Background on Amchitka

SUMMARY

Amchitka Island in the western Aleutians was the scene of three underground nuclear tests (1965-1971). Although the island is currently uninhabited, it is an ancestral home for the Aleut People, the nearest community of whom is at Adak. The possibility that radionuclides might migrate from the test shot cavities carried by ground water through the rock, eventually reaching the sea, has prompted an investigation to determine whether there is current evidence that the marine ecosystem, including the near shore food web, subsistence foods, and commercial fish, are contaminated. The study also identifies species that would be suitable for future biomonitoring of the Amchitka marine environment.

This chapter addresses the following topics:

The relevant history of Amchitka
The history of nuclear testing at Amchitka
The potential contaminant path from the test cavities to the sea
Previous data for contaminants at Amchitka
Comparative data for radionuclides in marine biota

INTRODUCTION

The Aleutian chain extending westward toward Asia from the Alaskan mainland is a geologically dynamic area where continental plates collide, where young volcanoes are active, and where cold upwellings bring to the surface nutrients that support the rich ocean life (Johnson 2003). Amchitka Island is about 40 miles long by 2-3 miles wide, with a surface area of about 30,000 hectares (74,000 acres)(Merritt 1977). It is mostly a low relief, boggy, tundra-covered island, lying in the central Aleutians, about 1340 miles southwest of Anchorage, at latitude 51.5 N and 179 E longitude (Figure 2.1). Amchitka is bordered on the north by the Bering Sea and on the south by the Pacific Ocean. The waters are highly productive and support rich and varied ecosystems with high biodiversity of invertebrate and vertebrate marine life. Many species of fish important to subsistence and commercial fisheries are abundant in the Aleutian area including Walleye Pollock, Pacific Cod, Halibut, Rock Sole, Rockfishes, and Salmon. The King Crab fishery, once heavily over-fished, is now tightly managed and apparently sustainable. There is also a diversity of birds (seabirds, waterfowl, raptores) and marine mammals (Whales, Seals, Sea Otters, Sea Lion).

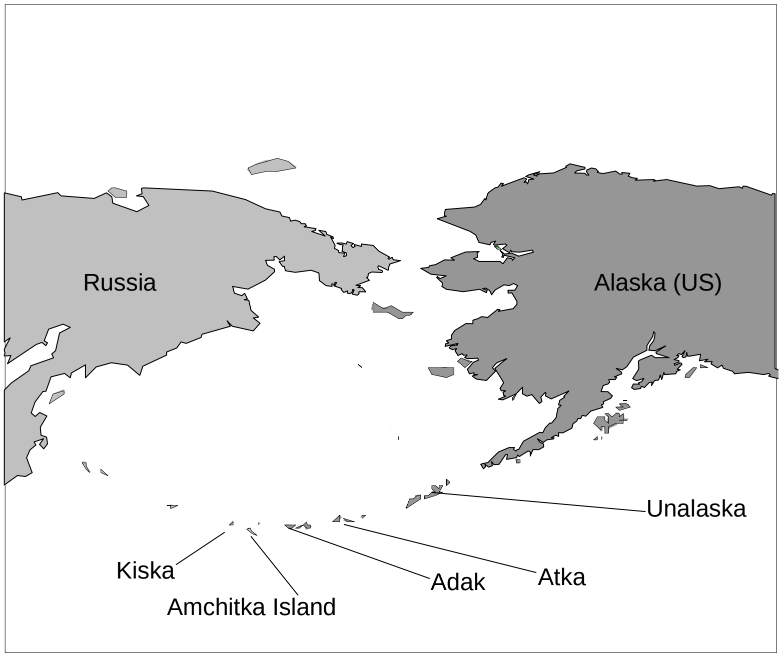

Figure 2.1. Map of Amchitka Island, in the Aleutian chain in the Northern Pacific/Bering Sea ecosystem.

The National Research Council's Committee on the Bering Sea Ecosystem published a report on *The Bering Sea Ecosystem* (NRC 1996) addressed sustainability of marine resources in the light of climate change and fishing pressure. It identified several major changes including:

1. Steller Sea Lion decline by 50-80%
2. Northern Fur Seal decline on Pribiloffs by 50% between 1950 and 1980
3. Harbor Seal decline by 90% since the 1970's in the Gulf of Alaska
4. Seabird declines in the Pribilofs and eastern Aleutians
5. Decline in whales and increase in Pollock

It also reported that indigenous fishermen had occasionally over-fished local resources, but that commercial exploitation beginning with Russians in the 18th century impacted resources sufficiently to cause starvation for local people. These fisheries over fished flatfish and rockfish. Whale exploitation peaked in the 1950's to 1970's and the elimination of whales is considered one factor in the population explosion of Pollock which became the dominant commercial species in the past 25 years, although about 25 species of fish, crustacea, and mollusks are considered important commercially (NRC 1996). There is concern that the huge Pollock fishery has reduced its population, and contributed to Sea Lion decline (NRC 2003).

A comprehensive study of Bering Sea oceanography and ecology (Loughlin and Ohtani 1999), included chapters on ecosystem dynamics (Loughlin et al. 1999), groundfishes (Mito et al. 1999), and seabirds of the western Bering

Sea (Shuntov 1999). The multi-disciplinary volume, *The Environment of Amchitka Island*, Alaska. Merritt and Fuller 1977; provides invaluable information on the geology, ecology and contamination of Amchitka. Greenpeace (1996) subsequently reported evidence of terrestrial and freshwater radioactivity.

