masses. It should be noted that all accepted data falls within the range of the reported Relative Detection Limit (RDL) for individual samples with very few outliers. The acceptance criteria for data was based on a

sensitivity trigger rule where measurements were only reported where the values exceeded the estimated individual sample measurement RDL. Some analyses were also rejected based on a Relative Standard Deviation (RSD) (or stability) trigger rule. In this instance, if the RSD between individual runs for any individual sample analysis exceeded 20% then the measurement data was rejected. This RSD rule would override the sensitivity rule even where reported values exceeded the RDL.

Performance tests of the ICPMS system were assessed by analyzing a 5 pg g^{-1} solution of a Certified Reference Material (CRM-128) (NBL, 1984). CRM-128 was specifically prepared by the New Brunswick Laboratory (NBL) for calibrating mass spectrometers. The material contains a certified $^{239}Pu/^{242}Pu$ atom ratio of 0.99937 ± 0.00026. SRM-128 is not certified as an assay reference material, individual isotope measurements of ^{239}Pu (and ^{242}Pu) do attest to the performance of the instrument across multiple analytical runs and service maintenance visits. The average $^{239}Pu/^{242}Pu$ atom ratio measured in CRM-128 over the course of the Amchitka-2016 analytical campaign was 0.988 ± 0.017 (N=31) (or 98.9 % of the certified value). The average ^{239}Pu assay value was 106 ± 4% (N=31) of the information value reported by the New Brunswick Laboratory.

The LM specified reporting units were given as pCi kg^{-1}, wet weight. It was decided to include more conventional SI units (in Bq kg^{-1}, wet weight) in this hardcopy data report (as reported in Appendix 1 and 2, respectively).

4.0 Conclusion

The activity concentration of ^{239}Pu and ^{240}Pu was successfully measured in all available biological samples collected during the 2016 Amchitka sampling event. Detectable levels of ^{239}Pu were reported for many fish and algal samples, mostly at or near the detection limits of the instrument. Few samples contained detectable levels of ^{240}Pu. All data appear to satisfy internal and external quality assurance measures within the uncertainty of the measurements.

5.0 References

CRESP (2005). Amchitka Independent Science Assessment: Biological and Geophysical Aspects of Potential Radionuclide Exposure in the Amchitka Marine Environment, Consortium for Risk Evaluation with Stakeholder Participation (CRESP), C.W. Powers, J. Burger, D. Kosson, M. Gochfeld, and D. Barnes, eds., Piscataway, New Jersey.

Hamilton, T.F., S. R. Kehl, and R. M. Berry (2018a). Processing of Biological Samples (Wet, Dry and Ash Weights), Data Report, Part I, AMCHITKA PROJECT, WFO Project D201231, Lawrence Livermore National Laboratory, LLNL-SR-751699.

Hubaux, A., and G. Vos (1970). Decision and detection limits for linear calibration curves. *Anal. Chem.*, *42*, 849−85

Martinelli, R.E., T.F. Hamilton, R.W Williams and S.R. Kehl (2009). Separation of uranium and plutonium isotopes for measurement by multi collector inductively coupled plasma mass spectroscopy, J. Radioanal. Nucl. Chem., 282, 343-347.

NBL (1984). https://science.energy.gov/~/media/nbl/pdf/price lists/certificates/CRM_128_Plutonium _239-242_ Atom_Standard_March_2008.pdf

USDOE (2016). Environmental Sampling Plan for the Amchitka, Alaska, Site and Adak Island 2016 Sampling Event, Office of Legacy Management (LM), U.S Department of Energy (USDOE), Colorado, LMS/AMC/S12630 (not for public release).

USDOE (2014). Long-Term Surveillance Plan for the U.S. Department of Energy Amchitka, Alaska, Site, Office of Legacy Management (LM), U.S Department of Energy (USDOE), Colorado, LMS/AMC/S01980.

USDOE (2013). Amchitka Island, Alaska, Biological Monitoring Report 2011 Sampling Results, Office of Legacy Management (LM), U.S Department of Energy (USDOE), Colorado, LMS/AMC/SO8833.

Appendix 1

Measurement of Pu isotopes (^{239}Pu, ^{240}Pu) in biological samples (pCi kg^{-1}, wet weight)

Sample ID	Sample Location	Sample MDA, pCi		^{239}Pu, pCi kg^{-1} (wet weight)		^{240}Pu, pCi kg^{-1} (wet weight)		trigger	
		^{239}Pu	^{240}Pu	value	RDL	value	RDL	^{239}Pu	^{240}Pu
AMC13.1-16050001-001	DOLL-AD-001	0.002	0.01		0.005		0.03	RSL	RSL
AMC13.1-16060002-003	DOLL-AD-003	0.002	0.01		0.003		0.02	MDL	MDL
AMC01.1-16060002-001	DOLL-AI-001	0.002	0.01		0.003		0.02	MDL	MDL
AMC14.1-16050001-001	FUCU-AN-01	0.002	0.01		0.0004		0.003	RSL	RSL
AMC14.1-16050001-002	FUCU-AN-02	0.002	0.01	0.0016 ± 0.0003	0.0004		0.003		MDL
AMC14.1-16050001-003	FUCU-AN-03	0.002	0.01	0.0013 ± 0.0002	0.0004		0.003		MDL
AMC15.1-16050001-001	FUCU-AS-01	0.002	0.01	0.0006 ± 0.0001	0.0004		0.003		MDL
AMC15.1-16050001-002	FUCU-AS-02	0.002	0.01	0.0006 ± 0.0001	0.0004		0.003		MDL
AMC15.1-16050001-003	FUCU-AS-03	0.002	0.01		0.0004		0.003	RSL	MDL
AMC05.1-16050001-001	FUCU-CN-01	0.002	0.01	0.0007 ± 0.0001	0.0004		0.002		MDL
AMC05.1-16050001-002	FUCU-CN-02	0.002	0.01	0.0006 ± 0.0001	0.0004		0.003		MDL
AMC05.1-16050001-003	FUCU-CN-03	0.002	0.01	0.0008 ± 0.0001	0.0004		0.002		MDL
AMC02.1-16050001-001	FUCU-LS-01	0.002	0.01	0.0015 ± 0.0001	0.0005		0.003		MDL
AMC02.1-16050001-002	FUCU-LS-02	0.002	0.01	0.00072 ± 0.00004	0.0004		0.003		MDL
AMC02.1-16050001-003	FUCU-LS-03	0.002	0.01	0.0018 ± 0.0003	0.0004		0.003		MDL
AMC03.1-16050001-001	FUCU-ML-01	0.002	0.01	0.0012 ± 0.0002	0.0005		0.003		MDL
AMC03.1-16050001-002	FUCU-ML-02	0.002	0.01	0.0012 ± 0.0002	0.0005		0.003		MDL
AMC03.1-16050001-003	FUCU-ML-03	0.002	0.01	0.0005 ± 0.0001	0.0004		0.003		MDL

Sample ID	Sample Location	Sample MDA, pCi		^{239}Pu, pCi kg^{-1} (wet weight)		^{240}Pu, pCi kg^{-1} (wet weight)		trigger	
		^{239}Pu	^{240}Pu	value	RDL	value	RDL	^{239}Pu	^{240}Pu
AMC14.1-16050001-011	GREN-AN-01	0.002	0.01		0.002		0.02	MDA	MDL
AMC14.1-16050001-012	GREN-AN-02	0.002	0.01	0.007 ± 0.001	0.003		0.02		MDL
AMC14.1-16050001-013	GREN-AN-03	0.002	0.01	0.006 ± 0.001	0.002		0.01		MDL
AMC14.1-16050001-014	GREN-AN-04	0.002	0.01	0.003 ± 0.001	0.002		0.02		MDL
AMC14.1-16050001-015	GREN-AN-05	0.002	0.01	0.0027 ± 0.0005	0.002		0.02		MDL
AMC14.1-16050001-016	GREN-AN-06	0.002	0.01	0.005 ± 0.001	0.005		0.03		MDL
AMC14.1-16050001-017	GREN-AN-07	0.002	0.01		0.003		0.02	MDL	MDL
AMC14.1-16050001-018	GREN-AN-08	0.002	0.01	0.004 ± 0.001	0.003		0.02		MDL
AMC14.1-16050001-019	GREN-AN-09	0.002	0.01		0.002		0.01	MDL	MDL
AMC14.1-16050001-020	GREN-AN-10	0.002	0.01		0.002		0.01	MDL	MDL
AMC15.1-16050001-011	GREN-AS-01	0.002	0.01		0.003		0.02	RSD	MDL
AMC15.1-16050001-012	GREN-AS-02	0.002	0.01	0.004 ± 0.001	0.002		0.02		MDL
AMC15.1-16050001-013	GREN-AS-03	0.002	0.01		0.002		0.01	MDL	MDL
AMC15.1-16050001-014	GREN-AS-04	0.002	0.01	0.007 ± 0.001	0.002		0.02		MDL
AMC15.1-16050001-015	GREN-AS-05	0.002	0.01		0.002		0.02	MDL	MDL
AMC15.1-16050001-016	GREN-AS-06	0.002	0.01		0.003		0.02	MDL	MDL
AMC15.1-16050001-017	GREN-AS-07	0.002	0.01		0.002		0.01	MDL	MDL
AMC15.1-16050001-018	GREN-AS-08	0.002	0.01		0.002		0.02	RSD	MDL
AMC15.1-16050001-019	GREN-AS-09	0.002	0.01		0.002		0.01	MDL	MDL
AMC15.1-16050001-020	GREN-AS-10	0.002	0.01		0.003		0.016	MDL	MDL
AMC05.1-16050001-011	GREN-CN-01 *	0.002	0.01		0.004		0.03	RSD	RSD

Sample ID	Sample Location	Sample MDA, pCi		^{239}Pu, pCi kg^{-1} (wet weight)		^{240}Pu, pCi kg^{-1} (wet weight)		trigger	
		^{239}Pu	^{240}Pu	value	RDL	value	RDL	^{239}Pu	^{240}Pu
AMC05.1-16050001-012	GREN-CN-02	0.002	0.01	0.011 ± 0.001	0.002		0.014		MDL
AMC05.1-16050001-013	GREN-CN-03	0.002	0.01	0.009 ± 0.002	0.003		0.02		MDL
AMC05.1-16050001-014	GREN-CN-04	0.002	0.01	0.008 ± 0.001	0.003		0.02		MDL
AMC05.1-16050001-015	GREN-CN-05	0.002	0.01	0.011 ± 0.003	0.003		0.02		MDL
AMC05.1-16050001-016	GREN-CN-06	0.002	0.01	0.027 ± 0.002	0.003		0.021		RSD
AMC05.1-16050001-017	GREN-CN-07	0.002	0.01	0.008 ± 0.001	0.003		0.021		MDL
AMC05.1-16050001-018	GREN-CN-08	0.002	0.01	0.015 ± 0.002	0.004		0.026		MDL
AMC05.1-16050001-019	GREN-CN-09	0.002	0.01	0.025 ± 0.004	0.004	0.100 ± 0.007	0.028		
AMC05.1-16050001-020	GREN-CN-10	0.002	0.01	0.015 ± 0.002	0.004		0.025		MDL
AMC02.1-16050001-011	GREN-LS-01	0.002	0.01	0.015 ± 0.003	0.002		0.01		MDL
AMC02.1-16050001-012	GREN-LS-02	0.002	0.01	0.003 ± 0.001	0.002		0.01		MDL
AMC02.1-16050001-013	GREN-LS-03	0.002	0.01	0.006 ± 0.001	0.003		0.02		MDL
AMC02.1-16050001-014	GREN-LS-04	0.002	0.01	0.006 ± 0.001	0.003		0.02		MDL
AMC02.1-16050001-015	GREN-LS-05	0.002	0.01	0.004 ± 0.001	0.003		0.02		MDL
AMC02.1-16050001-016	GREN-LS-06	0.002	0.01	0.0029 ± 0.000	0.002		0.01		MDL
AMC02.1-16050001-017	GREN-LS-07	0.002	0.01	0.014 ± 0.001	0.003		0.02		MDL
AMC02.1-16050001-018	GREN-LS-08	0.002	0.01	0.006 ± 0.001	0.003		0.02		MDL
AMC02.1-16050001-019	GREN-LS-09	0.002	0.01	0.007 ± 0.001	0.002		0.01		MDL
AMC02.1-16050001-020	GREN-LS-10	0.002	0.01	0.0030 ± 0.0002	0.002		0.02		MDL
AMC03.1-16050001-011	GREN-ML-01	0.002	0.01	0.008 ± 0.001	0.003		0.02		MDL

