# Implications For Groundwater Models, Risk Evaluations, Future Biomonitoring And Long Term Stewardship At Amchitka Island

## SUMMARY

The radionuclide data presented in chapter 11, along with data in chapters 5, 6, 7 and 10, provide a basis for examining the safety of the foods, reducing the uncertainty in the groundwater and risk assessment models, and providing information to develop future biomonitoring and long-term stewardship plans at Amchitka. In this chapter we address the following issues:

1. The species present that would be at risk if there were migration of radionuclides into the sea.
2. The safety of sea foods in terms of radionuclides.
3. Whether the levels of radionuclides are high enough to pose harm to species or the ecosystem.
4. Whether there is currently geophysical evidence relevant to freshwater contaminant seepage at Amchitka and what additional data might provide a basis for predicting or detecting where or when contaminant migration into the marine environment might occur.
5. Whether there is currently any evidence from radionuclide levels and ratios in biota that might be attributable to the Amchitka test shots.
6. The species that might be appropriate for long-term monitoring.
7. Questions that remain after this phase of *Science Plan* work and recommendations CRESP is making about future research,

Overall, the data support the following conclusions:

- There is a wide range of biota in the benthic and intertidal habitats around Amchitka that could be at risk if radionuclides seeped into the marine environment.
- The foods consumed by humans are safe with respect to radionuclides, and levels of radionuclides are well below published human health risk guidance levels.
- Some of the biota that could be exposed are sedentary, while others are more mobile. There is a potential for bioaccumulation and biomagnification up the food chain.
- Substantial localized discharge of freshwater through the ocean floor within the study area was not indicated based on ocean floor salinity measurements. Thus, no specific preferential pathway (i.e., large freshwater flow through geologic faults) for contaminant migration along with fresh groundwater from test shots was found.
- Significant regions of the ocean floor in the region of the *Cannikin* and *Long Shot* test sites have significant sediment accumulations. Sediments typically have the potential to accumulate specific contaminants, supporting the need to monitor sedentary biota that may uptake contaminants present in sediment deposits.

- Geophysical investigations indicate that all three test shots were within the transition zone between fresh and salt groundwater, and that greater subsurface pore volume was present than assumed by earlier studies, suggesting very long travel times for any contaminant migration from the test shots to the marine environment.
- Our data do not suggest that radionuclides in biota collected from Amchitka are attributable to the Amchitka test shots.
- A combination of sedentary and mobile organisms at different trophic levels would be ideal for a continued biomonitoring program at Amchitka, largely because different radionuclide isotopes concentrate at different nodes on the food chain. Algae bioconcentrate plutonium and uranium to a high degree, are plentiful, and should be considered as an indicator species for long-term biomonitoring. Marine fish are good concentrators of cesium, are key components of the Aleut and general population diet, and should also be a component to consider in future biomonitoring efforts.

## INTRODUCTION

The Amchitka *Science Plan* 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 public has great concerns about any radiation, and there are many sources of radiation, both natural and anthropogenic (Burger 1995). Our overall objective in this chapter is to use the data and conclusions generated by the geophysical and biological studies in order to examine the safety of the foods, to reduce the uncertainty in the groundwater and risk assessment models, and to provide information to develop future biomonitoring and long-term stewardship plans at Amchitka. Amchitka is one of 129 DOE sites requiring long-term stewardship (Wells and Spitz 2003), and is surely the most remote.

In this chapter we address the following questions:

1. Are there species present that would be at risk if there were seepage of radionuclides into the sea?
2. Are the seafoods safe in terms of radionuclides?
3. Are the levels of radionuclides high enough at Amchitka to pose harm to species or the ecosystem?
4. Is there geophysical evidence relevant to freshwater seepage at Amchitka and whether additional data might provide a basis for predicting or detecting where or when contaminant migration into the marine environment may occur?
6. Is there currently any evidence that biota have radionuclide levels that might be attributable to the Amchitka test shots?

7. What species might be appropriate for long-term monitoring?
8. What questions remain after this phase of *Science Plan* work and what recommendations is CRESP making about future research?

The focus of the Amchitka *Science Plan* was on research and data collection aimed at assessing food safety, ecosystem receptors, and reducing uncertainties in the DOEs groundwater and human health risk assessment models. Chapters 5 - 11 present the geophysical and biological data from the expeditions and subsequent analysis. This research and data collection leads to better knowledge and understanding, but it cannot provide all the answers to reasonable concerns about future impacts on human health and the environment. Only a long-term stewardship program with a well-designed biomonitoring plan can allay concerns about future risks (U.S. Fish & Wildlife Service 2000). Ultimately, institutional frameworks and policies are needed to ensure environmental and human health (Figure12.1).

Figure 12.1. View of *Ocean Explorer* docked in Constantine Harbor (left) and Square Bay intertidal zone (right) on Amchitka Island (photos by J. Burger).

## METHODS

Our approach in this chapter is to relate the geophysical and biological data obtained during the expeditions and analysis phases to the questions posed above. The data we use to answer these questions came not only from CRESP's original data generated and analyzed from the expeditions, but from previous data available on bathymetry and radionuclide levels from the region and elsewhere in the northern hemisphere. These analyses were then used to:

1. Examine food safety by comparing the levels in Amchitka biota with known human health risk levels.

2. Consider food chain uptake and risks by comparing the levels in biota from Amchitka with those from elsewhere.
3. Elucidate the factors that reduce uncertainty in the risk models and groundwater models in light of our geophysical and biological data.
4. Provide the criteria that should be considered in selecting species for bioindicators for long-term biomonitoring by examining which species accumulated radionuclides, as well as a suite of characteristics of those species (e.g. trophic level, availability, suitability, accessibility).

In general, the results are presented in chapters 5-11. The main function of this chapter is to discuss the implications of the results, such as overall food safety and reductions in uncertainty. Therefore, the result section of this chapter selects and evaluates information gathered on the expedition and presented in the previous chapters (Figure 12.2).

Figure 12.2. Ocean Explorer returning to Adak (Photo by J. Burger).