Concern over worrisome environmental change in the Bering Sea has prompted the National Science Foundation Office of Polar Programs to develop a multi-institution, multidiscipline *Bering Ecosystem Study Plan* for the eastern Bering Sea (BEST 2004) which will focus on the “mechanisms and processes” involved in transfer of materials “through the ecosystem to upper-trophic-level consumers, including humans.” The effort will require multiple expeditions over several years, including deployment of instrument arrays and satellite remote sensing. Although still in the planning stage it is anticipated that the results will complement and illuminate those obtained by CRESP, and will incorporate some of the ideas in the CRESP Science Plan that were not implemented due to lack of funding.

This chapter addresses the following questions:

1. What is the relevant history of Amchitka?
2. What is the history of nuclear testing at Amchitka?
3. What is the potential contaminant path from the test cavities to the sea?
4. What previous data exist for contaminants at Amchitka?
5. What comparative data exist for radionuclides in marine biota?

History of Amchitka

Human settlement in the Bering Sea dates back more than 10,000 years and the land bridge exposed by lower sea levels during the late Pleistocene provided access for human migration from Asia to the Americas. For further details see CRESP 2003, NRC 1996, 2003. At various times in the past 10,000 years, Amchitka has supported a substantial human population, perhaps 1000 people or more (McCartney, 1977). With Russian colonization of the Aleutian Islands and subsequent development of the commercial fur industry (Chevigny, 1998), the Aleut population fell precipitously due to disease, forced relocation, and rapid depletion of resources, including the near-extinction of Sea Otters (Kenyon 1969). There was little improvement when Alaska was purchased by the United States in 1867, but eventually some protection of fur-bearing animals was put in place. In 1913 Amchitka and other islands were designated a federal wildlife refuge.

At the onset of World War II, the island contained only an abandoned Aleut village (Garfield and Cole, 1995). After the Japanese interned the Aleut inhabitants of Attu Island, the U.S. forcibly relocated many Aleut communities to camps in southeastern Alaska, and destroyed their villages (Kohlhoff 1995). Non-Native civilian residents were allowed to remain in the Aleutians during the war years. Some villages have since been re-established, and while none are very close to Amchitka, Aleuts and the world at large derive food from the surrounding seas (http://www.st.nmfs.gov/st1/commercial/index.html). CRESP interviews in Aleut villages indicate that the people view this region as their historic home and their possible future home.

In January 1943 the U.S. military began colonizing Amchitka to build an airbase from which the assault on Japanese-held Kiska could be launched. The military built roads, a 10,000 foot airstrip, and a breakwater across Constantine Harbor. Military occupancy reached 15,000 troops, and continued intermittently after the end of the War.

Amchitka and Nuclear Testing

From early in the nuclear era the Atomic Energy Commission covetously eyed Amchitka as a test site, both for its remoteness from the U.S. mainland and its proximity to the Soviet Union. The quest for suitable nuclear testing areas, the planning and implementation of the nuclear tests, and the controversies and legal action surrounding the Amchitka test shots, have been described in Kohlhoff's (2002) recent book *Amchitka and the Bomb*. *Operation Windstorm* began in 1950 with the intent to detonate both surface and underground bombs on Amchitka. This effort was abandoned in 1952. Attention was redirected to Amchitka in the early 1960s, with the result that three underground nuclear tests were eventually conducted there: *Long Shot* (1965), *Milrow* (1969), and *Cannikin* (1971). Details on the three tests follow:

Long Shot	Oct 29, 1965	80 kilotons	710 meters deep
Milrow	Oct 2, 1969	c1000 kilotons	1219 meters deep
Cannikin	Nov 6, 1971	c5000 kilotons	1791 meters deep

In addition to the immediate and long-term consequences of the tests themselves, the infrastructure established to prepare for the tests left a variety of physical scars to heal over time, as well as contaminants requiring remediation. The Department of Energy has removed much of the infrastructure and completed most of the terrestrial remediation.

To transfer Amchitka from Environmental Management to Long-term Stewardship, DOE needed to ascertain whether there was evidence that radionuclides had or could reach the marine environment, and it needed to obtain baseline information for future environmental monitoring or biomonitoring. These needs prompted the current study.

Amchitka Island is unusual among the DOE's Cold War legacy sites in a number of ways:

- Underground nuclear explosions of exceptional size including the largest US underground test (*Cannikin*).
- Location within an actively deforming tectonic plate boundary characterized by intense earthquake activity.
- Remote location and difficulty of access.
- Proximity to Asia.
- Protected status as a national wildlife refuge with endangered species.
- Location within an important international fishery region.

- A marine environment that supports the subsistence life style of indigenous people.

Likewise, the *Cannikin* test was unique in a number of ways. It was the first major project under the National Environmental Policy Act of 1969 and was required to have an environmental impact statement. It was the largest mined shaft in the United States with a single elevator shaft of 6000 ft; down which a 400 ton load was lowered into a 52 ft diameter chamber. The post-blast cavity is estimated at about 1200-1300 ft diameter based on the empirical equation that the cavity radius in meters = k times the cube root of the yield (in kilotons), where k has been estimated from other blasts to be in the range of 10 to 12 (Charles Fairhurst pers com), and the *Cannikin* yield was about 5000 kilotons see Figure 2.2. About a meter of uplift occurred along the adjacent Bering Sea Coast which permanently reduced the littoral zone along that shoreline.