Sample ID	Sample Location	Sample MDA, pCi		^{239}Pu, pCi kg^{-1} (wet weight)		^{240}Pu, pCi kg^{-1} (wet weight)		trigger	
		^{239}Pu	^{240}Pu	value	RDL	value	RDL	^{239}Pu	^{240}Pu
AMC03.1-16050001-012	GREN-ML-02	0.002	0.01	0.009 ± 0.001	0.002		0.01		MDL
AMC03.1-16050001-013	GREN-ML-03	0.002	0.01	0.011 ± 0.001	0.002		0.02		MDL
AMC03.1-16050001-014	GREN-ML-04	0.002	0.01	0.014 ± 0.001	0.002		0.01		MDL
AMC03.1-16050001-015	GREN-ML-05	0.002	0.01	0.003 ± 0.002	0.002		0.01		MDL
AMC03.1-16050001-016	GREN-ML-06	0.002	0.01	0.004 ± 0.001	0.002		0.01		MDL
AMC03.1-16050001-017	GREN-ML-07	0.002	0.01	0.011 ± 0.002	0.002		0.01		MDL
AMC03.1-16050001-018	GREN-ML-08	0.002	0.01	0.009 ± 0.001	0.002		0.01		MDL
AMC03.1-16050001-019	GREN-ML-09	0.002	0.01	0.005 ± 0.001	0.003		0.02		MDL
AMC03.1-16050001-020	GREN-ML-10	0.002	0.01	0.017 ± 0.001	0.003		0.02		MDL
AMC05.1-16050001-021	ILOR-01	0.002	0.01	0.005 ± 0.002	0.001		0.01		MDL
AMC05.1-16050001-022	ILOR-02	0.002	0.01	0.016 ± 0.002	0.003		0.02		MDL
AMC05.1-16050001-023	ILOR-03	0.002	0.01	0.008 ± 0.001	0.003		0.02		MDL
AMC05.1-16050001-024	ILOR-04	0.002	0.01		0.002		0.01	MDL	MDL
AMC05.1-16050001-025	ILOR-05	0.002	0.01	0.0040 ± 0.0005	0.002		0.01		MDL
AMC05.1-16050001-026	ILOR-06	0.002	0.01	0.005 ± 0.001	0.002		0.01		MDL
AMC05.1-16050001-027	ILOR-07	0.002	0.01	0.010 ± 0.001	0.003		0.02		MDL
AMC05.1-16050001-028	ILOR-08	0.002	0.01	0.017 ± 0.002	0.003	0.082 ± 0.011	0.02		
AMC05.1-16050001-029	ILOR-09	0.002	0.01	0.016 ± 0.003	0.003		0.02		MDL
AMC05.1-16050001-030	ILOR-10	0.002	0.01	0.013 ± 0.001	0.003		0.02		MDL
AMC14.1-16050001-021	ILOR-AN-01	0.002	0.01		0.003		0.02	RSD	MDL

Sample ID	Sample Location	Sample MDA, pCi		^{239}Pu, pCi kg^{-1} (wet weight)		^{240}Pu, pCi kg^{-1} (wet weight)		trigger	
		^{239}Pu	^{240}Pu	value	RDL	value	RDL	^{239}Pu	^{240}Pu
AMC14.1-16050001-022	ILOR-AN-02	0.002	0.01	0.004 ± 0.001	0.002		0.01		MDL
AMC14.1-16050001-023	ILOR-AN-03	0.002	0.01	0.009 ± 0.001	0.002		0.02		MDL
AMC14.1-16050001-024	ILOR-AN-04	0.002	0.01		0.003		0.02	MDL	MDL
AMC14.1-16050001-025	ILOR-AN-05	0.002	0.01	0.003 ± 0.001	0.002		0.02		MDL
AMC14.1-16050001-026	ILOR-AN-06	0.002	0.01	0.003 ± 0.001	0.002		0.01		MDL
AMC14.1-16050001-027	ILOR-AN-07	0.002	0.01		0.002		0.01	MDL	MDL
AMC14.1-16050001-028	ILOR-AN-08	0.002	0.01	0.003 ± 0.001	0.002		0.01		MDL
AMC14.1-16050001-029	ILOR-AN-09	0.002	0.01	0.016 ± 0.002	0.002		0.02		MDL
AMC14.1-16050001-030	ILOR-AN-10	0.002	0.01	0.004 ± 0.001	0.002		0.02		MDL
AMC15.1-16050001-021	ILOR-AS-01	0.002	0.01		0.002		0.01	RSD	RSD
AMC15.1-16050001-022	ILOR-AS-02	0.002	0.01	0.009 ± 0.002	0.002		0.01		MDL
AMC15.1-16050001-023	ILOR-AS-03	0.002	0.01	0.0043 ± 0.0004	0.002		0.01		MDL
AMC15.1-16050001-024	ILOR-AS-04	0.002	0.01	0.055 ± 0.002	0.002		0.01		MDL
AMC15.1-16050001-025	ILOR-AS-05	0.002	0.01		0.002		0.02	RSL	MDL
AMC15.1-16050001-026	ILOR-AS-06	0.002	0.01		0.003		0.02	RSL	RSD
AMC15.1-16050001-027	ILOR-AS-07	0.002	0.01	0.015 ± 0.001	0.003		0.02		MDL
AMC15.1-16050001-028	ILOR-AS-08	0.002	0.01		0.002		0.01	MDL	MDL
AMC15.1-16050001-029	ILOR-AS-09	0.002	0.01	0.003 ± 0.001	0.002		0.02		MDL
AMC15.1-16050001-030	ILOR-AS-10	0.002	0.01	0.006 ± 0.001	0.004		0.03		MDL
AMC02.1-16050001-021	ILOR-LS-01	0.002	0.01		0.003		0.02	RSD	MDL
AMC02.1-16050001-022	ILOR-LS-02	0.002	0.01	0.007 ± 0.001	0.002		0.01		MDL
AMC02.1-16050001-023	ILOR-LS-03	0.002	0.01	0.006 ± 0.001	0.003		0.02		MDL
AMC02.1-16050001-024	ILOR-LS-04	0.002	0.01	0.011 ± 0.001	0.002		0.02		MDL
AMC02.1-16050001-025	ILOR-LS-05	0.002	0.01	0.011 ± 0.002	0.002		0.01		MDL
AMC02.1-16050001-026	ILOR-LS-06	0.002	0.01	0.0064 ± 0.0004	0.002		0.01		MDL

Sample ID	Sample Location	Sample MDA, pCi		^{239}Pu, pCi kg^{-1} (wet weight)		^{240}Pu, pCi kg^{-1} (wet weight)		trigger	
		^{239}Pu	^{240}Pu	value	RDL	value	RDL	^{239}Pu	^{240}Pu
AMC02.1-16050001-027	ILOR-LS-07	0.002	0.01	0.0041 ± 0.0005	0.002		0.01		MDL
AMC02.1-16050001-028	ILOR-LS-08	0.002	0.01	0.008 ± 0.001	0.003		0.02		MDL
AMC02.1-16050001-029	ILOR-LS-09	0.002	0.01	0.012 ± 0.002	0.003		0.02		MDL
AMC02.1-16050001-030	ILOR-LS-10	0.002	0.01	0.011 ± 0.001	0.003		0.02		MDL
AMC03.1-16050001-021	ILOR-ML-01	0.002	0.01	0.023 ± 0.005	0.004		0.03		MDL
AMC03.1-16050001-022	ILOR-ML-02	0.002	0.01	0.019 ± 0.003	0.006		0.04		MDL
AMC03.1-16050001-023	ILOR-ML-03	0.002	0.01	0.007 ± 0.002	0.003		0.02		MDL
AMC03.1-16050001-024	ILOR-ML-04	0.002	0.01	0.007 ± 0.001	0.003		0.02		MDL
AMC03.1-16050001-025	ILOR-ML-05	0.002	0.01	0.007 ± 0.001	0.002		0.02		MDL
AMC03.1-16050001-026	ILOR-ML-06	0.002	0.01	0.010 ± 0.001	0.002		0.01		MDL
AMC03.1-16050001-027	ILOR-ML-07	0.002	0.01	0.010 ± 0.002	0.003		0.02		MDL
AMC03.1-16050001-028	ILOR-ML-08	0.002	0.01	0.006 ± 0.001	0.003		0.02		MDL
AMC03.1-16050001-029	ILOR-ML-09	0.002	0.01	0.008 ± 0.002	0.002		0.02		MDL
AMC03.1-16050001-030	ILOR-ML-10	0.002	0.01	0.005 ± 0.001	0.003		0.02		MDL
AMC14.1-16050001-031	ROCK-AN-01	0.002	0.01	0.025 ± 0.005	0.002		0.01		RSD
AMC14.1-16050001-032	ROCK-AN-02	0.002	0.01		0.002		0.01	RSD	MDL
AMC14.1-16050001-033	ROCK-AN-03	0.002	0.01	0.039 ± 0.002	0.001		0.01		MDL

Sample ID	Sample Location	Sample MDA, pCi		^{239}Pu, pCi kg^{-1} (wet weight)		^{240}Pu, pCi kg^{-1} (wet weight)		trigger	
		^{239}Pu	^{240}Pu	value	RDL	value	RDL	^{239}Pu	^{240}Pu
AMC14.1-16050001-034	ROCK-AN-04	0.002	0.01	0.007 ± 0.001	0.003		0.02		MDL
AMC14.1-16050001-035	ROCK-AN-05	0.002	0.01		0.003		0.02	RSD	MDL
AMC14.1-16050001-036	ROCK-AN-06	0.002	0.01		0.002		0.01	MDL	MDL
AMC14.1-16050001-037	ROCK-AN-07	0.002	0.01		0.002		0.01	MDL	MDL
AMC14.1-16050001-038	ROCK-AN-08	0.002	0.01		0.002		0.01	RSD	MDL
AMC14.1-16050001-039	ROCK-AN-09	0.002	0.01		0.002		0.01	MDL	MDL
AMC14.1-16050001-040	ROCK-AN-10	0.002	0.01		0.002		0.01	MDL	MDL
AMC15.1-16050001-031	ROCK-AS-01	0.002	0.01		0.003		0.02	MDL	MDL
AMC15.1-16050001-032	ROCK-AS-02	0.002	0.01		0.003		0.02	MDL	MDL
AMC15.1-16050001-033	ROCK-AS-03	0.002	0.01		0.004		0.03	MDL	MDL
AMC15.1-16050001-034	ROCK-AS-04	0.002	0.01		0.003		0.02	MDL	MDL
AMC15.1-16050001-035	ROCK-AS-05	0.002	0.01	0.005 ± 0.001	0.003		0.02		MDL
AMC15.1-16050001-036	ROCK-AS-06	0.002	0.01		0.003		0.02	MDL	MDL
AMC15.1-16050001-037	ROCK-AS-07	0.002	0.01	0.011 ± 0.002	0.004		0.02		MDL
AMC15.1-16050001-038	ROCK-AS-08	0.002	0.01	0.020 ± 0.002	0.003		0.02		MDL
AMC15.1-16050001-039	ROCK-AS-09	0.002	0.01	0.003 ± 0.001	0.002		0.01		MDL
AMC15.1-16050001-040	ROCK-AS-10	0.002	0.01	0.0039 ± 0.0005	0.003		0.02		MDL
AMC05.1-16050001-031	ROCK-CN-01	0.002	0.01	0.011 ± 0.002	0.003		0.02		MDL
AMC05.1-16050001-032	ROCK-CN-02	0.002	0.01		0.002		0.01	RSD	MDL
AMC05.1-16050001-033	ROCK-CN-03	0.002	0.01	0.017 ± 0.002	0.003		0.02		MDL

