BIOMONITORING FOR ECOSYSTEM AND HUMAN HEALTH PROTECTION AT AMCHITKA ISLAND

Authors

Joanna Burger, Michael Gochfeld, David S. Kosson and Charles W. Powers

January 13, 2006

[Final with revisions to Draft 1.13.06]

Consortium for Risk Evaluation with Stakeholder Participation II

An organization of The Institute for Responsible Management

675 Hoes Lane, Room N-112

Piscataway, New Jersey 08854

(732) 235-3460

(732) 235-9607 FAX

www.cresp.org

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ABSTRACT

Following a Letter of Intent signed by the Department of Energy (DOE) and the State of Alaska, CRESP designed and executed an *Independent Science Plan* to determine whether the foods from the marine environment around Amchitka were safe, to investigate the biological and geophysical aspects of potential radionuclide exposure, and to develop information for planning long-term biomonitoring. The full report, *Amchitka Independent Science Assessment: Biological and Geophysical Aspects of Potential Radionuclide Exposure in the Amchitka Marine Environment* (Powers et al. 2005), along with an addendum, provides data, conclusions, and recommendations. The key biological conclusions were that the foods tested are currently safe for human consumption, there is a rich and diverse marine ecosystem that may be at risk if there were significant seepage, and there are species at different trophic levels that could serve as bioindicators for a long-term stewardship plan at Amchitka.

The purpose of the present report is to provide CRESP's recommendations for a Biomonitoring Plan at Amchitka, particularly with respect to what radionuclides to examine, what species should serve as bioindicators, where to monitor, and when to monitor. The CRESP conclusions are based on the data presented in the full CRESP report (Powers et al. 2005) and addendum (Powers et al. 2006). The data and justifications used are presented in the present report. CRESP recommends the following components for biomonitoring as part of the Long-term Stewardship Plan for Amchitka:

Radionuclides: Cs-137, Co-60, I-129, Tc-99, Am-241 and the Plutonium/Uranium series.
Species: Fucus, Alaria fistulosa, Blue Mussel, Dolly Varden, Black Rockfish, Pacific Cod, Halibut, Glaucous-winged Gull.
Tissues: Soft tissue of kelp and mussels (all isotopes), muscle for other species (Cs-137, Co-60, I-129, Tc-99).
Location: All three test shots for kelp, mussels, Black Rockfish and gulls; two sides of Amchitka for halibut and cod; Airport Creek and Cannikin for Dolly Varden.
Timing: Regular biomonitoring on a 5-year Plan. **Plus:** collection of expanded bioindicators following a significant geologic event or a significant increase[a] in radionuclide content in routine bioindicators. In the event that the collection has been triggered by an increase in radionuclide content in routine bioindicators, all expanded indicators should be analyzed for radionuclides. In the event the trigger has been a geologic event, analysis of the eight regular bioindicators should be sufficient unless the analysis reveals a significant increase in radionuclide content in these bioindicators.

The Letter of Intent stipulates 5-year review of the long-term stewardship plan, making it reasonable to biomonitor on this schedule. 5-year biomonitoring might include either one sampling period, or two. All information provided by Regular Biomonitoring should be made available to relevant stakeholders for their consideration and to ensure continued stakeholder input into future biomonitoring.

For The Full CRESP Report and Addendum, go to www.cresp.org

[a] Refer to footnote [b] on page 29.

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INTRODUCTION

Amchitka is a DOE site in the Aleutian chain in the northern Pacific that was the scene of three underground nuclear tests in 1965, 1969 and 1971. The island was designated a wildlife preserve as early as 1913, but was released for military activity during World War II (Kohlhoff 2002). Today it is part of the Alaska Maritime National Wildlife Refuge system under the aegis of the US Fish & Wildlife Service (USFWS). DOE reports that it has remediated surface contamination on the island, and it plans to "close" the site, and transfer it from its environmental management program to its Office of Legacy Management (OLM) in late 2006. OLM will retain responsibility for the shot cavities. As part of this transfer, DOE has committed to develop and implement a Long-term Stewardship Plan to deal with the radionuclide wastes that will remain in place in the shot cavities.

For Amchitka, the issue is not one of surface cleanup but of monitoring for, and if found mitigating, significant risks resulting from potential subsurface transport of radionuclides into the marine environment and into the food chain. There had been intense public concern and active stakeholder involvement surrounding the subsurface environment. A Letter of Intent in June 2002 between DOE and the State of Alaska, Department of Environmental Conservation (ADEC), set forth a plan to address the subsurface issues. The Letter of Intent stipulated, among other actions, that there be conducted a scientific assessment by an independent scientific group (CRESP), and that closure in place was contingent upon the results of the actions required by the LOI, including the scientific assessment. Plans for that assessment were to be developed by CRESP and implemented only after the plan was approved by four parties (the LOI signatories and USF&WS and A/PIA). The LOI also specified that the assessment was to serve as a basis for the long-term stewardship plan; the four parties would act as an independent review group to discuss the assessment, work on reaching agreement about leaving radionuclides in place, and long-term stewardship. Also, the stewardship plan is to be reviewed every five years to assure that human health and the environment are adequately protected.

CRESP completed its work, and reported it in *Amchitka Independent Science Assessment: Biological and Geophysical Aspects of Potential Radionuclide Exposure in the Amchitka Marine Environment* (Powers et al. 2005) and *Addendum* (Powers et al 2006) - both available on the CRESP website. This report, focused on biomonitoring, relies on the CRESP report and its addendum and is in response to a request by the Office of Legacy Management (DOE) to provide more focused scientific recommendations on biomonitoring to the four parties.

One important aspect of any Long-term Stewardship Plan is monitoring and surveillance. For Amchitka, monitoring of groundwater wells is not feasible, given the depth of the test cavities, the remoteness of the island, and the number of wells that would be needed (and associated cost and maintenance). Further, since the route of exposure of concern is food safety, biomonitoring provides the best and possibly the only feasible and credible approach to empirical assessment of the potential risk to the marine environment, to the food chain, and to human consumers of algae, shellfish, fish and birds. The scientific assessment, as stipulated in the Letter of Intent and its approved focus on radiological assessment of the marine environment was to, and does, form the basis for both the baseline and other development of a future biomonitoring plan.

The objective of this report is to address key issues of a biomonitoring plan in detail, including selection of species, selection of radionuclides, and a bioindicator matrix of species/radionuclides. The rationale for species collection, along with the data used to select bioindicators is described in detail, along with temporal patterns. Recommendations are based on the radionuclide data from specimens collected during two biological expeditions in 2004. A full description of the objectives, methods, data, and interpretation of the CRESP Amchitka biological and radiological expeditions can be found in Powers et al. (2005) and the addendum to that report (Powers et. al. 2006). Other aspects discussed briefly include logistics, administration, and institutional controls.

GUIDING PRINCIPLES

There are four principles that CRESP notes are critical for success in developing the monitoring aspects of long-term stewardship plans: 1) Sustainability, 2) Stakeholder involvement, 3) Rigorous scientific methodology, and 4) Continued iteration and cooperative-management. Sustainability requires a continued commitment to ensure that the marine resources, food chains, and human foods are protected from harm from radionuclide seepage. However, sustainability also requires continued funding, ongoing interest, and the ability to provide meaningful results in a cost-effective and timely manner. Any plan should be iterative, and involve cooperative management among diverse agencies and stakeholders.

Stakeholders should be involved in all aspects of the marine environment characterization and data collection, and their involvement was critical for CRESP in doing the best science possible. CRESP continues to be committed to this involvement in all phases of the work. Thus, this report is put forth as the science base for discussion among the relevant agencies and institutions, as well as all interested and affected parties.

In our efforts to achieve rigorous scientific methods and approaches for the Amchitka situation, our deliberations were guided by: 1) Sensitivity: the program should detect contamination from radionuclide release to the marine environment as early as possible , 2) Specificity: the program should continue to provide background results if a significant release to the marine environment from the test shot has not occurred. If elevated radionuclide levels are detected they should be detected early enough and at low enough levels to allow for protective measures to avoid or minimize unacceptable human health risks. Also the program should be able to distinguish if an elevated radionuclide level is indicative of possible seepage from Amchitka test shots versus alternative sources. This requires that some radionuclides will be considered as indicative of an Amchitka nuclear test shot signal or be distinguished from other sources.

Our studies and report will allow CRESP successors to interpret future radiological data from Amchitka using the following techniques: 1) comparison with CRESP's detailed data base (clearly the intent of the LOI), 2) comparison with previous data from Amchitka, 3) comparison with human health guidance levels and ecological hazard levels, and 4) comparison with potential health effects. The CRESP report and its addendum were developed to provide those implementing a biomonitoring plan a single source for data on all four techniques and data available at the time of its publication.

We note that Amchitka poses a particularly daunting and unusual monitoring challenge. The species selected for biomonitoring should also be placed within a context of the bioindicators work published in the peer-reviewed literature, as well as DOE practices. The general scientific literature available to guide this work is, in fact, quite limited. For example, only 5 % of the papers on bioindicators in the peer-reviewed literature for 4 key ecological journals expected to have papers on biomonitoring (*Science for Total Environment, Ecotoxicology and Environmental Safety, Environmental Pollution, and Environmental Science and Technology*) included radioisotopes. Over 55 % of these papers used plants as bioindicators for radionuclides. Fish and birds accounted for less than 5 % of the papers on bioindicators of radiation (Burger, review). These analyses included general ecological journals and not specialized journals such as radioecology or engineering journals. Similarly, on the OLM website there is a listing of the monitoring and surveillance plans currently in use. A search of this data base indicated that there were

82 reports that list monitoring, none of which list biomonitoring. Some integrated monitoring plans of individual sites have biomonitoring components, but these are usually ecological and involve population numbers, reproductive success, and invasive species (DOE 2005b).

THE BERING SEA ECOSYSTEM

The marine resources in the Bering Sea/North Pacific ecosystem are extremely important because this ecosystem is diverse and rich biologically, supports important food chains leading to endangered and threatened species, provides subsistence foods for local peoples, and supports an important commercial fishery. Not only does this region support sensitive populations of marine mammals, but it is the site of large populations of Bald Eagles (our national emblem), and some of the United States' largest and most diverse seabird colonies (Johnson 2003). Since Amchitka itself is part of the Alaska Maritime National Wildlife Refuge, the integrity of the marine ecosystem with its attendant seabird and marine mammal populations, is of interest to a wide range of governmental and non-governmental agencies and individuals.

Commercial fishing in the Bering Sea region is extremely important, although it is difficult to arrive at comparative measures. The NRC (2003) noted that over 40 % of all the United States fish and shellfish landings (by weight) derive from the Eastern Bering Sea (including Dutch Harbor). Mito et al. (1999) noted that the total catch of groundfishes on the eastern Bering Sea shelf and the Aleutian Basin is 2-3 million metric tons per year. While Pollock is the species with the highest commercial catch in the western Bering Sea, Pacific Cod is second, and is increasing in tonnage (NRC 1996, Alaska Journal of Commerce. 2004). In the eastern Bering Sea the main catch is also Pollock and Cod, along with Yellowfin Sole (NRC 1996). For the region, both Pollock and Cod are key commercial species. Cod are also one of the most commonly eaten marine foods in Aleut villages, such as Atka (Jewett 2002), Nikolski and Unalaska (Hamrick and Smith 2003). Thus, the same resources that support commercial fisheries in the region also support important traditional hunting and fishing (NRC 1993).

