Conceptualization of Amchitka Field Work

SUMMARY

The Amchitka *Science Plan* is a comprehensive plan for the investigations necessary to provide a firm scientific basis for developing long-term stewardship plans for Amchitka, for assessing the safety of foods from marine resources in terms of radionuclides, as well as risk to biota themselves and the food web, and for reducing uncertainties in calculating contaminant movement through the groundwater and other factors considered by DOE in its report on Amchitka hydrology (DOE 2002b) and draft screening human health risk assessment (2002a). By February of 2004, CRESP leadership knew that less than one-third of the resources needed to carry out that full *Science Plan* would be available during the single season expedition and analytic follow up. Other constraints, such as designated projects and safety concerns shaped the scope and sequence of CRESP work. Nevertheless, CRESP's Amchitka leadership team developed a conceptual framework to guide the geophysical and biological field work actually conducted by CRESP, subsequently analyzed and summarized in this report. In this chapter, we discuss the answers to the following questions:

What concepts shaped the relative priority given to the different projects found in the plan, and how was that overall conceptual plan changed due to financial and timeline constraints?

What concepts shaped the biological component?

What concepts shaped the relationships among the geophysical projects?

What concepts shaped the relationship between the geophysical projects and the biological component?

This chapter provides the framework developed to provide a conceptual basis for the projects undertaken in the Amchitka expeditions of 2004. A fuller description of each project can be found in the *Science Plan* and the results of those studies can be found in the relevant chapters of this report. The geophysical tasks included: review of prior oceanographic data and geological information, bathymetry data collection, studies to examine whether there is evidence of freshwater discharge into the ocean floor and, if so, at what depth, evidence of accumulation of sediment and the linking of this information to hydrological models earlier developed by DOE (2002b) and magneto-telluric imaging of the island subsurface near the test sites. The biological component involved the refinement of the sampling plan, the collection of biota at Amchitka and Kiska, the preparation of samples for analysis, and the radiologic analysis of samples. The final development of the projects was an iterative process of refining each project in light of the goals and objectives of the other projects in a way that was consistent with available funding and timeframes for each of the several components. A Conceptual Site Model to further depict possible pathways of exposure to critical receptors in the marine ecosystem around Amchitka helped shape that planning effort and the execution of the project.

INTRODUCTION

Environmental scientists, like environmental managers, regulators and stakeholders, are faced with understanding the complex geophysical, biological, ecological, exposure pathways to affected receptors, and contamination conditions of sites and to do so within the context of current and future land uses, current and future resource use, and potential risks to humans and the environment. Among the tools that are available to both managers and investigators, Conceptual Site Models (CSMs) can be useful in distilling the essential features of their site and the risk management challenges posed for a wide range of stakeholders. CSMs are graphic depictions of potential exposure conditions on a contaminated site illustrating sources, hazards, environmental transport, pathways and exposure routes (and barriers), and receptors (Mayer et al., 2005). They were first used in the assessment process by the U.S. Environmental Protection Agency (EPA) in the late 1980s (EPA, 1987, 1988), and were later modified to include quantitative data, off-site populations, and land use characteristics (EPA, 1991, 1992). CSM's have also been used by the Department of Energy. The Office of Environmental Safety and Health developed guidance and advocated their use in the 1990's, and in 2003, CSM's were specifically delineated and required in the Guidance that accompanied the Department's Risk-Based End States Policy (455.1, 2003) for those DOE sites where RBES Vision Statements were written. CSM's have generally been used where there are a number of remediation decisions or choices, and/or multiple future land use options. Since there are no remediation options for the radiation trapped in and around the underground nuclear test cavities at Amchitka, why were they used by CRESP to guide its work?

The function of the CSMs is to identify all critical exposure pathways and receptors (ecological receptors as well as humans) since this tool enhances our understanding of ecological and human exposure pathways, and thus helps improve risk assessment. CSMs could then be available to guide any response actions aimed at keeping receptors away from these pathways in the event such precautions are ever needed. The task of attempting to sort through which of these factors would be key to scientific work to understand those exposure patterns as they would affect a marine environment where nuclear test shots had been conducted at various depths in a remote island is especially challenging and difficult to understand. From the inception of this project, CRESP researchers have recognized the importance of developing depictions of the relationship between these key elements of CSM's and how its proposed assessment work intended to clarify them. In early drafts of the *Science Plan*, a cartoon of a 2-year plan and the way its various elements would relate projects to evaluate those pathways with both physical and biological sampling projects was created (see Figure 7, p. 35 of the Plan). And as the full plan evolved, a graphic that sought to relate all of the recommended *Science Plan* projects to those pathways, and also to the Groundwater Model (DOE, 2002b) and to its draft Screening Risk Assessment (DOE, 2002a), was created. It sought to provide a complete picture of how all of the tasks in the entire project were related to possible movement of radionuclides in the test shots through the island's geology and hydrology and the submarine groundwater discharge into the ocean, through the marine ecosystem to possible human consumption. The full plan called for expenditures estimated to be about $11.3 million, including a small contingency. Reproduced here as Figure 3.1 is Figure 13 from p. 67 of the *Science Plan* with the specific elements of this Amchitka-specific CSM highlighted in green (as they were not in the *Science Plan* document itself).

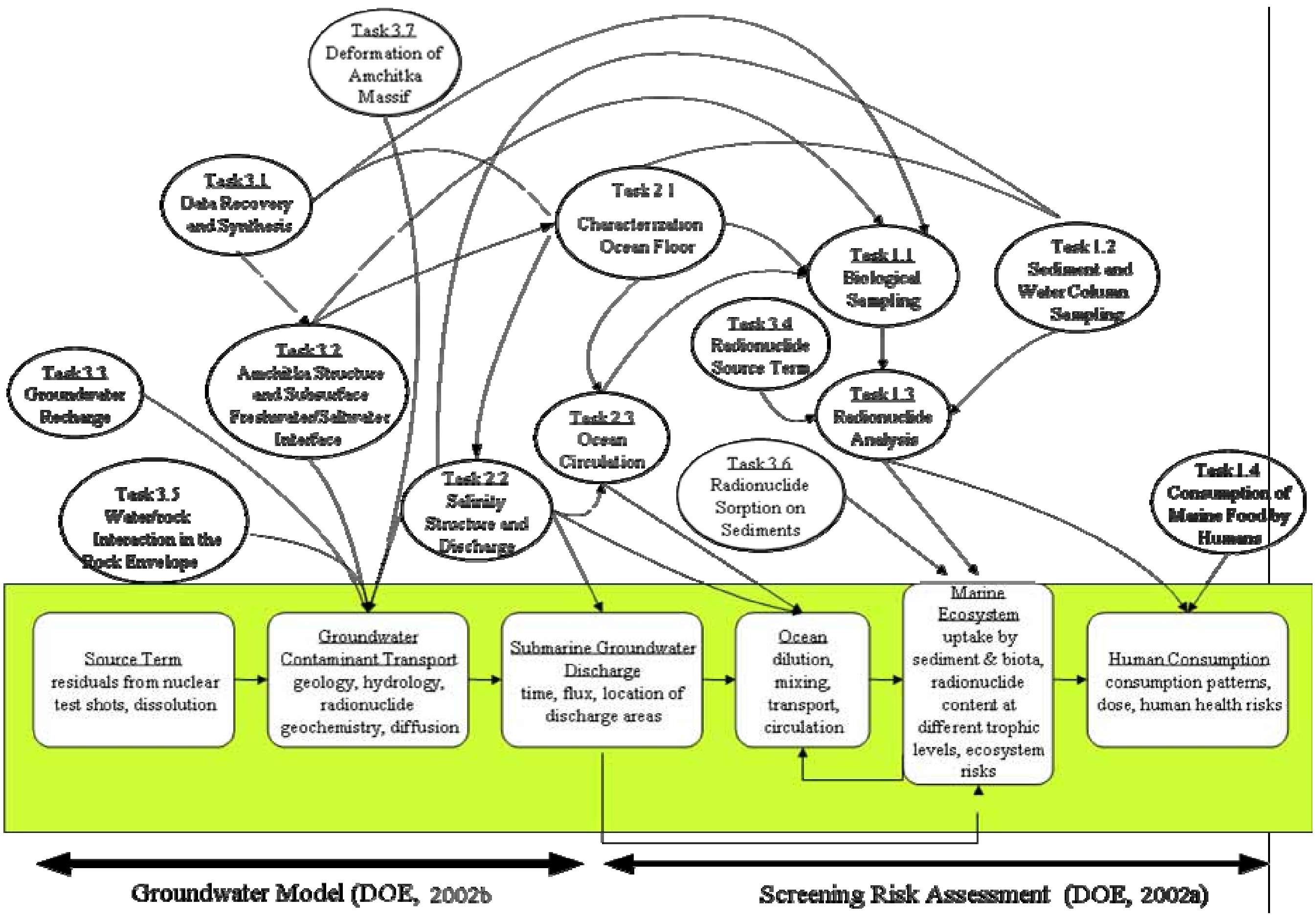

Figure 3.1. Original conceptual model as found in the CRESP Amchitka Independent Assessment *Science Plan*, p. 67

The reader is referred to the *Science Plan* itself where the Plan's work is described conceptually at pp 39-54, and then to the detailed description of the studies (pp. 86-131) defined as tasks and depicted above that were designed to implement these concepts. Taken together, these tasks addressed what CRESP viewed as the main complement of the technical issues associated with an evaluation of potential radionuclide seepage at Amchitka. It is important to note that these tasks were, in fact, a focused and coherent set of projects intended to provide an integrated assessment, not a laundry list of research ideas. The full *Science Plan* represented a plan that had already been reduced in scope from the broader set of approaches and studies defined at the CRESP/UAF workshop and in other scientific discussions. For example, see pages 44-45 where the *Science Plan's* authors discuss that when seeking to understand the Amchitka substructure and the subsurface freshwater/saltwater interface, CRESP recommended the use of magnetotelluric soundings and groundwater recharge measurement where it could have called for the boring of many deep wells seeking to track groundwater contamination and thus to seek direct evidence of radionuclide movement through the Amchitka massif toward the marine environment. This option was not pursued, the plan explains, because of the enormous associated expense, the environmental damage and disruption such drilling in a wildlife habitat would cause, and the belief among CRESP researchers that a comprehensive marine sampling program could serve as a baseline for subsequent monitoring, rendering such drilling unnecessary.