## RESULTS

### Species at Risk

The data on species at risk, as indicated by the species selected for collection in the Amchitka *Science Pla*n, are presented in chapter 10. There were few differences in intertidal and benthic marine species presence between Amchitka and Kiska. The same seabirds nested on Amchitka and associated islands, as nested on Kiska and associated islands. While some marine species were collected at all depths, others were more common in shallow water or in deeper water. However, for the depths examined, there was no station with an absence of benthic organisms. Further, a wide range of subsistence foods were collected in the intertidal zones at both Amchitka and Kiska, and subsistence fish were collected in the traditional manner from small skiffs. Similarly, commercial fish were collected in the NOAA trawls at both Amchitka and Kiska. For more details about the species at risk, see chapter 10. The data, however, indicate that there are species that would be at risk if there were contaminant migration from the Amchitka test shots to the marine environment. Various species of Kelp, the primary producers, are one base of many marine food chains, and are also efficient concentrators of actinides.

### Food Safety

One of the primary objectives of the Amchitka *Science Plan* was to assess whether there is currently any risk to humans from the consumption of foods from the Amchitka region as a result of radionuclides. While the data generated can lend itself to a complex set of human health risk assessments, with several different consumption level scenarios, that was not a goal of the study. Instead, we examine the levels of radionuclides found in the biota collected around Amchitka in comparison to health risk standards adopted by the *Codex Alimentarius* of the World Health Organization and Food and Agriculture Organization of the United Nations, as well as the U.S. Food and Drug Administration's Derived Intervention Level (Figure 12.3).

Figure 12.3. Residents filleting Pink Salmon on Nikolski (left) and commercial Halibut on Pribilof Islands (right) (right) (Photo by J. Burger).

One way to address the question of risk is to examine the levels of radionuclides in biota that are eaten. In the table below we give the highest measured level for any species where levels were above the MDAs (Table 12.1). The MDAs in this study were well below levels identified as posing a threat to human health. Levels below the MDA are clearly not a cause for concern. It is difficult to relate effects levels with concentrations found in tissues of biota. This is a function of laboratory researchers measuring only dose and effects. Also needed are laboratory studies that relate dose to both effects and tissue levels. In the absence of tissue levels known to cause effects, we compare the highest radionuclide levels in the sample tissues we analyzed with proposed international standards and guidelines for food (FAO/WHO 2004). Table 12.1 shows whether radionuclide isotopes are mainly naturally-occurring or anthropogenic, the *Codex Alimentarius* levels, and the maximum levels obtained at either Amchitka or Kiska in this study. *Codex Alimentarus* is the proposed international guideline for radionuclides in food. These are food safety values, intended to screen food sources as acceptable for consumption for at least a one year time frame. In other words, the *Codex* levels would not trigger any action and the food could enter the commercial food stream.

As is clear from Table 12.1, the maximum levels obtained in this study were all an order of magnitude or greater below the *Codex* levels, suggesting no cause for concern in terms of human food safety. Unfortunately, there are no *Codex* standards for U-234, U-236 and U-238. A fuller discussion can be found under Food Safety in the discussion section of this chapter. Yet, it should be noted that the National Research Council's BEIR VII report from its Committee on Biological Effects of Ionizing Radiation, recently concluded that the linear non-threshold model is still the model of choice for understanding radiation risk, and even very low doses of radiation pose a small risk of cancer or other health problems. There is no threshold below which exposure can be viewed as completely harmless (BEIR 2005).

Table 12.1. Maximum levels (Bq/kg, wet weight) of radionuclide isotopes that are above the MDAs to indicate the species where there could be any possibility of risk. There were no values above the MDA for Sr-90, Tc-99 and Co-60. Blanks mean that there were no values above the MDAs for that species, including the 1000 g samples (but see Appendix 12.A for all maximum values). X = no analysis conducted (usually due to small size of individual organisms, or few individuals). For source, A = anthropogenic, and N = natural. *Codex Alimentarus* is the proposed international guideline for radionuclides in food (FAO/WHO, 2004).

| SPECIES | Cs-137 | Am-241 | Pu-239,240 | U-234 | U-235 | U-236 | U-238 |
|---|---|---|---|---|---|---|---|
| Main source | A | A | A | N | N | A | N |
| Codex levels (Bq/Kg, ww) | 1,000 | 1.0 | 1.0 | e | 100 | | e |
| **PRIMARY PRODUCERS** | | | | | | | |
| Alaria fistulosa | | | 0.207 | 1.95 | 0.127 | 0.022 | 1.62 |
| Alaria nana | | 0.033 | 0.0429 | 1.31 | 0.0823 | | 1.19 |
| Fucus | | 0.035 | 0.059 | 5.1 | 0.254 | 0.044 | 4.47 |
| Ulva[b] | | 0.0746 | | 0.578 | | | 0.471 |
| **GRAZERS/FILTER FEEDERS** | | | | | | | |
| Sea Urchin | | d | d | d | d | d | d |
| Rock Jingle | | 0.031 | 0.034 | 0.513 | 0.020 | 0.011 | 0.447 |
| Limpet[b](Chinese hat) | | | x | x | x | x | x |
| Blue Mussel[b] | | | x | x | x | x | x |
| **LOWER PREDATORS** | | | | | | | |
| Dolly Varden | | | x | x | x | x | x |
| Atka Mackerel | | | | 0.963 | 0.065 | | 0.94 |
| Red Irish Lord | | | x | 0.567 | x | x | 0.607 |
| Rock Greenling | | | | | | | |
| Yellow Irish Lord | | | | 0.567 | | | 0.607 |
| Black Rockfish | 0.1886 | 0.029 | | 2.18 | 0.116 | | 1.83 |
| Ocean Perch | | | | 0.655 | | | 0.654 |
| Eider (birds)[b] | | | x | x | x | x | x |
| Eider (eggs) | | | | | | | |
| **HIGHER TROPHIC LEVEL** | | | | | | | |
| Gulls (birds)[a] | 0.09 | | | | | | 0.449 |
| Gulls (eggs)[b] | | | x | x | x | x | x |
| Pigeon Guillemot | | | 0.312 | | | | |
| Tufted Puffin | | | | | | | 0.424 |
| **TOP TROPHIC LEVEL** | | | | | | | |
| Octopus[b] | 0.30 | | x | x | x | x | x |
| Bald Eagle[b] | | | x | x | x | x | x |
| Walleye Pollock | 0.46 | 0.022 | 0.02 | 0.857 | 0.053 | | 0.779 |
| Halibut | 0.45 | | 0.0173 | 0.239 | 0.0476 | | 0.111 |
| Pacific Cod | 0.6 | 0.0145 | | 0.2 | | | 0.225 |
| Sea Lion[b,c] | 0.55 | | x | x | x | x | x |