BACKGROUND ON AMCHITKA AND LONG-TERM STEWARDSHIP AT DOE

Amchitka is one of 129 DOE sites requiring long-term stewardship (Wells and Spitz 2003), and is the most remote.

PERSPECTIVE ON AMCHITKA AND CLOSURE

Closure of Amchitka is fundamentally different from other DOE sites because it is an underground nuclear test site that is remote, of intense interest to a wide range of stakeholders, and in one of the most productive biological communities in the Pacific. At the time of the test shots (ca 1970), there was intense controversy about testing at Amchitka, including the potential health risks to humans, the serious damage to the marine ecosystem and endangered species, and the possible generation of tsunami activity. The controversy continues to the present (Kohlhoff 2002, Younker 2002), with increasing concern about the possibility of subsurface transport of radionuclides from the three test shot cavities to the marine environment, and thus through the food chain to people. A primary concern, whether the subsistence foods of the Aleut people, and the commercial fish and shellfish were safe to eat, was answered with respect to radionuclides by the CRESP report (Powers et al. 2005). The biota tested indicated that radioisotope levels in the foods are currently below accepted food safety guidelines and provided no indication of impact from the Amchitka test shots.

CRESP developed the Amchitka *Science Plan,* which included a complex set of geophysical and biological projects to provide the science necessary to assess whether there are currently any risks to humans and marine biota from radionuclides in the marine environment around Amchitka that could be attributable to the nuclear test shots. The focus of the Amchitka *Science Plan* was on research and data collection aimed at assessing food safety and reducing uncertainties in the DOEs groundwater and human health risk assessment models. Stakeholder input was a critical component of the CRESP work, from the development of the *Science Plan* to the completion of the research itself (Burger et al. 2005).

The expeditions to Amchitka were conducted in June, July and August of 2004, with subsequent radionuclide analysis and interpretation. The CRESP report, *Amchitka Independent Science Assessment: Biological and Geophysical Aspects of Potential Radionuclide Exposure in the Amchitka Marine Environment* (Powers et al. 2005), has been released, and is available on the web at www.cresp.org. The CRESP research dealt entirely with the marine environment; surface evaluation has been conducted by others (Greenpeace 1996, Dasher et al. 2002). The next step is to develop a long-term stewardship program (U.S. Fish & Wildlife Service 2000) with a well-designed biomonitoring plan. Ultimately institutional frameworks and policies are needed to ensure protection of the environment and human health.

SPECIES AT RISK AND POTENTIAL HUMAN RISK ON AMCHITKA: CRESP DATA

One of the key issues in the screening risk assessment (DOE 2002b) was whether there is sufficient biota near Amchitka to take up radionuclides if there were seepage, and to transfer radionuclides through the physical environment to the food chain to top-level predators, including humans. The food chains at both Amchitka and Kiska included primary producers, filter feeders, grazers, and many levels of predators. The marine ecosystems were diverse and flourishing. Our biological collections, described in chapter 9 of the CRESP report (Powers et al. 2005), indicate that the same biota were present in the marine environment around Amchitka as were present at Kiska, the reference site. There were no significant differences in presence, and there were no differences in the difficulty of collecting these species at the two places. Thus, the data generated by CRESP studies indicate that there are species that may be at risk if there were significant seepage from the Amchitka test shots to the marine environment. Most of the species collected were ones that are subsistence foods of the Aleuts, and some are commercially important species for the Bering Sea/Northern Pacific ecosystem. Further, there were flourishing colonies of seabirds and marine mammals breeding on Amchitka (and Kiska) Island. A Sea Lion rookery persists on Amchitka, protected with ship exclusion zones.

The CRESP expedition found that there were sedentary species present from the intertidal to 90 feet depths (the deepest safe dive depths during the CRESP expedition), with no indication that the kelp forests did not continue beyond this depth. There were also species with very low mobility (Sea Urchins, Rock Jingles, some fish) that could serve as indicators of local exposure. These species are indicative of a fairly complex, sedentary base to diverse food chains, leading to higher trophic levels. In short, there are species present that may be at risk from radionuclide seepage and that can also be used for monitoring purposes.

The species present that may be at risk if there were significant seepage of radionuclides occurring over a short time period are also the same species that form the basis for complex marine food webs that are of interest to resource trustees, and the general public. Many of these species also form the basis for the subsistence lifestyle of the Aleut and Pribilof Islanders (Hamrick and Smith 2003) who might visit

Amchitka, and for commercial fisheries in the region (NFI 2005).

While quantitative data on consumption rates for people living in the Aleutians are sparse, food preferences and use have been examined (Hamrick and Smith 2003). Fish, birds and marine mammals are an important part of their year-around diet (APIA, 2002; Patrick, 2002, Hamrick and Smith, 2003). Interviews with the residents of the Aleutians (Unalaska, Nikolski, Atka) and discussions with our team members (R. Snigaroff, D. Snigaroff, T. Stamm), identified a variety of organisms that are consumed either as important dietary items or "treats". Interviews showed that 30-90 % of the food consumed in various island villages is subsistence food (Patrick 2002), and Cod is one of their preferred foods (APIA 2002; Patrick 2002; Hamrick and Smith 2003).

Of the fish collected as part of the CRESP study, Halibut and Cod are two of the most commonly eaten animal protein items in Nikolski and Unalaska (Hamrick and Smith 2003), as well as in Atka (Jewett 2002). Other commonly eaten meat and fish included Moose (not in the Aleutians), Reindeer (Caribou are present on a few islands), and several species of salmon (Hamrick and Smith 2003). In Atka we surveyed residents about traditional foods; the most frequently asked questions about contaminants were for gumboots (chitons) and Halibut (both species we examined), followed by Sea Lion and Pacific Cod. In this study we address only concentrations of radionuclides in the foods (not heavy metals or organochlorines). Collecting data on consumption patterns is methodologically challenging and controversial (Burger 2000, 2002, Burger et al. 1998, 1999, 2002, Vorhees 2004, Strauss 2004), but it is generally clear that there are no quantitative data from the Aleutians (Moya 2004). In a review of fish consumption data, Moya (2004) summarized the data sets that were available on Native American populations, and none were from Alaska.

DOE SURVEILLANCE AND MONITORING PLANS

The Office of Legacy Waste Management is responsible for the writing and production of long-term stewardship plans for DOE sites that have legacy wastes that will remain on site. Surveillance and monitoring at these sites is often a continuing, yearly activity, with 5-year CERCLA reviews, where appropriate (DOE 2005a), and the plans are posted on the OLM website (OLM 2005). Developing long-term stewardship plans improves long-term management of risks (DOE 2005c). The long-term stewardship planning guidance document (DOE 2005c) describes monitoring and surveillance within the context of engineered controls for wastes left in place. Within this context, there is routine maintenance, reporting requirements, monitoring activities, and emergency response and corrective actions. DOEs "Site Transition Framework for Long-term Surveillance and Maintenance" (DOE 2006) notes the importance of the characterization of important ecological resources, and associated potential receptors. CRESP compared marine resources around the test shots and Kiska (Powers et al. 2005), and developed a conceptual site model for potential receptors at Amchitka (Burger et al. in press).

Amchitka is perhaps unique among DOEs OLM sites in that it is both remote and there are no engineering solutions to the underground radioactive wastes left in place. Biomonitoring is therefore for the purposes of documenting potential seepage, assessing potential risk to humans and the environment, and developing strategies to deal with seepage-related risks if they occur. Biomonitoring can be expected to provide reassurance to stakeholders. Whereas other sites can monitor radionuclides or other contaminants in soil, sediment or groundwater, at Amchitka it is essential to monitor radionuclides in marine biota as an indicator of possible seepage and risk to marine resources.

A BIOMONITORING PLAN FOR AMCHITKA

There are five key aspects of a biomonitoring plan to assess potential risks from radionuclides: 1) What radionuclides to monitor, 2) What biological species to monitor, 3) A matrix for species by radionuclides for monitoring, 4) Where to monitor, and 5) When to monitor. The CRESP data base (Powers et al. 2005, Addendum) provides the basis for the first four aspects. The fifth is informed by the biological data, geological data, and a range of other stakeholder/manager factors. Other critical aspects of a biomonitoring plan include the magnitude of the collection and analytic effort (e.g. how many individuals or composites of each species, how many radionuclides for each species), the logistics of the biomonitoring, interpretation and response to results, and the institutional controls necessary to ensure plan efficiency, efficacy, and continuance. The elements of the plan to be discussed below include:

ELEMENTS OF A PLAN

1. Radionuclides to monitor (WHAT radionuclides)

2. Species to monitor (WHAT biota)

3. Bioindicators: A biological species by radionuclides matrix

4. Where to monitor (WHERE)

5. Temporal Patterns of monitoring (WHEN)

ENSURING PEACE OF MIND

A regular Biomonitoring Plan for Amchitka must be conducted within a framework of characterization, biomonitoring, and response. That is, the CRESP data (Powers et al. 2005, 2006) provides the baseline for characterization of radionuclide presence and levels in marine biota around Amchitka. Regular biomonitoring should assess the continued safety of marine foods and the food chain. However, two events should trigger non-routine biomonitoring to assess whether there is cause for concern that should elicit an appropriate response action (see Fig. 1, page 30).

SELECTION OF RADIONUCLIDES TO MONITOR

CRESP Amchitka Expedition

A suite of radionuclides was selected for the CRESP analysis, based on information obtained from the groundwater models and human health risk assessments (DOE 2003a, 2003b), and our knowledge of radionuclides of interest for human health, ecological health, and source identification. This suite of isotopes was identified in the *Amchitka Science Plan*, and was reviewed by people with appropriate clearance and access to the classified source term, whom we expected to provide advice if our selection list was missing key isotopes.

In general, the main isotopes posing a risk to human health and ecological receptors are Cs-137, Sr-90, Tc-99 and I-129, all of which accumulate in soft tissue, although Sr-90 accumulates mainly in bone. U and Pu isotopes and their daughters are primarily alpha emitters; they provide information on the potential source of the isotopes, and mainly accumulate in bone and kelp. Uranium and plutonium are also toxic chemically at high doses, but they are transported rather slowly in groundwater. The source of many radionuclides, such as Cs-137 and Sr-90, in terrestrial, freshwater, and marine environments is mainly global fallout from historic atmospheric testing (Dahlgaard et al. 2004). Isotopes selected for analysis for the CRESP Amchitka Study (Powers et al. 2005) are listed below. (Note that several of these emit more than one type of radiation):

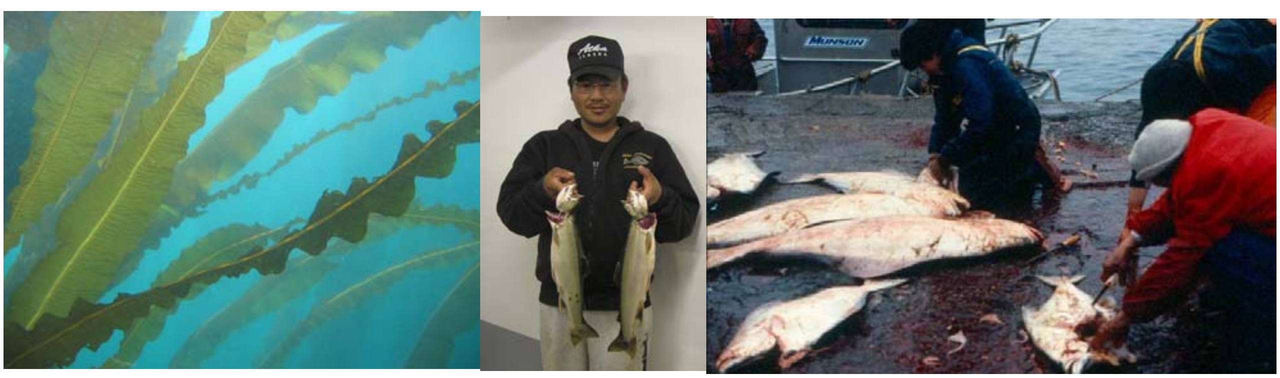
Primarily Gamma emitters: Cs-137, Eu-152, Co-60

Primarily Alpha emitters: Pu-238,239,240,241, U-234,235,236,238, Am-241

Primarily Beta emitters: Sr-90, I-129, Tc-99

Recommended Radionuclides for Biomonitoring

The suite of isotopes selected for biomonitoring in this report are those that are of interest for human health and the environment, and that were assessed in the Amchitka samples (Powers et al. 2005). In the table below we provide the rationale for our choice. Others that were not analyzed, but may be of interest are included in the table below, with CRESP's evaluation for biomonitoring.