Although CRESP recommended support of the full plan, the *Science Plan* as approved contained acknowledgment that full funding for the plan might not be forthcoming. What was assured at plan approval time was funding of $3.1 million, committed by DOE-EM through NNSA-Nevada to support the project. In a series of discussions among the four entities, whose approval for the *Science Plan* was required before CRESP was to proceed, a list of agreed studies was developed and the list of those studies, by task, was included in the final *Science Plan* (See p. 74). The approved plan reflects an agreement among the parties about funding priorities. It did not explore how the combination of tasks whose funding was agreed upon would actually achieve a coherent program related to a conceptual model (CRESP's or any other). No such conceptualization was developed at the time of plan and funding approval. When the approved tasks are highlighted in relation to the original conceptual model, the result is Figure 3.2. The tasks to be funded are the shaded blue tasks or parts thereof. Where only a fraction of the task was funded, the shaded area does not cover the entire task title.

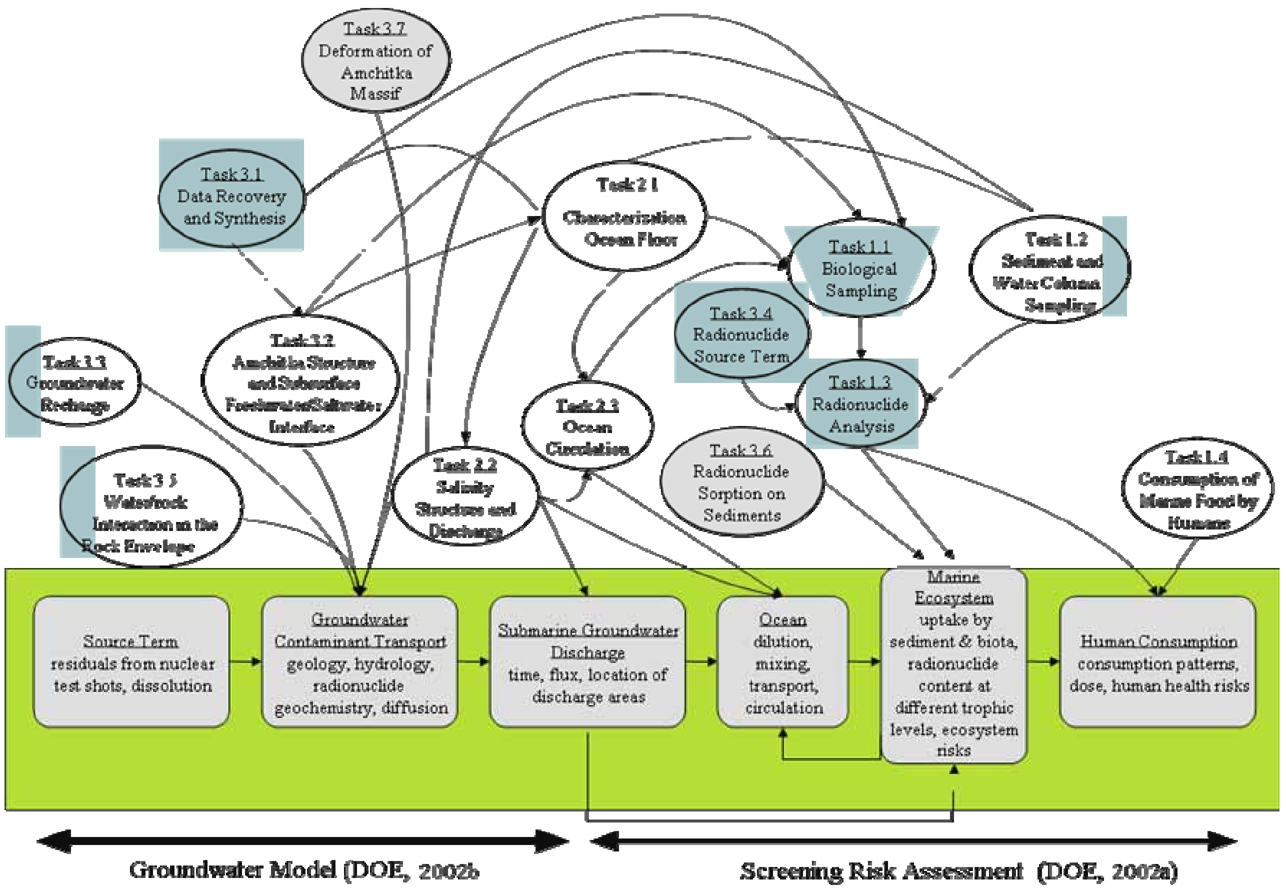

Figure 3.2. Shaded portions represent funded task (or parts thereof) from original conceptual model as found in the *Science Plan*, p. 67. Only part of the planned biological collection and analysis were funded.

As discussed in Chapter 1 (Introduction), by late February of 2004, it had become clear to the CRESP Amchitka leadership team that 1) CRESP would have just a single fieldwork season under the 2003 *Science Plan* and would need to complete its Amchitka report in 2005[1]; 2) since additional funds had not been found to fund the Plan, the resources available to CRESP would be $3.1 million (less than a third the original estimated cost of the *Science Plan*) and 3) the Interagency Amchitka Policy Group, four entities whose approval was required under the Letter of Intent, had, although clearly in active dialogue with CRESP researchers, largely stipulated which of the Plan's projects the Group considered essential to be carried out.[3] CRESP's Amchitka leadership clearly

[1] Again, for two reasons, the original goal set forth in the 2002 Letter of Intent of providing data to the various parties so that the information from it would inform a stewardship plan to be completed in 2005 had not changed and, in any event, CRESP's II own grant period would, unless extended by the Department, end in September 2005.

[3] See the final line item in the approved budget which provides $200K that is earmarked as follows: "# captures designation of $200 K to fully fund tasks as needed or to fund additional tasks." See p. 74, *Science Plan*, Appendix 1.C.

recognized that the individual tasks to be carried out in its 2004-5 work were specified, once the Plan was approved and as DOE resources began to be made available. Hence the foci of CRESP's efforts that emerged from those June 2004 discussions had largely been defined and CRESP's discretion was largely limited to being able to develop more specific plans for the approved projects and to determine whether CRESP could find savings for those tasks that might then support additional work. There was one additional constraint on both the scope and sequence of the expedition's work that emerged from development in the spring of 2004 of the required Health and Safety plan for the expedition (see Chapter 4). It was determined that the first work to be done at Amchitka should allow CRESP to assess whether its research activities either on this very remote island's surface or in the marine environment itself (at the surface and at diving depths), would pose any significant radiation risk to CRESP's research workers. In practical terms, then, it was decided that safety monitoring of the physical samples brought back to the expedition's research ship and/or taken on the surface of the island should precede or accompany activities that could create researcher exposures to either the marine or island surface environments.