Sample ID	Sample Location	Sample MDA, pCi		^{239}Pu, pCi kg^{-1} (wet weight)		^{240}Pu, pCi kg^{-1} (wet weight)		trigger	
		^{239}Pu	^{240}Pu	value	RDL	value	RDL	^{239}Pu	^{240}Pu
AMC05.1-16050001-034	ROCK-CN-04	0.002	0.01	0.011 ± 0.001	0.002		0.01		MDL
AMC05.1-16050001-035	ROCK-CN-05	0.002	0.01	0.005 ± 0.001	0.002		0.01		MDL
AMC05.1-16050001-036	ROCK-CN-06	0.002	0.01	0.013 ± 0.002	0.003		0.02		MDL
AMC05.1-16050001-037	ROCK-CN-07	0.002	0.01	0.014 ± 0.001	0.003		0.02		MDL
AMC05.1-16050001-038	ROCK-CN-08	0.002	0.01	0.0040 0.0004	0.002		0.01		MDL
AMC05.1-16050001-039	ROCK-CN-09	0.002	0.01	0.006 ± 0.001	0.002		0.02		MDL
AMC05.1-16050001-040	ROCK-CN-10	0.002	0.01	0.003 ± 0.001	0.003		0.02		MDL
AMC02.1-16050001-031	ROCK-LS-01	0.002	0.01	0.005 ± 0.001	0.002		0.01		MDL
AMC02.1-16050001-032	ROCK-LS-02	0.002	0.01	0.011 ± 0.002	0.002	0.046 ± 0.003	0.02		
AMC02.1-16050001-033	ROCK-LS-03	0.002	0.01	0.013 ± 0.001	0.002	0.040 ± 0.002	0.01		
AMC02.1-16050001-034	ROCK-LS-04	0.002	0.01	0.006 ± 0.001	0.003		0.02		MDL
AMC02.1-16050001-035	ROCK-LS-05	0.002	0.01	0.008 ± 0.001	0.003		0.02		MDL
AMC02.1-16050001-036	ROCK-LS-06	0.002	0.01		0.003		0.02	RSD	MDL
AMC02.1-16050001-037	ROCK-LS-07	0.002	0.01	0.008 ± 0.001	0.002		0.01		MDL
AMC02.1-16050001-038	ROCK-LS-08	0.002	0.01		0.002		0.02	RSD	MDL
AMC02.1-16050001-039	ROCK-LS-09	0.002	0.01	0.003 ± 0.001	0.002		0.01		MDL
AMC02.1-16050001-040	ROCK-LS-10	0.002	0.01	0.003 ± 0.001	0.002		0.01		MDL
AMC03.1-16050001-031	ROCK-ML-01	0.002	0.01	0.008 ± 0.001	0.002		0.01		MDL
AMC03.1-16050001-032	ROCK-ML-02	0.002	0.01		0.003		0.02	RSD	MDL
AMC03.1-16050001-033	ROCK-ML-03	0.002	0.01	0.0077 ± 0.0004	0.002		0.01		MDL
AMC03.1-16050001-034	ROCK-ML-04	0.002	0.01		0.003		0.02	RSD	MDL
AMC03.1-16050001-035	ROCK-ML-05	0.002	0.01	0.010 ± 0.001	0.003		0.02		MDL
AMC03.1-16050001-036	ROCK-ML-06	0.002	0.01	0.0059 ± 0.0003	0.001		0.01		MDL
AMC03.1-16050001-037	ROCK-ML-07	0.002	0.01	0.006 ± 0.001	0.002		0.01		MDL
AMC03.1-16050001-038	ROCK-ML-08	0.002	0.01		0.002		0.01	RSD	MDL
AMC03.1-16050001-039	ROCK-ML-09	0.002	0.01	0.0033 ± 0.0005	0.002		0.01		MDL
AMC03.1-16050001-040	ROCK-ML-10	0.002	0.01	0.0031 ± 0.0004	0.002		0.01		MDL

MDL = Below Detection Limit; RSD = > 20% Relative Standard Deviation between measures

Appendix 2

Measurement of Pu isotopes (^{239}Pu, ^{240}Pu) in biological samples (mBq kg^{-1}, wet weight)

Sample ID	Sample Location	Sample MDA, mBq		^{239}Pu, mBq kg^{-1} (wet weight)		^{240}Pu, mBq kg^{-1} (wet weight)		trigger	
		^{239}Pu	^{240}Pu	value	RDL	value	RDL	^{239}Pu	^{240}Pu
AMC13.1-16050001-001	DOLL-AD-001	0.1	0.5		0.18		1	RSL	RSL
AMC13.1-16060002-003	DOLL-AD-003	0.002	0.01		0.10		0.6	MDL	MDL
AMC01.1-16060002-001	DOLL-AI-001	0.002	0.01		0.10		0.6	MDL	MDL
AMC14.1-16050001-001	FUCU-AN-01	0.002	0.01		0.02		0.1	RSL	RSL
AMC14.1-16050001-002	FUCU-AN-02	0.002	0.01	0.06 ± 0.01	0.02		0.1		MDL
AMC14.1-16050001-003	FUCU-AN-03	0.002	0.01	0.05 ± 0.01	0.02		0.1		MDL
AMC15.1-16050001-001	FUCU-AS-01	0.002	0.01	0.021 ± 0.004	0.02		0.1		MDL
AMC15.1-16050001-002	FUCU-AS-02	0.002	0.01	0.021 ± 0.004	0.02		0.1		MDL
AMC15.1-16050001-003	FUCU-AS-03	0.002	0.01		0.02		0.1	RSL	MDL
AMC05.1-16050001-001	FUCU-CN-01	0.002	0.01	0.025 ± 0.004	0.01		0.1		MDL
AMC05.1-16050001-002	FUCU-CN-02	0.002	0.01	0.023 ± 0.005	0.02		0.1		MDL
AMC05.1-16050001-003	FUCU-CN-03	0.002	0.01	0.030 ± 0.004	0.01		0.1		MDL
AMC02.1-16050001-001	FUCU-LS-01	0.002	0.01	0.055 ± 0.004	0.02		0.1		MDL
AMC02.1-16050001-002	FUCU-LS-02	0.002	0.01	0.027 ± 0.002	0.02		0.1		MDL
AMC02.1-16050001-003	FUCU-LS-03	0.002	0.01	0.06 ± 0.01	0.02		0.1		MDL
AMC03.1-16050001-001	FUCU-ML-01	0.002	0.01	0.04 ± 0.01	0.02		0.1		MDL
AMC03.1-16050001-002	FUCU-ML-02	0.002	0.01	0.04 ± 0.01	0.02		0.1		MDL
AMC03.1-16050001-003	FUCU-ML-03	0.002	0.01	0.017 ± 0.003	0.02		0.1		MDL
AMC14.1-16050001-011	GREN-AN-01	0.002	0.01		0.09		0.6	MDA	MDL
AMC14.1-16050001-012	GREN-AN-02	0.002	0.01	0.26 ± 0.02	0.10		0.6		MDL
AMC14.1-16050001-013	GREN-AN-03	0.002	0.01	0.23 ± 0.05	0.08		0.5		MDL
AMC14.1-16050001-014	GREN-AN-04	0.002	0.01	0.10 ± 0.02	0.09		0.6		MDL
AMC14.1-16050001-015	GREN-AN-05	0.002	0.01	0.10 ± 0.02	0.09		0.6		MDL
AMC14.1-16050001-016	GREN-AN-06	0.002	0.01	0.20 ± 0.04	0.17		1		MDL
AMC14.1-16050001-017	GREN-AN-07	0.002	0.01		0.1		0.7	MDL	MDL
AMC14.1-16050001-018	GREN-AN-08	0.002	0.01	0.15 ± 0.04	0.1		0.6		MDL
AMC14.1-16050001-019	GREN-AN-09	0.002	0.01		0.07		0.5	MDL	MDL

Sample ID	Sample Location	Sample MDA, mBq		^{239}Pu, mBq kg^{-1} (wet weight)		^{240}Pu, mBq kg^{-1} (wet weight)		trigger	
		^{239}Pu	^{240}Pu	value	RDL	value	RDL	^{239}Pu	^{240}Pu
AMC14.1-16050001-020	GREN-AN-10	0.002	0.01		0.09		0.6	MDL	MDL
AMC15.1-16050001-011	GREN-AS-01	0.002	0.01		0.09		0.6	RSD	MDL
AMC15.1-16050001-012	GREN-AS-02	0.002	0.01	0.13 ± 0.03	0.09		0.6		MDL
AMC15.1-16050001-013	GREN-AS-03	0.002	0.01		0.08		0.5	MDL	MDL
AMC15.1-16050001-014	GREN-AS-04	0.002	0.01	0.26 ± 0.05	0.09		0.6		MDL
AMC15.1-16050001-015	GREN-AS-05	0.002	0.01		0.09		0.6	MDL	MDL
AMC15.1-16050001-016	GREN-AS-06	0.002	0.01		0.1		0.6	MDL	MDL
AMC15.1-16050001-017	GREN-AS-07	0.002	0.01		0.08		0.5	MDL	MDL
AMC15.1-16050001-018	GREN-AS-08	0.002	0.01		0.09		0.6	RSD	MDL
AMC15.1-16050001-019	GREN-AS-09	0.002	0.01		0.07		0.5	MDL	MDL
AMC15.1-16050001-020	GREN-AS-10	0.002	0.01		0.09		0.6	MDL	MDL
AMC05.1-16050001-011	GREN-CN-01 *	0.002	0.01		0.2		1	RSD	RSD
AMC05.1-16050001-012	GREN-CN-02	0.002	0.01	0.41 ± 0.05	0.1		0.5		MDL
AMC05.1-16050001-013	GREN-CN-03	0.002	0.01	0.34 ± 0.06	0.1		0.7		MDL
AMC05.1-16050001-014	GREN-CN-04	0.002	0.01	0.31 ± 0.03	0.1		0.7		MDL
AMC05.1-16050001-015	GREN-CN-05	0.002	0.01	0.40 ± 0.09	0.1		0.8		MDL
AMC05.1-16050001-016	GREN-CN-06	0.002	0.01	1.0 ± 0.1	0.1		0.8		RSD
AMC05.1-16050001-017	GREN-CN-07	0.002	0.01	0.30 ± 0.02	0.1		0.8		MDL
AMC05.1-16050001-018	GREN-CN-08	0.002	0.01	0.56 ± 0.08	0.1		1		MDL
AMC05.1-16050001-019	GREN-CN-09	0.002	0.01	0.94 ± 0.14	0.2	3.7 ± 0.3	1		
AMC05.1-16050001-020	GREN-CN-10	0.002	0.01	0.54 ± 0.06	0.1		0.9		MDL
AMC02.1-16050001-011	GREN-LS-01	0.002	0.01	0.54 ± 0.10	0.08		0.5		MDL
AMC02.1-16050001-012	GREN-LS-02	0.002	0.01	0.12 ± 0.02	0.07		0.5		MDL
AMC02.1-16050001-013	GREN-LS-03	0.002	0.01	0.23 ± 0.04	0.1		0.7		MDL
AMC02.1-16050001-014	GREN-LS-04	0.002	0.01	0.24 ± 0.03	0.09		0.6		MDL
AMC02.1-16050001-015	GREN-LS-05	0.002	0.01	0.13 ± 0.03	0.1		0.7		MDL
AMC02.1-16050001-016	GREN-LS-06	0.002	0.01	0.11 ± 0.02	0.09		0.6		MDL
AMC02.1-16050001-017	GREN-LS-07	0.002	0.01	0.51 ± 0.05	0.1		0.7		MDL