Alaria, Dolly Varden, Halibut

TABLE 1. Isotopes to be considered for Biomonitoring. * denotes the CRESP recommendation for radioisotopes for biomonitoring. A = mainly or exclusively anthropogenic, N = mainly or exclusively natural. n=some natural occurrence. Tissue refers to where the isotope concentrates, not necessarily our suggested tissue for analysis (see tables in biota selection, below). Under tissue, kelp refers to the fronds (blades) of kelp. All the radionuclides we address can cause an increased cancer risk (See EPA, 1999 for cancer slope factors). Sources of information are listed at the end of the table[a].

RADIO ISOTOPE	**TYPE** **occurrence**	**HALF-LIFE**	**TISSUE**	**RATIONALE**
RECOMMENDED				
*Cs-137	gamma A	30.2 years	muscle kelp	• By-product of nuclear reactions and detonations, and from medical uses. • Fall-out is the main source of cesium in the environment. • It is mobile in ground water and the food chain. • Cesium accumulates in the soft tissues of biota (i.e. muscle). • It is the muscle and other soft tissues that are consumed by people and by other predators • The most likely exposure route for humans is through the food chain. • Moderately high specific activity[c]. • It is the longest-lived high-yield fission product.
*Co-60	gamma, beta A, n	5.3 years	bone liver kidney muscle kelp	• Produced for industrial and medical applications, and is a by-product of nuclear reactions. • Not typically associated with nuclear test detonations (thus if present, it is probably not due to Amchitka; useful as a signature). • For some applications, external exposure can occur. • It can be analyzed with other gamma emitters with little additional cost • Very high specific activity
*I-129	beta & weak gamma A	15.7 million years	thyroid muscle kelp	• By-product of nuclear reactors and weapons detonations • I-129 accumulates in the thyroid of vertebrates • Can cause thyroid cancer. • Very mobile in the environment. • Low specific activity.
*Tc-99	beta, gamma A, n	212,000 years	muscle kelp, bone, thyroid	• By-product of detonations and fuel cycle activities, but some occurs as waste from hospitals and research facilities. • Very mobile in the environment. • Concentrates in brown algae. • Low specific activity.
*Am-241	alpha some gamma A	433 years	muscle kelp, bone, liver	• By-product of nuclear reactions and from weapons detonations. • Can accumulate in the food chain. • In the actinide series • Moderately high specific activity
*Pu-238	alpha A	87.7 years	muscle kelp, bone, liver	• Used as a thermal fuel for space craft. • Decays to U-234. • Analyzed in the actinide series • Pu-238 is rare in the environment. • Moderately high specific activity
*Pu-239 *Pu-240	alpha A alpha A	24,100 years 6,560 years	muscle, kelp, bone, liver	• By-produce of nuclear reactions and accidents (Chernobyl), and used in weapons testing. • Remains in the body for decades. • Pu-239 decays to U-235 • Pu-240 decays to U-236 • In the actinide series • Usually analyzed together. • Both have medium specific activity

*U-235 *U-236	Alpha A, n alpha A	700 million years 23 million years	muscle kelp, bone, kidney	• Primarily anthropogenic as the fuel for reactors. • In the actinide series, will be analyzed together. • Both U-235 & U-236 have very low specific activity.
U-234 *U-238	alpha N alpha N	240,000 years 4.5 billion years	Muscle, kelp bone kidney	• Primarily natural, and provides a check on analytical methods and with background levels from elsewhere. • In the actinide series, and can be analyzed together. • U-234 has low specific activity, while U-238 has very low specific activity.
NOT RECOMMENDED				
Eu-152	gamma	13.5 years	Muscle kelp	• By-product of fission. • Presents short-term exposure risks. • No levels above MDA for CRESP Amchitka data base. • High specific activity
Sr-90	beta	29 years	Muscle kelp bone	• By-product of uranium and plutonium fission. • No levels above MDA in the CRESP data base. • Less likely to bioaccumulate in marine organisms than other radioisotopes because it behaves like calcium. • There is stable Sr-89 in seawater, which competes with Sr-90 for binding. • Sr-90 can replace calcium and be deposited in bone, but can also be swamped by excess available calcium. • High-yield, moderately long-lived fission product. • Of interest to humans because of food chain exposure and accumulation, especially in freshwater systems. • Accumulates in bone, but also in other tissues. • Associated with bone cancer, soft tissue cancer, and leukemia. • High specific activity
Tritium	beta A	12.3 years	water	• By-product of nuclear reactions and detonations. • Produces short-term risk because of its relatively short half-life in the environment, and in the body. • Moves like water through the food chain, but does not bioconcentrate. • Rapid dispersion; thus to be effective, tritium testing should be linked to known faults or fissures where seepage is expected (and none showed up in the CRESP geophysical work). • Was not examined in CRESP data set due to quantities of water required for analysis, lack of temporal integration into biota and the food chain, and short half-life. • Not useful for long-term monitoring because of time since test detonation. • Separate analytical train. • Very high specific activity
Iodine-131	beta A	8 days	thyroid	• By-product from weapons detonations and medical usage. • Acute risk, but very rapid decay (thus can't be detected except after acute exposure event) • Bioaccumulates in thyroid, causes thyroid cancer. • Biological half-life is about 100 days for thyroid. • Very high specific activity

a. Sources: AMAP (2003), Argonne National Laboratory (2005), Grand Junction (2005), U.S. EPA (2005) for individual radioisotopes, U.S. EPA (2002).
b. The cancer risk coefficients (or cancer slope factors) are the increased cancer risk per Bq of exposure.
c. For specific activity, very high = more than 10,000 GigaBq/gram, high = 100-10,000 GigaBq/gr, medium = 1-100 GigaBq/gr, low = 0.01-1 BigaBq/gr.

Any monitoring and surveillance plan requires consistency to elucidate status and trends. The table below (Table 2) gives some of the key methods used in the CRESP data base and that should be used in future analysis of biological samples from Amchitka. The counting times and weight of samples for Cs-137 are critical for detection above the MDA.

The CRESP protocol, followed by EPA and other laboratories, was to composite at least 5 individuals of about the same size and weight obtained from the same sampling locations to form a single composite sample for analysis. Thus, it is critical to be able to locate (with GPS) the exact location of each individual sample, used to form each composite sample, as well as to attribute them to the closest test shot (Milrow, Long Shot, and Cannikin).

To achieve comparability, analysis of the recommended radionuclides for biomonitoring can be accomplished by using three analytical trains: gamma analysis, Tc-99 analysis, and actinide series analysis.

TABLE 2. Methods of Radionuclide Analyses. The following methods were employed by CRESP in baseline radionuclide analysis (Powers et al. 2005) to be used in future biomonitoring.

RADIOISOTOPE	METHOD	RECOMMENDED DETECTION LIMITS
Cs-137, Co-60, I-129	Gamma spectroscopy (HPGe) with low energy photon capability to simultaneously measure all three isotopes; typical analytical conditions include: 1000g (homogenized) samples, 3 days minimum counting times.	Cs-137 = 0.1 bq/kg or better; I-129 = 0.5 bq/kg or better and Co-60 = 0.2 bq/kg
Tc-99	Chemical digestion and preparation followed by inductively coupled plasma mass spectroscopy; typical analytical conditions require 15-100 g homogenized sample for chemical digestion.	Tc-99 = 1.0 bq/kg
Uranium and Plutonium series	Chemical digestions and preparation followed by either alpha spectroscopy or tandem ion mass spectroscopy for individual isotope quantification; typical analytical conditions require 15-100 homogenized sample for chemical digestion.	Pu series and U series and Am-241 = 0.1 bq/kg or better (0.05 preferred)

Glaucous-Winged Gull

SPECIES TO MONITOR

Usually bioindicator species are selected based on those described in the literature, on their status as primary producers or top-level predators of interest, or on their previous use at a given site (Burger 2006). There are few studies where more than two species serve as bioindicators for contaminants of interest; it is an assumption that these species are the best bioindicators. Yet, only with data from a series of organisms within the same ecosystem can differences among species be evaluated to select the best species to be used as bioindicators for monitoring status and trends. Furthermore, not all organisms within an ecosystem can be evaluated, and some selection from the hundreds of species present in an ecosystem is essential. This selection phase, however, is rarely studied or described. Yet, this is a critical step, particularly for situations where long-term monitoring is part of a stewardship program for a contaminated site.

The CRESP Data Base Available for Bioindicator Selection

The Amchitka data base is described fully in Powers et al. (2005) and in the Addendum to the report (Powers et al. 2006). The species/radionuclide matrix was composed of the following, although not all species (and tissues) were analyzed for all radionuclides:

Species:	6 species of algae
	6 species of grazers/filter feeders
	11 species of fish
	5 species of birds (including eggs of 2 species)
	1 Sea Lion, captured in a subsistence hunt by Aleuts
Radionuclides:	Cs-137
	I-129
	Co-60
	Eu-152
	Am-241
	Sr-90
	Tc-99
	Pu-239,240
	U-234
	U-235
	U-236
	U-238

There were no samples above the MDA (Minimum detectable activity) for I-129, Co-60, Eu-152, Sr-90, and Tc-99.

Table 3 summarizes the values that were above the MDA. This table includes all the analyses in the CRESP data set (those in Powers et al. 2005 and the addendum, 2006). This table provides a basis for understanding which species had radionuclide values that were above the Minimum Detectable Activity level (MDA).

TABLE 3. Number of Composites above the MDA. Shown are the number of values above the MDA/total composites analyzed for the key radionuclides examined at Amchitka and Kiska, 2005. Cesium samples were only the 1000 gram samples. Primary Source: A = anthropogenic, N = natural.