Articulation of the conceptual models and its relationship to a pared down and revised conceptual framework proved essential to CRESP and to the development of this report. In the Winter and Spring of 2004, the CRESP leadership worked to convert the conceptual models it had set forth in the original *Science Plan* into a modified plan that necessarily left out many of the tasks, but sought to retain as many key elements of the plan's concepts and mission as possible. That is to say, the team consciously defined how the expedition and analysis that it would carry out with the $3.1 million available would be related to the original conceptual model. As indicated in the Introduction, the effort to redefine such a model was taking place within the context of a very complicated set of other very major logistical and timing challenges.[4] CRESP leadership was in the Spring of 2004 challenged to assess what it could reasonably (and safely) accomplish while adjusting its overall conception of what its work would contribute to the *Science*

[4] For example, CRESP needed to reach agreement on the ship that would carry it to Amchitka and to the reference site (that, as of April was still being defined), assure that it could link the time for CRESP's expedition available on that ship to the times key researchers had available, and determine what technical equipment it could secure to implement essential aspects of its work. CRESP had decided (see below) that the optimal way to achieve new bathymetric data that it could relate to earlier work at the Island was to utilize the side-scan sonar instruments that the Navy had committed to NOAA to bring to the Aleutians as part of bathymetric work NOAA was doing elsewhere in the Aleutians in the summer of 2004. NOAA could not commit to an actual timetable for its work and its use, and dates of its use, until May when certain appropriations and bidding processes were complete. And, although NOAA was fully supportive of the CRESP effort, CRESP could not move forward to forge an agreement with either the ship or with the Navy until the NOAA plans were set. By mid-May all of the issues had been decided. On the assumption that CRESP could successfully deploy this aspect of its geophysical expedition prior to the biological expedition, CRESP could then finally commit to adding an additional component, the magnetotulleric component, for on-island investigations. The final logistical pieces to assure the coordination of all these elements were not complete until just before the Ocean Explorer left port in Seattle where the ship had to be stocked with large equipment. Indeed, enormous effort was required to assure that every piece of needed equipment arrived in Adak (the CRESP launch location for all its summer 2004 expedition phases) for the appropriate phase of the expedition. These issues are further discussed in both the Introduction (Chapter 1) and in the Mounting an Expedition discussion (Chapter 4). These logistics are germane since what tasks **could** be done had continually to be matched to the **purpose** the selected tasks would serve as component parts of a coherent program.

Plan's purpose. The final development of the tasks was, of course, an iterative process of refining each project in light of the goals and objectives of the other projects in a way that was consistent with available funding and timeframes available for safe achievement of each of the several components (see Chapter 1).

Since the biological components of the Plan had been defined as essential (and the costs associated with them constituted the majority of the total estimated cost of the approved tasks) the conceptual models developed by the leader of that biological effort, Joanna Burger, were fundamental to CRESP planning. In a very real way, the other non-biological elements of the program were, conceptually, subsidiary to the biological ones in two ways. First, with a clear picture of the goals and specific needs for a sampling program well defined by Burger, the CRESP leadership could work to define some aspects of its additional work to "support" that effort with the needed data. Specifically, since CRESP had to do all of its sampling in a single season, it was essential to link efforts to better define the ocean floor where sampling would later take place and would conceptually serve to "extend" the CRESP exploration of data further from the shore in ways that could be linked (through GPS devices) with what fishing, near-shore sampling and diving sampling would show. Key elements of the conceptual models that supported the biological effort were, in fact, developed in the Spring of 2004 and those models have already resulted in an article prepared before the expedition was undertaken (Burger, et. al. in press-a). That model and its relationship to the original *Science Plan* are described here first. Its relationship to the complete model is explored later in the chapter.

That is, we discuss here:

What is the conceptual framework for the biological component?

Later sections of the chapter address the additional questions:

What conceptual model guided the geophysical projects and the relationships among the geophysical projects?

What is the relationship between the geophysical projects and the biological component?

WHAT IS THE CONCEPTUAL FRAMEWORK FOR THE BIOLOGICAL COMPONENTS?

The biological component involved the refinement of the sampling plan, the collection of biota at Amchitka and Kiska, the preparation of samples for analysis, and the radiological analysis of the samples. A complete conceptual model to depict possible pathways of exposure to critical receptors in the marine ecosystem around Amchitka for the biological component actually involved the development of three conceptual site models (CSMs) for Amchitka Island as a method of exploring how hazards and risks can be viewed for a site with long temporal and large spatial scales of hazards, with potential for large-scale exposure if it occurs, and when there exists no current technology for hazard elimination or blockage of the underground pathways from the test shots. We developed one CSM that is modeled on other CSMs developed for other nuclear test shots sites by the DOE, an expanded CSM that is specific to Amchitka itself and includes a wide array of receptor groups, and a third CSM that includes the wider Aleutian region. We also developed an extended list of receptor species to illustrate the range of biota at risk as a function of exposure zone and mobility.

The conceptualization of the biological component involved 1) Developing Conceptual Site Models for exposure pathways and receptors, and 2) Refining the overall biological collections to reflect the expanded receptor matrix. As already noted, Conceptual Site Models (CSMs) typically portray complex physical, ecological, and contamination conditions on sites. Complete CSMs include sources, environmental media (air, water, soil, food), pathways of environmental transport, indications of any barriers or remedies that exist or are proposed, and actual or potential pathways to human and ecological receptors. Their accompanying texts typically provide failure analyses for such barriers. Conceptual Site Models should be part of a larger decision support process that includes collection, analysis and interpretation of data within a framework of stakeholder participation, because they clarify and focus the information contained in complex tabular, graphic, and text presentations from risk assessment and environmental impact analysis (Bardos et al., 1996). It should be noted, however, that CSMs are theoretical models that should be backed up with field data for each specific site, and with input from the affected stakeholders. Because no barriers to contaminant movement are possible at Amchitka, the CRESP CSMs were developed with special care to insure that our overall sampling regime encompassed the major pathways of exposure and receptor groups. CRESP chose to collect biological data to help define the conceptual site models, rather than solely using computer models of contaminant movement. Ultimately the Amchitka data can be used effectively in the complex computer generated models of movement of radionuclides through marine environments (after Higley et al 2003a). .

Hence, CRESP developed its CSMs for Amchitka Island as a method of exploring how hazards and risks can be viewed for a site with long temporal and large spatial scales of hazards, the potential for long-scale exposure if it occurs, and where there is no current technology for hazard elimination or blockage. We developed one CSM that is modeled after other CSMs developed for other DOE test shots sites, an expanded CSM that is unique to Amchitka itself, and a third CSM that includes the wider Aleutian region (see Appendix 3.1). Amchitka Island, and its surrounding marine ecosystem, is unusual among DOE-contaminated sites because of its remoteness, its relationship to a marine environment, and the importance of its ecological resources and seafood productivity. CSMs are particularly valuable for both guiding the plans for and implementing long-term stewardship, where contamination is left in place, and where CSMs provide insights on pathways and the nature and extent of the receptors at risk.

Because these models were developed in the sSpring of 2004, before CRESP had its own new data, the assumptions used about where in the sea the contamination might appear were those that had been developed in the preparation of the *Science Plan,* as is seen on the attached graphic:

Initial Biological Component CSM's

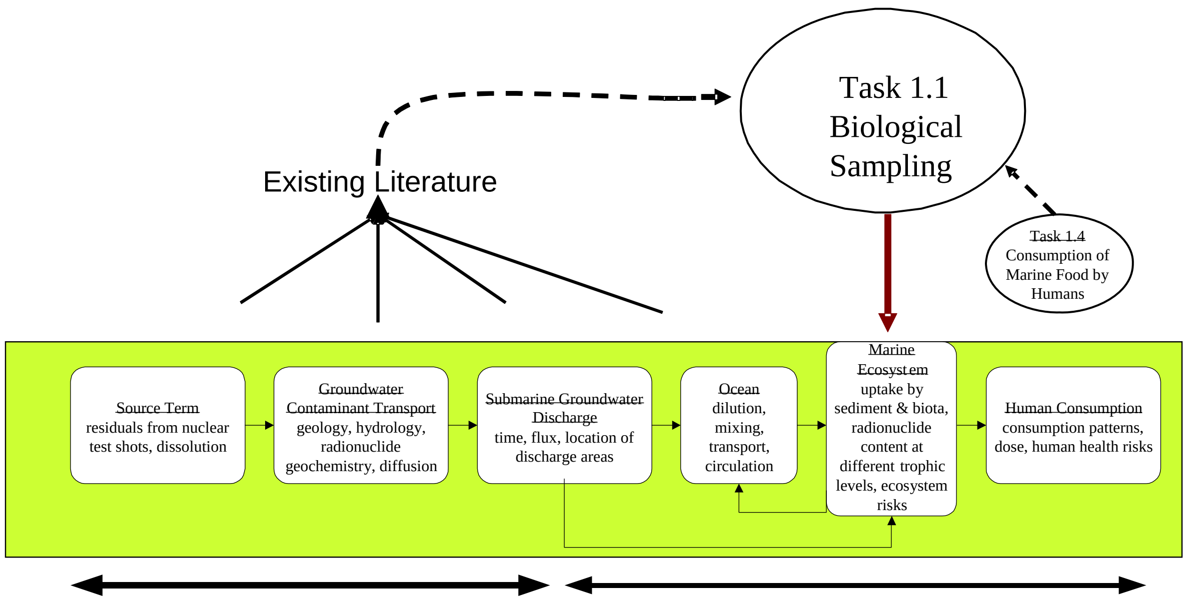

Figure 3.3. Relationship of biological component and conceptual models to total *Science Plan* conceptual model as their inception. Note: source term information is classified. Task 1.4 was not funded.

From the development of the *Science Plan*, CRESP had summarized the available data about how during an underground nuclear test, intense heat melts adjacent rock, creating a cavity of molten rock (Laczniak et al., 1996), and rapid cooling turns it into glass. As the rocks cool, some of the radioactive material is trapped in the glass, while other radionuclides reside outside the glass and are potentially mobile; some even ascend the rubble chimney (Smith, 1995). The resulting glass is subject to slow dissolution in groundwater and to mechanical breakdown, but the molten glass retards the rapid transport of chemicals (Kersting et al., 1999; Haschke et al., 2000).