In 1973, with no further testing plans, the AEC transferred the land back to the USFWS, and it was declared a biosphere reserve. However, the DOE retained responsibility for radiation contamination, as it developed its environmental management capability through the 1990's (Burger 1999, Burger et al 2003a). 1977 saw the publication of Merritt and Fuller's comprehensive volume on Amchitka and its ecosystems. In 1991 USFWS initiated a study of contaminants, and in 1996 Greenpeace (1996) issued a report of radiation surface contamination with Am-241. Dasher et al. (2002) did not find evidence of ongoing leakage of radionuclides to the surface, and noted that current tritium levels at *Long Shot*, reflect the escape of gases through the chimney rubble to the surface, followed by decay consistent with its 12 year half life.

The Department of Energy has supported development, by the Desert Research Institute, of a stochastically based conceptual groundwater flow and contaminant transport model for Amchitka Island (DOE 2002b). The groundwater flow model addresses density-driven flow characteristic of island hydrology. A stochastic modeling approach, Monte Carlo analysis, was used to address the uncertainty in hydraulic conductivity, recharge, fracture porosity, and macro-dispersivity. The statistical properties defining each probability density function were estimated from previous studies, from modeling, and from literature. With the results from the groundwater model, the conceptual transport model estimates the maximum and minimum boundaries of possible sub-sea seepage zones as well as the travel time required for key radionuclides to reach these zones.

Based on the ground water modeling, DOE commissioned the *Screening Risk Assessment for Possible Radionuclides in the Amchitka Marine Environment* (October 2002 draft; DOE 2002a). Both documents provided valuable information in developing the CRESP *Amchitka Science Plan*. The assumption of rapid dissipation, precluding any localized buildup of radionuclides may be realistic under some circumstances, but was non-conservative. Each of these models reflect extensive work and each identifies extensive uncertainties. A major limitation is that the source terms (what radionuclides actually reside in the cavities and their condition) remain classified, requiring many assumptions.

Geophysical and biological studies provide information that can reduce the uncertainties in these models.

The Bering Sea continues to be a focus of scientific investigation both to assess the impacts of society and technology on the marine system, but also to determine the societal impacts of global changes affecting this system (BEST 2004). The *BEST Science Plan*, developed concurrently with but independently of the *Amchitka Science Plan*, addressed the issues of marine ecosystem productivity and transfer to “upper trophic levels consumers, including marine mammals and people.” (BEST 2004). That program too emphasizes multidisciplinary approaches, and continues as a multi-year effort.

The safety for humans of consuming a particular food with a particular contaminant level can be estimated relative to published standards and guidelines derived for the protection of individuals from a variety of adverse effects. Such standards are generally based on the most sensitive, non-trivial health endpoint. Whereas it is desirable to use analogous approaches to protecting biota and ecosystems (Burger and Gochfeld, 1996, 2001, 2004), ecosystems are more complex, and individuals are of relatively little importance (Burger and Gochfeld 1997a). Comparing concentrations to thresholds (Cairns 1992) is not sufficient. Effects which may be predictable at the individual level, have unpredictable effects at the ecosystem level, and this applies to radiation effects as well as toxic chemicals (Bréchignac 2003).

Radiation and Radionuclides

Radiation can be awesome and frightening, partly because of its invisibility. Acute radiation exposure produce dramatic acute health effects, and in mammals the lethal dose lies between 2 and 12 grays (Woodhead et al, 2003), but most health concerns are related to cancer arising from relatively low doses. Risk assessment for cancer follows a linear no-threshold model (Upton 2002). Although the applicability of this model remains controversial, it is the approach that is used by U.S. and International agencies, and this has been reaffirmed in the BEIR VII report issued in June 2005. The implication is that even a small increased amount of radiation carries with it an increase of risk.

Ionizing radiation is an omnipresent part of the human environment. Natural sources include cosmic radiation, and radiation emanates from the earth itself. Small amounts of radionuclides, particularly potassium-40, occurs naturally in our bodies. This natural background varies geographically and particularly with altitude. Against this unavoidable background humans have added a variety of anthropogenic radiation sources, each of which contributes to exposure and risk (BEIR 2005). The United States standard for the general population is to limit exposure to no more than 100 millirems per year above this background (NRCP 1987), and by using various approaches exposure can be kept as low as reasonably achievable (ALARA). CRESP followed this guideline when it adopted this general population limit of 100 mrem/year, instead of the occupational standard of 5000 mrem/year (see Chapter 4). Anthropogenic sources include diagnostic and therapeutic medical applications, industrial sources, and contamination from nuclear powerplants and military activities including the building and detonation of nuclear weapons, as well as nuclear accidents and radioactive waste.

During the era of above ground nuclear testing, atmospheric fallout created a thin, though non-homogenous blanket of radionuclides, over much of our planet. Many of us are old enough to remember the concerns voice about how this radiation, particularly strontium-90 deposited on grass, eaten by cows, and transferred to milk, would impact a generation. It is against this blanket of historic global fallout, still readily detectable today, that any localized radiocontamination in the Aleutians must be examined. And in the marine environment the naturally occurring polonium-210 radiation exceeds even the fallout contribution (Aarkrog et al. 1997). Approximately 69% of Cs-137 in the ocean is from global fallout, the rest being from local fallout, reprocessing, and Chernobyl (Aarkrog 2003). Seeking evidence of localized contamination, possibly escaping from sources whose contents remain classified, and distinguishing such contamination from other anthropogenic sources, posed the challenge that CRESP undertook.

