DOI: 10.1007/s00267-004-0126-6

Science, Policy, and Stakeholders: Developing a Consensus Science Plan for Amchitka Island, Aleutians, Alaska

JOANNA BURGER
Division of Life Sciences
Consortium for Risk Evaluation with Stakeholder Participation (CRESP)
and Environmental and Occupational Health Sciences Institute (EOHSI)
Rutgers University,
Piscataway, New Jersey 08854-8082, USA

MICHAEL GOCHFELD
CRESP and EOHSI
UMDNJ–Robert Wood Johnson Medical School
Piscataway, New Jersey 08854, USA

DAVID KOSSON
CRESP and Vanderbilt University,

CHARLES W. POWERS
BARRY FRIEDLANDER
CRESP and EOHSI
UMDNJ–Robert Wood Johnson Medical School
Piscataway, New Jersey 08854, USA

JOHN EICHELBERGER
DAVID BARNES
LAWRENCE K. DUFFY
STEPHEN C. JEWETT
CRESP and University of Alaska
Fairbanks, Alaska, USA

CONRAD D. VOLZ
Department of Environmental and Occupational Health,
Graduate School of Public Health,
Forbes Allies Center, University of Pittsburgh,
Pittsburgh, Pennsylvania, 15206, USA

ABSTRACT / With the ending of the cold war, the U S Department of Energy is responsible for the remediation of radioactive waste and disposal land no longer needed for nuclear material production or related national security missions. The task of characterizing the hazards and risks from radionuclides is necessary for assuring the protection of health of humans and the environment. This is a particularly daunting task for those sites that had underground testing of nuclear weapons, where the radioactive contamination is currently inaccessible. Herein we report on the development of a Science Plan to characterize the physical and biological marine environment around Amchitka Island in the Aleutian chain of Alaska, where three underground nuclear tests were conducted (1965–1971). Information on the ecology, geology, and current radionuclide levels in biota, water, and sediment is necessary for evaluating possible current contamination and to serve as a baseline for developing a plan to ensure human and ecosystem health in perpetuity. Other information required includes identifying the location of the salt water/fresh water interface where migration to the ocean might occur in the future and determining groundwater recharge balances, as well as assessing other physical/geological features of Amchitka near the test sites. The Science Plan is needed to address the confusing and conflicting information available to the public about radionuclide risks from underground nuclear blasts in the late 1960 s and early 1970s, as well as the potential for volcanic or seismic activity to disrupt shot cavities or accelerate migration of radionuclides into the sea. Developing a Science Plan involved agreement among regulators and other stakeholders, assignment of the task to the Consortium for Risk Evaluation with Stakeholder Participation, and development of a consensus Science Plan that dealt with contentious scientific issues. Involvement of the regulators (State of Alaska), resource trustees (U S Fish and Wildlife Service), representatives of the Aleut and Pribilof Island communities, and other stakeholders was essential for plan development and approval, although this created tensions because of the different objectives of each group. The complicated process of developing a Science Plan involved iterations and interactions with multiple agencies and organizations, scientists in several disciplines, regulators, and the participation of Aleuts in their home communities, as well as the general public. The importance of including all parties in all phases of the development of the Science Plan was critical to its acceptance by a broad range of regulators, agencies, resource trustees, Aleut/Pribilof communities, and other stakeholders.

KEY WORDS: Department of Energy; Amchitka, Alaska; Underground nuclear testing; Conflict resolution; Consensus-building; Environmental planning; Human health; Marine ecosystem; Biota; Radionuclides; Aleutians; Earthquakes

---

*Author to whom correspondence should be addressed; email: burger@biology.rutgers.edu

With the ending of the Cold War in 1989, the United States Department of Energy (DOE) was faced with the environmental management of wastes remaining from weapons development and production (called legacy waste). It was also required to develop new missions for its sites or to plan to release them for other land uses compatible with residual waste and risk. In the 1980s, the prevailing view was that contaminated sites, such as DOE sites, other defense sites, and Superfund sites, should be cleaned up to residential standards and returned to productive and unrestricted uses. In the 1990s and early 2000s, policy-makers and managers began to fully understand the enormous costs of remediation and the technological constraints to remediation and to recognize that not all land must be used for residential purposes (Burger an others 2003). There is general agreement that cleanup and remediation of contaminated sites is an important and urgent task facing the United States (Crowley and Ahearne 2002). However, cleanup itself is not without risk to workers, neighbors, and the environment (Inhaber 2001; Burger 2002; Gochfeld 2004).

Risk to workers, the public, and the environment is usually examined using the risk assessment paradigm codified by the National Research Council (NRC 1983, 1993). Even with an accepted risk paradigm, there are disparities in the assessment and management of ecological and human health risks by different governmental agencies, between federal and state agencies, and between government and other stakeholders because each can use different assumptions (Kamrin 1997). Risk assessment depends on characterization of the hazards, pathways, and receptors at risk (Burger and others 2003), a task that might be time-consuming and costly, involving facilities, surface contamination, and groundwater contamination. The task becomes more difficult as the depth of radionuclide contamination increases. For the underground nuclear test cavities, characterizing the risks is complicated by the difficulty of examining the source, pathways, and time course of potential risks to receptors. Moreover, information about the radionuclides present is classified and unavailable to the public.

The characterization of the hazards and risks to human and ecological receptors has proceeded at uneven rates at the different DOE sites. Some sites are fully characterized, whereas others have received relatively little attention because of the difficulty of evaluating certain nuclear activities. The characterization task is particularly daunting for the underground nuclear test sites such as Amchitka Island, whereas the risks from surface contamination are more amenable to characterization. The DOE is moving toward closure of its contaminated sites, transfer of usable land to other DOE activities or other entities, or transfer of contaminated lands to a DOE division responsible for legacy waste management. Closure occurs when the DOE is no longer responsible for the site, although it retains legal responsibility for any radionuclide contamination. The future of Amchitka, and some other underground test sites, is for closure and institutional controls to handle any possible future risk from radionuclides left in place.