Transport of the material depends upon the physical state of the source, local geochemistry, the extent of fractures or fissures, and local hydrology. Rainfall percolating through the soil, forming groundwater, is the main vehicle for carrying material from the vicinity of the test cavities, through the rock to the sea (Figure 3.4). Rainwater driven downward and outward by hydrostatic pressure dissolves contaminants and carries them through the fractures and fissures, ultimately releasing them into sea.

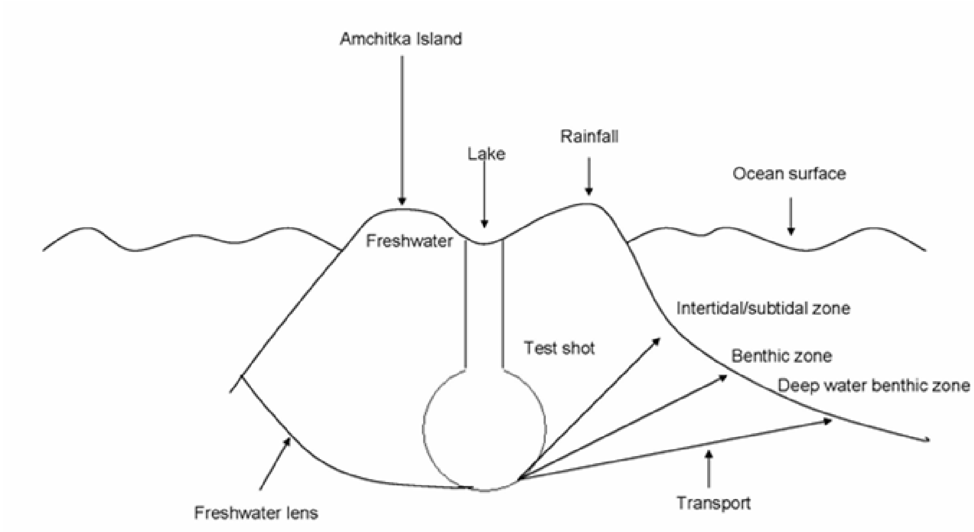

Figure 3.4. Schematic of Amchitka showing possible transport to the sea in relation to which the CRESP sampling program was developed.

In the case of Amchitka, the depth of the shot cavities, the movement of ground water, and the probable trajectory of movement from the shot cavity, means that any releases would most likely occur into the marine environment, rather than on the surface of the island itself (CRESP, 2003). The possible transport of surface contaminants by surface waters identified by Greenpeace (1996) was outside the scope of CRESP's study. The issue of concern to all stakeholders is whether or not radionuclides and other contaminants have already migrated to the sea, and if they have (or do in the future), do they provide a risk to marine food web or seafood (CRESP, 2003). Part of the objectives in developing CSMs for Amchitka is in providing another tool for understanding risks to the marine environment, in providing a model for expanded receptor matrices that could be used for other contaminated sites, and suggesting a tool that could be used for evaluating other environmental health concerns. These CSMs will also be useful risk communication tools regarding Amchitka itself, as more information becomes available, particularly from the present study.

There are three features of Amchitka which are critical to CSM development: 1) if radionuclides are released into the sea, the primary risk is to marine receptors, not to receptors on Amchitka Island itself (other DOE CSMs deal primarily with on-site risks), 2) many marine receptors that live around Amchitka are mobile or highly mobile, and can carry radionuclides and contaminants into and out of the Amchitka system, and 3) many of the marine resources are eaten by the Aleutian people and exploited by commercial fisheries. (Figure 3.5) Thus, the potential for off-site movement is expanded to include the entire Aleutian chain, the Bering Sea, and the rest of the United States, as well as other nations.

Fig 3.5. Aleut fishing team: Ron Snigaroff with Halibut and Dan Snigaroff with Dolly Varden. (Photos J. Burger)

Although the DOE did not develop CSMs for Amchitka Island, these documents were prepared for other sites where underground nuclear test shots were conducted (e.g. DOE, 2004). These CSMs served as a model of how DOE views the exposure risks from underground nuclear test shots. Using these models as a starting point, a general CSM was developed that assumes that residual contamination from the test shots is present in groundwater, and that releases through subsurface fractures and fissures to the sea leads to direct contact or food chain exposure in the marine environment (Figure. 3.6).

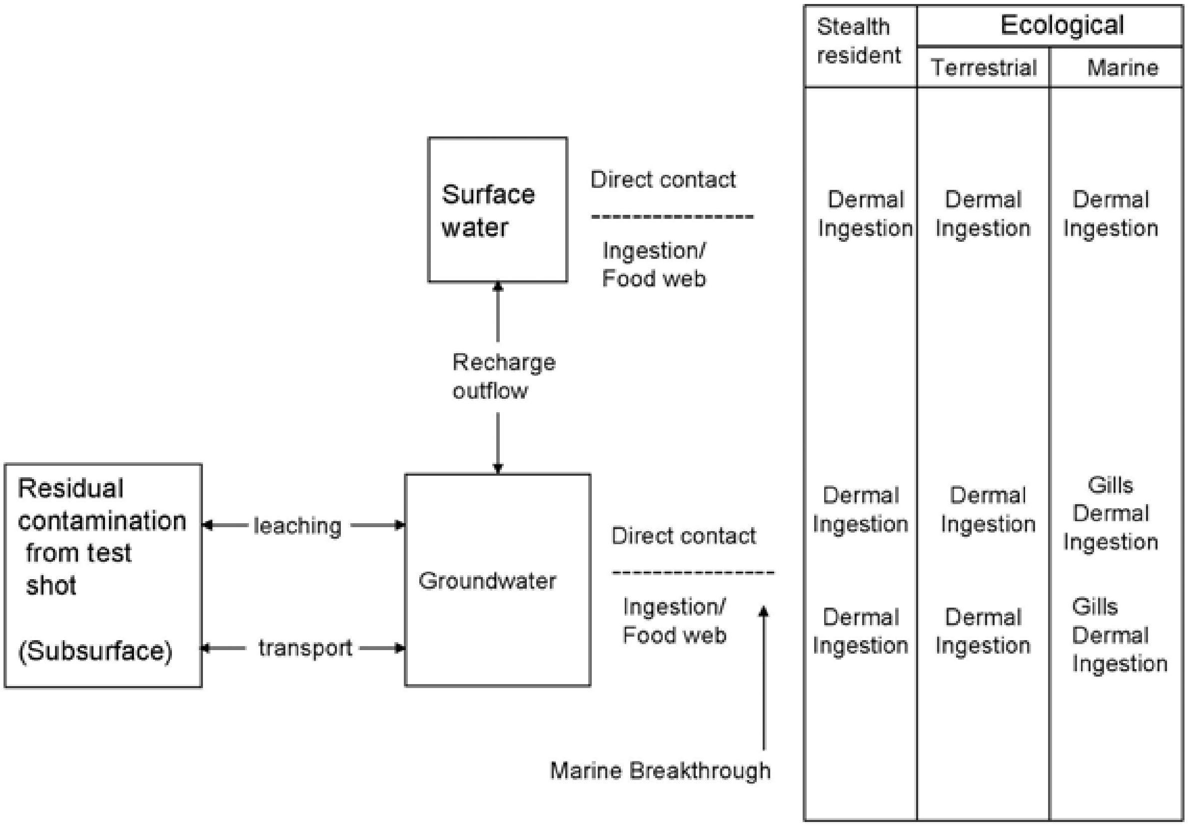

Figure 3.6. General CSM for contaminated surface and subsurface soils, modeled after the Department of Energy's CSMs for other underground test shot (after DOE 2004).

Although the possibility is extremely remote that groundwater could contaminate surface water on the island, this pathway is also included. If contaminated groundwater were to enter the marine environment, three receptor groups could be affected: a stealth resident, terrestrial ecoreceptors (that feed in the marine environment), and marine ecoreceptors. A stealth resident is someone who might live on a remote section of the island for months or years without anyone knowing about it. The major pathways would be by direct contact and food chain exposure. In the marine environment, exposure routes to biota would be dermal, ingestion, gills, and by food chain bioaccumulation (Figure 3.7).