Sample ID	Sample Location	Sample MDA, mBq		^{239}Pu, mBq kg^{-1} (wet weight)		^{240}Pu, mBq kg^{-1} (wet weight)		trigger	
		^{239}Pu	^{240}Pu	value	RDL	value	RDL	^{239}Pu	^{240}Pu
AMC02.1-16050001-018	GREN-LS-08	0.002	0.01	0.21 ± 0.04	0.1		0.6		MDL
AMC02.1-16050001-019	GREN-LS-09	0.002	0.01	0.26 ± 0.03	0.07		0.4		MDL
AMC02.1-16050001-020	GREN-LS-10	0.002	0.01	0.11 ± 0.01	0.09		0.6		MDL
AMC03.1-16050001-011	GREN-ML-01	0.002	0.01	0.31 ± 0.05	0.1		0.8		MDL
AMC03.1-16050001-012	GREN-ML-02	0.002	0.01	0.34 ± 0.04	0.08		0.5		MDL
AMC03.1-16050001-013	GREN-ML-03	0.002	0.01	0.40 ± 0.05	0.09		0.6		MDL
AMC03.1-16050001-014	GREN-ML-04	0.002	0.01	0.50 ± 0.04	0.08		0.5		MDL
AMC03.1-16050001-015	GREN-ML-05	0.002	0.01	0.11 ± 0.06	0.08		0.5		MDL
AMC03.1-16050001-016	GREN-ML-06	0.002	0.01	0.14 ± 0.02	0.08		0.5		MDL
AMC03.1-16050001-017	GREN-ML-07	0.002	0.01	0.42 ± 0.06	0.08		0.5		MDL
AMC03.1-16050001-018	GREN-ML-08	0.002	0.01	0.31 ± 0.02	0.08		0.5		MDL
AMC03.1-16050001-019	GREN-ML-09	0.002	0.01	0.17 ± 0.03	0.1		0.7		MDL
AMC03.1-16050001-020	GREN-ML-10	0.002	0.01	0.65 ± 0.04	0.1		0.6		MDL
AMC05.1-16050001-021	ILOR-01	0.002	0.01	0.19 ± 0.06	0.05		0.3		MDL
AMC05.1-16050001-022	ILOR-02	0.002	0.01	0.58 ± 0.07	0.1		0.7		MDL
AMC05.1-16050001-023	ILOR-03	0.002	0.01	0.30 ± 0.05	0.1		0.6		MDL
AMC05.1-16050001-024	ILOR-04	0.002	0.01		0.06		0.4	MDL	MDL
AMC05.1-16050001-025	ILOR-05	0.002	0.01	0.15 ± 0.02	0.09		0.6		MDL
AMC05.1-16050001-026	ILOR-06	0.002	0.01	0.18 ± 0.04	0.09		0.5		MDL
AMC05.1-16050001-027	ILOR-07	0.002	0.01	0.37 ± 0.03	0.09		0.6		MDL
AMC05.1-16050001-028	ILOR-08	0.002	0.01	0.61 ± 0.06	0.1	3.0 ± 0.4	0.8		
AMC05.1-16050001-029	ILOR-09	0.002	0.01	0.6 ± 0.1	0.1		0.8		MDL
AMC05.1-16050001-030	ILOR-10	0.002	0.01	0.49 ± 0.02	0.1		0.8		MDL
AMC14.1-16050001-021	ILOR-AN-01	0.002	0.01		0.1		0.7	RSD	MDL
AMC14.1-16050001-022	ILOR-AN-02	0.002	0.01	0.15 ± 0.04	0.08		0.5		MDL
AMC14.1-16050001-023	ILOR-AN-03	0.002	0.01	0.34 ± 0.03	0.09		0.6		MDL
AMC14.1-16050001-024	ILOR-AN-04	0.002	0.01		0.1		0.6	MDL	MDL
AMC14.1-16050001-025	ILOR-AN-05	0.002	0.01	0.11 ± 0.02	0.09		0.6		MDL

Sample ID	Sample Location	Sample MDA, mBq		^{239}Pu, mBq kg^{-1} (wet weight)		^{240}Pu, mBq kg^{-1} (wet weight)		trigger	
		^{239}Pu	^{240}Pu	value	RDL	value	RDL	^{239}Pu	^{240}Pu
AMC14.1-16050001-026	ILOR-AN-06	0.002	0.01	0.13 ± 0.02	0.08		0.5		MDL
AMC14.1-16050001-027	ILOR-AN-07	0.002	0.01		0.06		0.4	MDL	MDL
AMC14.1-16050001-028	ILOR-AN-08	0.002	0.01	0.10 ± 0.02	0.08		0.5		MDL
AMC14.1-16050001-029	ILOR-AN-09	0.002	0.01	0.61 ± 0.07	0.09		0.6		MDL
AMC14.1-16050001-030	ILOR-AN-10	0.002	0.01	0.16 ± 0.03	0.09		0.6		MDL
AMC15.1-16050001-021	ILOR-AS-01	0.002	0.01		0.08		0.5	RSD	RSD
AMC15.1-16050001-022	ILOR-AS-02	0.002	0.01	0.33 ± 0.06	0.08		0.5		MDL
AMC15.1-16050001-023	ILOR-AS-03	0.002	0.01	0.16 ± 0.02	0.08		0.5		MDL
AMC15.1-16050001-024	ILOR-AS-04	0.002	0.01	2.0 ± 0.1	0.07		0.4		MDL
AMC15.1-16050001-025	ILOR-AS-05	0.002	0.01		0.09		0.6	RSL	MDL
AMC15.1-16050001-026	ILOR-AS-06	0.002	0.01		0.1		0.7	RSL	RSD
AMC15.1-16050001-027	ILOR-AS-07	0.002	0.01	0.55 ± 0.06	0.09		0.6		MDL
AMC15.1-16050001-028	ILOR-AS-08	0.002	0.01		0.06		0.4	MDL	MDL
AMC15.1-16050001-029	ILOR-AS-09	0.002	0.01	0.11 ± 0.02	0.09		0.6		MDL
AMC15.1-16050001-030	ILOR-AS-10	0.002	0.01	0.21 ± 0.05	0.2		1		MDL
AMC02.1-16050001-021	ILOR-LS-01	0.002	0.01		0.1		0.7	RSD	MDL
AMC02.1-16050001-022	ILOR-LS-02	0.002	0.01	0.26 ± 0.02	0.07		0.5		MDL
AMC02.1-16050001-023	ILOR-LS-03	0.002	0.01	0.21 ± 0.04	0.1		0.6		MDL
AMC02.1-16050001-024	ILOR-LS-04	0.002	0.01	0.41 ± 0.03	0.09		0.6		MDL
AMC02.1-16050001-025	ILOR-LS-05	0.002	0.01	0.40 ± 0.08	0.07		0.4		MDL
AMC02.1-16050001-026	ILOR-LS-06	0.002	0.01	0.24 ± 0.02	0.06		0.4		MDL

Sample ID	Sample Location	Sample MDA, mBq		^{239}Pu, mBq kg^{-1} (wet weight)		^{240}Pu, mBq kg^{-1} (wet weight)		trigger	
		^{239}Pu	^{240}Pu	value	RDL	value	RDL	^{239}Pu	^{240}Pu
AMC02.1-16050001-027	ILOR-LS-07	0.002	0.01	0.15 ± 0.02	0.06		0.4		MDL
AMC02.1-16050001-028	ILOR-LS-08	0.002	0.01	0.29 ± 0.03	0.1		0.7		MDL
AMC02.1-16050001-029	ILOR-LS-09	0.002	0.01	0.45 ± 0.06	0.1		0.6		MDL
AMC02.1-16050001-030	ILOR-LS-10	0.002	0.01	0.40 ± 0.04	0.1		0.7		MDL
AMC03.1-16050001-021	ILOR-ML-01	0.002	0.01	0.84 ± 0.19	0.2		1		MDL
AMC03.1-16050001-022	ILOR-ML-02	0.002	0.01	0.71 ± 0.10	0.2		1		MDL
AMC03.1-16050001-023	ILOR-ML-03	0.002	0.01	0.25 ± 0.06	0.1		0.6		MDL
AMC03.1-16050001-024	ILOR-ML-04	0.002	0.01	0.25 ± 0.03	0.1		0.6		MDL
AMC03.1-16050001-025	ILOR-ML-05	0.002	0.01	0.26 ± 0.04	0.09		0.6		MDL
AMC03.1-16050001-026	ILOR-ML-06	0.002	0.01	0.35 ± 0.04	0.08		0.5		MDL
AMC03.1-16050001-027	ILOR-ML-07	0.002	0.01	0.38 ± 0.06	0.1		0.7		MDL
AMC03.1-16050001-028	ILOR-ML-08	0.002	0.01	0.23 ± 0.03	0.09		0.6		MDL
AMC03.1-16050001-029	ILOR-ML-09	0.002	0.01	0.30 ± 0.07	0.09		0.6		MDL
AMC03.1-16050001-030	ILOR-ML-10	0.002	0.01	0.19 ± 0.04	0.1		0.8		MDL
AMC14.1-16050001-031	ROCK-AN-01	0.002	0.01	0.91 ± 0.19	0.08		0.5		RSD
AMC14.1-16050001-032	ROCK-AN-02	0.002	0.01		0.07		0.5	RSD	MDL
AMC14.1-16050001-033	ROCK-AN-03	0.002	0.01	1.4 ± 0.1	0.05		0.3		MDL
AMC14.1-16050001-034	ROCK-AN-04	0.002	0.01	0.27 ± 0.05	0.1		0.8		MDL
AMC14.1-16050001-035	ROCK-AN-05	0.002	0.01		0.1		0.6	RSD	MDL
AMC14.1-16050001-036	ROCK-AN-06	0.002	0.01		0.09		0.6	MDL	MDL
AMC14.1-16050001-037	ROCK-AN-07	0.002	0.01		0.07		0.4	MDL	MDL
AMC14.1-16050001-038	ROCK-AN-08	0.002	0.01		0.06		0.4	RSD	MDL
AMC14.1-16050001-039	ROCK-AN-09	0.002	0.01		0.08		0.5	MDL	MDL
AMC14.1-16050001-040	ROCK-AN-10	0.002	0.01		0.08		0.5	MDL	MDL
AMC15.1-16050001-031	ROCK-AS-01	0.002	0.01		0.09		0.6	MDL	MDL
AMC15.1-16050001-032	ROCK-AS-02	0.002	0.01		0.1		0.8	MDL	MDL
AMC15.1-16050001-033	ROCK-AS-03	0.002	0.01		0.1		1	MDL	MDL