a. Glaucous-winged Gulls, adult and young. b. 1000 g samples only for Cs-137. All 100 g samples were below MDAs.
c. Highest value was for the liver sample. d. Sea Urchins were analyzed for Cs-137 and other gamma emitters, and for Sr-90; other actinides are awaiting further methods development due to chemical anomalies in urchins. e. U-235 has nearly an identical dose per unit intake, in Sv/Bq, as U-234 or 238 with only a 3 or 4% difference. Therefore guideline values for U-234 and U-238, if developed, should be he same as those for U-235. If, however, U-235 is being used as an indicator for total uranium, then the permitted does for each of the primary isotopes would be approximately 1/3 of the current U-235 value, or about 33 Bq/kg.

A second objective of the CRESP study was to determine whether the levels of radionuclides in the biota are sufficiently high to pose a risk to the organisms themselves, or to other nodes on the food chain. There are far fewer data or standards on effects levels for different radionuclides, but the levels found in biota were well within the ranges reported for other, non-contaminated sites worldwide, and were well below those from contaminated sites (see Chapter 11 and Appendix 2.A for data, Figure 12.4).

Figure 12.4. Glaucous-winged gull chick and Kelp holdfast. (Photos J. Burger, S. Jewett)

Geophysical Data and Risk

Substantial localized discharge of freshwater through the ocean floor within the study area was not indicated based on ocean floor salinity measurements. Thus, no specific preferential pathway (i.e., large freshwater flow through geologic faults) for contaminant migration along with fresh groundwater from test shots was found. Measurement of salinity near the ocean floor did not result in the identification of specific locations for high rate seepage or discharge of freshwater groundwater. There is no evidence for consistent, large-volume, or broad scale freshwater outflow in the bottom waters of the study region from 20 m to 100 m offshore from the *Cannikin* and *Long Shot* test sites. Measurements at 6 out of 70 sampled locations indicated slight anomalies that may be the result of either freshwater discharge or measurement interferences that cannot be distinguished. As a result, there were no specific localized areas identified that suggest higher priority for biological sampling. Further investigation of the areas indicating anomalies and use of sediment pore water sampling may indicate locations warranting more detailed attention during future biological sampling.

Some regions of the ocean floor in the region of the *Cannikin* and *Long Shot* test sites have (as seen through direct observation and side-scan sonar readings) significant sediment accumulations. Sediments typically have the potential to accumulate specific contaminants, supporting the need to monitor sedentary biota that may uptake contaminants present in sediment deposits. This finding is contrary to earlier assumptions (DOE 2002a) that the ocean floor in these areas was devoid of sediment accumulations because of energetic ocean currents.

Geophysical (specifically magnetotelluric) investigations suggest that all three test shots were within the transition zone between fresh and salt groundwater, and that greater subsurface pore volume was present than assumed by earlier studies, suggesting very long travel times for any contaminant migration from the test shots to the marine environment. This information, in conjunction with groundwater transport modeling, suggests that very long time periods of years will be required under current geophysical conditions for contaminant migration from the test shot locations to the marine environment.

Distinguishing possible Amchitka test shot contamination from other sources

The Pu-240/Pu-239 ratio has been used as an indicator of the source of radionuclide contamination in marine (and terrestrial) environments. A ratio of close to 0.18 has been considered typical of global fallout in a variety of environmental samples (Hirose et al, 2003; Buesseler, 1997). Sediment and seawater samples from the North Pacific have been shown to have a wide range of ratios, with values up to 0.34. The higher ratios reflect regional fallout characteristic of the Pacific Proving Grounds nuclear tests (Buesseler, 1997). Dasher et al (2002) report ratios of 0.205 to 0.235 for Amchitka *Fucus*, while freshwater moss and sediment below 0.2.

## DISCUSSION AND IMPLICATIONS

The marine resources in the Bering Sea/North Pacific ecosystem are extremely important because this ecosystem is generally diverse and rich biologically, supports important food chains leading to endangered and threatened species, provides subsistence foods for local peoples, and provides important commercial fishery stocks. 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.

Over 40 % of all the United States fish and shellfish landings (by weight) derive from the Eastern Bering Sea (including Dutch Harbor, Best 2004). 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 at present, Pacific Cod is second, and is increasing in tonnage (NRC 1996). 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. Hence, commercial fishing in the Bering Sea region plays an important role in human consumption from the sea. 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).

The Amchitka *Science Plan* was designed to examine the questions of food safety, ecosystem health, uncertainty reduction involved with the groundwater models and human health screening risk assessments, and provide insights useful for bioindicator selection for long-term stewardship plans for Amchitka. Each of these aspects will be discussed below, as well as methodological and logistical problems, and suggestions for future studies.

## Methodological and Logistical Issues

Any scientific study encounters methodological and logistical problems inherent in field and laboratory research. Four issues were germane to nearly all aspects of our expeditions: money, time constraints, remoteness of the field site, and weather. The main constraint was money, in that the complete Amchitka *Science Plan* – even the biological component - was not fully funded, making it essential to make choices about both the extent and nature of the funded aspects.

Our study of Amchitka also suffered from severe time constraints, partly imposed by the nature of the funding stream and partly from the need on the part of DOE and other stakeholders to have the information provided by the project as early as possible. Whereas we had initially envisioned at least two field seasons, this did not occur, making it difficult to conduct preliminary analyses and methods development. Many of these difficulties are described in chapter 4.