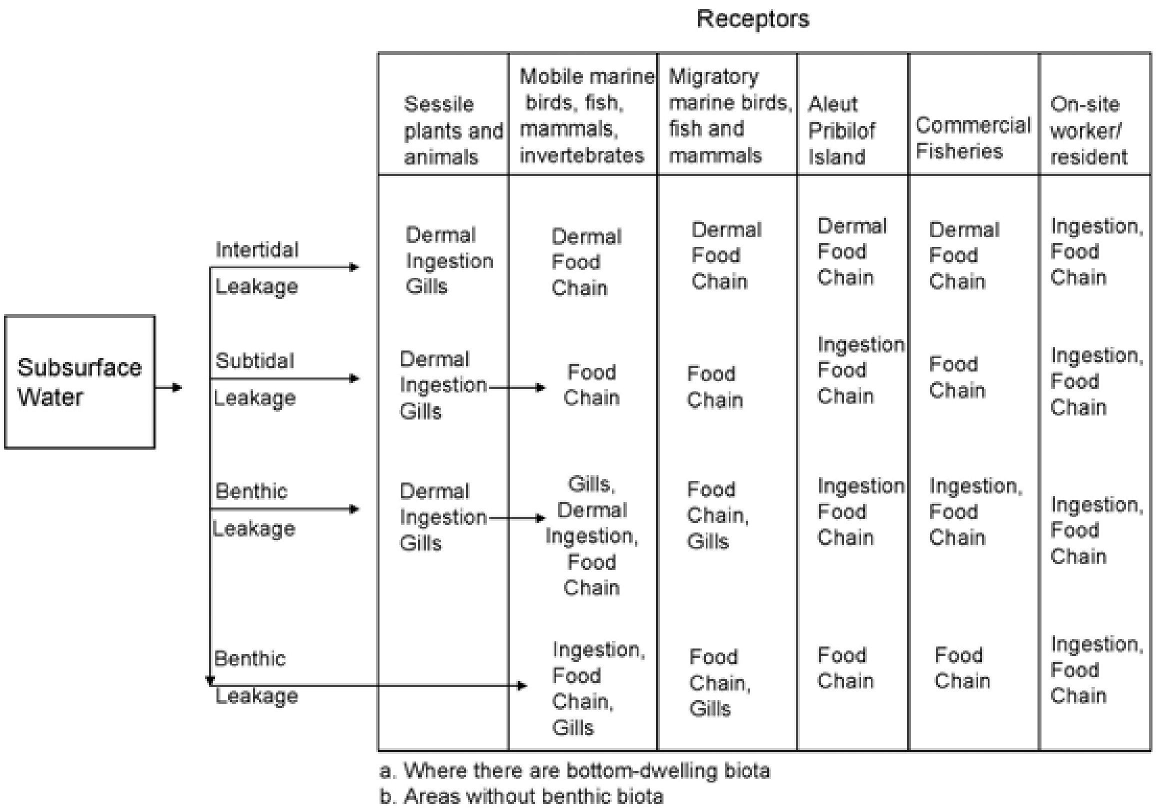

Figure 3.7. General CSM for exposure from Amchitka Island with expanded receptor matrix. The source (residual contamination from underground test shots) and associated pathways to subsurface water is shown in Figure 3.4.

However, this general CSM does not fully identify and explain all of the potential transport and exposure pathways or receptors because it does not consider the interactions and mobility of many ecological receptors that are initially exposed. In reality, transport of radionuclides to the sea floor can occur in the intertidal or subtidal regions (with and without sessile benthic organisms, such as kelp *Alaria*). The receptors then can be exposed by dermal, gills, ingestion, and through the food chain. Organisms at all trophic levels are exposed to the potential for radionuclides directly (gills, dermal, ingestion of primary producers), but also by other organisms at different levels on the food chain. Kelp, for example, are sessile plants that live in the intertidal/subtidal, and are rooted in the sediment. Their habitat exposes them to radionuclides mainly if releases occur in this zone. Exposure can involve uptake through the base or adsorption to the surface of the Kelp.

A range of ecoreceptors at different trophic levels would then be exposed through movement up the food chain. Further, humans, such as the Aleut/Pribilof Islanders or consumers of commercial fish, may be exposed by eating foods that have bioaccumulated contaminants from the water (gills, dermal), but also through biomagnification up the food chain. These features require an expansion of the pathways and receptors shown by the CSM, and require use of a matrix to depict the resources at risk (Table 3.1). The wide array of vertebrate species is of great interest to Aleuts, commercial fisheries, resource trustees, and the public. It is supported by a diverse food chain base of algae, plankton, small invertebrates, and larval fish. Many of these species live on and around Amchitka Island (see chapter 10). The productive kelp bed ecosystem around Amchitka supports abundant nearshore fishes (Estes 1978, Figure 3.8).

Figure 3.8 Kelp beds and fish (Rock Greenling) around Amchitka Island. (Photo S. Jewett)

Table 3.1 Major ecoreceptors at risk in the Amchitka Island marine ecosystem.

	Intertidal	Subtidal	Deepwater	Surface
Sessile/ benthic	Kelp (Alaria, Laminaria,Fucus) Sea Lettuce (Ulva spp.) Chiton (Cryptochiton stelleri) Blue Mussels (Mytilus trossulus) Limpets (Tectura scutum)	Mussel, Rock Jingle (Pododesmus macroschisma)		
Mobile	Bald Eagle (Haliaeetus leucocephalius) Glaucous winged gull (Larus glaucescens) Common Eider (Somateria mollissima)	Sculpin (Hemilepidotus spp.) Rock Greenling (Hexagrammos lagocephalius) Octopus (Octopus dofleini) Sea Urchin (Strongylocentrotus) Basket Star (Gorgonocephalius spp.)	King Crab (Lithodes aequispinus) Sculpin (Hemilepidotus spp.) Walleye Pollock (Theragra chalcogramma Black Rock Fish (Sebastes melanops) Ocean Perch (Sebastes alutus) Atka Mackerel (Pleurogrammus momopterygius)	Sea Otter (Enhydra lutris) Harbor Seal (Phoca vitulina) Sea Lion (Eumetopias jubatus) Bald Eagle (Haliaeetus leucocephalius) Puffins (Fratercula cirrhata) & other seabirds
Migratory	Black Oystercatcher (Haematopus)		Halibut (Hippoglossus stenolepis) Pacific Salmon (Oncorhynchus spp.) Dolly Varden (Salvelinus malma) Pacific Cod (Gandus macrocephalus)	Harbor Seal (Phoca vitulina) Steller Sea Lion (Eumetopis jubatus) Common Eider (Somateria mollissima)

The expanded receptor matrix for Amchitka should be a species matrix that provides a more complete picture of the ecotypes and species at risk. Linking the information in Table 3.1 with the receptor matrix allows managers, regulators, and other stakeholders to understand both the species and risk and the pathways of exposure. While this receptor matrix provides an indication of the types of receptors and major pathways not included in the general CSM, it still fails to identify all of the key risk factors for organisms within the marine environment because they are exposed to contamination from other sources not associated with Amchitka.

Marine systems are unbounded, and contaminants can enter the system from other sources (Figure 3.9). For example, Amchitka is potentially influenced by Russian sites of disposal of nuclear submarine wastes. Finally, atmospheric deposition from atmospheric nuclear testing has contributed to worldwide radiation exposure. Thus, while the DOE is interested in specific CSMs for Amchitka because of its legal responsibilities for the radionuclides, a broader perspective is needed for stakeholders. The Aleutian and Pribilof Islanders are particularly concerned because their traditional foods could be affected even though no one currently resides on Amchitka itself (Patrick, 2002).

There are two major sources of inputs and outputs in the Amchitka marine ecosystem: movement of contaminants themselves in water and air, and movements of the animals into and out of the system. Understanding the regional ecosystem is critical for Amchitka because some of the prevailing currents come from the west, potentially bringing radionuclides and other contaminants from the activities of Russia and other Asian countries (shown in Figure 3.10). While managers of contaminated sites may not know all the other regional sources of contaminants, it is important to diagram the known sources. There are two main possible sources of additional radionuclides into the Amchitka ecosystem: atmospheric deposition, and oceanic transport.

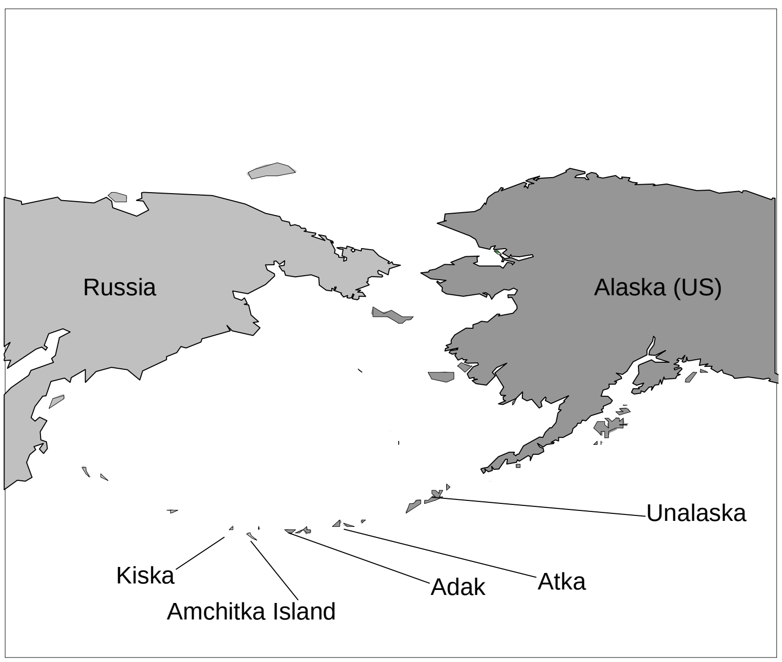

Figure 3.9. Map of Amchitka Island, in the Aleutian chain in the Northern Pacific/Bering Sea ecosystem.