Sample ID	Sample Location	Sample MDA, mBq		^{239}Pu, mBq kg^{-1} (wet weight)		^{240}Pu, mBq kg^{-1} (wet weight)		trigger	
		^{239}Pu	^{240}Pu	value	RDL	value	RDL	^{239}Pu	^{240}Pu
AMC15.1-16050001-034	ROCK-AS-04	0.002	0.01		0.1		0.7	MDL	MDL
AMC15.1-16050001-035	ROCK-AS-05	0.002	0.01	0.20 ± 0.02	0.1		0.7		MDL
AMC15.1-16050001-036	ROCK-AS-06	0.002	0.01		0.1		0.6	MDL	MDL
AMC15.1-16050001-037	ROCK-AS-07	0.002	0.01	0.42 ± 0.09	0.1		0.9		MDL
AMC15.1-16050001-038	ROCK-AS-08	0.002	0.01	0.75 ± 0.07	0.1		0.7		MDL
AMC15.1-16050001-039	ROCK-AS-09	0.002	0.01	0.11 ± 0.03	0.06		0.4		MDL
AMC15.1-16050001-040	ROCK-AS-10	0.002	0.01	0.15 ± 0.02	0.1		0.7		MDL
AMC05.1-16050001-031	ROCK-CN-01	0.002	0.01	0.40 ± 0.09	0.1		0.7		MDL
AMC05.1-16050001-032	ROCK-CN-02	0.002	0.01		0.08		0.5	RSD	MDL
AMC05.1-16050001-033	ROCK-CN-03	0.002	0.01	0.62 ± 0.06	0.10		0.7		MDL
AMC05.1-16050001-034	ROCK-CN-04	0.002	0.01	0.41 ± 0.04	0.08		0.5		MDL
AMC05.1-16050001-035	ROCK-CN-05	0.002	0.01	0.18 ± 0.03	0.07		0.5		MDL
AMC05.1-16050001-036	ROCK-CN-06	0.002	0.01	0.48 ± 0.06	0.1		0.7		MDL
AMC05.1-16050001-037	ROCK-CN-07	0.002	0.01	0.52 ± 0.05	0.1		0.6		MDL
AMC05.1-16050001-038	ROCK-CN-08	0.002	0.01	0.15 ± 0.02	0.06		0.4		MDL
AMC05.1-16050001-039	ROCK-CN-09	0.002	0.01	0.23 ± 0.03	0.09		0.6		MDL
AMC05.1-16050001-040	ROCK-CN-10	0.002	0.01	0.12 ± 0.03	0.1		0.6		MDL
AMC02.1-16050001-031	ROCK-LS-01	0.002	0.01	0.17 ± 0.03	0.07		0.4		MDL
AMC02.1-16050001-032	ROCK-LS-02	0.002	0.01	0.42 ± 0.06	0.09	1.7 ± 0.1	0.6		
AMC02.1-16050001-033	ROCK-LS-03	0.002	0.01	0.50 ± 0.05	0.07	1.5 ± 0.1	0.4		
AMC02.1-16050001-034	ROCK-LS-04	0.002	0.01	0.21 ± 0.02	0.1		0.7		MDL
AMC02.1-16050001-035	ROCK-LS-05	0.002	0.01	0.30 ± 0.03	0.1		0.8		MDL
AMC02.1-16050001-036	ROCK-LS-06	0.002	0.01		0.1		0.8	RSD	MDL
AMC02.1-16050001-037	ROCK-LS-07	0.002	0.01	0.28 ± 0.03	0.08		0.5		MDL
AMC02.1-16050001-038	ROCK-LS-08	0.002	0.01		0.09		0.6	RSD	MDL
AMC02.1-16050001-039	ROCK-LS-09	0.002	0.01	0.10 ± 0.02	0.08		0.5		MDL
AMC02.1-16050001-040	ROCK-LS-10	0.002	0.01	0.13 ± 0.02	0.07		0.4		MDL

Sample ID	Sample Location	Sample MDA, mBq		^{239}Pu, mBq kg^{-1} (wet weight)		^{240}Pu, mBq kg^{-1} (wet weight)		trigger	
		^{239}Pu	^{240}Pu	value	RDL	value	RDL	^{239}Pu	^{240}Pu
AMC03.1-16050001-031	ROCK-ML-01	0.002	0.01	0.31 ± 0.03	0.08		0.5		MDL
AMC03.1-16050001-032	ROCK-ML-02	0.002	0.01		0.1		0.6	RSD	MDL
AMC03.1-16050001-033	ROCK-ML-03	0.002	0.01	0.29 ± 0.01	0.07		0.5		MDL
AMC03.1-16050001-034	ROCK-ML-04	0.002	0.01		0.09		0.6	RSD	MDL
AMC03.1-16050001-035	ROCK-ML-05	0.002	0.01	0.38 ± 0.04	0.1		0.7		MDL
AMC03.1-16050001-036	ROCK-ML-06	0.002	0.01	0.22 ± 0.01	0.05		0.3		MDL
AMC03.1-16050001-037	ROCK-ML-07	0.002	0.01	0.21 ± 0.02	0.07		0.5		MDL
AMC03.1-16050001-038	ROCK-ML-08	0.002	0.01		0.08		0.5	RSD	MDL
AMC03.1-16050001-039	ROCK-ML-09	0.002	0.01	0.12 ± 0.02	0.06		0.4		MDL
AMC03.1-16050001-040	ROCK-ML-10	0.002	0.01	0.12 ± 0.01	0.06		0.4		MDL

MDL = Below Detection Limit; RSD = > 20% Relative Standard Deviation between measures

Lawrence Livermore National Laboratory
Technical Information Department
Livermore, CA 94551

Appendix E

University of Miami 2016 Tritium Sample Report

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UNIVERSITY OF MIAMI
ROSENSTIEL
SCHOOL of MARINE &
ATMOSPHERIC SCIENCE

Tritium Laboratory
4600 Rickenbacker Causeway
Miami, Florida 33149-1031

Ph: 305-421-4100
Fax:305-421-4112
E-mail: Tritium@rsmas.miami.edu

August 25, 2016

TRITIUM LABORATORY

Data Release #16-072 - Amendment
Job # 3419

NAVARRO RESEARCH & ENGINEERING, INC.
TRITIUM SAMPLES

James Happell

Digitally signed by James Happell
DN: cn=James Happell, o=University of Miami, ou=RSMAS, email=jhappell@rsmas.miami.edu, c=US
Date: 2016.08.25 13:53:52 -04'00'

Dr. James D. Happell
Associate Research Professor

Distribution:
Navarro Research & Engineering, Inc.
Attn: Paul Darr
2597 Legacy Way
Grand Junction, CO 81503

COMMENTS ON TRITIUM RESULTS

Tritium Scale New Half-life

Tritium concentrations are expressed in TU, where 1 TU indicates a T/H abundance ratio of 10^{-18}. The values refer to the tritium scale recommended by U.S. National Institute of Science and Technology (NIST, formerly NBS), and International Atomic Energy Agency (IAEA). The TU-numbers are based on the NIST tritium water standard #4926E. Age corrections and conversions are made using the recommended half-life of **12.32 years**, i.e., a decay rate of λ = 5.626% $year^{-1}$. In this scale, 1 TU is equivalent to 7.151 dpm/kg H_2O, or 3.222 pCi/kg H_2O, or 0.1192 Bq/kg H_2O (Bq = disint/sec).

TU values are calculated for date of sample collection, REFDATE in the table, as provided by the submitter. If no such date is available, date of sample arrival at our laboratory is used.

The stated errors, eTU, are one standard deviation (1 sigma) including all conceivable contributions. In the table, QUANT is quantity of sample received, and ELYS is the amount of water taken for electrolytic enrichment. DIR means direct run (no enrichment).

Remark: From 1 Jan 1994 through 31 Dec 2001 we used the previously recommended value for the half-life, 12.43 years. The use of the new number, 12.32 years will in practice increase the reported TU-values by 0.9 %. This is insignificant since our reported values carry 1 sigma uncertainties of 3 % or more.

It is interesting to note that before 1994 we used the older, then recommended value of 12.26 years.

Very low tritium values

In some cases, negative TU values are listed. Such numbers can occur because the net tritium count rate is, in principle the difference between the count rate of the sample and that of a tritium-free sample (background count or blank sample). Given a set of "unknown" samples with no tritium, the distribution of net results should become symmetrical around 0 TU. The negative values are reported as such for the benefit of allowing the user unbiased statistical treatment of sets of the data. For other applications, 0 TU should be used.

Additional information

Refer to Services Rendered (Tritium), Section II.8, in the "Tritium Laboratory Price Schedule; Procedures and Standards; Advice on Sampling", and our Web-site www.rsmas.edu/groups/tritium.

Tritium efficiencies and background values are somewhat different in each of the nine counters and values are corrected for cosmic intensity, gas pressure and other parameters. For tritium, the efficiency is typically 1.00 cpm per 100 TU (direct counting). At 50× enrichment, the efficiency is equivalent to 1.00 cpm per 2.4 TU. The background is typically 0.3 cpm, known to about ± 0.02 cpm. Our reported results include not only the Poisson statistics, but also other experimental uncertainties such as enrichment error, etc.

End

Client: NAVARRO CORPORATION Purchase Order: NEED IT
Recvd : 16/05/24 Contact: Paul Darr, paul.darr@lm.doe.gov
Job# : 3419 2597 Legacy Way
Final : 16/08/25 Amchikta Samples Grand Junction, CO 81503

Cust LABEL INFO	JOB.SX	REFDATE	QUANT	ELYS	pCi/L	err	MDL
AMC01.2-16050001-001	3419.01	160518	1000	275	6.38	0.29 *	0.29
AMC02.2-16050001-001	3419.02	160516	1000	275	1.44	0.29	0.29
AMC02.2-16050001-002	3419.03	160517	1000	275	1.47	0.29	0.29
AMC02.2-16050001-003	3419.04	160517	1000	275	1.36	0.29	0.29
AMC02.2-16050001-004	3419.05	160516	1000	275	1.23	0.29 *	0.29
AMC02.2-16050001-005	3419.06	160516	1000	275	1.28	0.29	0.29
AMC02.2-16050001-006	3419.07	160515	1000	275	1.26	0.29	0.29
AMC02.2-16050001-007	3419.08	160515	1000	275	1.64	0.29	0.29
AMC02.2-16050001-008	3419.09	160517	1000	275	1.42	0.29	0.29
AMC02.2-16050001-009	3419.10	160515	1000	275	1.64	0.29	0.29
AMC02.2-16050001-010	3419.11	160515	1000	275	1.47	0.29	0.29
AMC02.2-16050001-011	3419.12	160515	1000	275	1.47	0.29	0.29
AMC02.2-16050001-012	3419.13	160517	1000	275	1.33	0.29	0.29
AMC02.2-16050001-013	3419.14	160517	1000	275	1.51	0.29	0.29
AMC02.2-16050001-014	3419.15	160517	1000	275	1.36	0.29 *	0.29
AMC02.2-16050001-015	3419.16	160517	1000	275	1.70	0.29	0.29
AMC02.2-16050001-016	3419.17	160516	1000	275	1.38	0.29	0.29
AMC02.2-16050001-017	3419.18	160516	1000	275	1.24	0.29	0.29
AMC02.2-16050001-018	3419.19	160516	1000	275	1.42	0.29	0.29
AMC02.2-16050001-019	3419.20	160516	1000	275	1.45	0.29	0.29
AMC02.2-16050001-020	3419.21	160516	1000	275	1.32	0.29	0.29
AMC02.2-16050001-021	3419.22	160516	1000	275	1.37	0.29	0.29
AMC02.2-16050001-022	3419.23	160516	1000	275	1.66	0.29	0.29
AMC02.2-16050001-023	3419.24	160516	1000	275	1.33	0.29	0.29
AMC02.2-16050001-024	3419.25	160516	1000	275	1.34	0.29 *	0.29
AMC02.2-16050001-025	3419.26	160517	1000	275	1.44	0.29	0.29
AMC02.2-16050001-026	3419.27	160516	1000	275	1.43	0.29	0.29
AMC02.2-16050001-027	3419.28	160516	1000	275	1.23	0.29	0.29
AMC02.2-16050001-028	3419.29	160516	1000	275	1.48	0.29	0.29
AMC02.2-16050001-029	3419.30	160516	1000	275	1.28	0.29	0.29
AMC02.2-16050001-030	3419.31	160516	1000	275	1.53	0.29	0.29
AMC02.2-16050001-031	3419.32	160516	1000	275	1.12	0.29	0.29
AMC02.2-16050001-032	3419.33	160516	1000	275	1.33	0.29	0.29
AMC02.2-16050001-033	3419.34	160516	1000	275	1.61	0.29	0.29
AMC02.2-16050001-034	3419.35	160516	1000	275	1.42	0.29 *	0.29
AMC02.2-16050001-035	3419.36	160516	1000	275	1.28	0.29	0.29
AMC02.2-16050001-036	3419.37	160516	1000	275	2.54	0.29	0.29
AMC02.2-16050001-037	3419.38	160516	1000	275	1.58	0.29	0.29
AMC02.2-16050001-038	3419.39	160516	1000	275	2.27	0.29	0.29
AMC02.2-16050001-039	3419.40	160516	1000	275	1.23	0.29	0.29
AMC02.2-16050001-040	3419.41	160516	1000	275	1.80	0.29	0.29
AMC02.2-16050001-044	3419.42	160516	1000	275	1.33	0.29	0.29
AMC02.2-16050001-045	3419.43	160516	1000	275	1.39	0.29	0.29
AMC02.2-16050001-046	3419.44	160516	1000	275	1.18	0.29	0.29
AMC02.2-16050001-047	3419.45	160516	1000	275	1.36	0.29 *	0.29
AMC03.2-16050001-001	3419.46	160514	1000	275	0.99	0.29	0.29
AMC05.2-16050001-001	3419.47	160515	1000	275	1.44	0.29	0.29
AMC13.2-16050001-001	3419.48	160521	1000	275	7.30	0.29	0.29
AMC14.2-16050001-001	3419.49	160520	1000	275	1.37	0.29	0.29
AMC15.2-16050001-001	3419.50	160519	1000	275	1.23	0.29	0.29

* Average of duplicate runs

Report Date: 19 August 2016

Case Narrative for JOB 3419 Navarro

A total of 50 samples arrived safely on May 24, 2016 in good condition with a complete Chain of Custody.