Amchitka Island (Figure 1) is a DOE site in the Aleutian chain in the northern Pacific that was the scene of three nuclear test shots in 1965, 1969, and 1971. The island was designated a wildlife preserve, part of the US National Wildlife Refuge system established in 1913, but it was released for military activity during World War II (Kohlhoff 2002). Today, it is again part of the-Alaska Maritime National Wildlife Refuge system under the aegis of the US Fish & Wildlife Service (USFWS). DOE has remediated surface contamination on the island, and it plans to "close" the site, delete it from its environmental management program, and transfer it to its office of Legacy Waste Management, which will retain responsibility for the shot cavities. DOE believes that no further remediation is required.

At the time (approximately 1970), there was considerable controversy about testing at Amchitka, including the potential health risks to humans, the serious damage to the marine ecosystem and endangered species, and the possible generation of tsunami activity. The controversy continues to the present (Kohlhoff 2002; Younker 2002), with increasing concern about the possibility of subsurface transport of radionuclides from the three test shot cavities to the marine environment (DOE 1997) and thus to the food chain. One of the primary concerns is whether the subsistence foods of the Aleuts and the commercial fish and shellfish are safe to eat. Within the DOE, responsibility for Amchitka lies with the National Nuclear Security Administration's Nevada site office (NNSA/NSO), which is also responsible for a number of other underground test sites. The DOE, State of Alaska, and federal regulators, natural resource trustees, the Aleuts and Pribilof islanders and other stakeholders disagreed about the path forward to DOE's closure of Amchitka Island.

The DOE took the position that development of a groundwater model and human health risk assessment would provided a sufficient science base to move forward to closure. Other stakeholders (including the State of Alaska) did not agree. The disagreement was solved in the signing of a Letter of Intent (12 June

2002) between the DOE and State of Alaska, which mandated that closure would be focused on the development of an "agreed upon" assessment science plan by the Consortium for Risk Evaluation with Stakeholder Participation (CRESP). The DOE would then fund the Science Plan (or some portion), which would provide the data that would serve as a basis for long-term stewardship (which includes monitoring and any required future action to reduce risk to humans and the environment). The Letter also stipulated that DOE would conclude its groundwater model and human health risk assessment in 2003 and provide the results to the relevant parties and to CRESP for inclusion in its work.

In this article, we report on the process of arriving at a consensus for this path forward as a case study to examine how different agencies and stakeholders view the role of science in decision-making. We discuss the production of a Science Plan for the characterization of the hazards and risks associated with the Amchitka underground nuclear tests to achieve closure of the site and to plan for Amchitka as a National Wildlife Refuge. All parties had to appear the Science Plan that would provide the necessary science basis for moving toward and future monitoring to protect human and ecological health. With the increasing complexity of environmental problems, particularly large-scale remediation/restoration projects, consensus building, iterative science, and management planning become more critical. Reaching a consensus on a policy for dealing with contaminated lands is a national priority and, indeed, is a priority for Europe generally (Hollins and Percy 1998). This article presents a framework for moving forward in contentious and complicated situations. We present background on the DOE and Amchitka and describe the initial agreement and the development of a Science Plan.

Background on the Department of Energy Cleanup

There are over 100 sites in 34 states in the DOE's "Complex." These sites differ greatly in size (from a few acres to over a thousand square miles), have different degrees of contamination, and are in different stages of remediation. It is potentially very costly and complex to clean up many of the DOE's sites. The degree of cleanup depends partly on future land uses (NRC 1995; DOE 1996a, 1996b; Leslie and others 1996). Some areas at these DOE sites are so highly contaminated that remediation with current technologies is not feasible or, in some cases, is not desirable, and these sites are destined for long-term storage of nuclear and chemical waste. When contaminated sites cannot be cleaned up or they have a continued mission, they become part of legacy management of nuclear wastes. This involves reducing the risks to humans and ecosystems through maintenance of security and prevention of off-site migration (DOE 1996b).

In 1989, the DOE established an Office of Environmental Management (EM) to manage the remediation tasks at their facilities (Sink and Frank 1996; Daisey 1998). Since 1994, EM's budget has averaged $6 billion a year in constant 1992 dollars (Frisch and others 1998), mostly for maintenance of facilities rather than hazard reduction. The DOE's cleanup task represents 20% of the world's environmental remediation market (Sink and Frank 1996). Clearly, the total cost to the country is enormous.

The growing realization of technological constraints, cost, and risk (to workers and the environment) led DOE/EM to conclude that cleanup should be conducted with the end land use in mind, leading DOE's EM office to articulate -a risk-based end-state vision program for its sites (DOE 2003). Cleanup and continued monitoring should be partly based on health risk to human and ecological receptors, With consideration of an end state compatible with residual contamination and risk (DOE 2003). However, the removal of radionuclides from underground test cavities in Nevada, at Amchitka, and elsewhere is not possible because of the depth of the shot cavities and the incorporation of radionuclides into the nuclear glass produced by the heat of the blasts (CRESP 2003).

Background on Amchitka Island

Amchitka Island is part of the Alaskan Maritime National Wildlife Refuge bordered on the south by the North Pacific and on the north by the Bering Sea (Figure 1). The marine biological resources in the region are of high value in cultural, commercial, and ecological terms (NRC 1996). The western Aleutians, where the North Pacific plate subducts obliquely beneath North America at 7–8 cm/year, is one of the most volcanically and seismically active regions of the world (Jacob 1984; Page and others 1991). Most of the Richter 7 quakes occur along the Pacific "rim of fire," which includes the Aleutian chain.

In World War II, the island served as a military base opposing the Japanese occupation of nearby Kiska Island. In the 1960s, Amchitka was chosen for underground nuclear tests that were too large for the Nevada Test Site. The remoteness of Amchitka, the tectonic activity (which might "hide" nuclear tests in seismic noise), and its proximity to the Soviet Union were all