Atmospheric deposition from historic nuclear testing, as well as nuclear accidents, can be divided arbitrarily into local (close to source), regional, and global. Global transport has been extensively studied for ^{90}Sr and ^{137}Cs as well as mercury, less well for other radionuclides, and has been measured directly (deposition monitoring) in sea water (Aoyama and Hirose, 2003), in soil (Holgye et al. 2004), and in biota (Kirchner and

Dailland, 2002), including on Amchitka itself (Dasher et al. 2002). Global transport generally confers a uniform distribution within a local area, although regional variations attributable to precipitation regimes exist (Simon et al. 2004).

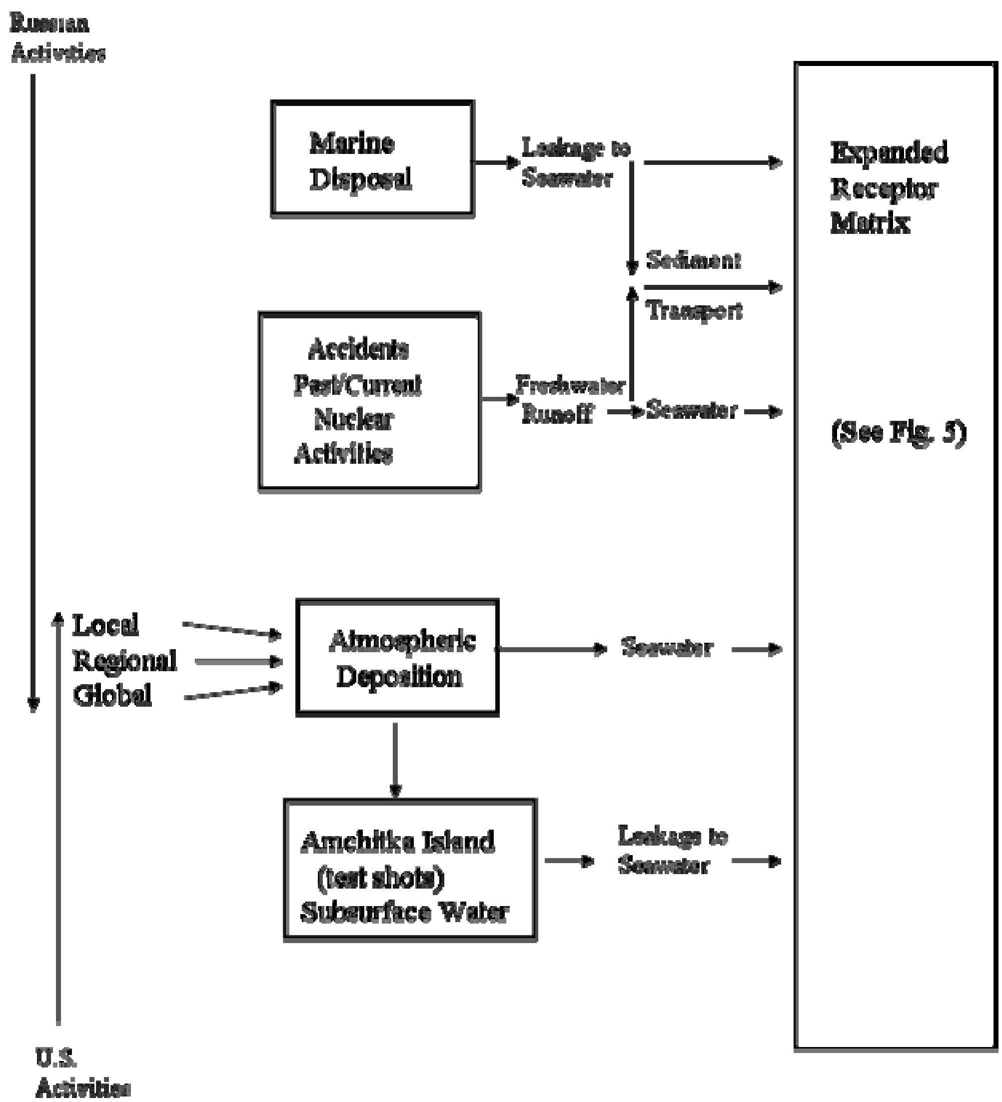

Figure 3.10. Expanded CSM for the Northern Pacific/Bering Sea ecosystem.

Radionuclide migration from numerous sources in the Former Soviet Union (FSU) threatens coastal Alaska and especially the western Aleutian Islands by a complex set of marine transport mechanisms. These pathways must be incorporated into the CSM for Amchitka Island as they may contribute significantly to levels of radionuclides in Amchitka Island seawater, sediment and biota. The factors involved in understanding this cross-Aleutian transport involve knowledge of FSU waste sites and source terms (Suokko and Reicher, 1993), the amount of nuclear waste that was directly released into the marine ecosystem, and waste that was improperly or inadequately contained and will ultimately be released over time into the marine environment (US GAO/RCED, 1995). Other important factors include weather patterns, ocean current circulation, sediment flow and transport, fishing fleet activity patterns, the globalization of the seafood markets, and fish and marine mammal range and migration patterns (for a fuller description, see Appendix 3.1).

The CSMs developed above lead directly to the sampling plan CRESP developed for the biological component. That is, the CSM (Figure 3.7) identified three main classes of receptors: 1) ecoreceptors (sessile, mobile, and highly mobile), 2) commercial fisheries, and 3) subsistence consumers. Human and ecological receptors depending on the terrestrial resources are not considered here because the current CRESP project is for the marine environment (and not the terrestrial environment of Amchitka). Our sampling plan incorporated the three types of receptors, as well as using the three types of receptors as methods of collection. That is, not only did CRESP design the sampling regime to collect biota for food chain nodes, commercial fish species, and subsistence foods, but these biota were in turn collected by ecologists (including scientist/divers), Aleuts hunters/fishers, and by a fisheries biologist on a NOAA trawl.

WHAT CONCEPTUAL MODEL GUIDED THE GEOPHYSICAL PROJECTS AND THE RELATIONSHIPS AMONG THE GEOPHYSICAL PROJECTS?

As seen earlier, the approved *Science Plan* provided only very limited resources and indefinite guidance for what could be accomplished to address the complete set of questions originally to have been addressed by the tasks defined as the geophysical science component of the plan, Originally these components had constituted about half of the estimated cost of the complete plan, but in the final approved budget for the DOE-funded portion just over 10% of the budget originally estimated for the geophysical tasks, and that final budget, allowed for only about 6% of the original geophysical expenditures. The *Science Plan's* original approach to the geophysical sciences task was defined generally at pp. 36-45 of the *Science Plan* and then the tasks defined more completely at pp. 97-132. These physical tasks are regrouped in relation to the overall conceptual model in Figure 3.11. As is seen in that figure, they can be grouped to separate out the source term, the geological deformation factors from those elements of the project that sought to understand what was the hydrological context of contaminant movement within the substructure and then to explore the context of the possible contaminantmovement within the island's marine environment.