Processing began on May 25, 2016. Analytical work and data package have been reviewed and are in compliance with the requirements of the SOW.

The water samples were distilled According to the Tritium Laboratory Standard Operating Procedures (see attachment).

The water samples were then electrolytically enriched for approximately 10 days.

The sample remaining in the cells after enrichment were vacuum distilled.

The enriched sample was then reduced to hydrogen gas through a magnesium oven and stored in a high pressure stainless steel trap.

The sample was then injected into a low level beta gas proportional counter and the tritium was measured.

One replicate sample was analyzed for every ten samples analyzed.

No significant technical difficulties occurred.

Cust LABEL INFO	LABSAMPLEID	PREP DATE	ANALYSIS DATE	ANALYTICAL METHOD	RESULT	UNIT OF MEASURE	UNCERTAINTY	DETECTION LIMIT	DATA QUALIFIER
AMC01.2-16050001-001	3419.01	5/25/2016	6/6/2016	ENRICH-H3	6.38	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-001	3419.02	5/25/2016	6/6/2016	ENRICH-H3	1.44	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-002	3419.03	5/25/2016	6/6/2016	ENRICH-H3	1.47	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-003	3419.04	5/25/2016	6/6/2016	ENRICH-H3	1.36	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-004	3419.05	5/25/2016	6/6/2016	ENRICH-H3	1.23	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-004	3419.05	7/22/2016	8/3/2016	ENRICH-H3	1.19	pCi/L	0.29	0.29	REPLICATE
AMC02.2-16050001-005	3419.06	5/26/2016	6/8/2016	ENRICH-H3	1.28	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-006	3419.07	5/26/2016	6/6/2016	ENRICH-H3	1.26	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-007	3419.08	5/26/2016	6/6/2016	ENRICH-H3	1.64	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-008	3419.09	5/26/2016	6/6/2016	ENRICH-H3	1.42	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-009	3419.10	5/27/2016	6/8/2016	ENRICH-H3	1.64	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-010	3419.11	5/27/2016	6/8/2016	ENRICH-H3	1.47	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-011	3419.12	5/27/2016	6/8/2016	ENRICH-H3	1.47	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-012	3419.13	5/27/2016	6/9/2016	ENRICH-H3	1.33	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-013	3419.14	5/27/2016	6/9/2016	ENRICH-H3	1.51	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-014	3419.15	5/31/2016	6/13/2016	ENRICH-H3	1.36	pCi/L	0.29	0.29	GOOD

AMC02.2-16050001-014	3419.15	7/22/2016	8/3/2016	ENRICH-H3	1.26	pCi/L	0.29	0.29	REPLICATE
AMC02.2-16050001-015	3419.16	5/31/2016	6/13/2016	ENRICH-H3	1.70	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-016	3419.17	5/31/2016	6/13/2016	ENRICH-H3	1.38	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-017	3419.18	5/31/2016	6/13/2016	ENRICH-H3	1.24	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-018	3419.19	5/31/2016	6/10/2016	ENRICH-H3	1.42	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-019	3419.20	6/1/2016	6/13/2016	ENRICH-H3	1.45	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-020	3419.21	6/1/2016	6/13/2016	ENRICH-H3	1.32	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-021	3419.22	6/1/2016	6/14/2016	ENRICH-H3	1.37	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-022	3419.23	6/1/2016	6/14/2016	ENRICH-H3	1.66	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-023	3419.24	6/1/2016	6/13/2016	ENRICH-H3	1.33	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-024	3419.25	6/1/2016	6/14/2016	ENRICH-H3	1.34	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-024	3419.25	7/22/2016	8/4/2016	ENRICH-H3	1.35	pCi/L	0.29	0.29	REPLICATE
AMC02.2-16050001-025	3419.26	6/2/2016	6/13/2016	ENRICH-H3	1.44	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-026	3419.27	6/2/2016	6/14/2016	ENRICH-H3	1.43	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-027	3419.28	6/2/2016	6/14/2016	ENRICH-H3	1.23	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-028	3419.29	6/2/2016	6/15/2016	ENRICH-H3	1.48	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-029	3419.30	6/3/2016	6/15/2016	ENRICH-H3	1.28	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-030	3419.31	6/3/2016	6/15/2016	ENRICH-H3	1.53	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-031	3419.32	6/3/2016	6/15/2016	ENRICH-H3	1.12	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-032	3419.33	6/3/2016	6/16/2016	ENRICH-H3	1.33	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-033	3419.34	6/3/2016	6/16/2016	ENRICH-H3	1.61	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-034	3419.35	6/6/2016	6/17/2016	ENRICH-H3	1.42	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-034	3419.35	7/22/2016	8/4/2016	ENRICH-H3	1.32	pCi/L	0.29	0.29	REPLICATE
AMC02.2-16050001-035	3419.36	6/6/2016	6/17/2016	ENRICH-H3	1.28	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-036	3419.37	6/6/2016	6/17/2016	ENRICH-H3	2.54	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-037	3419.38	6/6/2016	6/17/2016	ENRICH-H3	1.58	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-038	3419.39	6/6/2016	6/17/2016	ENRICH-H3	2.27	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-039	3419.40	6/6/2016	6/17/2016	ENRICH-H3	1.23	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-040	3419.41	6/7/2016	6/17/2016	ENRICH-H3	1.80	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-044	3419.42	6/7/2016	6/20/2016	ENRICH-H3	1.33	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-045	3419.43	6/7/2016	6/20/2016	ENRICH-H3	1.39	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-046	3419.44	6/7/2016	6/20/2016	ENRICH-H3	1.18	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-047	3419.45	6/7/2016	6/21/2016	ENRICH-H3	1.36	pCi/L	0.29	0.29	GOOD
AMC02.2-16050001-047	3419.45	7/25/2016	8/5/2016	ENRICH-H3	1.38	pCi/L	0.29	0.29	REPLICATE
AMC03.2-16050001-001	3419.46	6/8/2016	6/21/2016	ENRICH-H3	0.99	pCi/L	0.29	0.29	GOOD
AMC05.2-16050001-001	3419.47	6/8/2016	6/21/2016	ENRICH-H3	1.44	pCi/L	0.29	0.29	GOOD

AMC13.2-16050001-001	3419.48	6/8/2016	6/21/2016	ENRICH-H3	7.30	pCi/L	0.29	0.29	GOOD
AMC14.2-16050001-001	3419.49	6/8/2016	6/22/2016	ENRICH-H3	1.37	pCi/L	0.29	0.29	GOOD
AMC15.2-16050001-001	3419.50	6/9/2016	6/21/2016	ENRICH-H3	1.23	pCi/L	0.29	0.29	GOOD

QC Deliverables

Preparation Blank:

Parameter Name	Parameter Result	Uncertainty	Instrument ID
BEND 34	0.16	0.29	9126
BEND 35	0.00	0.29	1135
BEND 36	-0.13	0.29	2128
BEND 37	0.06	0.29	3147
BEND 47	-0.13	0.29	1190

Replicate Data:

Parameter Name	Parameter Result	Replicate Result
AMC02.2-16050001-004	1.23	1.19
AMC02.2-16050001-014	1.36	1.26
AMC02.2-16050001-024	1.34	1.35
AMC02.2-16050001-034	1.42	1.32
AMC02.2-16050001-047	1.36	1.38

Laboratory Control Samples:

Parameter Name	True Concentration	Measured Concentration	Percent Recovery	Instrument ID
BETA 8.3	33,396	33,335	99.82	3135
BETA 8.4	33,371	30,585	91.65	4137
BETA 9.1	33,371	30,457	91.27	5093
BETA 9.2	33,340	33,804	101.39	7133
BETA 9.3	33,329	34,767	104.31	6107
BETA 11.1	33,109	33,621	101.55	3183

Appendix F

Lawrence Livermore National Laboratory

Data Report, Part II: Measurement of Cs Isotopes (^{134}Cs, ^{137}Cs) in Seawater and Freshwater Samples

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LLNL-SR-751691

AMCHITKA PROJECT

Data Report, Part II

Measurement of Cs isotopes (^{134}Cs, ^{137}Cs) in seawater and freshwater samples

T.F. Hamilton
S.R. Kehl
R.M. Berry

March 2018

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LAWRENCE LIVERMORE NATIONAL LABORATORY
GLOBAL SECURITY PRINCIPAL DIRECTORATE

AMCHITKA PROJECT
WFO Proposal D201231

Data Report, Part II

Measurement of Cs isotopes (^{134}Cs, ^{137}Cs) in seawater and freshwater samples

T.F. Hamilton, S.R. Kehl, and R.M. Berry

March 2018

Lawrence Livermore National Laboratory, LLNL-SR-751691, March 2018

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    2.2 Target Radionuclides and Selection Criteria for Methods of Analysis
    2.3 Sample Delivery/COC Documentation
3.0 Cs Isotope Measurements in Seawater and Freshwater
    3.1 Sample Preparation
    3.2 Detection and Measurement
    3.3 Quality Assurance
4.0 Results and Discussion
5.0 Conclusion
6.0 References

APPENDIX 1. ^{134}Cs and ^{137}Cs in Sea Water and Freshwater Samples

[CD copies of this report along with excel data listings are available upon request].

TABLES and FIGURES

Table 1. List of targeted radionuclides, laboratory methods and estimated detection limits (2016 Amchitka Sampling Event) (after DOE, 2016).

Table 2. Quality Assurance Measurements of ^{137}Cs in IAEA-443.

Table 3. Coefficient of Variation (CV) Between Replicate ^{137}Cs Sample Counts.

1.0 Prologue

The following data report was prepared under contract with the U.S. Department of Energy (DOE), Office of Legacy Management (LM), Grand Junction, Colorado, in support of the Long-Term Surveillance Plan (LTSP) for the Aleutian Islands nuclear site test on Amchitka Island (USDOE, 2014). Following the 2016 sampling event, the Lawrence Livermore National Laboratory (LLNL) received a collection of seawater, freshwater and biological samples for analysis of targeted radionuclides. The sampling activities implemented in 2016 for Amchitka Island and its reference site of Adak, Alaska, were similar in purpose to those conducted previously (USDOE, 2013; 2014). Added emphasis was placed on seawater sampling near an area of potential leakage off the Long Shot test detonation site. There was also an interest in conducting analyses of targeted radionuclides with lower limits of detection for the expressed purpose of directing future trending analysis (USDOE, 2016). The targeted radionuclides of interest included tritium(^{3}H), cesium-134 (^{134}Cs), cesium-137 (^{137}Cs), plutonium-239 (^{239}Pu), and plutonium-240 (^{240}Pu). ^{134}Cs was presumably included to assess the residual impact of inputs from Fukushima.