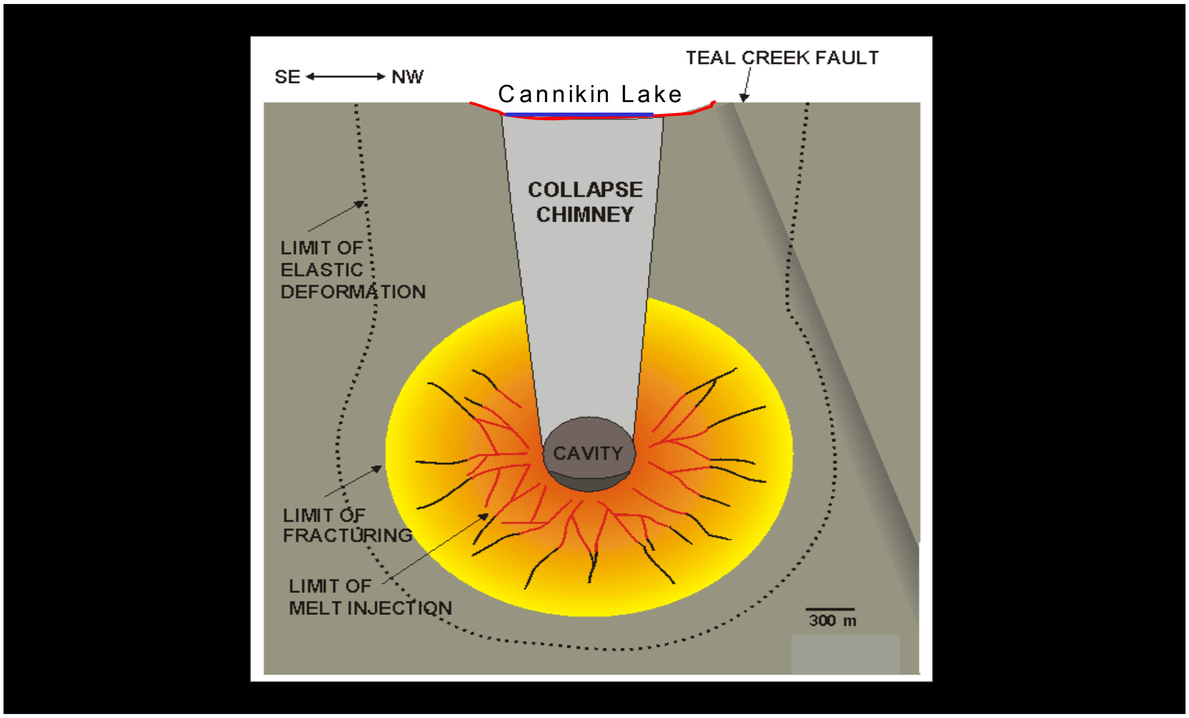

Figure 2.2. Shot cavity schematic (after Lazniak et al, 1996). Most of the radionuclides are contained within melt breccia pooled on the floor of the blast cavity, while a lesser amount may be deposited by gases from the blast traveling up the collapse chimney. This generic diagram is applied schematically to the *Cannikin* case. Cannikin Lake occupies a portion of the region of surface collapse. Neighboring normal faults such as Teal Creek may be intersected by shot-

induced fracturing, depending upon the radial extent of the shot-induced fracture zone and the orientation of the fault plane (Source: Nevada Nuclear Security Administration-DOE)

Contaminant Path

Figure 2.2 is a schematic cross-section of the *Cannikin* test shot cavity and fracture zone. Understanding the risk from radionuclides to humans and other receptors in the Amchitka marine ecosystem involves understanding how the contaminants could move from the source (shot cavities) through the rock to seawater and sediments, and then through the marine food web to high level consumers, including humans. If radioactive material reaches humans from the tests on Amchitka it will have started as the contents of the shot cavity, the “source term”, traveled as a solute or colloidal suspension in groundwater through the subsurface rock to the ocean, become incorporated in the marine food chain, and been harvested and consumed by humans or other higher level vertebrates, the “receptors”. The *Science Plan* aimed at identifying whether consumption of contaminated food by humans and other high-level species is currently a concern. However, detection of radionuclides in the Amchitka marine ecosystem does not necessarily indicate that the contamination originated from the Amchitka test shots. In addition to natural radioisotopes, other potential sources of radionuclide contamination include historical global fallout, as well as sunken submarines and waste intentionally dumped at sea (Layton et al, 1997). The global fallout from above ground nuclear testing in the 1950s and 1960s produced a worldwide layering of radionuclides. Two of the main fallout radionuclides: Cs-137 and Sr-90 have half-lives of about 30 years, such that a little more than one half-life has transpired since the end of above-ground testing. Until 1991 the Soviet Union dumped various radioactive wastes including submarine reactors in the sea (Layton et al. 1997).

Source Term

In an underground test, intense heat from the blast melts rock creating a liquid filled cavity with a pool of molten rock on its floor (Figure 8; Lazniak et al., 1996). Rapid cooling of the molten rock turns it to glass (vitrification), trapping the minerals in a very resistant glassy matrix. Some radionuclides such as ^{137}Cs, ^{90}Sr, ^{14}C, ^{129}I and others may have a sizeable percentage residing outside of the melt glass, hence in a much more mobile form. Since details on the products and characteristics of the test shots remain classified, stakeholders remain uncertain about whether some radionuclides were mobile, about whether some of the rock or glass might be subject to solubilization, and whether contaminants could find a way through porose rock or through fractures and/or faults in the rock, ultimately reaching the sea. Other chemical reactions may also be responsible for, or contribute to, the more rapid than expected movement of Plutonium in groundwater (Haschke, et al., 2000).