The lack of two field seasons had a number of ramifications, including: 1) necessity to optimize the scheduling of the geophysical and biological expeditions in only one year, 2) inability to do some methods development before the main biological sampling expedition, 3) inability to set the final selection of species until the main expedition, 4) lack of knowledge about the size of some species, and their abundance (partly ameliorated by preliminary work in Adak prior to the expedition), 5) insufficient lead time to obtain marine mammal collecting permits.

The remoteness of the site, over 1300 miles from Anchorage, meant that considerable attention had to be devoted to personnel safety, particularly for the divers. We were thus unable to dive deeper than 90 feet, and many stations could not be sampled because wind, waves and surge made it too dangerous to transfer to and from skiffs or to be in the water. Likewise, some shallow dives could not be completed because of surge that could bash divers on rocks. The remoteness of the site also meant that we had to have redundancy in case any equipment broke down or we needed more supplies than anticipated. And the remoteness of the site, and the use of a ship, meant that communications were limited.

Weather in the Aleutians is often problematic, and both daily plans and weekly plans had to be changed to fit the conditions. That is, when storms or winds were bad on one side of Amchitka we moved to the other side, and storms determined when we crossed to Kiska. Further, severe winds and wave action prevented some shipboard sample preparation because it was not safe to move about, stand at work stations, or handle dissecting and filleting knives. Heavy fog prevented deployment of small skiffs to go to the islands or intertidal zone for specimen collection, and sometimes prevented subsistence fishing.

Species at Risk

One of the key issues in the groundwater models and the screening risk assessment (DOE 2002a, 2002b) is whether there are sufficient biota near Amchitka to take up radionuclides if there were contaminant migration from the Amchitka test shots to the marine environment, and to transfer radionuclides through the physical environment to the food chain to top-level predators, including humans. The diverse food chains at both Amchitka and Kiska included primary producers, filter feeders, grazers, and many levels of predators (Merrell 1977, O'Clair 1977).

In 2004 the marine ecosystems were diverse and flourishing. Our biological collections, described in chapter 10, 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 most species at the two places. Thus, the data generated by our studies indicate that there are species that would be at risk if there were migration of radionuclides into 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 Islands. Sea Lion rookeries are all protected with exclusion zones.

Our expedition found that there were sedentary species present from the intertidal to 90 feet depths (the deepest we could safely dive), 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 would be at risk from any radionuclide leakage.

The species present could all be at risk if there were significant migration of radionuclides from the seabed occurring over a short time period. These same species form the basis for complex marine food webs that are of interest to resource trustees, and the general public. Moreover, the 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.

Food Safety

One of the primary objectives of the Amchitka *Science Plan* was to assess whether there is currently any radionuclide risk from the consumption of foods from the Amchitka region. While a great deal of attention has been devoted to food safety for rural subsistence foods from mainland Alaska (Nobmann et al. 1992, Egeland et al. 1998; Duffy et al., 1999; Rothschild and Diffy, 2002; Jewett et al., 2003), relatively little has been devoted to subsistence foods of the Aleut peoples. Quantitative data on consumption rates are particularly lacking, although 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, Adak, 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 we collected, 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) 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 only address concentrations of radionuclides in the foods, and not other contaminants, such as heavy metals or PCBs (White and Risebrough 1977, Figure 12.5). Risk from the consumption of fish, however, is a function of all contaminants, including radionuclides.

Figure 12.5. Commercial fishing trawlers at Dutch Harbor (Photos J. Burger)


Collecting data on consumption patterns is methodologically challenging and controversial (Burger 2000, 2002, Burger et al. 1998, 1999a,b, 2002a,b, Vorhees 2004, Strauss 2004), but we could not find 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. Without quantitative site-specific consumption data for subsistence residents of the Aleutian and Pribilof Islands, it is problematic to conduct risk assessments. Our initial project to collect consumption data in these communities was not funded by DOE (see chapter 1).

Nonetheless, it is possible to examine food safety by comparing the concentration data obtained from this study with established food safety standards for each of the isotopes of interest (see Table 12.1 above), and with average values obtained in other studies (see tables in chapter 11). The CRESP Amchitka/Kiska data set is very diverse and complex. Below we present comparisons for Pacific Cod because of its overall importance to commercial fisheries, subsistence fishers, and as a top-level predator on a complex food web. Further, levels of Cs-137 have been examined in Cod from around the Northern Hemisphere. It is worth noting that the Amchitka/Kiska mean Cs-137 level for Pacific Cod was similar to other un-contaminated sites (references listed in Table 11.16). The average value for Cs-137 from the studies given below is 0.31 Bq/kg, higher than the 0.20 obtained at Amchitka/Kiska. This is in marked contrast to Cs-137 levels in Cod from contaminated sites in the Irish Sea (6.44 Bq/kg) and the Baltic Sea (8.86 Bq/kg), where levels are an order of magnitude higher.

| | |
|---|---|
| Cod: | |
| Amchitka/Kiska | 0.20 Bq/kg, |
| Arctic | 0.20 Bq/kg |
| Barents Sea | 0.29 Bq/kg |
| North Sea | 0.38 Bq/kg |
| Norw | 0.32 Bq/kg |
| North Atlantic | 0.28 Bq/Kg |
| English Channel | 0.20 Bq/Kg |

Pacific Cod is one of the 25 most important commercially species of the approximately 450 species of fish, shellfish and crustacean species in the Bering Sea region (NRC 1996). Cod and Pollock remain the keys to Alaska's seafood industry (Alaska J. Commerce 2004). Further, Cod and Pollock consistently are in the top ten seafoods for U.S. per-capita consumption (by pounds, NFI 2005). In 2003 (the last year data are available), the list was Shrimp, canned Tuna, Salmon, Pollock, Catfish, and Cod (NRI 2005).