The systematics and specific objectives of the 2016 sampling event and the associated analytical program were formulated by LM in partnership with the Alaska Department of Environmental Conservation (ADEC), the *Aleutian Pribilof Islands Association, Inc.* (APIA) (a federally recognized tribal organization of the Alet people in Alaska), and the Argonne National Laboratory (ANL). A specific project goal for the 2016 sampling event was to attest to the possibility that selected residual radionuclides from underground nuclear tests conducted on Amchitka Island may enter the marine food chain, and result in potential ecological and human health effects.

LLNL was tasked to provide analytical support for the project with electronic data reporting. Samples of seawater (unfiltered) (N=25) and freshwater (unfiltered) (N=2) were received for analysis of ^{134}Cs and ^{137}Cs. A larger subset of marine biota and algae samples were received for analysis of ^{134}Cs-^{137}Cs and ^{239}Pu-^{240}Pu isotopes. The biological sample collection included Dolly Varden (*Salvelinus malma*) (N=3), Greenling (*Hexagrammos spp*) (N=50), Irish Lord (*Hemilepidotus spp*) (N=50), Rockfish (*Sebastes spp*) (N=50) and Rockweed (*Fucus distichus*) (N=15). Cs isotopes were determined by high resolution gamma-spectrometry after separation of the analytes of interest, along with added carrier, on a small quantity of micro-crystalline ammonium molybdophosphate (AMP). Pu isotopes were measured by quadrupole

Inductively Coupled Plasma Mass Spectrometry (ICP-MS). During early discussion with the sponsor, some consideration was to be given to conducting measurements of Pu isotopes in waters and biological samples by Accelerator Mass Spectrometry (AMS).

The scope of work as outlined in the sampling plan covered specific Quality Assurance Objectives (QAOs) with respect to achievable limits of detection for each of the targeted radionuclides. Livermore scientists found that the agreed-to limits of detection contained in the 2016 sampling plan were not necessarily supportive of the overall program goals to provide quantitative data and information for future trending analysis. To improve quantification of Cs isotopes by gamma-spectrometry and allow for a more detailed comparative assessment to be conducted between sampling events, the project reporting deadline was extended to allow for longer count times. Even with the longer count times (up to 5 days), about 20% of the marine biota samples contained no reportable Cs isotope activity. These samples were subsequently recounted on a Small Anode Germanium (SAGe) well detector system with improved measurement precision. Also, with agreement from the sponsor, a subset of seawater and freshwater samples were analyzed for iodine-129 (^{129}I) using AMS with the aim of providing information on the potential impacts of other source-terms on marine radioactivity, especially with respect to Fukushima. No other AMS measurements were subsequently conducted under the terms of the contract award to LLNL.

N = number of individual samples received for analysis.

2.0 Scope of Analytical Project at LLNL

2.1 Objective

Provide analytical measurement data and reporting under the 2016 Amchitka sampling event.

2.2 Statement of Work

1. Measure the ^{137}Cs, ^{134}Cs, ^{239}Pu and ^{240}Pu content of marine biota and algae samples as supplied under the 2016 Amchitka Sampling Event using a combination of high-resolution gamma-spectrometry (Cs isotopes) and Inductively Coupled Plasma Mass Spectrometry (Pu isotopes).
2. Measure the ^{137}Cs and ^{134}Cs content of freshwater and seawater as supplied under the 2016 Amchitka Sampling Event using a SAGe well gamma detector system.

3. Provide EDD and hard copy reporting of analytical data with a description of methodologies and supporting quality assurance measures.

2.2 Target Radionuclides and Selection Criteria for Methods of Analysis

Previous studies conducted by CRESP (Consortium for Risk Evaluation with Stakeholder Participation) (CRESP, 2015) and LM under the LTSP for the Aleutian Islands nuclear site test on Amchitka Island show that reported levels of anthropogenic radionuclides contained in marine biota from the site were at or below the acceptable consumption risk range of 10^{-4} to 10^{-6} excess risk of cancer. The aim of the current sampling event was to optimize the design of the sampling and analytical program. This was done not only to provide additional confirmatory measurements of the possible health risk posed by consumption of marine foods from the region but to yield high quality data for trending analyses. Under a formal strategic planning process, pre-determined sample locations and DQOs were devised to reduce uncertainties in assessing food safety and provide adequate detection sensitivity to support future statistical trending analyses. This included placing minimum requirements on the quantity of biological materials to be collected (within practical limitations) based on estimated limits of detection for prescribed measurement techniques.

A listing of targeted radionuclides, methodologies and estimated limits of detection for the 2016 Amchitka sampling event is contained in Table 1 (after USDOE, 2016).

2.3 Sample Delivery/COC Documentation

Biological samples collected in the field were sealed inside labeled plastic bags and shipped frozen. All biological fauna samples were received as whole animals. It should be noted, however, that several fish samples were received with their gut cavities open (Hamilton *et al.*, 2018a). Water samples were shipped in single 20-L (5-gallon) polyethylene carboys with no preservation. Samples were received in two (2) separate air cargo flights into San José International Airport in northern California, and then immediately transported by road (app. 30 miles) to LLNL. Biological samples were subsequently stored frozen at LLNL prior to processing. Each sample shipment was accompanied by Change-of-Custody (COC) documentation listing the task code, COC ID, sample ID, location code, matrix type (biota or water), date and time of sampling, collection code (grab or composite), number of sample containers (typically 1 ea.), and

the type of sample analysis to be performed. Upon arrival of the samples at LLNL, a validation check was performed of samples received against the COC listing and any variances identified (see Hamilton *et al*., 2018a). All COC listed samples were accounted for. Sample AMC01.1-16060002-001 (DOLL-AI-01) and AMC13.1-16060002-003 (DOLL-AD-01) were received in the 2nd sample shipment without accompanying COC documentation.

The report shown here contains measurement data for the analysis of ^{134}Cs and ^{137}Cs in seawater and freshwater samples (N=50). The writeup includes a description of the methodologies employed along with the results of any quality assurance measures that were undertaken.

Table 1. List of targeted radionuclides, laboratory methods and estimated detection limits (2016 Amchitka Sampling Event) (after USDOE, 2016).

Analyte	Laboratory Method	Estimated MDA (Bq)	A Priori MDA (Bq kg^{-1} - wet weight)[a]		
			Based on 100 g sample	Based on 1000 g sample	Based on 5000 g sample
Biological samples					
^{134}Cs	Gamma-spectrometry	0.3	3	0.3	0.06
^{137}Cs	Gamma-spectrometry	0.3	3	0.3	0.06
^{239}Pu	Quad ICP-MS	0.008	0.08	0.008	0.0016
^{240}Pu	Quad ICP-MS	0.02	0.2	0.02	0.004
^{239}Pu	AMS	0.00001	0.0001	0.00001	0.000002
^{240}Pu	AMS	0.00003	0.0003	0.00003	0.000006
Seawater and freshwater Samples					
^{134}Cs	Gamma-spectrometry (SAGe)	0.006	0.3[b]		
^{137}Cs	Gamma-spectrometry (SAGe)	0.003	0.15[b]		
^{3}H	Electrolytic enrichment followed by gas proportional counting	0.01184[c]			

[a] MDA expressed on sample mass basis [represents the Relative Detection Limit (RDL)].

[b] Based on a 20-liter sample (Bq m^{-3}).

[c] Bq L^{-1} (Tritium Laboratory, Rosenstiel School of Marine and Atmospheric Science, Miami, FL).

Abbreviations:

MDA = Minimum Detection Activity

AMS = Accelerator Mass Spectrometry

ICP-MS = Inductively Coupled Plama Mass Spectrometry

g = grams

SAGe = Single Anode Germanium

3.0 Cs Isotope Measurements in Seawater and Freshwater

3.1 Sample Preparation

Unfiltered water samples were received in 20-L plastic carboys. Prior to treatment, a subsample of water (app. 1 Liter) was taken for possible analysis of ^{129}I by AMS. The remaining water was subsequently weighted, acidified with 50 mL of concentrated HCl, and then allowed to stand for a minimum period of 24-hours after addition of 10 mg of stable Cs carrier and 3 x 10^9 atoms of ^{242}Pu tracer. ^{242}Pu tracer was added in this instance as a precautionary measure pending a decision from the sponsor to include analysis of Pu isotopes in water. The water samples were then adjusted to pH 2-3 with NH_4OH solution, and Cs isotopes extracted onto 10 g of AMP by mixing in the product as a slurry and allowing the material to settle out overnight. The Cs-AMP was then recovered by decantation and centrifugation, placed in a 30 mL plastic counting tube (scintillation-style vial), and dried in an oven at 60 °C. The counting tube was then capped and weighted, and the Cs-AMP pellet counted by high-resolution gamma-spectrometry. The recovery of stable Cs was measured by X-ray Fluorescence (XRF) (Ametek, 200T) based external calibration using powered AMP samples containing known quantities of stable Cs.

3.2 Detection and Measurement

^{134}Cs and ^{137}Cs sample activities were measured using a SAGe well-detector system coupled to a PC-based work station operating under Canberra Apex-Gamma Lab Productivity Suite software with LabSOCS-generated efficiency calibrations for a 10 g AMP geometry. Count times usually varied between 48 and 64 hours.

3.3 Quality Assurance

The water samples were processed in parallel with reagent blanks (N=10) containing 20-L of 18 Meg Ohm deionized water, and subaliquots (N=6) of a certified reference material obtained from the International Atomic Energy Agency (IAEA-443 Irish Seawater) (IAEA, 2009). A series of samples were re-counted to examine the reproducibility of the measurements. The LM specified reporting units were in pCi kg^{-1}. More conventional SI reporting units of Bq m^{-3} are included in this hardcopy data report (Appendix 1).

4.0 Results and Discussion

The results of analyses of ^{134}Cs and ^{137}Cs in seawater and freshwater samples collected during the 2016 Amchitka sampling event are shown in Appendix I.

No reportable levels of ^{134}Cs were observed in water samples although ^{134}Cs was identified in the gamma software spectral output for sample SEAW-LS-43-DE-DUP and SEAW-AS-01-SH. The estimated equivalent activity concentration of ^{134}Cs in these samples was around 0.6 ± 0.3 and 0.4 ± 0.2 Bq m^{-3}, respectively. This compares with the reporting (Relative Detection Limit, RDL) of around 1 Bq m^{-3}.

Qualifiable levels of ^{137}Cs were detected in all water samples. With exception of a single low-level freshwater sample (FRES-AI-01), the average measurement precision for ^{137}Cs in water was around ±10%. The average measurement bias for ^{137}Cs in six (6) replicate analyses of Certified Reference Material (IAEA-443, Irish Sea water) was -1% (Table 2). The average Co-efficient of Variation between 5 replicate counts was 12%, or 8% on excluding the low-level replicate count on sample FRES-AI-01 (Table 3). These measures fall well within the statistical uncertainty of individual measurements. No ^{137}Cs or ^{134}Cs was detectable in sample reagent blanks. The mean Cs sample recovery was 93.9 ± 3.2 % (N=50).

Table 2. Quality Assurance Measurements of ^{137}Cs (IAEA-443, Irish Sea Water).

Sample ID	^{137}Cs	
	Bq kg^{-1}	**Measurement Bias, %**
IAEA-443 #1	0.35 ±0.01	-3%
IAEA-443 #2	0.36 ±0.01	1%
IAEA-443 #3	0.38 ±0.02	6%
IAEA-443 #4	0.35 ±0.01	-3%
IAEA-443 #5	0.34 ±0.01	-7%
IAEA-443 #6	0.35 ±0.01	-3%
	Average = 1 %	

IAEA-443 Certified value = 0.36 Bq kg^{-1}
(95% confidence level 0.01)

Table 3. Coefficient of Variation (CV) Between Replicate ^{137}Cs Sample Counts.