High seismic activity resulting in several recent quakes greater than Richter 7.0 in the Rat Island group near Amchitka, has also caused stakeholders to question whether such instability could disrupt the cavities causing, facilitating or accelerating release of contaminants. Aleutian residents and other attendees at CRESP public meetings also questioned why this source information should remain classified, and in the absence of this information they were anxious to see the results of a comprehensive scientific investigation, as well as long term seismic monitoring.

Rock Envelope

Fluid flow through the rock substrate of the island can be porous flow through the rock itself or fracture flow (e.g., Carrigan et al. 1996) which can be comparatively rapid flow. Faults are a special case of fractures that are subject to repeated displacement. In some cases, faults would be expected to favor transmissivity (e.g., Faunt, 1997; Lopez et al, 1995; Caine and Forster, 1999); in other cases they may block flow. Basic changes in interpretation of the geology and geophysics of the area in the three decades since the last test, demonstrate the plausibility that radionuclides could be transported from the shot cavities to the ocean (CRESP 2002).

Ground Water

Ground water would be the carrier for radionuclides from the test sites. Characterizing groundwater recharge and flow and identifying the freshwater-saltwater interface, were important factors in understanding and predicting how radionuclides might migrate from the cavities to the sea. Substantial effort was devoted to developing appropriate studies in the *Science Plan* (CRESP 2003), although not all could be carried out due to budget limitations. Another issue beyond the scope of CRESP's investigation, is the possible influence that thermal gradients created by the explosions could have had on ground water flow regime and radionuclide transport.

Marine Environment

If contaminated groundwater were to emerge from Amchitka into the ocean, it will gradually mix with seawater. Before being diluted to negligible concentration, the contaminants may be accumulated on sediments, adsorbed onto Kelp, or they may be taken up by living organisms either from the water or sediments. Figure 2.3 illustrates the marine food chain. If a flow emerges from an orifice in a fault, analogous to a spring on dry land, there will be a distinct plume of contaminated water that trails downstream in the ocean current. Gradual seepage, however, is a more likely scenario. The *Screening Risk Assessment* (DOE 2002a) considered a kelp-bed scenario as one model that would retard the rapid dilution/dispersion of contaminants. However, it did not consider sediments or kelp as a mechanism for localized accumulation of radionuclides. Site specific data are needed to validate the models.

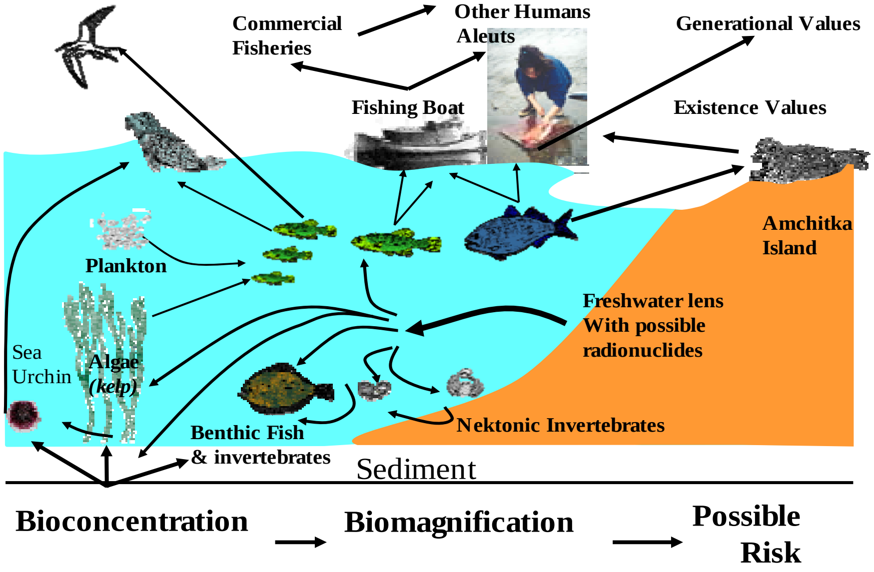

Figure 2.3. A generalized marine food web. Through the process of bioaccumulation, bioconcentration and biomagnification, radionuclides can move through the food chain to higher trophic levels, including humans. Concern should include not only present and future risk to receptors, but existence values and Intergenerational factors. (© Joanna Burger)

In conclusion, large quantities of radionuclides have been sequestered in the three test shot cavities in vitreous-like rock where mobility for some radionuclides is believed to be low while others are probably mobile (Dasher et al 2002). The current situation is one of uncertainty regarding the actuality or potential for radionuclides to be mobilized, to travel with ground water (DOE 2002b), enter the marine environment (DOE 2002a), and to move through the food chain.

Major technological developments that facilitate study of the geophysical and biological environment include 1) enormous increase in the computing power and data storage capacity of portable computers; 2) availability of the Global Positioning System (GPS) technology; 3) improvements in the diversity and power of tools for marine investigations generally; 4) improved radiological and chemical analytic techniques; 5) improved understanding of ecosystems and ecological and human health risk; and 6) recognition of the importance of stakeholder involvement (PCCRARM 1997).