SPECIES	Cs-137	Am-241	Pu-238	Pu-239, 240	U-234	U-235	U-236	U-238
SOURCE	A	A	A	A	N	A	A	N
PRIMARY PRODUCERS								
Alaria fistulosa	0/4	0/19	1/19	6/19	19/19	8/19	2/19	19/19
Alaria nana	0/2	2/21	0/21	3/21	21/21	9/21	0/21	21/21
Fucus	0/4	2/14	0/14	5/14	14/14	14/14	1/14	14/14
Ulva	0/3	1/12	2/12	0/12	12/12	0/12	0/12	12/12
Laminaria (3 species)		0/18	0/18	3/18	18/18	3/18	0/18	18/18
GRAZERS/FILTER FEEDERS								
Sea Urchin	0/3							
Giant Chiton	0/1							
Rock Jingle	0/3	7/21	0/21	6/21	21/21	3/21	1/21	21/21
Limpet (Chinese hat)	0/2							
Blue Mussel	0/2	1/9	0/9	0/9	9/9	2/9	0/9	9/9
Horse Mussel	0/2	1/8	0/8	1/8	8/8	2/8	0/8	8/8
LOWER PREDATORS								
Dolly Varden	3/3							
Atka Mackerel	1/3	0/1	0/1	0/1	1/1	1/1	0/1	1/1
Rock Greenling	0/5							
Yellow Irish Lord	1/3	0/3	0/3	0/3	3/3	0/3	0/3	3/3
Northern Sole	0/2							
Ocean Perch	1/3	0/1	0/1	0/1	1/1	0/1	0/1	1/1
Eider (birds)	0/2							

SPECIES	**Cs-137**	**Am-241**	**Pu-238**	**Pu-239, 240**	**U-234**	**U-235**	**U-236**	**U-238**
Eider (eggs)	0/2							
MEDIUM TROPHIC LEVEL								
Gulls (birds)	1/2	0/8	0/8	0/8	0/8	0/8	0/8	1/8
Gulls (eggs)	0/2							
Pigeon Guillemot		0/3	0/3	1/3	0/3	0/3	0/3	0/3
Tufted Puffin	0/2	0/3	0/3	0/3	0/3	0/3	0/3	1/3
Black Rockfish	3/3	1/1	0/1	0/1	1/1	1/1	0/1	1/1
Walleye Pollock	1/2	1/2	0/2	1/2	2/2	1/2	0/2	2/2
TOP TROPHIC LEVEL								
Octopus	4/4							
Bald Eagle	0/2							
Halibut	3/4	0/7	0/7	1/7	6/7	1/7	0/7	7/7
Pacific Cod	8/14	1/21	0/21	0/21	17/21	0/21	0/21	17/21
Sea Lion	1/1							

*Note: For Sea Lion, both muscle and liver were analyzed and had values above the MDA.

Alaria, Blue Mussels, Fucus

Table 4 below lists the maximum values for each radionuclide, by species. It provides a basis for further evaluation of which species might be useful bioindicators. That is, a species that has a high percentage of values above the MDA would be useful because levels can be tracked in future years. Those with the highest values have the greatest chance of being important in terms of early indicators of potential risk to ecological receptors and humans.

TABLE 4. Maximum Levels (Bq/kg, wet weight) for Key Radionuclides for Consideration of Possible Bioindicators. Although these can be used to examine food safety, they are also useful in immediately identifying the organisms which will concentrate radionuclides of interest first if there is seepage into the marine environment. Blank means the analysis was conducted, but the composite was below the MDA; x means there was no analysis conducted for this radionuclide or species.

SPECIES	Cs-137	Am-241	Pu-238	Pu-239,240	U-234	U-235	U-236	U-238
Main source	A	A	A	A	N	A	A	N
PRIMARY PRODUCERS								
Alaria fistulosa			0.015	0.207	2.06	0.16	0.022	2.11
Alaria nana		0.033		0.043	2.19	0.17		1.89
Fucus		0.035		0.059	5.1	0.254	0.044	4.47
Ulva		0.075	0.123		0.578			0.471
Laminaria	X			0.073	0.812	0.036		0.709
GRAZERS/FILTER FEEDERS								
Sea Urchin[a]								
Giant Chiton		X	X	X	X	X	X	X
Rock Jingle		0.031		0.060	0.513	0.024	0.011	0.447
Limpet(Chinese hat)		X	X	X	X	X	X	X
Blue Mussel		0.025			.949	0.045		0.844
Horse Mussel	X	0.021		0.048	2.78	0.142		2.28
LOWER PREDATORS								
Dolly Varden	0.780	X	X	X	X	X	X	X
Atka Mackerel	0.102				0.963	0.065		0.94
Rock Greenling	0.16	X	X	X	X	X	X	X
Yellow Irish Lord	0.25				0.567			0.607
Northern Sole		X	X	X	X	X	X	X

Ocean Perch	0.108				0.655			0.654
Eider (birds)		X	X	X	X	X	X	X
Eider (eggs)								
HIGHER TROPHIC LEVEL								
Gulls (birds)	0.094							0.449
Gulls (eggs)		X	X	X	X	X	X	X
Pigeon Guillemot	X			0.312				
Tufted Puffin								0.424
Black Rockfish	0.189	0.029			2.18	0.116		1.83
TOP TROPHIC LEVEL								
Octopus	0.302	X	X	X	X	X	X	X
Bald Eagle		X	X	X	X	X	X	X
Walleye Pollock	0.461	0.022		0.020	0.857	0.053		0.779
Halibut	0.445			0.017	1.20	0.048		0.179
Pacific Cod	0.602	0.015			0.290			0.2575
Sea Lion	0.554	X	X	X	X	X	X	X

Note [a]: Sea Urchins were analyzed for Cs-137 and other gamma emitters, and for Sr-90.

Methods of Species Selection

CRESP has advocated a holistic approach to long-term monitoring on Department of Energy facilities (Burger 1999). A bioindicator should provide information that is directly relevant to human exposure from the food chain, and to other higher level predators, or to the organisms themselves (Peakall 1992; Burger and Gochfeld 2004). Monitoring, or biomonitoring, is the centerpiece of human health and ecological assessment (Cairns 1990). Monitoring or surveillance are key to assessing the status or well-being for all ecological receptors (including humans) within functioning ecosystems (O'Connor and Dewling 1986). Environmental monitoring data may reflect abiotic systems (air, water, soil, sediment). Biomonitoring examines biological processes (numbers of organisms, mortality rates, reproductive rates), biochemical markers (enzyme activity, hormone levels), or toxicological markers (blood lead, urinary metabolites) and effects (Peakall 1992).

While biological processes have usually involved individuals or populations, recent attention has focused on ecosystem structure and function, such as species diversity, productivity, nutrient cycles, and food web relationships (Cairns 1990, Rapport et al. 1992). Similarly, there are larger scale human processes that are of interest (disease rates, migrations). In many cases, suites of indicators will be required (Harwell and Kelly 1990). In the case of Amchitka, monitoring should provide early warning of any potential change in radionuclide levels which might adversely affect humans and other ecological receptors within the marine ecosystem. Sufficient warning is essential to put in place measures to protect human health.

There are several characteristics that should be considered when selecting bioindicators (Table 5 below). First and foremost, an indicator should be sensitive to a stressor. As radionuclide levels increase, the bioindicator organism should reflect that change. Secondly, an ideal indicator should be specific; responding only to a particular stressor of interest. It should provide an early warning of potential harm before the harm is irreversible. Additionally the indicator species must be present in sufficient numbers and should occur at reference sites as well. Cost-effectiveness is crucial for sustaining any long-term monitoring program. Monitoring species that are familiar and of interest to the public will be easier to sustain than the monitoring of little known species.

TABLE 5. Features Useful for Bioindicator Selection (after Burger and Gochfeld (2004), Burger (2006) and Burger (unpublished).

FEATURE	IMPORTANCE
Biological	Sensitivity: Does it indicate what it should? Is it sensitive to change? Does it change in proportion to the magnitude of contamination? Specificity: Is it specific to the stressor of concern?
Methodological	Is it accessible in sufficient numbers? Can it be sampled by non-experts? Can it be monitored sustainably?
Sociological	Is it of interest to and understandable by stakeholders including the Aleut peoples, resource trustees, and Agencies. Is it cost-effective?
Mobility	Does it represent point source, local, or landscape scale contamination
Radionuclide Accumulator	Does the species accumulate radionuclides at detectable levels?

Methodological considerations are extremely important, particularly for remote ecosystems such as Amchitka. Basically, an indicator has to be usable and understandable. It should be easy to use in the field or in the laboratory. In this case, it should be a species that can be reasonably collected, preferably by generalist technicians, and is expected to be available in the future (Burger and Gochfeld 2004). In most cases, rare or endangered species are not good candidates because of the difficulty of collecting sufficient numbers for analysis over a period of years. However, there is great interest in monitoring the population of endangered species, which can contribute to a monitoring program. The results should be easy to analyze and to interpret, both for specialists and the public. Long-term monitoring programs, and their associated bioindicators, require the interest and support of the general public, as well as government acceptance and commitment, since public funds are needed to conduct these programs. Such interest is more easily gained if the bioindicators provide information about both human and ecosystem health (Burger and Gochfeld 1996, 2001, 2004).

Ideally a good bioindicator should be useful to test management or risk questions. In the case of Amchitka, all should be amenable to the questions: 1) Have radionuclide levels changed in the last 5 years (or other biomonitoring interval), 2) Are there differences in radionuclide levels among the organisms in the marine environments adjacent to each of the test shots, 3) Are there indications that subsistence or commercial foods are adversely and significantly affected, and 4) Does the bioindicator indicate something unique about the ecosystem. The latter question gets to the issue of different nodes on the food chain; information is needed about all trophic levels, including producers, filter feeders, grazers, and predators. Each one provides information about a different aspect of the ecosystem, which ultimately leads to top-level predators, including humans. And finally, the use of the bioindicator should fit within a reasonable time frame. For example, using lifetime reproductive success of a long-lived species is not practicable.

Another additional advantage would be if the species were used generally for other biomonitoring programs. For example, species regularly used for AMAP and EMAP programs would be useful because comparative data are available for elsewhere. In general, though, the EMAP programs do not examine radionuclides (Summers et al. 1995, Lazorchak et al. 2003). Monitoring schemes will be most useful if they include 1) multiple species representing different trophic levels, 2) indicator selection based on sound quantitative, existing information, 3) standardized protocols for collection, preservation, preparation and analysis, and 4) caution in interpreting population trends, levels of anthropogenic stressors, contaminant levels, and other parameters (Peakall 1992, Burger and Gochfeld 1996, 2001, 2004, Carignan and Villard 2001).

Finally, bioindicators should reflect accumulation of the contaminant of interest, in this case, radionuclides. Bioindicators for potential radionuclide exposure at Amchitka should be species that bioaccumulate radionuclides earlier than do other species within the system. Those that accumulate radionuclides at low levels, when other species have levels below the MDA, will be the most useful for long-term biomonitoring. In short, a bioindicator should provide early warning of exposure before there is risk of human harm or the damage is irreversible to the marine ecosystem.

CRESP developed a framework for species selection of the initial target species that might serve as bioindicators for Amchitka (Table 6). This framework served both to select the initial species for collection, and then to select among the species collected those that would be analyzed and considered for final bioindicator selection. It also provides insights into the process we used for final bioindicator selection for this report and stakeholder consideration.

TABLE 6. Target Species Framework. Stages in selection of a suite of biota from which bioindicators of environmental contamination should be selected (depending upon chemical or radionuclide concentrations).