Sample ID	Sample Location	^{137}Cs, Bq m^{-3} Measure #1	^{137}Cs, Bq m^{-3} Measure #2	CV (%)
AMC01.1-16050001-002	FRES-AI-01	0.18 ±0.1	0.26 ±0.1	26
AMC02.1-16050001-054	SEAW-LS-96-DE	2.05 ±0.2	2.47 ±0.2	13.1
AMC02.1-16050001-068	SEAW-LS-67-DE	1.84 ±0.2	1.71 ±0.2	5.2
AMC02.1-16050001-085	SEAW-LS-43-DE-DUP	1.50 ±0.2	1.43 ±0.1	3.4
AMC013.1-16050001-002	FRES-AD-01	2.17 ±0.1	2.51 ±0.2	10.3
			average = 12 %	

5.0 Conclusion

The mean activity concentration of ^{137}Cs in sea water collected under the 2016 Amchitka sampling event was 1.7 ± 0.3 Bq m^{-3} (0.045 ± 0.008 pCi kg^{-1}) with a range between 1.2 and 2.5 Bq m^{-3} (0.03 and 0.07 pCi kg^{-1}). No reportable ^{134}Cs was found. All data reported appears to satisfy internal and external quality assurance measures.

6.0 References

CRESP (2005). Amchitka Independent Science Assessment: Biological and Geophysical Aspects of Potential Radionuclide Exposure in the Amchitka Marine Environment, Consortium for Risk Evaluation with Stakeholder Participation (CRESP), C.W. Powers, J. Burger, D. Kosson, M. Gochfeld, and D. Barnes, eds., Piscataway, New Jersey, August.

Hamilton, T.F., S. R. Kehl, and R. M. Berry (2018a). Processing of Biological Samples (Wet, Dry and Ash Weights), Data Report, Part I, AMCHITKA PROJECT, WFO Project D201231, Lawrence Livermore National Laboratory, LLNL-SR-751699.

USDOE (2016). Environmental Sampling Plan for the Amchitka, Alaska, Site and Adak Island 2016 Sampling Event, Office of Legacy Management (LM), U.S Department of Energy, Colorado, LMS/AMC/S12630 (not for public release).

USDOE (2014). Long-Term Surveillance Plan for the U.S. Department of Energy Amchitka, Alaska, Site, Office of Legacy Management (LM), U.S Department of Energy, Colorado, LMS/AMC/S01980.

USDOE (2013). Amchitka Island, Alaska, Biological Monitoring Report 2011 Sampling Results, Office of Legacy Management (LM), U.S Department of Energy, Colorado, LMS/AMC/SO8833.

IAEA (2009). Interlaboratory Comparison: Radionuclides in Irish Sea Water IAEA-443, IAEA Analytical Quality in Nuclear Applications Series No. 10 (IAEA/AQ/10), International Atomic Energy Agency, Vienna.

Appendix 1

^{134}Cs and ^{137}Cs in Sea Water and Freshwater Samples

Sample ID	Sample Location	^{134}Cs				^{137}Cs					
		Bq m^{-3}		pCi kg^{-1}		Bq m^{-3}			pCi kg^{-1}		
		Value	RDL	Value	RDL	Value		RDL	Value		RDL
AMC01.1-16050001-002	FRES-AI-01	-	0.7	-	0.02	0.3	±0.1	0.3	0.007	±0.003	0.01
AMC02.1-16050001-041	SEAW-LS-64-DE	-	0.6	-	0.02	1.7	±0.1	0.3	0.046	±0.003	0.01
AMC02.1-16050001-042	SEAW-LS-115-DE	-	0.5	-	0.01	1.6	±0.1	0.2	0.043	±0.002	0.01
AMC02.1-16050001-043	SEAW-LS-124-DE	-	0.8	-	0.02	1.7	±0.1	0.3	0.048	±0.003	0.01
AMC02.1-16050001-044	SEAW-LS-109-DE	-	0.8	-	0.02	1.7	±0.1	0.3	0.046	±0.003	0.01
AMC02.1-16050001-045	SEAW-LS-110-DE	-	0.8	-	0.02	1.9	±0.1	0.4	0.051	±0.004	0.01
AMC02.1-16050001-046	SEAW-LS-112-DE	-	0.7	-	0.02	1.9	±0.1	0.3	0.051	±0.003	0.01
AMC02.1-16050001-047	SEAW-LS-116-DE	-	0.7	-	0.02	1.7	±0.1	0.4	0.046	±0.004	0.01
AMC02.1-16050001-048	SEAW-LS-102-DE	-	0.8	-	0.02	1.9	±0.1	0.6	0.051	±0.003	0.02
AMC02.1-16050001-049	SEAW-LS-120-DE	-	0.8	-	0.02	1.8	±0.2	0.4	0.048	±0.004	0.01
AMC02.1-16050001-050	SEAW-LS-123-DE	-	1.2	-	0.03	1.4	±0.2	0.6	0.037	±0.005	0.02
AMC02.1-16050001-051	SEAW-LS-125-DE	-	1.3	-	0.04	1.8	±0.2	0.6	0.049	±0.005	0.02
AMC02.1-16050001-052	SEAW-LS-113-DE	-	1.3	-	0.04	1.5	±0.2	0.8	0.042	±0.007	0.02
AMC02.1-16050001-053	SEAW-LS-84-DE	-	1.0	-	0.03	1.7	±0.2	0.5	0.047	±0.004	0.01
AMC02.1-16050001-054	SEAW-LS-96-DE	-	1.4	-	0.04	2.5	±0.2	0.7	0.068	±0.007	0.02
AMC02.1-16050001-055	SEAW-LS-74-DE	-	1.2	-	0.03	1.8	±0.2	0.6	0.050	±0.005	0.02
AMC02.1-16050001-056	SEAW-LS-43-DE	-	1.1	-	0.03	1.5	±0.2	0.5	0.041	±0.004	0.01
AMC02.1-16050001-057	SEAW-LS-29-DE	-	0.9	-	0.03	1.5	±0.1	0.4	0.041	±0.004	0.01
AMC02.1-16050001-058	SEAW-LS-35-DE	-	1.2	-	0.03	1.5	±0.1	0.4	0.041	±0.004	0.01
AMC02.1-16050001-059	SEAW-LS-38-DE	-	1.2	-	0.03	1.5	±0.2	0.5	0.041	±0.005	0.01
AMC02.1-16050001-060	SEAW-LS-46-DE	-	0.8	-	0.02	1.6	±0.2	0.5	0.043	±0.004	0.01
AMC02.1-16050001-061	SEAW-LS-36-DE	-	0.8	-	0.02	1.8	±0.1	0.4	0.049	±0.004	0.01

Sample ID	Sample Location	^{134}Cs				^{137}Cs					
		Bq m^{-3}		pCi kg^{-1}		Bq m^{-3}			pCi kg^{-1}		
		Value	RDL	Value	RDL	Value		RDL	Value		RDL
AMC02.1-16050001-062	SEAW-LS-52-DE	-	1.3	-	0.04	1.6	±0.2	0.5	0.045	±0.005	0.01
AMC02.1-16050001-063	SEAW-LS-55-DE	-	1.0	-	0.03	1.7	±0.1	0.4	0.047	±0.004	0.01
AMC02.1-16050001-064	SEAW-LS-58-DE	-	1.4	-	0.04	1.4	±0.2	0.5	0.039	±0.005	0.01
AMC02.1-16050001-065	SEAW-LS-57-DE	-	0.9	-	0.02	1.8	±0.1	0.4	0.050	±0.004	0.01
AMC02.1-16050001-066	SEAW-LS-61-DE	-	1.2	-	0.03	1.6	±0.2	0.6	0.044	±0.005	0.02
AMC02.1-16050001-067	SEAW-LS-63-DE	-	1.1	-	0.03	1.7	±0.1	0.4	0.046	±0.004	0.01
AMC02.1-16050001-068	SEAW-LS-67-DE	-	1.0	-	0.03	1.7	±0.2	0.5	0.047	±0.005	0.01
AMC02.1-16050001-069	SEAW-LS-68-DE	-	1.3	-	0.04	1.8	±0.2	0.5	0.049	±0.005	0.01
AMC02.1-16050001-070	SEAW-LS-70-DE	-	1.0	-	0.03	1.7	±0.1	0.4	0.047	±0.004	0.01
AMC02.1-16050001-071	SEAW-LS-73-DE	-	1.3	-	0.04	1.5	±0.2	0.5	0.041	±0.005	0.01
AMC02.1-16050001-072	SEAW-LS-81-DE	-	1.3	-	0.03	1.6	±0.2	0.6	0.045	±0.006	0.02
AMC02.1-16050001-073	SEAW-LS-79-DE	-	0.8	-	0.02	1.8	±0.1	0.3	0.048	±0.003	0.01
AMC02.1-16050001-074	SEAW-LS-80-DE	-	1.4	-	0.04	1.7	±0.2	0.5	0.046	±0.005	0.02
AMC02.1-16050001-075	SEAW-LS-87-DE	-	1.3	-	0.04	1.7	±0.2	0.4	0.046	±0.004	0.01
AMC02.1-16050001-076	SEAW-LS-89-DE	-	1.3	-	0.04	1.6	±0.2	0.5	0.042	±0.004	0.01
AMC02.1-16050001-077	SEAW-LS-91-DE	-	1.0	-	0.03	1.5	±0.1	0.3	0.040	±0.003	0.01
AMC02.1-16050001-078	SEAW-LS-94-DE	-	1.4	-	0.04	1.2	±0.2	0.5	0.033	±0.005	0.01
AMC02.1-16050001-079	SEAW-LS-98-DE	-	1.5	-	0.04	1.7	±0.2	0.5	0.047	±0.005	0.01
AMC02.1-16050001-080	SEAW-LS-99-DE	-	1.1	-	0.03	1.6	±0.1	0.4	0.044	±0.004	0.01
AMC02.1-16050001-084	SEAW-LS-109-DE-DUP	-	1.1	-	0.03	1.5	±0.1	0.4	0.040	±0.004	0.01
AMC02.1-16050001-085	SEAW-LS-43-DE-DUP	-	1.0	-	0.03	1.4	±0.1	0.4	0.039	±0.004	0.01
AMC02.1-16050001-086	SEAW-LS-36-DE-DUP	-	1.1	-	0.03	1.4	±0.2	0.6	0.038	±0.006	0.02

Sample ID	Sample Location	^{134}Cs				^{137}Cs					
		Bq m^{-3}		pCi kg^{-1}		Bq m^{-3}			pCi kg^{-1}		
		Value	RDL	Value	RDL	Value		RDL	Value		RDL
AMC02.1-16050001-087	SEAW-LS-80-DE-DUP	-	0.9	-	0.03	1.5	±0.1	0.3	0.042	±0.003	0.01
AMC03.1-16050001-041	SEAW-ML-01-SH	-	1.5	-	0.04	2.0	±0.2	0.6	0.054	±0.005	0.02
AMC05.1-16050001-041	SEAW-CN-01-SH	-	1.3	-	0.04	1.6	±0.2	0.5	0.044	±0.004	0.01
AMC013.1-16050001-002	FRES-AD-01	-	1.5	-	0.04	2.5	±0.2	0.6	0.069	±0.006	0.02
AMC014.1-16050001-041	SEAW-AN-01-SH	-	1.3	-	0.03	1.8	±0.2	0.6	0.048	±0.005	0.02
AMC015.1-16050001-041	SEAW-AS-01-SH	-	1.1	-	0.03	1.8	±0.2	0.5	0.050	±0.005	0.01

RSD = Relative Detection Limit (individual sample MDA normalized to sample mass, count time and analyte recovery)

Lawrence Livermore National Laboratory
Technical Information Department
Livermore, CA 94551