Pacific Cod are broadly distributed in the North Pacific, and are common at depths of 80 - 260 m, particularly on the shelf and upper slope. They migrate seasonally between the continental slope and shelf and along the continental slope, and range in age up to 25 years (Munk 2001). They feed on benthic epifauna, shrimps and crabs, and juvenile fish, including Pollock (Hood and Calder 1981), although in some places they eat mainly fish and crabs (Tokranov 1992). Tokranov (1992) found that nearly 70 % of the diet of Cod was Pollock, and the relative percent increased with size of the Cod. Cod are relatively high on an index of trophic level for the Bering Sea (Mito et al. 1999). Cod are eaten by larger fish such as Halibut and sharks, and also by Fur Seals and whales, and of course, people. The catch of Pacific Cod in the eastern Bering Sea had increased from the early 1960s to over 180 metric tons by the late 1980s (NRC 1996), and it remains an important commercial fish today.

Table 12.2 summarizes available data for a number of radionuclides of concern in this study. The first two columns list the range of values from Northern Hemisphere sites generally and from the contaminated Irish Sea (near Sellafield). The next gives the values for Amchitka. The FDA's Minimum reporting level is the minimum concentration reported in FDA food surveys (any values below this are reported as "zero"). The FDA DIL is the Derived Intervention level which is a guidance level for food that is imported into the United States (FDA 2004). It is based on short-term rather than lifetime exposure. The "Codex" refers to international guidelines proposed by the Codex Alimentarius committee of the Food and Agriculture Organization and World Health Organization. These are food safety values intended to screen food sources as acceptable for consumption for a one year time frame (FAO/WHO 2004). The last column is the concentrations in fish that would contribute a one in a hundred thousand ($10^{-5}$) increased cancer incidence, in a population consuming 100 kg of the fish per year over a lifetime.

Firstly, it is clear that the levels in the fish from Amchitka were often below the MDAs for many radionuclides, and were generally within the range of those reported from the northern hemisphere (Table 12.2). For all the fish analyzed from Amchitka, a person eating 100 kg of fish a year would be below the $10^{-5}$ risk level from cesium. This means that the added risk of developing cancer is less than 1 in 100,000, or that out of every 100,000 people, less than one person who would not otherwise have developed cancer, develops a caner.

Since the guidelines apply to food generally, they can also be used to consider the risk from consuming other foods, such as Octopus and Sea Lion. Sample sizes were very limited for these species, but for Cs-137, the mean values were 0.262 Bq/kg for Octopus (N = 4), and 0.55 and 0.40 Bq/kg for Sea Lion muscle and liver in one individual. Thus, both species are below the $10^{-5}$ risk level (but within the $10^{-6}$ risk level).

Table 12.2. Key values for radionuclides in fish (all concentrations in Bq/kg on wet weight basis). Range of concentrations in Northern Hemisphere studies and separately for the Irish Sea. FDA's Minimum Reporting Level(MRL)and Derived Intervention Level. Codex Alimentarius guidelines value(FAO/WHO 2004). Right hand column are concentrations in fish that would produce a 1 in 100,000 or $10^{-5}$ increased risk of cancer, assuming 100 kg fish consumption per year (MRL after FDA 2001, DIL after FDA 2004).

| Isotope | **Northern Hemisphere (range)** | **Irish Sea (range)** | **Amchitka Range** | **FDA MRL** | **FDA DIL** | **Codex guide** | **Risk Level for $10^{-5}$[g]** |
|---|---|---|---|---|---|---|---|
| Cs-137 | 0.4 to 0.33 | 0.31 to 11 | <mda-.602 0.14-0.311[h] | 5 | 1200[e] | 1000[b] | 1.4 |
| Sr-90 | 0.007 to 0.01 | 0.003 to 0.027 | All <3.23 | 0.1 | 160 | 100[c] | 0.8 |
| Tc-99 | no data[f] | 0.05 to 5.8 | All <mda | no MRL | no DIL | 10,000[d] | 13.2 |
| I-129 | no data | 0.005 to 1.6 | All <0.79 | no MRL | no DIL | 100[c] | 0.3 |
| Am-241 | 0.0012 | 0.0001 to 0.23 | <mda-0.27[j] | 200 | 2[a] | 1[a] | 0.4 |
| Pu-238 | 0.0000085 to 0.000054 | 0.0001 to 0.02 | All <0.033 | no MRL | 2[a] | 1[a] | 0.6 |
| Pu-239&240 | 0.0003 to 0.07 | 0.000013 | <mda-0.022 | no MRL | 2[a] | 1[a] | 0.3 |
| U-234 | 0.018 | 0.0036 to 0.0052[i] | <mda-0.857 | no MRL | no DIL | no guideline | 0.6 |
| U-235 | no data | 0.00003 to 0.0003[i] | <mda-0.53 | no MRL | no DIL | 100 | 0.6 |
| U-238 | no data | 0.0035 to 0.0046[i] | <mda-0.779 | no MRL | no DIL | no guideline | 0.6 |

a= Totals for all Am and Pu isotopes
b= Total for S-35, Co-60, Sr-90, Ru-103, Cs-134, Cs-137, Ce-144 and Ir-192.
c= Totals for Sr-90, Ru-106, I-129, I-131, U-235.
d= Totals for H-3, C-14 and Tc-99
e= Total for Cs-134 + Cs-137.
f= Lobster tissue ranged from 2.2 to 41.5 Bq/kg (ww).
g= $10^{-5}$ means a 1 in 100,000 change of a person getting cancer who would not otherwise have gotten cancer.
h= range of means for four species.
i = East Irish Sea, Scotland coast.
j = For all actinides bone was analyzed as a conservative measure.

## Ecosystem Harm

A second objective was to determine whether the levels of radionuclides in the biota are sufficiently high to pose a risk to the organisms themselves, or to other nodes on the food chain. In general, radiation protection has focused on humans, assuming that values protective of humans would be protective of other biota (Copplestone et al. 2004). Dosimetric models available for non-human biota are not as sophisticated as those for humans; they do not account for penetration of various emitted radiations in different tissues, for metabolic behavior of the radionuclides, for different biologic half-lives, or for geometry of the organisms (Barnthouse 1995, Jones et al. 2003). The development of kinetic models and screening methodologies are in the early phases of development (Higley et al. 2003a, 2003b).