Human Exposure and Food Webs

The *Screening Risk Assessment* (DOE 2002a) examined risk to humans, but not to other ecological receptors, which are of interest to the Aleuts, to natural resource trustees, and indeed to the nation. To the Aleut people, a clean environment equals clean food resources (R. Patrick, Personnel communication March 2003). The data collected on species in the marine environment would allow for ecological risk assessments to the species themselves, and to organisms that consume them. Understanding the potential risk to marine food webs independently of the risk to human consumers is an important consideration.

Plants and animals that are low on the food chain take up contaminants through contact with seawater and sediments; those higher on the food chain take up contaminants from their prey items. Once in the marine environment, radionuclides and other contaminants enter the food web, effectively moving from one trophic level to another, eventually reaching the larger marine organisms that are consumed by humans including Aleut people and distant people who purchase commercial fish of Aleutian origin (see Figure. 2.3).

If radionuclides occur in the water or sediment, exposure for marine organisms can occur through several pathways: 1) direct external exposure for sedentary organisms living on or near the location of a submarine freshwater discharge (such as sessile invertebrates and kelp), 2) direct external and internal exposure to mobile organisms moving in and around the discharge area (some mobile invertebrates, some small fish), 3) direct exposure of biota from uptake of radionuclides that have accumulated in sediments; 4) direct exposure to migratory organisms moving through the area of release (such as migratory fish, marine mammals, and birds), 5) indirect exposure of larger, migratory organisms (such as migratory marine mammals, seabirds, or larger fish), 6) indirect exposure of non-migratory organisms that prey on organisms that are directly exposed, and 7) indirect offshore exposure of migratory predators to prey that were directly exposed but have moved away from the source. Thus organisms containing radionuclides may be found close to a discharge source, or remotely.
Humans, as one potential receptor, are exposed mainly when they eat marine algae, invertebrates, fish, marine mammals and birds that were directly or indirectly exposed. There is also a remote potential for direct human external exposure through contact with contaminated water or sediments, or work on the island itself. The *Screening Risk Assessment* (DOE 2002a) addressed only internal exposure through the ingestion of marine foods. Humans might also receive external exposure from working with fishing gear if it had entered the plume, from diving in a plume, or from the handling of marine foods or craft items, although both the probability and magnitude of such exposures are likely to be low, they were addressed in the Health and Safety Plan for site workers (Appendix 4.E), and will be considered in risk communications for future site users (Burger et al. 2004).

Receptors of Concern

While the potential exposure of the entire marine ecosystem is of interest, some endpoints in the food chain are of greater interest, primarily high trophic level organisms (such as large predatory fish, marine mammals, seabirds, humans). Non-human receptors of particular concern are federally endangered or threatened species (a number of marine mammals and aquatic birds) and migratory species (such as some birds, large predatory fish). The U.S. Fish and Wildlife Service has control and responsibility for the Alaska Maritime National Wildlife Refuge, including most of the endangered and threatened species residing there. A major and successful rehabilitation program was undertaken for the Aleutian Canada Goose, formerly listed as endangered. This species is now numerous on Amchitka. The National Marine Fisheries Service (NMFS) is responsible for managing and protecting the endangered Steller Sea Lion as well as whales and seals. Sea Lion breeding habitat is located on the National Wildlife Refuge, but access control and enforcement is the responsibility of NMFS. The decline of marine mammals has been extensively reviewed (NRC 1996, 2003). Contaminants were considered to play a minor role in the decline while competition from the expanding commercial fishery has reduced food availability.

The Native communities, particularly the Aleutian/Pribilof Islands Association have a commitment to preserving the natural ecosystems of the Bering Sea and Aleutian Islands including Amchitka. This commitment includes the organisms that live in the marine environment. The communities are interested in the well-being of the organisms, as well as their subsistence values. This is an important cultural value that must be respected and incorporated into the study design (Patrick, 2002). Among humans in Alaska, Aleuts have the greatest risk of exposure to contaminants because of their subsistence use of "seafood" from the Bering Sea and North Pacific. They derive the majority of their food from the inshore waters and littoral zone. This includes consumption of marine plants, invertebrates (e.g., crabs and mollusks), fish, seabirds and their eggs, and seals and sea lions.

Commercial fishing is another route by which human exposure is possible, although most consumers would derive only a small percentage of their diet from the Amchitka vicinity. Any finding of significant radionuclide contamination could be economically serious to the Bering-North Pacific fishing industry.

Quality Assurance

All environmental sampling and monitoring projects used in making management or regulatory decisions must have a Quality Assurance Project Plan (QAPP) which establishes, among other things, the Data Quality Objectives (DQO) (CRESP 2003). Quality assurance refers to all the actions taken to ensure that a program or system adheres to standards, procedures, and performance requirements, such that the program can achieve its goals, and those who use its results can do so with confidence in the integrity and accuracy of the data (EPA DQO Guidance 1994). QA extends through the lifecycle of the data including not only data-gathering, analysis, and presentation, but updates and documentation. Quality assurance documents were prepared for the expeditions, for the laboratory preparations, and for each of the analytic laboratories (See Appendices 8.D & 8.G).

In the field and laboratory careful attention was paid to maintaining chain of custody, which continued through to the shipment of specimens from Rutgers to the analytic laboratories at Vanderbilt and INL (Appendix 8.H).