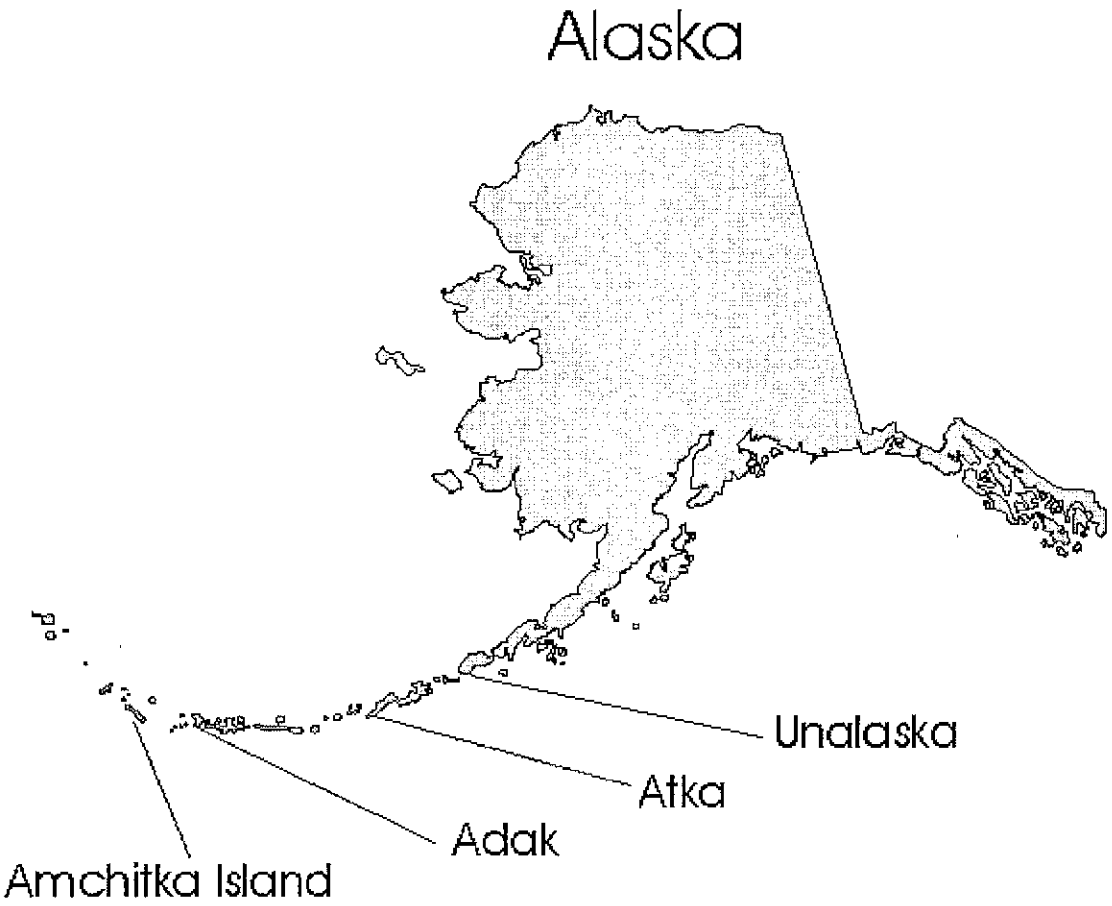

Figure 1. Map of the Aleutian chain showing the location of Amchitka Island.

considered key in the selection of the island (Kohlhoff 2002). The objections of local people and foreign governments did not change the decision to use Amchitka for the three nuclear tests in 1965, 1969, and 1971. Cannikin (1971) was the last and largest shot (5 megatons). The elevator shaft for the Cannikin shot was over 6000 ft below the surface, and the blast and subsequent subsidence resulted in a depression lake on the island surface. The three Amchitka test shots accounted for about 16% of the total energy released from the US underground testing program (Robbins and others 1991; Norris and Arkin 1998; DOE 2000), and Cannikin was the largest US underground blast. Although there was some release of radiation to the surface, the leaks were not considered to pose serious health risks at the time (Seymour and Nelson 1977; Faller and Farmer 1998).

The underground test created large cavities with glasslike walls that trapped most of the residual radionuclides. However, radionuclides were also distributed in the rubble-filled chimney and cavity. As rainfall recharges the freshwater aquifer in the island's subsurface, radionuclides dissolved in the flowing groundwater can be carried through natural faults and fissures, eventually entering the sea. The potential exists for transportation of radionuclides to the marine environment from all three cavities (DOE 2002a; CRESP 2003). No current technology exists to remediate the test cavities or to inactivate or entrap the radiation. Much of the radiation is probably already vitrified, which minimizes its hazard potential. Stakeholders, however, are concerned that information on the types, quantities, and conditions of the radionuclides in the cavities is classified, which limits the ability to plan and evaluate studies. Because there is no technology to remediate the test cavities, the only viable action is to obtain as much scientific information as possible to provide early warning so that any potential problems can be addressed as soon as possible. One key question is how much money to spend obtaining information necessary for effective stewardship of the test cavities and associated contamination.

Table 1. Key players involved in planning for the closure of Amchitka

Player	Primary goal	Secondary goals
US DOE	Closure of Amchitka Long-term stewardship	Reducing uncertainties in groundwater models and human health risk assessment
US Fish & Wildlife Service	Protection of fish and wildlife	Protection of human health and the environment
State of Alaska	Protection of human and ecological health	Long-term protection for the island's marine ecosystem
A/PIA	Protection of the subsistence foods	Protecting the marine ecosystem and maintenance of the lifestyle
Other environmentalists	Lack of radionuclides in food/biota	Watchdog for the DOE
CRESP	Protecting human and ecological health	Radionuclide levels in the food chain; gathering data for long-term biomonitoring

Public concern was voiced at the time of the tests, and formal protests were made by the State of Alaska, the Aleuts, environmentalist groups, and the governments of Japan and China (O'Neill 1994; Kohlhoff 2002). The three shots required an infrastructure on the island (buildings, roads); in 2001, the DOE removed all structures and remediated the surface contamination. Although Greenpeace (1996) concluded that surface radionuclide contamination occurred, Dasher and others (2002) did not confirm this. Nonetheless, considerable concern on the part of the 2 State of Alaska, USFWS, A/PIA, and other stakeholders existed (Table 1), as the DOE announced plans to terminate its responsibility for the island. Public concern was substantiated by interpretations of the geology and geophysics of the area, which demonstrated the plausibility that radionuclides could be transported from the shot cavities to the ocean (Eichelberger and others 2002). The DOE's groundwater model predicted that breakthrough might occur any time from 10 to 1000 years after the blasts check (DOE 2002a).