Step	Process
Identify interested and affected parties	• Identify the stakeholders with legal or agency mandates, those who are directly or indirectly affected, and those who are interested. • Identify mechanism for stakeholder involvement.
Literature review	• Review species present in ecosystem of interest • Review species used as bioindicators in the past for this or similar ecosystems
Expert review and advice	• Hold discussions with natural resource trustees and scientists having unique information about the species in that ecosystem. • Solicit resource trustee views on which species are of particular interest to them
Stakeholder review and advice	• Solicit views from interested and affected parties on the species of particular interest to them.
Select trophic levels for representation	• Consult with stakeholders above about trophic levels of particular interest • Decide on number of levels or nodes within trophic levels
Array possible species	• Array species in trophic levels. • Consider possible food web relationships where the top trophic level may not be a possible candidate for collection
Select organisms within trophic level for initial collection	• Include species whose locations or populations are amenable to collection • Include species of special interest to stakeholders listed above. • Consider three major groups: subsistence consumers, commercial fisheries, food web nodes (including ecosystem effects)
Include flexibility in form of ecological equivalents	• Recognize that in the field not all organisms might be amenable to collection. • Identify ecological equivalents that could serve the same trophic level function.

Candidate Species for Bioindicators at Amchitka

The species originally selected for collection by the CRESP team, based on information about: 1) the ecosystem, 2) the species trophic level, 3) bioaccumulation potential, and 4) radionuclide accumulation are arrayed below according to the important bioindicator characteristics. Additional biological information about the species is given in Appendix A. Table 7 provides information on the key bioindicator features, along with the species from Amchitka that fit these criteria.

TABLE 7. Possible Bioindicators. Shown are bioindicator features, importance, and possible species for bioindicators for long-term biomonitoring to evaluate human exposure and ecological risk.

FEATURE	IMPORTANCE	SPECIES
Human Exposure	Can it directly affect people because it is eaten	Any commercial or subsistence species including eggs
Food Chain Exposure	Is it at the base of the food chain	All Algae
Receptor Exposure	Can it directly affect the health of top level predators (large fish, seabirds, mammals)	Blue Mussel Horse Mussel Limpets Giant Chiton Sea Urchin Atka Mackerel Rockfish Rock Sole Rock Greenling young Pollock
Top level predators	Effects on predator populations and on humans who consume them.	Eagle Gull Tufted Puffin Pigeon Guillemot Octopus Black Rockfish Halibut Pacific Cod Walleye Pollock Sea Lion
Self-exposure	Bioindicator of effects of exposure on the organisms themselves	All species
Radionuclide levels	Concentrates isotopes of interest for human or ecological health, or for source identification	Actinides – Kelp, Rock Jingles, or Blue Mussels. Cs-137 - Top-level predators such as Pacific Cod, Pacific Halibut, Black Rockfish, Walleye Pollock, Octopus, Glaucous-winged Gull, Sea Lion

Selection among Candidate Species

Three findings of the CRESP data (Powers et al. 2005, CRESP 2006) are striking:

1) Cs-137 accumulated, although at very low levels, in high trophic level organisms.
2) Actinides accumulated, also at low levels, in lower trophic level organisms.
3) Some radionuclides were all below the minimum detectable activity levels, even though sufficient samples, of diverse organisms were analyzed (I-129, Co-60, Eu-152, Sr-90 and Tc-99). Further, we analyzed the tissues that were expected to have the highest concentrations to maximize the potential for detection (Powers et al. 2005).

These findings indicate that it is essential to carefully examine the radionuclide accumulation in low trophic level organisms for actinides, and high trophic level organisms for Cs-137. The CRESP data (from Powers et al. 2005, 2006) can be used to inform these choices. Given the findings above, it is essential to examine predators as bioindicators of Cs-137 (Table 8), and kelp/invertebrates as bioindicators for actinides (Tables 9 and 10).

These data indicate that higher trophic level organisms are the best accumulators of Cs-137, and therefore make the best bioindicators. We suggest the following species, all of which are subsistence foods:

- Glaucous-winged Gull - medium trophic level bird, of interest to Aleuts who eat the eggs; nests over test shots; feeds locally and easy to shoot for collection along the coast of Amchitka.
- Dolly Varden - low trophic level fish that accumulates Cs-137, that mostly lives in the ocean and spawns in freshwater lakes on Amchitka. Can be caught in freshwater by rod and reel.
- Black Rockfish - medium trophic level fish with low mobility (thus indicative of local exposure), high accumulator, easy to catch.
- Halibut and Cod - high trophic level, good accumulators of Cs-137, of interest to subsistence peoples and commercial fisheries. Can be caught with rod and reel.

While Sea Lion and Octopus are also good accumulators, they would be difficult to collect. Octopus requires divers and was difficult to collect in the CRESP expedition. Sea Lion, as an endangered mammal, is problematic to collect, and difficult to justify since some species of fish had as high levels of Cs-137.

TABLE 8. Examination of Predators for Use as Bioindicators for Cs-137. Given are the values in Bq/kg (wet weight) for 1000 gram samples only. For comparative purposes, all predators are listed. Trophic levels were based on previous information; at Amchitka, trophic levels may change slightly, depending upon the food webs.

Species	Number of 1000 g analyses	Percent above the MDA	All values above the MDA
LOW TROPHIC LEVEL			
Dolly Varden	2	100	0.70, 0.78
Atka Mackerel	3	33	0.102
Rock Greenling	5	0	-
Yellow Irish Lord	3	33	0.132
Northern Sole	2	0	-
Ocean Perch	3	33	0.108
Eider (birds)	2	0	-
Eider (eggs)	2	0	-
MEDIUM TROPHIC LEVEL			
Gulls (birds)	2	50	0.094
Gulls (eggs)	2	0	-
Tufted Puffin	2	0	-
Walleye Pollock	2	50	0.46
Black Rockfish	3	100	0.189, 0.130, 0.111
TOP TROPHIC LEVEL			
Octopus	4	100	0.236, 0.249, 0.260, 0.302
Bald Eagle	2	0	
Halibut	4	75	0.190, 0.315, 0.446
Pacific Cod	14	57	0.176, 0.188, 0.209, 0.315, 0.400, 0.472, 0.602
Sea Lion	1	100	0.554, 0.405

TABLE 9. Examination of Kelp/algae for Use as Bioindicators for Actinides. Given is the mean (± standard deviation, wet weight) in Bq/kg with the values plus half the MDA. Where there were few values above the MDA for an isotope, those are listed in parenthesis (no statistical test was performed). Blank cells = no values above MDA. A = primarily anthropogenic, N = primarily natural.

Isotope	Ulva	Fucus	Alaria nana	Alaria fistulosa	Laminaria	Chi square (p value)
Sample size	12	14	21	19	18	
Am-241 A	.(0.059)	(0.040, 0.022)	(0.039, 0.023)			3.22 $p < 0.52$
Pu-238 A	(0.024, 0.123)			(0.015)		
Pu-239,240 A		0.031 ± 0.017	0.031 ± 0.018	0.051 ± 0.05	0.020 ± 0.023	19.8 $p < 0.0005$
U-234 N	0.317 ± 0.121	3.124 ± 1.09	0.986 ± 0.518	1.005 ± 0.557	0.446 ± 0.209	52.3 $p < 0.0001$
U-235 N		0.147 ± 0.052	0.015 ± 0.015	0.052 ± 0.042	0.044 ± 0.041	43.6 $p < 0.0001$
U-236 A		(0.044)		(0.022, 0.016)		
U-238 N	0.246 ± 0.137	2.72 ± 0.953	0.843 ± 0.437	0.906 ± 0.484	0.431 ± 0.167	55.2 $p < 0.0001$

TABLE 10. Comparison of Kelp with Invertebrates for Use as Bioindicators for Actinides. Given are the means (± standard deviation, wet weight) in Bq/kg with the values plus half the MDA for those below the MDA. Where there are very few values above the MDA for an isotope, the actual values are given in parenthesis.

Isotope	Fucus	Alaria fistulosa	Rock Jingle	Blue Mussel	Horse Mussel	Chi square (p value)
Sample size	14	19	21	9	8	
Am-241	0.015 ± 0.008	0.013 ± 0.006	0.021 ± 0.011	0.017 ± 0.004	0.016 ± 0.004	6.56 $P < 0.16$
Pu-238		(0.015)				
Pu-239,240	0.31 ± 0.017	0.051 ± 0.05	0.024 ± 0.012	0.019 ± 0.004	0.022 ± 0.011	8.61 $P < 0.07$
U-234	3.124 ± 1.09	1.005 ± 0.557	0.446 ± 0.079	0.598 ± 0.194	0.844 ± 0.804	41.4 $P < 0.0001$
U-235	0.147 ± 0.052	0.052 ± 0.042	0.015 ± 0.026	0.021 ± 0.014	0.030 ± 0.048	33.5 $P < 0.0001$
U-236	(0.044)	(0.022, 0.016)	(0.011)			
U-238	2.74 ± 0.953	0.906 ± 0.484	0.345 ± 0.071	0.558 ± 0.165	0.730 ± 0.646	48.4 $P < 0.0001$

The data indicate that, of the algae species examined, *Alaria fistulosa* and *Fucus* are the best accumulators of the radioisotopes examined. *Alaria fistulosa* had the highest levels (or the most hits) of Pu-239,240, and U-236, the anthropogenic radionuclides of interest. *Fucus* can be collected from the intertidal; *Alaria fistulosa*, a subtidal species, can be collected by either grappling hooks or by pulling the fronds while in small boats. Since it is likely that this method of collection will result in obtaining largely the top part of the plant, it is important to note that: 1) the whole *Alaria* frond grows in one growing season, and 2) in a series of lab analyses for heavy metals we found that there were no significant differences in the levels of metals as a function of the part of the *Alaria* plant examined for lead and mercury, although cadmium concentrated in the holdfast. In all cases, the differences among parts were usually less than 2-fold (Burger, pers. comm).

Below we present the mean actinide values (Bq/kg, wet weight) for the two kelp (recommended as bioindicators) and for the three invertebrates to provide a basis for further selection (Table 10). For the invertebrates, there were no differences in either the percent detects for these isotopes, or in the mean values (except for U-238, with Horse Mussel being higher). Given that Blue Mussels are intertidal, and are part of the Aleutian subsistence diet, it is a preferred invertebrate for biomonitoring. Both Rock Jingle and Horse Mussel require diving, which does not seem warranted given the overall lack of difference.

In Table 10 we compare the two kelp and three invertebrates using a Kruskal-Wallis Chi Square. Where there were differences in mean level: *Fucus* had the highest levels of U-234, U-235, and U-238.

SPECIES BY RADIONUCLIDE MATRIX

Regular Biomonitoring

Taking the information provided under radionuclide selection (Tables 1 and 2) and for biological species selection (Tables 8-10), we derive the matrix for WHAT to biomonitor at Amchitka for the long-term biomonitoring plan (Table 11). Ideally, there should be at least 3-5 composites (5 individuals per composite) per test area (*Long Shot, Milrow, Cannikin*). The tissues to be used for analysis, for consistency with CRESP baseline data, should be: 1) fleshy frond for kelps, 2) Soft body tissue for mussels, 2) bone and muscle for the fish and birds. All the species listed below could be collected along the shore near the 3 test shots except for Dolly Varden, which can be collected in Cannikin Lake and Airport Creek.