Previous Environmental Sampling Efforts at Amchitka

In his very comprehensive discussion of contaminants on Amchitka, Crayton (2000) points out that interpreting complex patterns of multiple contaminants in different tissues of different species from different trophic levels is challenging and that there are no standardized guidelines. The Amchitka Bioenvironmental Program (ABP) which began in 1967, conducted environmental studies until the AEC terminated activities at the site in 1973 (Merritt and Fuller 1977). Of particular relevance is the chapter on radionuclides by Seymour and Nelson (1977) and on PCBs by White and Risebrough (1977), as well as the chapter on ecological consequences of the nuclear testing (Fuller and Kirkwood 1977). The main findings focused on polychlorinated biphenyls (PCBs) and on the pesticide DDT and its metabolite DDE. The study concluded that although concentrations on Amchitka were not high enough to impair reproduction of the target species, they were higher than expected on a seemingly remote island, and warranted further investigation.

The 1967-1968 Amchitka Bioenvironmental Program results were reported by Isakson and Seymour (1968) of Batelle Memorial Institute. The program collected algae, invertebrates, and fish from both coasts of Amchitka from summer 1967 to March 1968, and analyzed them for a variety of radionuclides. These results are summarized in Table 2.1. Unfortunately the detection levels are not given, but the authors state, “blank areas in columns for radionuclide values…indicate that those values were nonsignificant, which means that the values had a net sample count less than its 0.95 error.” They analyzed samples weighing 120 to 5875 g for periods of 6-13 hours. 27 of 55 fish, 8 of 12 algae, and 1 of 19 invertebrate samples yielded values above detection level for Cs-137. Quantifiable results ranged from 0.62 Bq/kg (wet weight) in Ocean Perch liver to 2.93 Bq/kg in Pollock skin. Of 16 fish muscle samples 14 had detectable values, mostly in the range of 0.3 to 1.2 Bq/kg, Cs-137.

Table 2.1. Cesium-137 values extracted from 1967-1968 *Amchitka Bioenvironmental Program report* (Isakson & Seymour 1968). The detection levels were not reported. A few samples were analyzed as replicates

		Number Analyzed	Number Detects	Range in Bq/kg (ww)	Mean +/-SD
FISH					
Pollock	Muscle	6	6	.062-1.24	0.96 ± 0.21
Ocean Perch	Muscle	1	1	.94-1.11	replicate
Pacific Cod	Muscle	4	4	1.05-1.34	1.14±.12
Halibut	Muscle	2	1	1.24	
Rock Greenling	Muscle	1	1	.89-.97	replicate
Sockeye Salmon	Muscle	2	1	0.95	
Atka Mackerel	Entire	1	1	0.74	
Red Irish Lord	Entire	1	1	0.33	
INVERTEBRATES					
Horse Crab	Entire	3	0	nd	
Lithodes crab	Entire	7	0	nd	
Green Sea Urchin	Entire	2	0	nd	
Mussels	Soft	2	0	nd	
Plankton	Entire	5	1	1.55	
ALGAE					
Fucus	Entire	2	2	.56-.78	
Laminaria	Entire	2	1	0.95	
Alaria	Entire	2	2	.28-.42	
Halosaccion	Entire	2	1	.20-.22	replicate
Ulva	Entire	2	0	nd	
Hedophyllum	Entire	2	2	.32-.66	

Isakson JS, Seymour AH. 1968. *Amchitka Bioenvironmental Program. Annual Progress Report: July 1, 1967-June 30, 1968: Radiometric and Elemental Analyses on Marine Organisms from Amchitka, Alaska*. Unpublished Report BMI-171-113 for Atomic Energy Commission Contract No. AT(26-1a)-171.

In 1993 the USFWS compiled a *Summary of Site Contamination on Amchitka Island, Alaska (*USFWS 1993*)* which identified locations of contaminated sites and sources on the island, and a contractor prepared work plans and remedial investigation reports submitted to the Army Corps of Engineers (Crayton 2000). In 1996 and 1997 Greenpeace conducted a survey of radionuclides in mosses and reported that there were detectable levels of americium and plutonium, with radionuclide ratios suggestive of a test shot rather than fallout origin (Greenpeace 1996).

The National Research Council examined *The Bering Sea Ecosystem* (NRC 1996), particularly with respect to declining species and sustainable harvests. The only contaminants considered were oiling of birds and mammals and plastic particles in seabirds. Chemical pollution was considered to have a low likelihood of contributing to the declines of marine mammals since the 1980's. Competition from commercial fisheries was considered a major factor. (Table 4.18 in NRC 1996).

In 1997 the USFWS conducted additional studies of contaminants in various birds, rats, and two fish species (Rock Greenling and Pacific Cod), for scientific names see Table 8.1. PCBs, DDE, and polyaromatic hydrocarbon residues were detected in Bald Eagle eggs, and the eggs also contained detectable amounts of ten of the 17 inorganics analyzed (reported on a dry weight or dw basis). This included mercury levels between 0.8 and 0.9 ppm (dry weight, equivalent to about 0.12-0.17 ppm wet weight). The levels of aluminum (up to 106 ppm/dw) and strontium up to 3.7 ppm(dw) "were the highest detected in any collected avifauna specimens" (Crayton 2000). Pelagic Cormorants had up to 12.6 ppm(dw) equivalent to about 4 ppm (ww) of mercury in tissues. Mercury levels in Pacific Cod organs ranged up to 0.32 ppm(dw) and in Rock Greenling tissues up to 0.35 ppm(dw) equivalent to about 0.1 ppm wet weight. Cadmium levels were also high in Rock Greenling ranging up to 3.7 ppm(dw) with a single outlier of 31 ppm (Crayton 2000). Lead levels on Amchitka birds and mammals were very low (mainly below detection level of 0.5 ppm), although Rock Greenling had up to 14 ppm (dw) in tissues.