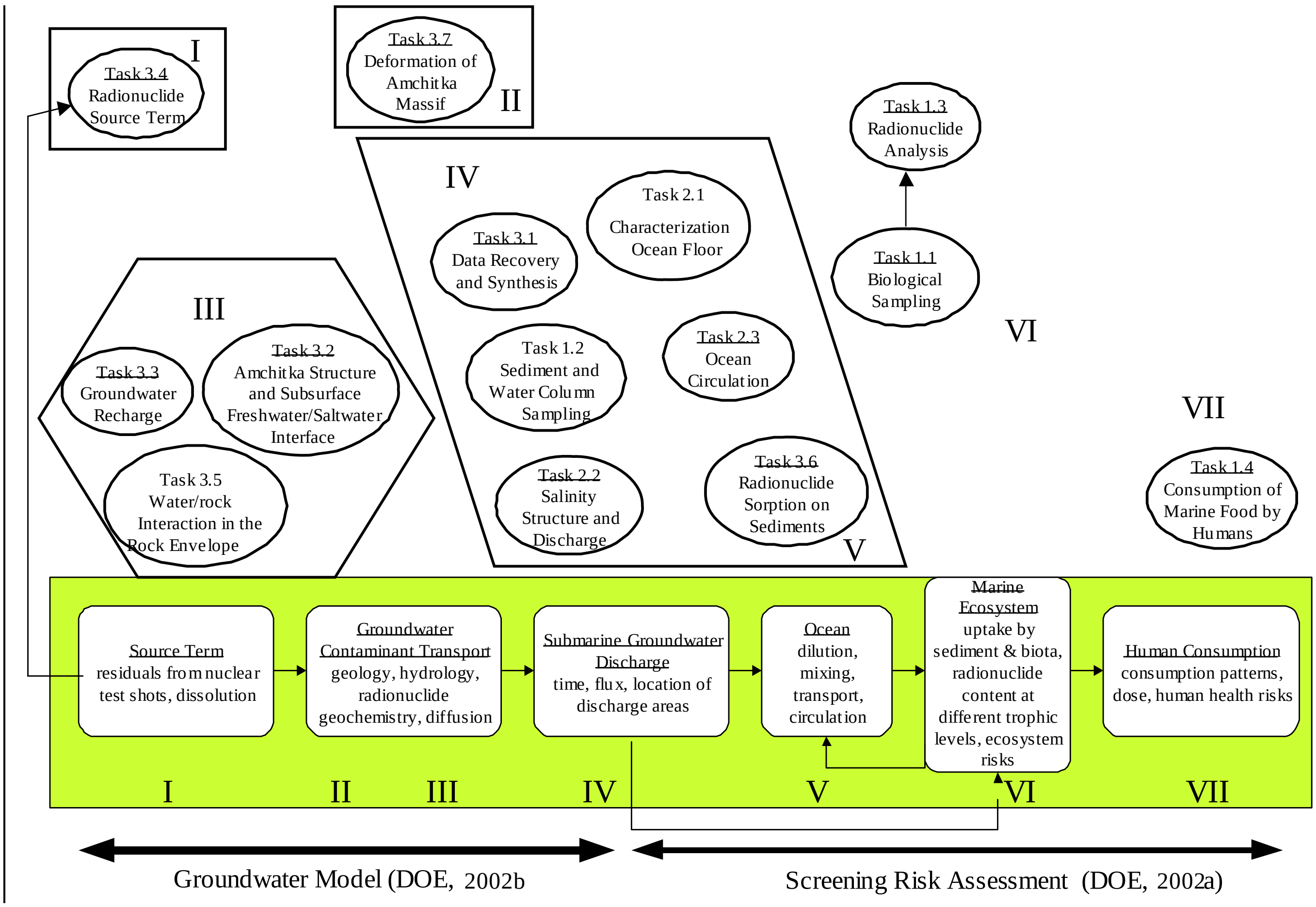

Figure 3.11. The geophysical tasks from the approved *Science Plan* grouped and related to the underlying conceptual model.

The challenge facing the CRESP Amchitka leadership team, and specifically David Kosson[5] was to determine what would constitute a coherent set of questions whose answers would address the now much more limited range of geophysical issues for which resources would be available. For two of the four tasks there was only fractional funding (physical water sampling [an 8% portion of the broader water and sediment sampling Task 1.2 as originally proposed] and water/rock interaction (primarily being supported by other UAF funding). The other directed funding was for data recovery and synthesis and for source term evaluation. If CRESP were to pursue just this limited work, there remained from the broad set of geophysical questions four major questions about the DOE hydrology model and draft screening risk assessment draft for which additional data seemed to CRESP essential:

1. *Is there evidence of freshwater discharge through the ocean floor in the areas that were previously identified as most likely to have discharge of freshwater through the ocean floor originating from the test shots?*

[5] Kosson was designated as the manager of the physical science tasks in the *Science Plan* and its development.

2. *Is there evidence of sediment accumulation on the ocean floor off-shore from the test shots?*
3. *What is the depth of the fresh-salt water interface at each test shot?*
4. *Would the use of more complex groundwater modeling approaches and newly available additional data on subsurface properties provide enhanced or alternative interpretations of contaminant transport from the test shots to the ocean floor?*

These questions could be captured graphically by a partial conceptual site model juxtaposed with the earlier Figure 3.4 graphic as follows:

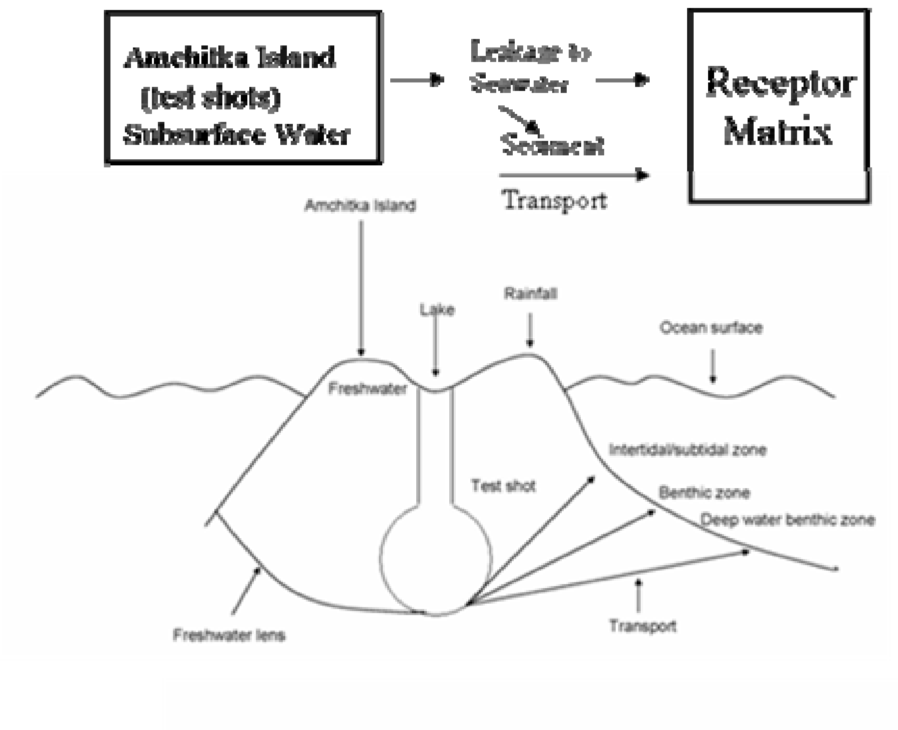

Figure 3.4. Schematic of CSM juxtaposed with graphic Amchitka showing possible transport to the sea.

Without answers to these questions, CRESP would have provided little additional understanding of the physical mechanisms that would explain what they had found in their analysis of biota in the biological components. That is, it would have provided little additional illumination for one of the major assessment purposes set for it in the original Letter of Intent, what the LOI called model verification in relation to two DOE studies (DOE 2002a, 2002b). Knowing that it faced a very broad set of uncertainties as to expenditures, but also knowing that it had begun to achieve cost savings in the evolving aspects of its work, including its logistics (such as ship costs), CRESP leadership in the Spring of 2004 endeavored to determine how best to maximize its capacity to address these questions. What evolved was the following:

1. *Is there evidence of freshwater discharge through the ocean floor in the areas that were previously identified as most likely to have discharge of freshwater through the ocean floor originating from the test shots?* This question was addressed

through the measurement of conductivity, temperature and depth (CTD) to determine salinity along transects off-shore from *Cannikin* and *Long Shot*. In addition, discrete water samples were taken from near the ocean floor at selected locations. Evidence of freshwater discharge, if found, also would be used as input to selection of biological sampling locations.[6]

2. *Is there evidence of sediment accumulation on the ocean floor off-shore from the test shots?* This question was addressed by use of sidescan sonar and collection of sediment samples from selected locations (Figure 3.12). Earlier information had indicated that the ocean floor in areas surrounding Amchitka was free of sediment because of strong ocean currents. However, if present, sediments may serve to locally accumulate radionuclides potentially discharged with groundwater through the ocean floor.[1] Pre-expedition research to recover and synthesize earlier data (one of the specifically approved tasks) under the direction of the same researcher helped facilitate needed conceptual integration to address this and the prior question.

Figure 3.12 Deploying the Sidescan sonar. (Photos D. Volz)

3. *What is the depth of the fresh-salt water interface at each test shot?* Initially, CRESP evaluated the efficacy of addressing this question by planning to fund Task 3.3, Groundwater Recharge (CRESP 2003). After equipment challenges, it was determined that a fuller range of data to address this question in a single expedition could be obtained through the use of the tools identified in Task 3.2, magnetotelluric measurements on Amchitka to image subsurface porosity and salinity in the vicinity of the test shots. This question is important because

[6] The investigations of this and the subsequent question were carried out under the direction of Professor Mark Johnson, University of Alaska Fairbanks. The full report of these results is provided as Appendix 5.A.

transport of radionuclides in the freshwater or transition zones to the ocean floor would be substantially more rapid than would occur if the test shots were in the saltwater zone. (See Figure 3.12 above) The depths of the transition zone and saltwater zone were important uncertainties in previous groundwater contaminant fate and transport modeling of radionuclides from the test shots. Additionally, the following questions were asked using the MT measurements: Can subsurface features associated with nuclear testing be imaged with MT? Can faults be detected through their effects on groundwater flow? Discussion of the MT investigation is the subject of Chapter 6.

4. *Would the use of more complex groundwater modeling approaches and limited additional data on subsurface rock properties provide enhanced or alternative interpretations of contaminant transport from the test shots to the ocean floor?* This question was addressed by developing alternative groundwater transport model scenarios in the vicinity of the *Long shot* test shot. Additional measurements were also made on porosity and diffusion rates in subsurface rock cores previously obtained from Amchitka. Discussion of these results is provided in Chapter 7.

CRESP was guided by the CSM's to these questions and then to the specific selection of tasks just described. As is seen in subsequent chapters, and then in the final synthetic review in Chapter 12, this conceptual framework, guided by CSM's, has provided CRESP with a capacity to provide and illustrate a coherent analysis of what it has found. Nevertheless, it is self-evident that there are important elements of its conceptual model for the physical studies that CRESP either deferred or did not undertake. Two are noteworthy here. We address another, Task 3.7 (concerning deformation of the Amchitka massif and the deployment of a seismic monitoring system) in Chapter 12.