TABLE 11. Proposed Bioindicators for Amchitka for Cs-137, I-129, Co-60, Tc-99, Pu-239,240 and other Actinides. These are the radionuclides that were detectable, are of interest for human and ecological health in the marine environment, and could be analyzed as a suite to detect any potential risk and for source identification. There are three analytical streams: gamma (Cs-137, Co-60, I-129), beta/gamma (Tc-99) and alpha (Pu and U series).

Species	Cs-137	I-129 Co-60	Tc-99	Pu-239, 240 and other actinides	Rationale
Fucus	X	X	X	X	• Primary Producer in intertidal
Alaria fistulosa	X	X	X	X	• Primary Producer • Intertidal and benthic
Blue Mussel	X	X	X	X	• Filter-feeder. • Subsistence food • Intertidal
Dolly Varden	X	X	X		• Low-level predator, Subsistence food, Saltwater fish that spawns in Amchitka lakes
Black Rockfish	X	X	X		• Intermediate predator • Subsistence food • Long lifespan • Low mobility
Pacific Cod	X	X			• Top level predator • Subsistence food and commercial fish • Intermediate lifespan • Intermediate mobility
Halibut	X	X			• Top level predator • Subsistence food and commercial fish • Long lifespan • Mobile
Glaucous-winged Gull	X	X			• Intermediate level predator • Subsistence food, (eggs) • Local • Long lifespan

Sampling Challenges for Regular Biomonitoring

The species selected for normal biomonitoring are those which CRESP feels can be collected in sufficient numbers to allow appropriate analysis. The species can be collected without the use of divers, with the following considerations:

- Fucus and Blue Mussels can be collected readily in the intertidal bays adjacent to all three test shots.
- Alaria fistulosa can be collected with grappling hooks and by hand from small boats. The kelp and mussels could be collected in 1-2 days per site.
- Dolly Varden can be collected from the lakes by hook and line, in 1-2 days.
- Rockfish, cod and Halibut can be collected by hook and line from small boats or the back of a larger ship. They should be collected by hook and line because that is the Aleut fishing method. The fish will require longer to collect because it depends upon the weather (it is easier to fish from small boats in calm weather), and knowledge of the places to fish. Black Rockfish and Pacific Cod will be relatively easy to collect, both from small boats and from the ship.
- Glaucous-winged Gulls are very common nesters near the test shots, and can either by shot near nesting colonies, or in the intertidal area near the test shots. All the gulls could be collected from near colonies in a day. If the season is appropriate, eggs should be collected (because they are a preferred Aleut subsistence food).

Other species, although they would provide additional information (such as Octopus) are extremely difficult to collect, even with divers in the water. Rock Jingles and Horse Mussels both require divers to collect, and do not appear to provide significantly more information than Blue Mussels, which also have the advantage of being a subsistence food.

Some sample reduction can be accomplished while collecting and while on the boat. For maximum flexibility, 450 g should be collected from each fish, bird, or kelp (200 g for a Cs composite, 200 g for archive, and 50 g for actinide analysis). It is challenging to collect enough Blue Mussels for 1000 g samples, but it is important because it provides for an intermediate trophic level that is an Aleut subsistence food.

Processing subsistence birds

BIOMONITORING FOLLOWING SIGNIFICANTLY INCREASED RADIONUCLIDE LEVELS OR GEOLOGIC EVENT

There are two circumstances where additional biomonitoring is necessary: 1) If there are significant radionuclide findings during the regular monitoring, and 2) Following a significant geological event (see next section). The CRESP data base provides the baseline for background levels at Amchitka (Powers et al. 2005, Addendum). A criterion should be established for triggering the expanded bioindicator monitoring, and this criterion should fit the needs of the relevant stakeholders. This aspect is described more fully below under temporal patterns of biomonitoring.

If there is volcanic activity or an earthquake in the vicinity of Amchitka, this should trigger additional biomonitoring, within a year of the event. Given the remoteness of Amchitka, and the difficulties of weather and logistical planning, it will be difficult to mount an expedition immediately, but it should be mounted as soon as is feasible because of the importance of the marine resources to subsistence peoples, commercial fisheries, and the marine ecosystem generally. The table below provides information useful for the expanded monitoring to address a significant geological event in the region of Amchitka. Table 7 provides the overall table of possible species for selection based on features of bioindicators.

We recommend a distinction in biomonitoring following a significant increase[b] in radionuclides in bioindicators or a significant geologic event:

1) A significant radiological finding (= increased radionuclide level) should be followed by collection of the expanded bioindicators in Table 12 (below), including radionuclide analysis of all organisms.
2) A significant geologic event should be followed by the collection of the expanded list of bioindicators, but the analysis of only the eight regular bioindicators (see Table 11). If there is a significant radiological finding in these eight indicators, radiological analysis of all of the collected organisms should be implemented. [c]

[b] Throughout the remainder of this report, we refer to a radiological finding during routine monitoring that would prompt the use of expanded collection and/or analyses of biomonitoring bioindicators. We consistently call such a finding "an increase in radionuclide levels". In a section called *Radiological Triggers* late in the report (p. 36) we provide decision makers with several methods and options for deciding when such an increase is sufficiently large as to be significant and to trigger an expansion of collection/analysis.

[c] This distinction between expanded bioindicator collection and analysis is suggested because any second collection at Amchitka will be costly and analysis of the screening bioindicators will be adequate if those results are negative.

These concepts are illustrated in Figure 1:

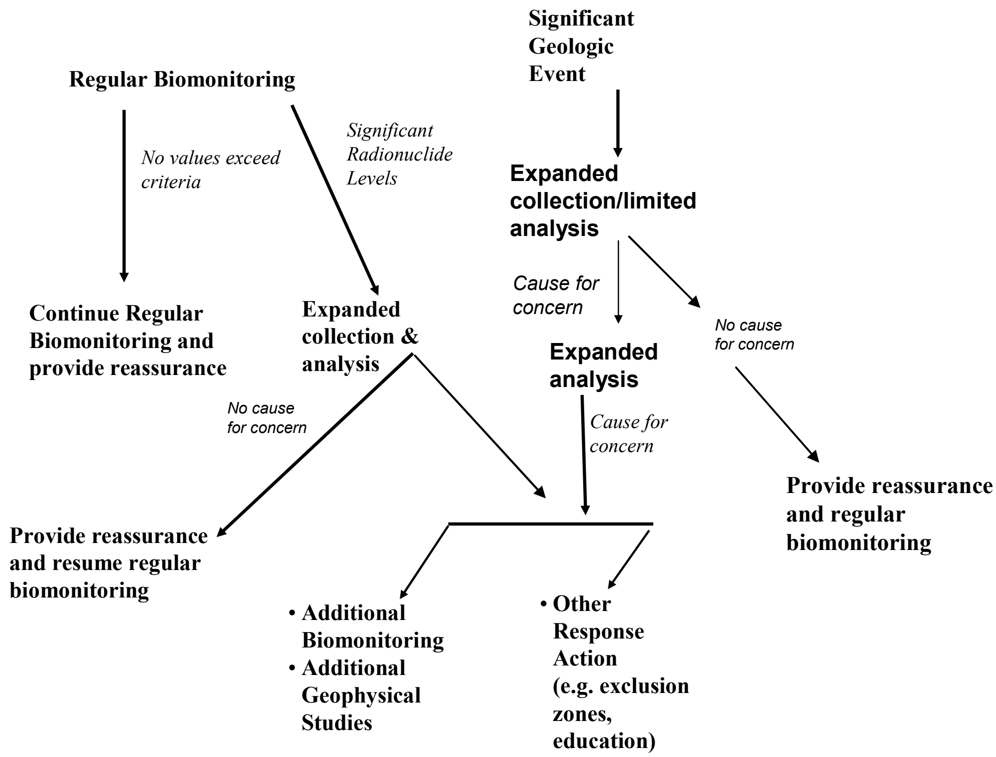


FIGURE 1. Sequence of responses to biomonitoring.

Table 12 provides CRESP's recommendations for an expanded bioindicator list for monitoring following an observed increase in radionuclide levels in routine bioindicator species or a significant geologic event. Some species that figured in the CRESP baseline sampling plan (Powers et al. 2005) are omitted from this list: 1) Some algae are eliminated because of overlap with other algae species; they did not appear to provide additional information, 2) Some species are so small or rare that it would be difficult to collect enough for 1000 gram samples (Chinese Hats), 3) Some species are sufficiently rare that their collection would be advisable only with special considerations (Eagles), and 4) Some species did not appear to provide more information on accumulation (Sole, Horse Mussels).

TABLE 12. Species Recommendations for Expanded Biomonitoring Following either Significant Increase of Radionuclide Levels or Significant Geologic Event. In the event of a significant radiological findings or geologic event, biological monitoring will be required. All bioindicators listed below are accumulators of some key radionuclides. This is not the full suite collected in the CRESP baseline study (Powers et al. 2005). Under some geologic events, magnetotellurics may also be required

Species	Rationale
PRIMARY PRODUCERS	
Ulva	• Primary producer • Subsistence food • Intertidal • Easy to collect by hand
Fucus	• Primary producer • Intertidal • Easy to collect by hand
Alaria fistulosa	• Primary producer • Benthic • More difficult to collect, from boats (or by diving)
LOW TROPHIC LEVEL	
Sea Urchin	• Grazer • Subsistence food, important to Sea Otters. • Benthic • Easy to collect by wading in intertidal
Blue Mussels	• Filter-feeder
	• Subsistence food • Intertidal • Easy to collect by hand on exposed rocks or pilings
Rock Jingle	• Filter-feeder • Benthic • Can be collected only by divers
LOWER PREDATORS	
Dolly Varden	• Lives in ocean, spawns in Amchitka Lakes • Subsistence food • Can be collected from Airport Creek and Cannikin Lake
Atka Mackerel	• Deepwater fish • Commercial fish of interest to ADEC • Hard to collect, only by trawls
Rock Greenling	• Benthic fish • Subsistence food • Possible to catch by hook and line inshore areas.

Yellow Irish Lord	• Ocean fish • Subsistence fish • Easy to catch by hook and line
Eider (birds or eggs)	• Coastal nester • Subsistence (both birds and eggs) • Nests are easy to locate in season, adults harder to shoot
MEDIUM TROPHIC LEVEL	
Gulls (birds or eggs)	• Nests adjacent to all three test shots • Subsistence (both eggs and birds) • Feeds intertidally • Long-lived • Very abundant, easy to collect
Tufted Puffin	• Nests along the coasts • Subsistence food • Feeds on fish • Abundant, easy to collect birds (not eggs)
Walleye Pollock	• Commercial fish (most important in region) • Difficult to catch, except by trawling
Black Rockfish	• Lives close to shore in bays. • Subsistence fish • Long-lived • Easy to catch on hook and line
TOP TROPHIC LEVEL	
Octopus	• Top invertebrate predator • Subsistence food • Difficult to catch, requires diving
Halibut	• Top benthic predator • Subsistence food, of high commercial value • Long-lived • Moderately difficult to catch by hook and line
Pacific Cod	• Top level water-column predator • Subsistence food, of high commercial value • Intermediate lifespan • Easy to catch
Sea Lion	• Top predator and endangered species • Subsistence food • Difficult to obtain permits • Difficult to collect

NOTE: see Munk (2001) and Tokranov (1992) for ecological information and ages of fish.