The Role of the Letter of Intent

It became clear to the DOE that the State of Alaska and other stakeholders did not consider the development of groundwater models and a human health risk assessment to be sufficient for closure of Amchitka. The State of Alaska felt (as did the USFWS and A/PIA) that more scientific information was necessary to serve as a basis for closure and implementation of long-term biomonitoring. This impasse was solved by developing a Letter of Intent among the parties that were required legally to agree on a closure plan. The Letter of Intent stipulated that an outside, independent science team (CRESP) would develop the Science Plan, in consultation with the DOE, State of Alaska, and other stakeholders (Figure 2). The Letter of Intent stipulated that NNSA (DOE/NNSA), as the responsible party, should 3 reach agreement with USFWS (as the landowner and natural resources trustee), the State of Alaska (as the state of record), and A/PIA (as the Aleut/Pribilof islanders representative). These three entities, however, do not completely represent the wide range of stakeholders for Amchitka, including the citizens of Alaska and people throughout the world who consume fish and shellfish from the North Pacific Ocean and Bering Sea.

CRESP included scientists from the University of Alaska who were already involved in relevant studies about Amchitka, ranging from subsistence consumption to geology of the region. A public workshop on the scientific knowledge about Amchitka held in February 2002 (CRESP 2002) provided the basis for the development of the Science Plan and established the importance of input from a wide range of stakeholders in the process. The Science Plan was to provide the environmental characterization needed to achieve closure and delineate the needs for future biomonitoring for Amchitka Island.

The Letter of Intent established a three-pronged process leading to closure of Amchitka: (1) the completion of groundwater models and a human health assessment by DOE's contractors, (2) the development of a Science Plan assessment by CRESP, and (3) the development of future stewardship plans (including biomonitoring) for Amchitka based on the former two. Although scientists can be expected to support the idea that "more research is needed," it should be noted that the decision to develop a science plan was taken among the signatories, without the input of scientists. The signatories then had input at all stages in the development of the Science Plan with respect to the kinds of science needed.

In this article, we use "stakeholders" to refer to any agency, group of people, or individuals that have an

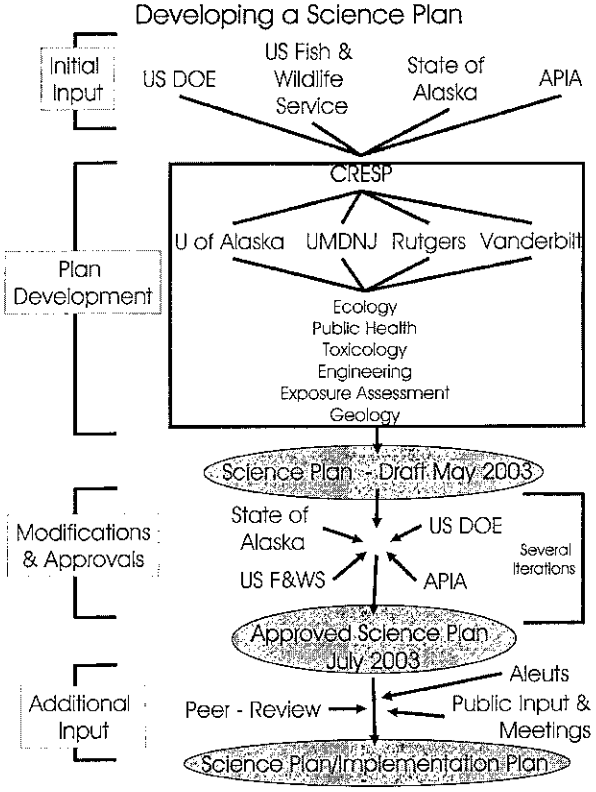

Figure 2. Model for developing a path forward toward closure of Amchitka, a DOE site with multiple agencies and stakeholders involved.

interest in the issues surrounding Amchitka. The four major stakeholders (State of Alaska, USFWS, A/PIA, and DOE) were all legally mandated to be involved in the process (see next section). Each represented either agency interests or local residents (A/PIA). In all cases, the people representing these groups were selected by the group itself. Each of the three major stakeholder groups (outside of DOE) had direct interests in the information because it applied directly to their food supply (A/PIA, Alaska Department of Health) or applied to natural resources for which they were responsible (USFWS, Alaska Department of Environmental Conservation). The general Aleut population had input through a series of meetings held in August 2003 in their villages on the Aleutians. Other stakeholders, such as the general public, had inputs through the internet and media outlets and through public meetings.

DOE's Groundwater Models and Human Health Risk Assessment

In 2003, the DOE released groundwater models developed by the Desert Research Institute and a human health risk assessment (DOE 2002a; 2002b). In our view, both were technically well done, but relied on assumptions that were not conservative or agreed upon generally. The groundwater models concluded that breakthrough of radionuclides from test cavities could occur between 10 and 1000 years following the blasts (DOE 2002a). The risk assessment concluded that even if the radionuclides reached the marine environment, there would be no adverse effect on human health because its authors assumed instant dilution (i.e., no radionuclides would reach receptors). There was no basis for this assumption, however, because breakthrough could occur in shallow water areas where marine biota (including kelp) could take up the radionuclides. Food-chain effects could then result in radionuclides reaching higher trophic level fish, birds, and marine mammals (as well as human consumers). Dilution would eliminate these risks only if breakthrough occurred far out in the deep ocean, where there were no receptors living on the bottom. Neither the groundwater model nor the health risk assessment dealt with ecological receptors.

The development of the groundwater model and a health risk assessment by DOE (DOE 2002a, 2002b) did not engender confidence in a variety of stakeholders that Amchitka did not pose a health risk to humans and ecological receptors. Critics noted that the risk assessment, from which DOE concluded that risks to the marine environment and humans would be negligible (DOE 2002b), did not use conservative assumptions. The DOE models did not use site-specific information on either contaminant levels or consumption rates by the subsistence Aleuts. Biomonitoring of radionuclide levels in biota collected around Amchitka was terminated in 1973 (Merritt and Fuller 1977), contributing to the general feeling of stakeholders that there were no firm scientific grounds for NNSA's conclusion that there was no risk to marine resources or to people consuming resources from this region. Thus, confidence was low that the models accurately represented local risks to the marine ecosystem or to humans consuming foods from these waters. Not only are there subsistence communities on the Aleutians, but the marine waters of the Bering Sea represent the largest commercial fish and shellfish resources for the united states.