Laboratory studies have established that radiation can cause a number of detrimental effects in biota, including mortality, lowered reproduction, and genetic damage (AMAP 2003). Differences among species are often due to exposure pathways, uptake and bioavailability, dose-effect relationships, and ecosystem processes (e.g. nutrient availability, productivity). Acute lethal dose varies by orders of magnitude among organisms: mollusks and algae are nearly a 100 times more sensitive than mammals (AMAP 2003). This suggests that developing radiation standards for humans, and assuming they will protect non-human biota, will not work, especially for aquatic ecosystems.

There are several efforts underway to develop frameworks for criteria and approaches for protecting the environment (Copplestone et al. 2001, 2004, Higley et al. 2003a, 2003b, ICRP 2004). Mainly however, current guidelines are for exposure: standards for aquatic biota are 0.01 Gy/day (IAEA 1992, UNSCEAR 1996). Needed however, are standards for tissue levels, which can be used in the field to evaluate possible effects in biota.

International and national agencies and scientific organizations have recently revisited the issue of guidelines for ecological protection to radionuclide contamination in the marine environment. Current generic aquatic guidelines state that chronic dose rates of 10 mGy/day "would provide adequate protection for the population" (IAEA, 1992). The UNSCEAR qualifies the chronic dose rate limit to a small proportion of the individuals in aquatic populations – and assumes that a lower average dose rate would be needed for whole aquatic populations (UNSCEAR, 1996). The U.S. NCRP suggests that if either models or actual measurements arrive at levels of 2.5 mGy/day to the maximally exposed aquatic organisms, then "the potential ecological consequences to the endemic population should be conducted" (U.S.NCRP, 1991). The 2005 draft statement of the International Commission on Radiological Protection on The Protection of the Environment does not retract or modify any of the previous guidelines (ICRP, 2005). The ICRP is early in the process of developing a framework for the assessment of radiation effects in non-human species in order to provide a scientific basis for environmental decision-making and planning.

The concentrations of radionuclides found in biota in the current study are compared to the noted international ecological guidelines. Comparing the radionuclide concentrations in biota (Bq/kg) to these guidelines in mGy/day, requires certain assumptions. The highest measured concentration of Cs-137 was in a Pacific Cod (0.6 Bq/kg). The Committed Dose Equivalent per unit intake for Cs-137 is about $1.35 \times 10^{-8}$ seiverts per becquerel (Sv/Bq) (EPA 1988, CEFAS 2003), and for a gamma emitter, one Sv= 1 Gray of dose. Therefore, a predator that eats one kilogram of Cod per day, containing the maximum level found in this study, would obtain the equivalent of

$$0.6 \text{ Bq/kg} * 1.35 \times 10^{-8} \text{ Sv/Bq} = 8.10 \times 10^{-9} \text{ Sv/kg OR } 8.10 \times 10^{-9} \text{ Gy/day.}$$

This translates into $8.1 \times 10^{-6}$ milligray/day or about 1 /100,000 of the guideline level. Although the dose conversion is based on humans, it is reasonably applicable to large vertebrate predators such as marine mammals. A 680 kg male Steller Sea lion consuming about 5% of its body weight per day (c35 kg), would receive approximately 0.0003 mGray per day from this source. It is therefore unlikely that any harm to Sea Lions is attributable to Cs-137. Actinide levels in fish were too low to support similar calculations. In any case, the radiation burden from natural radionuclides appears to outweigh that of the Cs-137.

Species Selection for Bioindicators for Future Biomonitoring

One of the objectives of the *Science Plan* was to provide insights into possible indicator species selection for future biomonitoring and long-term stewardship at Amchitka. 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 and the environment.

There are four overall characteristics that should be considered when selecting bioindicators (Table 12.2 below). First and foremost, an indicator should be sensitive to a stressor. The indicator should change as soon as the stressor occurs and the response should be in proportion to it. Secondly, the indicator should be specific; responding only to a particular stressor of interest. This criterion is seldom met. 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 little known species.

Table 12.3. Major Features Useful for Bioindicator Selection.

| FEATURE | IMPORTANCE |
|---|---|
| Biological | Does it indicate what it should?<br>Is it sensitive to change?<br>Does it change in proportion to the magnitude of contamination?<br>Is it specific to the stressor of concern? |
| Methodological | Is it accessible in sufficient numbers? Can it be sampled by non-experts?<br>Can it be monitored sustainably? |
| Sociological | Is it of interest to and understandable by stakeholders including the Aleut peoples, resource trustees, and Agencies?<br>Is it cost-effective? |
| Mobility | Does it represent point source, local, or landscape scale contamination? |

Methodological considerations are actually extremely important, particularly for remote ecosystems such as Amchitka. Basically, an indicator has to be usable and understandable. It should be easy to access in the field or study in the laboratory. In this case, it should be a species that can be reasonably collected, 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 statistical analysis over a period of years. On the other hand there is great interest in monitoring the population of endangered species, which can contribute to a monitoring program. An indicator should be usable by non-specialists. If it requires highly trained specialists, even for field collections, it will not be employed for a long period. Likewise, 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, they should address the questions: 1) have radionuclide levels changed in the last 5 years, 2) are there differences in the marine environments adjacent to each of the test shots, 3) are there indications that subsistence or commercial foods are affected, and 4) does it 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) species representing different trophic levels, 2) indicator selection based on sound quantitative, information, 3) standardized protocols, and 4) caution in interpreting population trends, levels of anthropogenic stressors, contaminant levels, and other parameters (Peakall 1992, Burger and Gochfeld 1996, 2004, Carignan and Villard 2001).

In short, a bioindicator should provide early warning of any potential harm before there is any risk of human exposure or the damage is irreversible to the marine ecosystem. Some possible candidates appear below. Each, however, requires a careful analysis, which is beyond the scope of this report.