WHERE TO MONITOR

CRESP found no *a priori* reason for restricting sampling to only one of the three Amchitka sites (*Long Shot, Milrow, Cannikin*) based on radionuclide data on biota, or on the results of magnetotelluric studies. The only exceptions are the Halibut and Pacific Cod; they should be collected from two locations: adjacent to Milrow, and adjacent to LongShot/Cannikin (these fish move within this region). Sampling should be centered at the coastal point nearest each test cavity, and should fan out in both directions along the coast flanking the nearest point.

The data below illustrates the fact that there is no reason to restrict sampling to only one or two test shot regions for Pu-239, 240. There was no significant difference in the percent of samples with levels above the MDA for the three test shot areas.

TABLE 13. Plutonium Levels at the Three Amchitka Test Shots. Shown are the levels of Pu-239,240 for Kelp at the three test shots. Table indicates no significant differences in either the percent of values above the MDA, or in the mean values at each site.

	Milrow	Long Shot	Cannikin	Chi square (p)
Total analyzed	18	22	11	
Number > MDA	7	3	4	0.37 P < 0.83
MDA for kelp Bq/kg	0.044 ± 0.032	0.050 ± 0.025	0.045 ± 0.046	4.04 P < 0.13
Actual Values > MDA and number of samples analyzed				
Alaria fistulosa	0.207 0.080 (N = 4)	0.131 0.103 (N = 8)	0.041 (N = 3)	
Alaria nana	(N = 3)	(N = 6)	0.043 0.035 (N = 4)	
Fucus distichus	0.056 0.052 0.047 0.044 (N = 5)	0.059 (N = 5)	(N = 0)	
Laminaria	0.073 (N = 6)	(N = 3)	0.063 (N = 4)	

OPTIONS FOR TEMPORAL PATTERNS OF BIOMONITORING

The question of how often to monitor should be a function of: 1) predictions based on the groundwater models, 2) predictions based on food chain accumulation, 3) logistical considerations, 4) stakeholder concerns, 5) institutional constraints, and 6) significant geological events that might disrupt the normal groundwater flow and patterns. Moreover the Letter of Intent specifies a review of the long-term stewardship plan every five years, and it would be useful to have up-to-date biomonitoring data for this evaluation. While CRESP did not focus on this aspect, we present some possible options below for regular biomonitoring. Although the DOE groundwater models (DOE 2002a) predict very slow rates of change in groundwater flow, CRESP considered several schedule options and presents the pros and cons of each for stakeholder evaluation.

Atka (top), Homer (bottom) Stakeholder meetings 2005

TABLE 14. Possible Temporal Patterns of Biomonitoring. CRESP Suggestions for Options for Temporal Pattern of Biomonitoring at Amchitka.

PERIOD	ORGANISMS	RATIONALE
Every year	All bioindicators	• This is the usual practice at DOEs OLM sites (every monitoring and surveillance plan listed on the OLM website has annual monitoring, N = 82 reports, OLM 2005). • Not necessary because of the speed of movement of the groundwater. • Not practical because of the remoteness
Every other year	All bioindicators or half of organisms for a 5-year cycle	• Recommend collecting half of the organism in year 1, analysis in year 2, collect other half of organisms in year 3, analysis in year 4, full report in year 5. Results posing any risk reported immediately. • Allows for regular staffing and involvement of stakeholders.
Every 5 years	All bioindicators	• May be all that is required by radionuclide baseline, • However, may be difficult to mount every five years. • Five year monitoring is stimulated in the LOI[a]
Every 10 years	All bioindicators	• Minimum suggested by groundwater flow models • Difficult to maintain stakeholder involvement.
Whenever there is a significant radiological finding	The full suite of indicators	• When there is cause for concern from radionuclide levels found in the bioindicators, expanded biomonitoring is required to ascertain if there is a significant release of radionuclides to the marine environment from Amchitka test shots.
Whenever there is a significant geologic event	The full suite of indicators	• Because of uncertainty in where a seep may occur, need to collect full scale bioindicators; but analyze only the eight main bioindicators. If there is a significant radiological finding, all organisms should be analyzed • Suggest adding Kiska reference site for comparison.

a. Letter of Intent signed by DOE and ADEC in 2002, setting forth CRESP's role in the development of the independent science assessment of Amchitka.

TRIGGERS FOR RADIOLOGICAL AND GEOLOGICAL MONITORING

Radiological Triggers:

The results of each biomonitoring cycle can serve to reassure stakeholders, inform the evaluation process, or if potential adverse impact is indicated, trigger more extensive monitoring or initiate advisories and restriction. There is no single standard approach to setting criteria for establishing a trigger, and there is potentially a wide range of criteria for trigger points (for example, criteria for triggering expanded bioindicator monitoring).

The CRESP data base provides the baseline for background levels at Amchitka (Powers et al. 2005, Addendum, Table 8-10 above).The underlying statistical consideration is whether a current round of monitoring data contains values which are unlikely to have been present under conditions represented by the baseline (2004) results, hence represents an increase in radionuclide concentrations in indicator biota that requires further investigation. An increase may be due to seepage from a test cavity, to an unrelated source, or may represent a sampling artifact. For radionuclides which decay with a half-life of 30 years or less, the decay rate must be taken into account when comparing new values to old baselines.

The recommended sampling approach (see above) is to collect three to five composite samples of each selected bioindicator species from the vicinity of each test site. Each composite sample consists of 5 or more individuals of the same species from the same sampling site. If radionuclide release from one of the test shot locations occurs, it would not likely occur or be detected at more than one site at a time. Therefore, each of the three sites should be analyzed separately. This will avoid masking an occurrence. But since the CRESP background apparently represented the marine biota in the absence of any seepage, the baseline data can be pooled. Thus CRESP recommends that the composites from each site be compared to the pooled baseline on a species by species basis. Possible triggers for consideration are:

1. New mean values for one or more species at a site are statistically greater than baseline mean values with alpha set at 0.05 (single tailed test). This provides a 5% probability of a false positive resulting in expanded bioindicator testing.

2. New mean values for one or more species at a site are statistically greater than baseline mean values with alpha set at 0.10 (single tailed test). This provides a 10% probability of a false positive resulting in expanded bioindicator testing.

3. New mean values for a given species at a site are not statistically greater than baseline mean value, but one composite is more than 2 standard deviations above the mean (the corresponding probability of a false positive is about 2.5%).

4. New mean values for a given species at a site are not statistically greater than baseline mean value, but one composite is more than 1 standard deviation above the mean (the corresponding probability of a false positive is about 16%).

5. Two composite values from the same species or one composite from 2 or more species at a site exceed the baseline maximum for the corresponding species. There is less than a 1% probability that this would occur by chance alone.

6. One value for any organism exceeds the baseline maximum for that species by greater than 3 times the previous maximum value. Depending on the number of composites in the baseline and the distribution, there is about a <5% probability that this would occur by chance alone.

The occurrence of a false positive would result in expanded bioindicator testing when not warranted by the actual field conditions. Thus it is desirable to minimize the probability of a false positive. However this does not come without consequences. Reducing the probability of a false positive increases the probability of a false negative. A false negative means that an actual increase would not be detected. Therefore, a balance, based on stakeholder values and judgment is necessary to select the appropriate trigger thresholds for expanded biomonitoring. Unfortunately, it is not possible to estimate the false negative probabilities before obtaining the actual data.

Geologic Trigger: Responses to Significant Geologic Events

Seismic activity may or may not significantly impact radionuclide release to the marine environment. CRESP is very aware that many Alaskans fear that it will speed such release. Estimation of the magnitude for specific seismic events that would trigger such releases and how they would do so remains uncertain. In the present situation, the question is how such impacts and concerns about them would or should affect additional biomonitoring.

CRESP has the following understanding of the major factors which would be involved in such a seismic-related release and how those factors and the uncertainties associated with them might shape biomonitoring timing. Radionuclides remaining from the underground nuclear tests are present in the subsurface test shot cavities as a combination of (i) isotopes incorporated into glass phases formed during cooling of the shot cavity, (ii) isotopes incorporated into crystalline phases formed during cooling of the shot cavity, (iii) adsorbed onto naturally occurring geologic materials, and (iv) dissolved in groundwater within the pores of the test shot cavity (rubble filled after test shot chimney collapse) or within the pores of naturally occurring geologic materials. The vast majority of the residual radionuclides is associated with solid phases as described in (i) through (iii) above. As groundwater slowly flows through the test shot cavities, dissolved radionuclides are carried away towards the marine environment and additional radionuclides dissolve from the solid phases into the new groundwater passing through the shot cavities and surrounding solid materials. The time for groundwater to flow from the test shot cavities to the marine environment has been estimated to be on the order of up to several hundred years or longer in the absence of significant seismic activity. However, considerable uncertainty remains as to the actual groundwater travel times.

Consequently, a significant seismic event has the potential to increase the rate of radionuclide migration from the test shot cavities to the marine environment through three possible mechanisms: (i) the energy associated with a seismic wave causes an increase in the hydraulic driving force (hydraulic head) for movement of groundwater from the test shots to the marine environment, or (ii) severe seismic activity in the immediate vicinity of the test shots causes mixing of the freshwater-saltwater groundwater transition zone, carrying radionuclides into the fresh groundwater, which moves more rapidly to the marine environment (albeit still over a period of decades or longer), or (iii) severe seismic activity in the immediate vicinity of the test shots causes the formation of subsurface fractures or compression of aquifer materials which provides more rapid pathways for groundwater containing radionuclides to move towards the marine environment (Wu, 2003; Montgomery and Manga, 2003). The effects of mechanism (i) have been reported to be transient, over a period of less than one day to several weeks (Brodsky et al, 2003;

Montgomery and Manga, 2003). Although mechanisms (i) and (ii) may substantially increase the rate of radionuclide containing groundwater movement to the marine environment, travel times from the test shots to the marine environment are still anticipated to be long (much faster, but likely on the same order of magnitude as in the rate of movement absent the disturbance for mechanism (i) and still on the order of decades for mechanism (ii)). Mechanism (iii) can result in substantial increase in the rate of radionuclide discharge to the marine environment, but the overall rate of release still would be constrained either by slow groundwater movement or the rate of radionuclide dissolving from the solid phases in the vicinity of the test shots. Of course, volcanic activity in the immediate vicinity of the test shots can cause rapid dispersal of radionuclides currently in the vicinity of the test shots.

Hence significant uncertainties remain that may be resolved or reduced by careful review of the existing literature and consultation with geologists having appropriate expertise. It may be possible to develop a heuristic algorithm relating the size and nature of the event and its proximity to the Island or its test shots to guide such timing – but uncertainty will inevitably remain. In any event, the answers to the question are beyond the scope for development of this biomonitoring plan – except that seismic events will inevitably be relevant to the timing of biomonitoring collection and analysis. Based on the above discussion, occurrence of severe seismic activity or volcanic activity near, and surely in the immediate vicinity, of Amchitka should likely serve as trigger for additional biomonitoring, The timing of such additional biomonitoring also should consider the lag time between the geologic event and potential impact on the indicator species.

If additional biomonitoring is indicated or selected based on geologic activity, it is suggested that the range of species collected should be expanded, but only those serving as routine bioindicators should initially be analyzed. In this way, the expense of multiple collection events is avoided if the routine bioindicators suggest an adverse impact and more extensive analysis are warranted.

TABLE 15: Possible Geologic Triggers for Expanded Bioindicator Collection. Factors that should enter into Volcano/Earthquake Triggers for immediate monitoring of the full suite of bioindicators.