Developing a Science Plan: The Role of a Multidisciplinary Approach

Developing a Science Plan for Amchitka involved a multidisciplinary approach to generating the information that was necessary to assess the hazards and risks

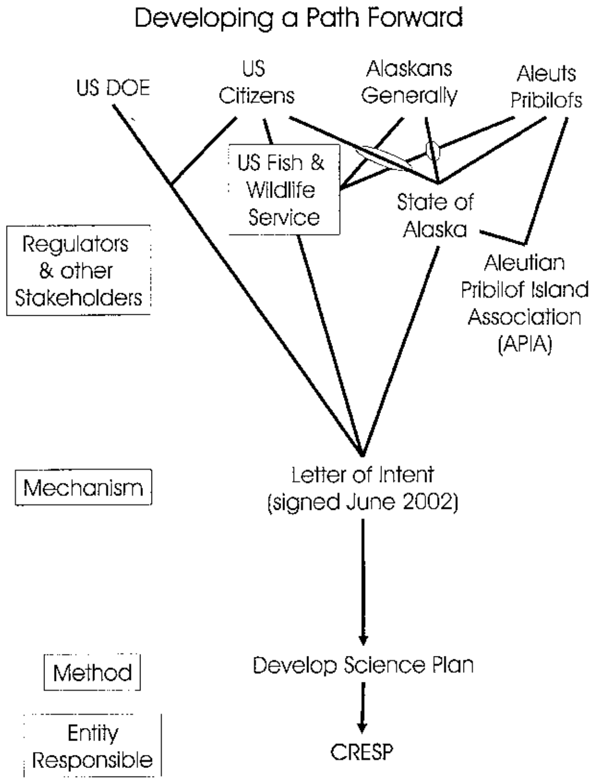

Figure 3. Model for developing a Science Plan for Amchitka Island.

Table 2. Main research areas for the Amchitka Science Plan necessary to provide sufficient information to assess current and future ecological and human health

Marine environment	Biological sampling
	Biodiversity
	Bioconcentration/bioaccumulation
	Water and sediment sampling
	Granulometry
	Laboratory analysis
	Food consumption (human)
Ocean conditions	Ocean floor structure
	Salinity structure
	Ocean circulation
Geology and hydrology	Data recovery
	Subsurface interface
	Groundwater recharge
	Radionuclide source term
	Water/rock interface
Stakeholder dimensions	Stakeholder involvement
	Synthesis for long-term monitoring

currently and in the future (Figure 3). Four major areas of inquiry were designated: the marine environment, ocean conditions, geology and hydrology, and stakeholder dimensions (Table 2). The overall objectives of the Science Plan were to determine whether current or future releases from the shot cavity to the marine environment pose a significant risk to human health and the marine ecosystem, to reduce uncertainties about the hazards and nature of the risks, and to devise and communicate an appropriate basis for a monitoring plan to detect potential significant risks in the future (CRESP 2003). From the outset, plan development involved not only scientists but also the four signatories named in the Letter of Intent, which included A/PIA (as the primary stakeholder of concern because of their subsistence lifestyle).

Numerous discussions among scientists in different disciplines and universities were followed by establishment of an Amchitka Oversight Committee. This was followed by the writing of the Science Plan itself (CRESP 2003) (Fig. 3). Within CRESP, the process was iterative, with numerous discussions of the kinds of data needed to evaluate risk to humans and the marine ecosystem, as well as the feasibility of obtaining the data. Once data needs were identified, specific research tasks could be developed, with discussions of temporal sequencing and prioritization. The tasks developed were germane to the goal of providing a comprehensive science base necessary to examine and evaluate current and future risks to humans and marine organisms. Moreover, tasks were interrelated. Data from physical oceanography could inform choice of locations for biological sampling, whereas the food consumption surveys would illuminate the choice of species for sampling.

Integrating Scientific Challenges with Political Considerations

Although the above section adequately describes the elements of the process, it does not capture the challenges in arriving at a Science Plan. Whereas some of the challenges were mainly scientific, political and philosophical considerations affected them. Others were mainly political, such as how to include stakeholders, the relative weight of different stakeholder concerns, the relative weight of human health concerns versus ecological health concerns, and the prioritization of scientific tasks. For example, was it more important to examine the safety of Aleut subsistence foods, commercial fisheries, or marine mammal/seabird food chains first? There were also logistical issues, such as the difficulty of collecting scientific data in the face of limited knowledge [e.g., sparse data on local bathymetry (profile on the seafloor)], the source term for the Amchitka shots is still classified, and the logistical challenge of working in a remote region with frequent weather interruptions.

Some of the scientific challenges included: the following 1) the nature of scientific information necessary to develop long-term biomonitoring and stewardship plans, (2) the relative roles of different kinds of information (physical geology, biology of marine ecosystems, consumption patterns of people), (3) the species for biological sampling, and (4) knowledge of uncertainties.

1. *Information needed.* The nature of information needed for development of future stewardship plans, along with the necessary assurances for human and ecological health were contentious from the start. NNSA was of the opinion that scientific data should be gathered to support their groundwater and human health risk assessments and that DOE's funds should be used only for that purpose. NNSA were adamant that radionuclides were the only contaminant of concern, even though their activities had resulted in other contamination. A/PIA, the State of Alaska, USFWS, and other stakeholders were concerned about the total contaminant (e.g., mercury, lead) environment because of the potential risk to Aleuts, pribilof islanders and other consumers (from commercial fisheries). Further, they believed that the collection of samples for analysis of other contaminants could be accomplished at the same time without much additional cost. However, NNSA refused to budge, and the other signatories had to yield on this point. The final Science Plan related only to radionuclide analysis, although NNSA agreed that samples could be archived for later contaminant studies. Further, they did not believe that they should support the collection of physical and geological information.

   The State of Alaska, USFWS, A/PIA, and CRESP believed that all the science necessary to understand the sources, pathways, and receptors in the marine ecosystem around Amchitka was essential to the development of stewardship plans. This resulted in tension throughout the process about the scope of the Science Plan, and DOE refused to budge on their initial estimate of total monies allocated to obtaining this information. The other three signatories, who had to agree to the final Science Plan, held out for designing a Science Plan that was complete. This tension resulted in several meetings and arguments that were not resolvable in totality. Ultimately, it was agreed among the four parties that a comprehensive Science Plan should be developed, including a clearly delineated subsection that would be financially supported by NNSA. This allowed all listed parties to agree to the final Science Plan while limiting NNSA's financial responsibility. NNSA did not agree that all elements of the plan were important. The source of support for the rest of the plan is still unidentified.