Table 12.4. Possible Bioindicators for Human Exposure, Top-level Predators, and Self-exposure.

| 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<br>Limpets<br>Sea Urchin<br>Atka Mackerel<br>Rockfish<br>Rock Sole<br>Rock Greenling<br>young Pollock |
| Top level predators | Effects on predator populations and on humans who consume them. | Eagle<br>Gull<br>Tufted Puffin<br>Pigeon Guillemot<br>Octopus<br>Halibut<br>Pacific Cod<br>Walleye Pollock<br>Sea Lion |
| Self-exposure | Direct 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 and Rock Jingles<br><br>Cs-137 - Top-level predators, such as Pacific Cod, Pacific Halibut, Black Rockfish, Walleye Pollock, Octopus, Glaucous-Winged Gull, Sea Lion |

The high rate of non-detects (values below the MDAs) makes it difficult to suggest bioindicators for a suite of radionuclides, including Sr-90, Co-60, Eu-152 and Tc-99.

Questions that remain and recommendations CRESP is making about future research

At the end of any research project, and surely at the end of this phase of the research program set forth in the Amchitka *Science Plan*, it is important to assess what science remains to be done and why. In this section we separate out four different questions that CRESP researchers have asked themselves as they have considered what the work reported here either does not answer or, indeed has raised.

1) Did the work on which we report here trigger any scientific questions the near-term answer to which would affect the human health?

> The answer is no, since food consumed by humans are safe with respect to radionuclides when the levels we analyzed in biota are evaluated in relationship to existing or proposed international standards and guidelines.

2) Did that work generate or further define research questions that are of scientific interest and worthy of study to enhance scientific understanding of the marine environment at Amchitka?

> Yes, and we provide a list of many of them below

3) Are there scientific issues and questions raised in the *Science Plan* but not addressed in this study that would, in CRESP's judgment, materially affect stakeholder peace of mind about the test shots at Amchitka?

> Yes, there were two general project areas in the *Science Plan*, specified to be outside the CRESP scope, that we consequently could not address with the same specificity as we did the studies on which we report here. Their subject matter is closely tied to palpable stakeholder concerns and we draw attention to them here.

4) Are there analyses and additional work that would significantly improve the Department's ability to develop and implement a long-term stewardship plan and biological monitoring plan?

> Yes, several would involve an expanded use of samples already collected in the 2004 expedition. Others would require additional expeditions or being tied to utilization of existing activities in the Aleutians

We address here questions about the three different types of future research that remain open.

## ADDITIONAL SCIENTIFIC RESEARCH QUESTIONS

Did our work generate or further define research questions that are of scientific interest and worthy of study to enhance scientific understanding of the marine environment at Amchitka? Science proceeds by building on previous work, which in itself suggests that any well-designed study will pose further questions, as well as answer the original questions. Any ecosystem study of contaminants, in this case radionuclides, will identify data gaps and areas of future interest to better understand the movement of radionuclides through complex physical environments and biological systems such as food webs. This is the case with the CRESP study as well. There are a number of avenues of future research that would greatly enhance our understanding of the marine environment around Amchitka. These studies would also enhance understanding of the Western Aleutians, Bering Sea and North Pacific, and can interface with the Eastern Bering Sea Study (BEST 2004).

1. Assessment of the benthic biotic community at deeper depths than we could examine (since breakthrough and seepage might occur there). Our expedition was limited to diving to 30 m depths because of health and safety concerns. However, a larger, dedicated research vessel might have on board the necessary equipment for divers to safely dive deeper. We found lush, functioning biotic assemblages at 30 m depths, with no indication of cessation at these depths. Thus, there are clearly functioning food webs at deeper depths that should be examined.

2. Consider the use of a submersible vessel for assessment of radionuclides in biota where geophysical anomalies were detected at deeper depths. A submersible vessel could also be used to assess the biota in the marine environment at deeper than 30 m to understand the complex food webs at these depths. This is particularly useful because commercial vessels trawl at these depths.

3. Broader assessment of contaminants in bird eggs because of their importance as a subsistence food. The CRESP Expedition was not timed primarily to sample bird eggs, and by July most eggs of most species had hatched. Eggs should be collected earlier in the season (June) when they are recently laid. Gull and Eider eggs are an important Aleut subsistence item because the birds nest on the ground, and are easily accessible, while many other seabirds that nest on cliffs are more difficult to access.

4. Development of more sensitive methods for quantification of low level radionuclides in species of small sizes (e.g. Blue Mussels, Sea Urchins, Chinese Hats, all of which are Aleut subsistence foods). These should be specifically targeted to obtain large sample sizes.

5. Targeted sampling of the top-level predators such as Octopus, Halibut, Sea Lion, and Eagles, and for the very long-lived species of fish (such as Black Rockfish). Obtain enough samples of these species for statistical analysis, within allowable limits so as not to affect

population dynamics of each species. Many of the fish in these cold northern waters live a long time (up to 100 years, Munk 2001), providing for the opportunity for assessing exposure from the time of the underground nuclear testing, and for bioaccumulation in older fish.

6. Analysis of a wider range of kelp and other algae species to refine the best one to three species to use for biomonitoring. This is a matter of assessing which species has the highest bioaccumulation factor for the different radionuclides of interest because they would provide the earliest warning of any potential future contaminant seepage. There were striking differences among these species in the levels of different radionuclides which could be exploited in any future biomonitoring plan.

7. A more complete assessment of commercial fisheries species, including King Crabs. The CRESP expedition was limited to collecting such species on one NOAA research trawl, which in turn was limited to one time period and one gear type. Additional funding would have allowed for sampling on a number of research or commercial vessels, broadening the data base of different species from the Amchitka region. It would also have been useful to collect fish from the Aleut/Pribilof Islanders commercial fisheries (such as the one at Atka)

8. Collection of consumption data from a number of villages, conducted by local residents. We suggest that this collecting include not only the well-established subsistence hunters in each village, but also late-teens, who will be the hunters/fishers of the future, but are also approaching reproductive ages.