EVENT	VARIABLE
Earthquake	Magnitude of quake
	Distance of quake from test shots
Volcano	Magnitude and type of volcano
	Location of volcano
	Distance of volcano from test shots

STAKEHOLDER AND AGENCY INVOLVEMENT

CRESP came into existence to fulfill a need recommended by the National Academy of Science in its *Building Consensus Report* to link DOE more closely with both its regulator and receptor stakeholder communities. CRESP found that having a wide range of stakeholders involved at all stages in the development of the *Amchitka Science Plan*, the planning and executing of the research, and the on-going process of bioindicator development has been valuable. Having stakeholder involvement has improved the science, the process, and the overall understanding of the issues. While the final development of Long-term Stewardship Plans is a DOE function, we provide the final table as a summary of the players involved in the CRESP work to date.

TABLE 16. Relevant Stakeholders. The following stakeholders have an interest in Long-term Stewardship of Amchitka. These entities should be involved in aspects of monitoring and stewardship at Amchitka. All aspects of this table are modifiable by the relevant stakeholders. Other stakeholders should be added where appropriate.

PLAYER	PRIMARY GOAL	SECONDARY GOAL
US DOE	*Closure of Amchitka *Implement a relevant and acceptable Long-term stewardship plan	*Reducing uncertainties in groundwater models and human health risk assessments
US Fish & Wildlife Service	*Protection of fish and wildlife *Stewardship of Amchitka as part of the AMNWR	*Long-term protection for the island's marine ecosystem
State of Alaska	*Protection of subsistence foods *Protection of commercial fisheries *Protect fish and wildlife	*Protecting the marine ecosystem and maintenance of Aleut lifestyle
A/PIA	*Protection of subsistence foods and of Aleut lifestyle	*Protection of the marine ecosystem
Aleut communities	*Protection of subsistence foods and lifestyle *Protect marine ecosystem	*Protect greater Bering Sea ecosystem *Evaluation of past risk to Aleut communities on other islands.
NOAA (NMFS)	*Protection of fishery and marine mammals	*Understanding biology and geology of Aleutian ecosystem
ACAT	*Protection of ecosystem and human health	*Watchdog for DOE
Other environmental groups	*Protection of ecosystem and human health	*Watchdog for DOE
Other citizens	*Protection of ecosystem and human health	*Evaluation of former worker risk *Evaluation of past damage to people on other islands.
UAF, CRESP, other scientists	*Understanding fate and transport of radionuclides and food chain accumulation. *Understanding biological and geological aspects of marine ecosystems *Enhancing risk communication	*Integration of biological, geological and sociological aspects of marine ecosystems. *Understanding public policy implications of long-term stewardship *Education and training of future scientists and policy makers

*A/PIA Aleutian Pribilof Island Association
*NOAA National Oceanographic and Atmospheric Administration which includes NMFS (National Marine Fisheries Service)
*ACAT Alaska Community Action on Toxics
*UAFG University of Alaska-Fairbanks
*CRESP Consortium for Risk Evaluation with Stakeholder Participation

CONCLUSIONS

The biomonitoring plan, a critical component of the long-term stewardship plan for Amchitka, should be iterative and responsive to changing conditions at Amchitka and among all stakeholder groups. Relevant stakeholders should be involved in both the design and execution and periodic evaluation of the plan such that it provides not only assurance of human and ecological health, but continued peace of mind for residents of the region, Alaska, and the Nation. While the features of Regular Biomonitoring can be carefully laid out, the possibility of expanded bioindicator collections and analysis following significant increases in radionuclide levels in bioindicators or a significant geologic event, must be an integral part of the plan. The response options for corrective actions at Amchitka are limited by the depth of the test shots (the location of the radionuclides), its remoteness, and the lack of technology to remediate the underground test shot radiation. This makes biomonitoring critical because it can provide early warning of any potential risk from radiation to humans and the environment. While all other DOE, Office of Legacy Management sites rely on at least annual surveillance and monitoring of media (groundwater, soil, sediment), this is not an option for Amchitka because of the depth of the test shots and the lack of groundwater wells. Biomonitoring is the preferred option, as developed in the implementation of the Letter of Intent, signed by the DOE and State of Alaska.

CRESP recommends the following aspects of a biomonitoring plan:

- Radionuclides: Cs-137, Co-60, I-129, Tc-99, and the Plutonium/Uranium series.
- Species: Fucus, Alaria fistulosa, Blue Mussel, Dolly Varden, Black Rockfish, Pacific Cod, Halibut, Glaucous-winged Gull.
- Tissues: Fronds of kelp and soft-tissue of mussels (all isotopes); Muscle of fish and birds and bird eggs (Cs-137, Co-60, I-129, Tc-99)
- Location: All three test shots (five sampling stations flanking the nearest coastal point or fault).
- Timing: Regular biomonitoring on a 5-year Plan.
  Plus: as soon as possible (but at least within one year) of significant increased radionuclide levels or a significant geologic event.

Nikolski 2003

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Appendix A. Rationale for species selection for radionuclide analysis (after Powers et al. 2005). These should serve as examples of the kinds of factors initially used by the CRESP team to select species for chemical/radiological analysis of biota collected near Amchitka Island. It provides an indication of the types of parameters to use in species selection. Scientific names given where no common name is available.

PRIMARY PRODUCERS: The following species are all primary producers in the marine ecosystem, are sedentary (and thus represent local exposure), and are the base of some food chains. They have wide distribution in marine ecosystems. Some species are eaten by Aleuts and others. Intertidal organisms could be collected relatively easily by visiting biologists.

Alaria fistulosa - This kelp generally occurs < 30 m in the benthic environment, representing the subtidal environment (requires diving for collection).

Alaria nana - This kelp occurs in the intertidal and shallow subtidal.

Fucus gardneri - This brown algae occurs in the intertidal, and there is reference data from other places, and from Amchitka. *Ulva fenestrata* - This green algae occurs in the intertidal, is eaten, and there is reference data from elsewhere.

Laminaria (2 species) - These brown algae sometimes occurs at somewhat deeper depths than the Alaria, so represents the benthic environment.

GRAZERS: Invertebrates that consume primary producers are eaten by organisms higher on the food chain, and are fairly sedentary representing local exposure. Some grazers are also eaten by the Aleuts.

Green Sea Urchin - Urchins are abundant at different depths and thus could represent good coverage of the marine floor environment. They are a primary food of Sea Otters, a species of concern (and one that has declined precipitously in the Aleutian Islands). They graze on kelp, other algae, and microorganisms. Sea Urchins are also eaten by Eiders and Gulls (based on the literature), and they are considered a delicacy by Aleuts. Intertidal urchins could be collected from land, and are the ones that would be available to Aleut subsistence hunters.

Giant Chiton - Chitons are grazers that occur at deeper depths and could represent that benthic environment.

Limpets (Chinese Hats) - These grazers are a subsistence food of Aleuts, but are quite small.

FILTER FEEDERS: Invertebrates that are filter feeders are also relatively low on the food chain, and occur at different depths. Some are eaten by Aleuts, as well as others.

Rock Jingle - They are less abundant than sea urchins, but are sedentary, and occur in the benthic environment. Diving required for collection.

Blue Mussels - Although they proved surprisingly uncommon at Amchitka, mussels have been used extensively as a bioindicator world-wide, and appear to be spreading into the far Aleutian islands. They are eaten extensively by many peoples, including Aleuts, and are intertidal in habitat, and so could be collected at low tide and from small boats.

Horse Mussels - Horse Mussels occupy the same trophic level as Blue Mussels, but occur in the benthic environment.

LOWER PREDATORS: Still relatively low on the food chain, these organisms represent the middle of some food chains, are eaten by Aleuts, and some are commercial seafoods.

Rock Greenling - This is a sedentary species, each male maintaining a small territory, hence representing local exposure, lives in the kelp zone. It is eaten by Aleuts (as are its eggs), and is eaten by organisms higher on the trophic chain, such as Cod and Gulls.

Atka Mackerel - This is a pelagic fish that spawns on rocky substrates nearshore, and is relatively low on the food chain, but is of commercial value and is migratory.

Sculpin (Yellow Irish Lord) - This is a less sedentary (but not migratory) species, eats invertebrates, and is sometimes eaten by Aleuts.

Northern Sole - Bottom dwelling fish that is also a predator.

Ocean Perch - Predator of pelagic invertebrates and forage fishes, relatively mobile and commercially important.

Eiders - Common Eiders are hunted extensively by Aleuts and their eggs are also eaten. It represents a low-trophic level for birds, since it eats mussels, snails, and urchins. It nests terrestrially (making it possible to collect easily) and feeds in the intertidal zone.

INTERMEDIATE TROPHIC LEVEL PREDATORS: These are generally abundant species, of especial interest to subsistence Aleuts. The fish are of commercial interest in the Bering Sea.

Black Rockfish - This is a relatively sedentary species (representing local exposure) that lives in the kelp zone and just outside the kelp zone. It is eaten by Aleuts and is a little higher on the food chain than the Rock Greenling.

Gulls - Glaucous-winged Gull eggs are considered a delicacy by Aleuts, adults are eaten, and gulls represent an omnivorous species. They eat urchins, sea stars, and fish (including Dolly Varden and Greenlings). Since there are nesting colonies at each of the test sites, and they normally feed within 5 miles of their colony, they represent local exposure. They do not migrate and so represent longer term exposure in the vicinity of Amchitka. They also can live to be 30 + years old.

Young Gull - There are nesting colonies adjacent to each of the 3 test shot areas, and on Kiska. Since parents feed their young entirely from local foods (usually within 5 miles of nesting colonies), they represent local exposure. Thus, chicks represent local exposure, from the previous few weeks, while adults represent longer-term exposure.

Tufted Puffin - They eat entirely fish of small to intermediate sizes. They are less localized to test shots, and represent exposure within a local area. They and their eggs are eaten by Aleuts.

Pigeon Guillemot - They eat mainly small fish and invertebrates, and are localized to the sides of islands during the breeding season.

TOP-TROPHIC LEVEL PREDATORS: At the top of the food chain, they represent the possibility for bioaccumulation. Many are long-lived, increasing the potential for bioaccumulation. Can be used as bioindicators for human exposure.

Octopus - Top-level predator within invertebrate food chains, can grow to considerable size that can live up to five years. Of special interest to Aleuts because it is a delicacy.

Walleye Pollock - This predatory fish is the major commercial species from the Bering Sea/North Pacific. They are mobile. Collected by trawling, rather than fishing near shore.

Pacific Cod - This fish can reach 50-60 pounds, and eats smaller fish, such as Rock Greenling and Atka Mackerel, as well as Octopus, squid, fish eggs, and crabs. It is both a preferred fish for the Aleut people and a major commercial species. It is mobile to migratory, moving from inshore to offshore.

Halibut - This fish is a top-level predator, can reach large sizes (up to 500 pounds) and advanced ages, and is highly prized both by Aleut and commercial fisheries, and is migratory.

Eagle - Top-level avian predator within marine ecosystems. Eats fairly large fish, and is of particular interest to U.S. Fish & Wildlife Service. Data on contaminants available for Amchitka.

Sea Lion - Top-level sea mammal within the marine ecosystem. This species was not targeted because of its listing on the Endangered/threatened Species List. However, it is an important subsistence food of Aleuts, and one was taken as a subsistence hunt while on the expedition.

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