   Once it was agreed that a Science Plan should be developed that addressed all the data necessary to understand human and ecological risk now and in the future, the scientists began to develop a plan. At that point, tensions developed among different disciplines about the magnitude and extent of research necessary to address risk from their viewpoint. Although all parties agreed that it was necessary to determine whether there was a health risk to human or ecological receptors, it was more difficult to decide on the types of geological and physical data necessary to predict where breakthrough of contamination from the shots would occur. Ultimately, this was decided by assuming that the experts in each discipline had designed the necessary research.
2. *Relative roles of different types of information.* At the outset of Science Plan development, scientists and relevant stakeholders agreed that information was necessary on ocean conditions, geology and hydrology, marine environment, and stakeholder dimensions. However, the relative importance of these different components in both the conceptual framework and the science tasks themselves was hotly debated. The initial draft (background information, theory, and objectives) was 85% geology and hydrology, providing the necessary information to understand the underlying bedrock, seismology and volcanism, and hydrology of Amchitka and the surrounding environment. The biological component was relatively minor and entailed less than a page of the long document. Although this draft provided essential background for understanding the physical processes at Amchitka (now and in the future), it did not satisfy many of the stakeholder's concerns about the health of the marine organisms, the safety of the Aleut subsistence foods, or the potential for future risk.

   After long, agonizing, and somewhat contentious discussions, the framework was reversed to start with the receptors of concern—the marine ecosystem, the Aleut subsistence foods, and commercial fisheries. This framework then led directly to designing the types of science projects necessary to address these concerns. Sampling and analyzing radionuclides in a range of marine biota became the centerpiece of the project. The geology, hydrology, and ocean condition observations and experiments were in support of understanding the risk to the receptors in the Amchitka ecosystem, including humans as the receptor of ultimate concern. In all cases, the question became "What would the project contribute to our understanding of the risk to the marine ecosystem and the Aleut/commercial marine food supply?" Thus, the geological and hydrological studies were aimed at providing information relevant to where the breakthroughs would occur (and thus locations for biological sampling, future biomonitoring), how to predict when an event had occurred that might result in increased risk (requiring increased and immediate sampling), and how contaminants (if they reached the ocean floor) would move within the physical system (thus exposing receptors).

3. *Biological sampling.* Selection of species to collect is central to any science plan aimed at understanding the status and trends of contaminants and the potential risk to human consumers (Burger and Gochfeld 2001). After much discussion with a variety of stakeholders and with information derived from the stakeholder workshop (CRESP 2002), it became clear that were three components: the marine. ecosystem, Aleut subsistence foods, and commercial fisheries. The relative importance of each differed among stakeholders (Table 1), but all three were of primary importance to the development of a comprehensive sampling regime. Information sources on all three were used to develop a sampling protocol. Stakeholder input and the scientific literature were used to obtain information for the marine ecosystem (Merritt and Fuller 1977; NRC 1996; Brodeur and others 2002; CRESP 2002; Morkill personal communication with other biologists), for the Aleuts and Pribilof islanders (CRESP 2002; Jewett 2002; Patrick 2002), and for commercial fisheries (NMFS 2003; AFSC 2003).

   In a major breakthrough in thinking about species selection, a sampling protocol was designed that specifically addressed the three components (marine ecosystem, Aleut foods, commercial fisheries) and would be conducted by (or in collaboration with) the three interest groups. This allowed the major stakeholders to be part of the design of the research protocol and to participate in the sampling.

4. *Knowledge uncertainties and restrictions.* One of the major difficulties was that the source term (identity and quantity of radionuclides in the test shot cavity/chimney) was classified, making it difficult to attribute any radionuclides in biological samples to Amchitka itself. This could be partly overcome by using the information provided in the groundwater model, which used surrogate, nonclassified information from other tests. However, these details were not adequately clarified in the document (DOE 2002b). Information on the reconstructed source term was used to determine the most likely radionuclides for analysis.

   Second, detailed information on bathymetry was unavailable, making it essential to conduct some bathymetric studies around Amchitka. Bathymetry, particularly in the near-shore or littoral zone, is essential because it influences both the movement of water and the distribution of organisms. Both are key components of understanding risk to marine organisms. 4

There were a number of logistical problems facing the development of a Science Plan. The challenge that drove nearly all science experiments and observations was the difficulty of working in the harsh sub-Arctic environment, where weather could be unpredictable and severe. Amchitka is remote, making logistical backup and resupply difficult or prohibitively costly. Moreover, experienced field workers estimated that a third of ship time would be unproductive due to adverse and unsafe weather conditions. Although sample preparation and data analysis can be conducted during these periods, it places restrictions on the overall sequencing of scientific studies.

The final, and perhaps most important, challenge was the inclusion of stakeholders in all phases of Science Plan development and execution. An important political issue was what stakeholders to include and how and when to include them. In this regard, there were formal stakeholders (A/PIA, USFWS, State of Alaska) as well as the Aleut and general public. Just as biologists were involved in designing the ecosystem sampling component, A/PIA and other stakeholders were involved in designing the relevant components. Further, inclusion of Aleuts in the expedition to participate in sampling was regarded as an essential aspect of a complete Science Plan. Stakeholder meetings and conferences among scientists and the Aleuts occurred in August 2003 to obtain additional input into the sampling regime and choice of species to be sampled. Species of special concern to the Aleuts were added at that time.