9. Support of additional geophysical and oceanographic investigations that may provide further insights into likely locations and time frames over which migration of radionuclides from the Amchitka test shots to the marine environment may occur. Priority should be placed on additional refinement of the groundwater transport models, incorporating the new information obtained from the magnetotelluric studies and bathymetry. This includes recognition of the asymmetry of Amchitka Island and subsurface heterogeneity. Additional magnetotelluric measurements on Amchitka Island can provide additional insights into location and role of geologic faults in groundwater transport and further refinement of understanding subsurface geology that would lead to further improvements in contaminant transport modeling. Further investigation of ocean floor for freshwater discharge off-shore of all three test shot locations may indicate locations warranting more detailed attention during future biological sampling. The areas indicating anomalies and use of sediment pore water sampling should be considered in the design of such a study.

10. To examine risk to subsistence and other consumers of fish and shellfish it is essential to examine all contaminants that contribute to the total risk (see Burger et al. 2001b, c, 2002a,b). While radionuclides provide one possible avenue for exposure and risk (if there were contaminant migration from the Amchitka test shots to the marine environment), the question of food safety includes the total risk from contaminants, making it very useful to model radionuclide exposure within a framework of other contaminants of interest, notably

mercury and PCBs, which were both emphasized by Aleut villagers. The risk from radionuclides may well pale when compared to the risks from other contaminants, and this part of the picture needs elucidating.

Finally, the geophysical results indicate that further groundwater modeling is warranted that considers the full range of geophysical information gained through this CRESP study. Factors to be considered should include subsurface fresh to salt water transition zones, subsurface heterogeneity, porosity variation, and actual island and off-shore (marine floor) topography. These modeling studies would result in reduced uncertainty in the travel times and discharge locations of groundwater from the test shots to the marine environment.

## REMAINING COMPONENTS OF THE *SCIENCE PLAN* THAT WERE NOT FUNDED

As laid out in chapter 1, only about one third of the complete Amchitka *Science Plan* was funded, and therefore a number of projects, physical and biological, were either partly funded, or not funded at all. For example, we could not complete all of the oceanographic studies (on the Pacific side), all of the biological sampling stations, nor all the radiological analyses. All aspects of the original *Science Plan* that were of interest to the stakeholders.

Two unfunded project areas stand out in major part because they are of such clear concern to stakeholders.

1) Among the geophysical projects, volcanic and seismic activity is of concern since stakeholder meetings in the Aleutian villages emphasized concern about such activity. Villagers are familiar with active volcanoes on nearby islands, and experience earthquakes periodically. There is a common belief that an earthquake could intersect a test cavity and release contamination. Development is needed of a detailed understanding of the benefits from enhanced seismic monitoring and the relationship of such monitoring to future actions and risks should large magnitude seismic activity occur. The CRESP expeditions did not deal with this issue, and therefore cannot comment on the usefulness of such a monitoring system.

2) Refined risk assessments involving detailed scenarios for Aleut and other island residents as well as consumers of fish from the region require not only details of radionuclide concentrations in a range of subsistence and commercial foods (such as are provided in this report), but also detailed information on consumption patterns by species of biota, age and size of biota, seasonality of consumption patterns, meal size, and age (and size) of the consumer (see EPA 1998, Burger et al. 1999a,b, 2002a,b). Such information was not available to CRESP for this report. The information provided in this report (see Chapter 11 and this chapter) about the relationship of radionuclide concentrations in biota to international standards and guidelines will address many stakeholder concerns. But, there remains to be undertaken the systematic consumption studies proposed in the

*Science Plan* but not funded. In their absence, detailed risk assessments for specific Aleut or other local subsistence consumers, cannot be credibly completed.

## RECOMMENDATIONS FOR DEVELOPING LONG-TERM STEWARDSHIP PLANS

Although the original DOE funding for this project under the Letter of Intent included development of a long-term stewardship plan, that work was never made part of the CRESP scope. Here we simply make several observations about what work might be useful for that plan.

First, we believe that in developing such a plan, it may well be useful to make regular use of the biennial NOAA trawl, especially targeting the trawls very close to Makarius Bay off *Milrow*. This could allow for regular, biennial sampling to provide any early warning of potential problems. However, the trawl does not currently go on the Bering Sea side of the island, making it less viable for long-term biomonitoring of Amchitka. It may also be useful to enlist the US Fish & Wildlife Service vessel personnel to collect intertidal algae for actinide analysis on a periodic basis.

Second, radiological data reported from this project provides a comprehensive picture of the marine ecosystem surrounding Amchitka. However, there are a number of follow-up questions that could, with further analysis of the biota already gathered, refine our understanding of isotope levels, which in turn would improve design of a biomonitoring plan for long-term stewardship. These include:

1. Which specific kelp or algae would optimize for actinides? This would involve an increase in the number of algae samples, and in the range of species analyzed from the test shots areas (specimens exist for this analysis). Such additional analyses might well allow for the selection of the species that are the best accumulators of the suite of actinides of interest, including plutonium isotopes.

2. Which top-level predatory fish are the best concentrators of Cs-137? An increased number of samples analyzed would make it possible to optimize for several qualities, including the best accumulator, the most sedentary (least mobile), and of the most interest to subsistence and commercial fisheries. Additional time and resources would enable analysis of a broader range of fish, with larger numbers per species, of 1000 g samples to ensure detectable levels.

3. Since we found a high level of actinides in primary producers (i.e. algae), analysis for actinide levels in an additional range of middle trophic-level organisms (specimens are available) would provide information both on sedentary species and those that might be useful for biomonitoring.

4. Bird eggs (and the birds themselves) are a preferred Aleut food, and an increase in analytic sensitivity is needed to provide information on appropriate bioindicators for this key subsistence food.

Third, there were several samples (mainly algae) with levels above the minimum detectable activity level for Pu-239,240. The levels were low and do not pose a health risk to people, and were within the ranges reported for other Northern Hemisphere locations. Nonetheless, data on the relationship of Pu-239 to Pu-240 could provide additional information on the possible source of the plutonium. Further analyses with existing samples could provide information on whether the plutonium comes from global fallout, from oceanographic transport, or a point source (such as Amchitka).