Sediment and Water Column Sampling

CRESP was given very limited funds for sediment and water column sampling and analysis (Task 1.2). It was given less than 10% of the estimated costs of that project (only the physical sampling of water was supported, not radionuclide analysis). CRESP took water and sediment samples in both phases of the expedition, although (as is seen in this chapter), it was encouraged to, and did, focus on using biota, not water and sediment, as its integrator of radionuclides in the marine environment. Had CRESP been able to locate freshwater discharge points, it would have pursued more extensive analyses of the water and sediment samples. However, none of the relevant results (the CTD's results, side-scan sonar results and, in fact, the biota analyses) provided a basis for interpretation of these samples

Source Term

CRESP was given the resources to attempt to relate the specific (classified) source term at Amchitka to the results it found in biota in that marine environment. In the conceptual model, it could either have pursued that question before the expedition or wait, as it did, until the results from the sampling created specific questions raised in such analyses. CRESP very self-consciously chose to be able to target any questions that arose from its findings, and then to actively pursue how best to find out how to interpret those anomalies consistent with what it, as an entity which reports all its results publicly, could then learn about the proper interpretation of its results. The conceptual model played a key role in clarifying where in its sequence of work the issues of the classified source term would emerge. Its results did not necessitate the use of funds for that purpose. (See Executive and Chapter 12).

Figure 3.13. Ecological receptors. Bald Eagle (upper left), Dan Snigaroff and J. Burger with Halibut (upper right). Frozen fish at Atka Cooperative (lower left), and Commercial Halibut taken by long-liner (lower right). (Photos J. Burger, M. Gochfeld)

Figure 3.14. Planning group meeting in Adak between the geophysical and biological expeditions: Vikram Vyas, Dan Volz, Mike Gochfeld, Bob Patrick, Larry Duffy, Chuck Powers, Joanna Burger, Mark Johnson and Martyn Unsworth (left to right).

WHAT IS THE RELATIONSHIP BETWEEN THE GEOPHYSICAL PROJECTS AND THE BIOLOGICAL COMPONENT?

The fact that CRESP had a single field season in which to do its work meant that it needed to anticipate both how the sequence of planned work (the physical phase to precede the biological component) and the work itself might be used to improve the overall results of the project. Amchitka was, for almost all of the CRESP team, a new and very remote environment whose geography both on-island and in the immediate marine environment, would be a challenge. CRESP's conceptual models made it clear that the maximum possible linkage between its studies would dramatically improve the comprehensiveness and coherence of its results. Not only did the on-island MT work need to be linked to what the team deploying the sidescan sonar and the CTD would do, but the biological sampling had to be directly linked to both sets of studies, then the totality of CRESP's data development work could be geographically arrayed to radiate out in a coherent way from the tests shots to where the possible contamination might be found in the marine environment. This required intense planning and coordination between CRESP team members (Figure 3.14). Figure 3.11 provides a picture of how, based on the conceptual model, these three sets of tasks were linked to provide just such a coordinated overall data collection effort. The figure shows the results of that coordination:

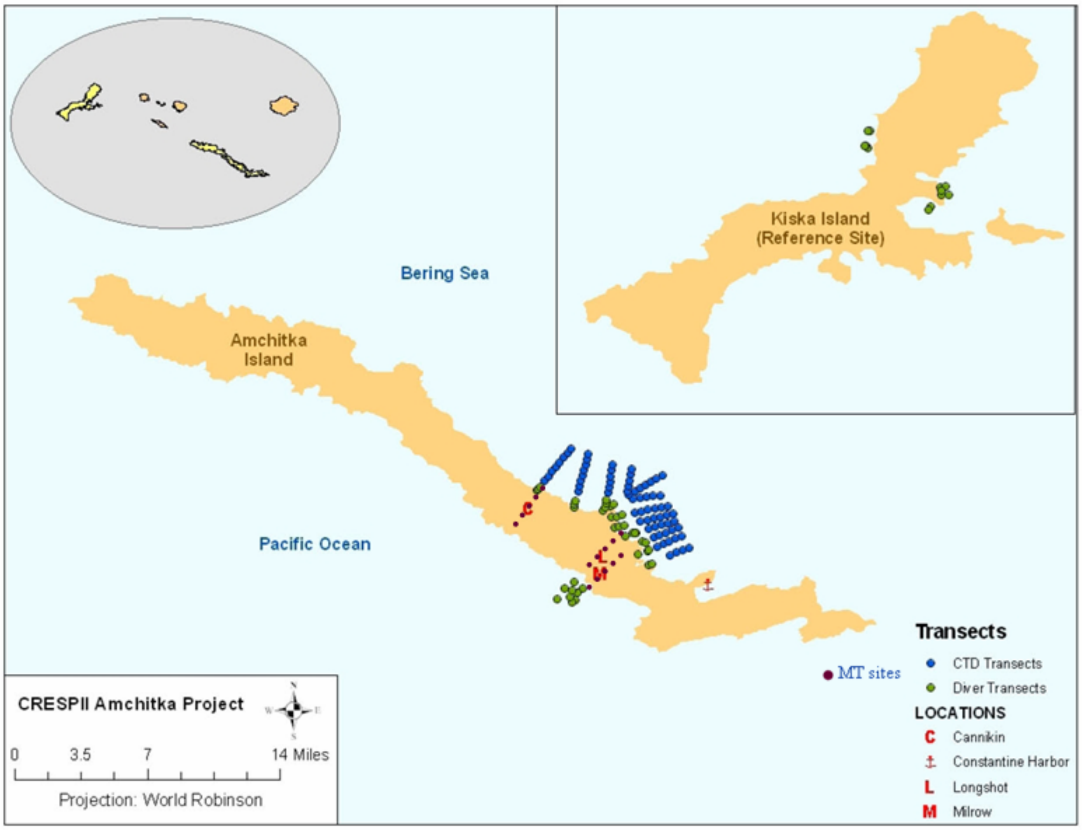

Figure 3.15. How the MT, the CTD and biological sampling regimes were organized to track the combined sampling and testing regimes.

The CTD data was collected along a series of parallel transects, centered around the best information available from the *Science Plan* and additional data recovery and synthesis in the Spring of 2004. The transects were then extended shoreward to intersect the coastline, and the biological sampling locations were then located in the intertidal, and at specified depths along the transects. This insured that the geophysical data collected was along the same transects as the biological collections. And the MT transects had similarly been coordinated with the CTD work.

To assist in the biological sampling effort, the following CRESP activities were completed:

1. Review prior bathymetry to identify ocean depths and locations of most likely discharge of freshwater originating from the test shots, and conduct new bathymetric measurements off-shore of *Cannikin* and *Long Shot*.

2. Review prior geological information to identify locations of faults that may serve as conduit for groundwater movement below the island.

3. Digitize and review historic maps and aerial photography of Amchitka.

4. Use mapping software "Blue Chart" to identify the GPS coordinates corresponding to specific depths along each of the transects.

The most important result of the interactions between the geophysical and biological scientists was evolution through the development of transects to be used by both. CRESP's pre-expedition research identified the most likely areas of discharge, which served as a basis for establishing the oceanographic transects which in turn were extended shoreward for the benthic sampling by the divers (*Cannikin* and *Long Shot*). The same methods were used to derive transects at *Milrow* and Kiska; where geophysical sampling could not be performed due to time and budget limitations. This ensured that the biological collections were made along the same transects as the geophysical sampling (Figure 3.15).

CONCLUSION

The Amchitka *Science Plan* is a comprehensive plan to gather the data needed to understand current and future potential for risk from radionuclide releases from the Amchitka underground nuclear test shots. It included a wide range of geophysical, biological, and sociological studies. However, the full plan was not funded, leaving some important aspects unexplored (such as geology, consumption studies), and others incompletely explored. This chapter provides the conceptual framework for the geophysical and biological projects undertaken on the expeditions of 2004 to Amchitka and Kiska Islands.

The geophysical and biological projects were each modified with the goals, objectives and methods of the others in mind, and thus each informed the other. Geological data was used by biologists to suggest the first location for transects (CRESP 2003), information on the likely habitats of biota (and thus of their exposure) was used to plot the initial set of transects, which in turn were modified by the geophysical scientists to select their transects. These transects were then extended shoreward to form the biological transects for collection of benthic organisms.

The conceptualization of the interrelationships of the geophysical and biological that CRESP developed provided the framework for the extensive field work conducted during the expeditions of 2004. Without the conceptualization the geophysical and biological components would have been less integrated and interdependent. The iteration provided for a synergism that improved the overall quality of the research, providing more overall understanding of the issues surrounding potential risks from any releases from the underground nuclear tests at Amchitka.

APPENDICES FOR CHAPTER 3 (See attached CD-ROM)

3.A Conceptual site Models as a Tool in evaluating ecological Health: the case of the department of Energy's Amchitka Island Nuclear Test Site by J. Burger, H.J. Mayer, M. Greenberg, C.W. Powers, C.D. Volz and M. Gochfeld

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