The Science Plan and Its Approval

The Science Plan had four main research areas: marine environment, ocean conditions, geology and hydrology, and stakeholder dimensions (Table 2). Once initially developed by CRESP, the Science Plan itself was subjected to three rounds of modifications and two meetings (February 2003 and 2003) among the four primary parties (DOE, USFWS, State of Alaska, A/PIA), a variety of scientists, and the Amchitka Oversight Committee. These 2-day meetings provided an open forum for the discussion of the goals and needs of different parties and stakeholders. Compromise on the parts of all parties was essential to reaching agreement about the science needed to move forward. Stakeholders held different priorities, not all of which could be accommodated with the funding initially available. For example, DOE/NNSA initially considered validation of its groundwater and risk assessment models as its first priority (Table 1), whereas others considered assessing food safety and ecosystem health as more important. DOE/NNSA eventually agreed to the importance of assessing food safety and ecosystem health, but only for radionuclides. Not all of the components were endorsed by all parties, but the four signatories (DOE, State of Alaska, A/PIA, and USFWS) signed off on the plan in July 2003 in the interests of compromise and moving into the data collection phase.

Lessons Learned

The process of arriving at a path forward for a contentious situation in which the knowledge base was disputed involved including a wide range of stakeholders as well as the primary legal entities. Further, the inclusion of an outside, university-based consortium of scientists was essential to assuring the agencies, trustees, and public that the necessary scientific information would be gathered in an unbiased manner to assess the hazards and potential risks. Where there is disagreement between two or more agencies, and among different publics, a focus on the science information needed to address the various concerns removes the discussion from past grievances to future needs. It allows the different parties to reconcile their data needs with those of others. The group can then reach a consensus on the present data needs for assessing current and future risks. Agreeing to develop a complete Science Plan, regardless of total costs, allows different parties to include their particular data needs—funding agencies such as the DOE can then agree to support that portion of the plan that relates to their mission. Continued iteration allows for both compromise and assessment of the importance of the different components.

Because there was no possibility of cleanup of the underground nuclear shot wastes, the need for baseline data to design a monitoring scheme that would provide early warning of any potential leakage was paramount in everyone's mind. Closure of Amchitka was not possible without confidence that the scientific basis was there to assess risks. Although technological solutions to any leakage are problematic, there are actions to abate any potential leakage, at least for people consuming resources from the region. Potential actions include (1) establishing a hazard zone of exclusion around parts of the island where resources would not be consumed for a given period of time, (2) limiting consumption of species with high or potentially high radiation levels, and (3) establishing guidelines for the size (or age) of organisms consumed. Establishing a database and a long-term biomonitoring scheme can provide sufficient early warning for meaningful public health initiatives. Remedies for wildlife in the region are more problematic and might rely on natural mechanisms of population recovery, although some reintroductions could be planned after ecosystem recovery.

The lessons learned include consensus building, iteration, transparency, openness, and communication (Figure 2 and Table 3). The importance of reaching consensus on a path forward depended on a credible organization to develop the Science Plan. The methods of involvement of all interested parties cannot be stressed too much. Iteration of any plans with the full involvement of not only the legally mandated parties but also other stakeholder is essential to creation and ultimate acceptance of a sound science-based approach.

Acknowledgments

We thank the people who contributed to the development of the Science Plan, including Monica Sanchez, Runore Wycoff, and Peter Sanders (Department of Energy, National Nuclear Security Administration, Nevada), Jenny Chapman (Desert Research Institute), Anne Morkill (USFWS), Robert Patrick (A/PIA), Ron King, David Rogers, and Doug Dasher (Alaska Department of Environmental Conservation), and the people of the villages of Unalaska, Nikolski, Atka, and Adak in the Aleutians. Over the year, our thinking about the characterization of contaminated sites has been influenced by B. D. Goldstein, J. Clark,

Table 3. Approaches and disciplines necessary for a complete Science Plan to characterize hazards and risks at Amchitka

Task	Disciplines
Biological sampling	Biology Statistics Exposure assessment Stakeholder liaisons
Physical sampling	Biology Geology
Radionuclide analysis	Biology Radioecology Chemists
Marine food consumption	Biology Sociology Exposure assessment Community liaisons
Ocean conditions	Environmental scientists Remediation/engineering
Groundwater recharge	Environmental scientists Remediation/engineering
Water rock interactions	Environmental scientists Remediation/engineering
Seismic activity	Geologists
Data recovery	Statistics, all disciplines
Stakeholder dimensions	Biologists, exposure assessment Sociologists Community liaisons

and A. Upton. This research was funded by the Consortium for Risk Evaluation with Stakeholder Participation (CRESP) through the Department of Energy (AI # DE-FC01-95EW55084, DE-FG 26-00NT 40938). JB and MG were also partially supported by NIEHS ESO 5022. The results, conclusion, and interpretations reported herein are the sole responsibility of the authors and should not in any way be interpreted as representing the views of the funding agencies.

Literature Cited

AFSC (Alaska Fisheries Science Center). 2003. Alaska fisheries. Available at wysiwyg://www/afsc/noaa.gov/species/pollock.htm.

Brodeur, R. D., M. T. Wildon, L. Ciannelli, M Doyle, and J. M. Napp. 2002. Interannual and regional variability in distribution and ecology of juvenile pollock and their prey in frontal structures of the Bering Sea. *Deep Sea Research II* 49:6051–6067.

Burger, J. 2002. Incorporating ecology and ecological risk into long-term stewardship on contaminated lands. *Remediation* 13:107–119.

Burger, J., and M. Gochfeld. 2001. On developing bioindicators for human and ecological health. *Environmental Monitoring and Assessment* 66:23–46.

Burger, J., M. Gochfeld, T. M. Leschine, J. R. Karr, M. Greenberg, and C. W. Powers. 2003. Shifting priorities at the Department of Energy's bomb factories: balancing protection of human and ecological health. *Environmental Management* 31:157–167.

CRESP (Consortium for Risk Evaluation with Stakeholder Participation). 2002. In Proceedings of the (Amchitka long-term stewardship workshop. CRESP/University of Alaska. Fairbanks, Alaska (held 12–14 February 2002).

CRESP (Consortium for Risk Evaluation with Stakeholder Participation). 2003. Amchitka Independet Assessment Science Plan. CRESP, Piscataway, New Jersey. Available at http:/www.cresp.org.

Crowley, K. D., and J. F. Ahearne. 2002. Managing the environmental legacy of U.S. nuclear-weapons production. *American Scientist* 90:514–523.

Daisey, J. M. 1998. A report on the workshop on improving exposure analysis for DOE sites, September, 1996, San Francisco, CA. *Journal of Exposure Analysis and Environmental Epidemiology* 8:3–8.