Burger and Gochfeld have undertaken several analyses of metal patterns in bird feathers as a bioindicator of heavy metal pollution. In the Pacific Basin, Burger and Gochfeld (1995) established a biomonitoring program for using seabirds as top trophic level predators (for example Burger and Gochfeld 2000a, 2000b, Burger et al. 2001a).

Comparative Data on Radionuclides in Biota

There is a large body of literature on radionuclides in Arctic and Subartic environments (OTA 1995). Much of these data have been summarized by Friedlander et al. in Appendix 2.A. Much of the sampling has been targeted to known problem areas or hot spots, such as the vicinity of nuclear fuel reprocessing centers in Europe. These tend to have levels about one or two orders of magnitude higher than uncontaminated reference sites. Results are provided in Tables 2.2 and 2.3.

The results reported in Table 2.2 and 2.3 were derived from different laboratories using different techniques and reporting methods. Some studies reported detection levels; others did not. The minimum detectable activity (or level) is called the MDA. It reflects the potential capacity of an analytical system to detect and quantify the radioactive concentrations of a specific radioisotope (for example, Cs-137 or Sr-90). The MDA is influenced by a number of factors, such as the radionuclide being tested, the counting system employed, the counting time, sample size and shape (its geometry), background interferences (or radiation levels), sample analytic counting uncertainty, etc. The MDA is independent of what concentrations are actually found. It has been stated that the MDA is "the value that one can legitimately advertise that one can measure with reasonable assurance" (Strom, 1998). A standardized process for computing MDAs were described in a classic work nearly 40 years ago, by Currie (Currie, 1968), and while methods for determining decision limits for measurements of radioactivity continue to be explored (Rigaud, 2003), Currie's approach is still a standard (Health Physics Society, 1996).

The concentrations of Cesium-137 reported for both type and location of marine fish (restricted to the Northern Hemisphere), are summarized in Table

2.3. While the pooled number of samples in some cases appears relatively small, it should be noted that up to 10,000 fish are represented by these pooled samples. Concentrations are remarkably similar, with the exception of the Irish and Baltic Seas – which have had higher residual radionuclide contaminations due to local conditions (i.e., nuclear processing facilities influencing the Irish Sea, and Chernobyl residuals as well as Russian river outflows, etc., entering the Baltic Seas). The cesium-137 concentrations in Cod are typically between 0.2 and 0.4 Bq/kg-ww, with Haddock, Plaice, Flounder, and Mackerel also in the same general range of concentrations. Values appear slightly lower in the waters near Japan and Hong Kong – areas not in the path of European reprocessing activity and far from the Chernobyl event of 1986.

Table 2.2. Average Concentrations of Cs-137 in Marine Biota: International Comparisons of Grouped Data (batches or pooled composites) from studies/surveys in which "non-detects" information is also provided. Concentrations in Bq/kg (wet weight) (see Appendix 2.A For details).

	Molluscs	**Fish**	**Crustaceans**
Atlantic Ocean - USA Coast	0.014		
Pacific Ocean - USA "lower 48"	0.23		
Sea of Japan	0.017*	0.096	
Sea of Okhotsk	< detect		
Hong Kong- South China Sea	< detect	0.25	< detect
Norwegian Sea	0.06	0.29	0.12
North Sea		0.28	
Barents Sea		0.29	
Irish Sea**	3.98	4.64	1.45
Baltic		7.88	
Channel		0.16	
North Atlantic(European)		0.81	

*= data grouped into “shellfish”
* Near the Sellafield Nuclear fuel reprocessing plant.

Table 2.3. Average concentrations of Cs-137 in fish from various studies in the northern hemisphere. All results in Bq/kg wet weight.

Location/Sea	Species	Cs-137 Bq/kg(ww)	
Japan	Flounder	0.05-0.09	
	Greenling	0.12	Japan Chemical Analysis Center, 2003
	Rockfish	0.05-0.09	
	Tilefish	0.12	
Hong Kong	Hair Tail	0.1	Li and Yeung, 2003
	Melon Coat	0.04	
Arctic Sea	Cod	0.2	Jensson et al, 2004
	Flounder	0.3	
	Haddock	0.3	
	Sculpin	0.3	
Barents Sea	Cod	0.29	Gafvert et al, 2003
	Haddock	0.2	CEFAS, 2003 & 2004
			Ryan et al, 2003
Norwegian Sea	Cod	0.32	Gafvert et al, 2003
	Haddock	0.17	CEFAS, 2003 & 2004
	Mackerel	0.14	Ryan et al, 2003
	Saithe	0.27 to 0.64	
N. Atlantic (European)	Cod	0.28	CEFAS, 2003 & 2004
	Haddock	0.47	Gafvert et al, 2003
	Mackerel	0.09	
	Plaice	0.36	

The data on radionuclides in biota are dispersed through unpublished and published literature. CRESP has synthesized this (Appendix 2A). Future studies should be targeted to representative species that can be obtained over a broad range, and are of interest and importance to stakeholders (Burger and Gochfeld 1996). Standardized collection and analytic methods achieving sensitive detection levels are clearly desirable.

APPENDIX FOR CHAPTER 2 (See attached CD-ROM)

2.A. A Review of Radionuclides in the Marine Environment by B. Friedlander, J. Burger and M. Gochfeld.

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