Dasher, D., W. Hanson, S. Read, S. Faller, D. Farmer, W. Efurd, J. Kelley, and R. Patrick. 2002. An assessment of the reported leakage of anthropogenic radionuclides from the underground nuclear test sites at Amchitka Island, Alaska, USA to the surface environment. *Journal of Environmental Radioactivity* 60:165–187.

DOE (Department of Energy. 1996a. Charting the course: The future use report. DOE/EM-0283. Department of Energy, Washington, DC.

DOE (Department of Energy). 1996b. Hanford site: Comprehensive facility and land use plan. DOE/EM-0283. Department of Energy, Washington, DC.

DOE (Department of Energy). 1997. Regional groundwater flow and tritium transport modeling and risk assessment of the underground test area, Nevada Test Site, Nevada. DOE/NV-477. Nevada Operations Office, Las Vegas, Nevada.

DOE (Department of Energy). 2000. United States Nuclear Tests July 1945 through September 1992. DOE/NV-209. . Nevada Operations Office, Las Vegas, Nevada.

DOE (Department of Energy) 2002. Modeling groundwater flow and transport of radionuclides at Amchitka Island's underground nuclear tests: Milrow, Long Shot, and Cannikan. DOE/NV-11508-51. Nevada Operations office, Las Vegas, Nevada.

DOE (Department of Energy). 2002b. Screening risk assessment for possible radionuclides in the Amchitka marine environment. DOE/NV-857. . Nevada Operations Office, Las Vegas, Nevada.

DOE (Department of Energy). 2003. Guidance for risk-based end state vision. Department of Energy, Washington, DC.

Eichelberger, J. C., J. Freymueller, G. Hill, and M. Patrick. 2002. Nuclear stewardship: lessons from a not-so-remote island. *Geotimes* 47:20–23.

Faller, S. H., and D. E. Farmer. 1998. Long-term hydrological monitoring program: Amchitka, Alaska. EPA-402-R-98-002. US Environmental Protection Agency, Washington, DC.

Frisch, M., L. Solitare, M. Greenberg, and K. Lowrie. 1998. Regional economic benefits of environmental management at the US Department of Energy's major nuclear weapons sites. *Journal of Environmental Management* 54:23–27.

Gochfeld, M. 2004. Risk-risk balancing for hazardous waste workers: alternative work, traffic fatalities, and unemployment. Risk Analysis.. 6

Greenpeace. 1996. Nuclear flashback: The return to Amchitka. Greenpeace, USA. 7

Hollins, M., and S. Percy. 1998. Environmental liability for contaminated land—towards a European consensus. *Land Use Policy* 15:191–133.

Inhaber, H. 2001. Public and occupational risks of the Nevada (USA) Test Site. *Environmental Management* 28:505–517.

Jacob, K. 1984. Estimates of long-term probabilities for future great earthquakes in the Aleutians. *Geophysical Research Letters* 11:295–298.

Jewett S. C. 2002. Radionuclide contamination in nearshore habitats around Amchitka Island, Alaska. In Proceedings of the Amchitka long-term stewardship workshop. CRESP/University of Alaska, Fairbanks, Alaska.

Kamrin, M. A. 1997. Environmental risk harmonization: federal/state approaches to risk assessment and management. *Regul. Toxicology and Pharmacology* 25:158–165. 8

Kohlhoff, D. W. 2002. Amchitka and the bomb: Nuclear testing in Alaska. University of Washington Press, Seattle, Washington.

Leslie, M., G. K. Meffe, J. L. Hardesty, and D. L. Adams. 1996. Conserving biodiversity on military lands: A handbook for natural resources managers. The Nature Conservancy, Arlington, Virginia.

Merritt M. L. R. G. Fuller(eds.). 1977. The environment of Amchitka Island, Alaska. US Technical Information Center (Report NVO-79. Energy Research and Development Administration, Washington, DC.

NCR (National Research Council). 1983. Risk assessment in the federal process. National Academy Press, Washington, DC.

NCR (National Research Council). 1993. Issues in risk assessment. National Academy Press, Washington, DC.

NCR (National Research Council). 1994. Building consensus through risk assessment and management of the Department of Energy's environmental remediation program. National Academy Press, Washington, DC.

NCR (National Research Council). 1995. Improving the environment: An evaluation of DOE's environmental management program. National Academy Press, Washington, DC.

NCR (National Research Council). 1996. The Bering Sea ecosystem. National Academy Press, Washington, DC.

NMFS (National Marine Fisheries Service). 2003. Species profiles—Alaska fisheries. Science Center of National Marine Fisheries Service, Washington, DC.

Norris, R. S., and W. M. Arkin. 1988. NRDC nuclear notebook known nuclear tests worldwide, 1945–48. Bulletin of the Atomic Scientists November/December. 9

O'Neill, D. T. 1994. The firecracker boys. St. Martin's Press, New York.

Page, R. A., N. N. Biswas, J. C. Lahr, and H. Pulpan. 1991. Seismicity of continental Alaska. Pages 47–68 *in* D. B. Slemmons, E. R. Engldahl, M. D. Zoback, D. Blackwell (eds.), Neotectonics of North America. Geological Society of America, Boulder, Colorado.

Patrick, R. 2002. How local Alaska native communities view the Amchitka issue. In Proceedings of the Amchitka long-term stewardship workshop. CRESP/University of Alaska, Fairbanks, Alaska.

Robbins, A., A. Makhijani, and K. Yih. 1991. Radioactive heaven and earth — The health and environmental effects of nuclear weapon testing in, on and above the earth. Apex Press, New York.

Seymour, A. H., and V. A. Nelson. 1977. Radionuclides in air, water, and biota. Pages 579–613 *in* M. L. Merritt, R. G. Fuller (eds.), The environment of Amchitka Island, Alaska. Report TID-26712. . Technical information Center Energy Research and Development Administration, Washington, DC.

Sink, C. H., and C. W. Frank. 1996. DOE forges partnerships for environmental cleanup. *Forum for Applied Research and Public Policy* 11:65–69.

Younker, L. 2002. How we got here: why the Amchitka site was chosen and what tests were conducted. In Proceedings of the Amchitka Island long-term stewardship workshop. CRESP/University of Alaska, Fairbanks, Alaska.