Final Report of the Consortium for Risk Evaluation with Stakeholder Participation

AMCHITKA INDEPENDENT SCIENCE ASSESSMENT:

Biological and Geophysical Aspects of Potential Radionuclide Exposure in the Amchitka Marine Environment

August 1, 2005

Consortium for Risk Evaluation with Stakeholder Participation II
An organization of The Institute for Responsible Management

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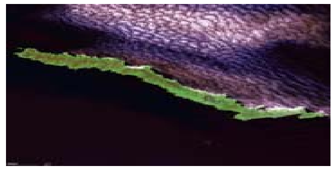

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Finally, at 9:25 in the morning of July 20, 2004, through the rocks that protect the docks at the harbor at Adak Island in the western Aleutians, I saw the *Ocean Explorer* bringing back the CRESP and Aleut researchers and with them the 3500 pounds of biota they had collected from the marine environments at Amchitka and reference site, Kiska. The two most physically challenging phases of the month and a half CRESP expeditions to implement key aspects of the Amchitka Independent Science Plan were safely completed. One additional researcher conducting a corroborative study on a NOAA trawl would return to Adak a week later. But, I believed that day, that the extraordinary logistical and technical effort that had essentially begun 2½ years earlier at a CRESP/University of Alaska workshop in Fairbanks was effectively all done -- except for the counting and charting of what we had learned on the expeditions on which we report here.

The expedition's end was, in fact, only the beginning of an equally taxing and intellectually demanding phase of work since the iterative process of developing an effective approach to the radiological analysis of such diverse biota (varied in texture, water content and many other factors) put unexpected burdens on every laboratory with whom we worked. Similarly, the task of converting the geophysical data into forms that would allow it to address important questions for augmenting what we learned from the biological analysis and at the same time putting it into dialogue with earlier work and modeling of Amchitka proved taxing and time absorbing as well.

The fact is that this report owes its existence and what I believe to be its high quality to an extraordinarily large group of committed and competent scientists, policymakers and others. We try to name those people in the lists of people identified by institution and alphabetically in the section which follows.

But there is a special subset of these people who deserve special mention. I want to begin by acknowledging the three people who, over the entire course of this effort have made what I believe to be an almost unparalleled effort because they very early on had a vision of what a truly exceptional scientific study could mean for the resolution of the issues that had shaped discussion of the possible effects of the nuclear tests at Amchitka and then doggedly and with personal sacrifice but most of all incredible wisdom and sensitivity to interdisciplinary similarity and difference have created the report you will read here. Joanna Burger, Rutgers University Professor of Biology, deserves the most explicit recognition here. It was her work with fish on the Savannah River that first caught the attention of officials in Alaska, and she took hold of this Amchitka effort soon after the winter 2002 workshop in Fairbanks and has simply helped drive the project past all obstacles. If the report gains the kind of credibility for being the archetypal study of a marine environment that I believe it is, Joanna will receive the reward she has earned. Right beside her, whether in getting fish and bird samples into the freezers on the *Ocean Explorer,* to persistently chasing down data useful for comparison or better interpretation or for quality checking both data management and data interpretation, is Michael Gochfeld, Professor of Environmental and Occupational Medicine at RWJMS-UMDNJ who like Joanna has been there through nearly every minute when the Science Plan was being formulated, when the health and safety plan was being defined and then implemented, and when the data from the CRESP study came in required expert review. Joanna and Mike together have made a consistent and sensible effort to make "stakeholder participation" not just a slogan but a reality, particularly among the Aleut people. And the third person in the trio who made this study possible is David Kosson, Chair of the Department and Professor of Civil and Environmental Engineering at Vanderbilt. Dave and I went to Fairbanks first, back in August 2000. He shaped a geophysical program that made sense in the *Science Plan* and then adjusted it wisely to sharp budgetary constraints. He has been as tireless as Joanna and Mike have been in the extremely challenging process of pursuing every analytic question and yet standing back from the data and helping us all understand the real significance of what we were learning. I truly do not believe that absent anyone of these CRESP researchers this study would have survived, let alone achieved what I believe is accomplished here. The work among the four of us from diverse intellectual perspectives was sometimes complex, but always rewarding.

That leaves an extraordinary list of people who – at the level of self-sacrifice and sheer energy and competent work – each contributed in extraordinary ways. Let me list a few of those people. From the early days, David Barnes and then John Eichelberger and Larry Duffy led the University of Alaska Fairbanks components of this effort and kept the faith through some complicated twists in the evolution of the project. David particularly has been a constant source of good judgment and belongs as one of the five editors.

When it came to leading the expedition to Amchitka and Kiska itself, Conrad Volz, PhD. of University of Pittsburgh's School of Public Health brought a lifetime of relevant experience to the enormously diverse and physically taxing

challenges of overseeing two back-to-back phases of the expedition. Steve Jewett from UAF safely led an expert diving team in treacherous conditions. Mark Johnson, also from UAF, headed a crack Navy team in exploring and interpreting the ocean bottom – both before and after the expedition. Martyn Unsworth, University of Alberta, gave a clinic on magnetotullerics to the team he took on shore at Amchitka and then converted their findings into improved understanding of the Amchitka massif. Jim Weston went further into the Aleutians than any other CRESP researcher in his expert work on the NOAA trawl. Bob Patrick and his Aleut fishers and hunters added dramatically to the authenticity of our work and to the expedition generally.

There were also teams of people in the laboratories in New Jersey, Tennessee and Idaho who refused to back down from the daunting task of preparing and getting the samples analyzed and recorded accurately while preserving the kinds of double blind processes that makes quality assurance possible. Vikram Vyas was key to the many and varied data management aspects of the analytic part of the project and went to Adak to assure he understood it well. Hank Mayer and Mike Greenberg contributed key project and interpretation help. Barry Friedlander developed the study's base for understanding how the Amchitka data compared to what other researchers world-wide are doing in marine radiological studies. Art Upton's Review Committee helped us twice: once helping us think about the Plan implementation and then assessing what we had done.

Meanwhile Lisa Bliss supported by Xiomara Waldron, Eric Siddiqui and Joy Hardy somehow kept us on track with effective project and financial management skills at CRESP headquarters.

Many non-CRESP people participated in getting this report to conclusion. Their contributions were diverse. Jerry Downing and his captains Ray Haddon and Glenn Jahnke made the process of taking researchers to the ends of the earth possible. We particularly acknowledge the contributions and critiques provided by the Interagency Amchitka Policy Group – both before, and after their approval of the *Science Plan*. Without the perseverance and good faith efforts of the leaders (and their colleagues) of the policy group to find common ground, this effort would have foundered. The following individuals were especially important:

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The degree of commitment to making this plan come alive bears absolutely no relation to resources provided or personal scientific interests preserved. There would be no plan, no expedition, no report if those factors had played the major role. As I have said throughout this project, this is a scientific work of art by talented people who have come to believe that scientific hypotheses and protocols can generate data that will help us relate earlier models to the reality of what now are the issues posed by the Amchitka subsurface and to assure that we do what is needed (and don't do what is not needed) to track those issues for the peace of mind and the well-being of those diverse communities who are affected by the waters of Amchitka far into the future.

And, yes, one other acknowledgement – one whose presence I felt especially strongly when the *Ocean Explorer* finally turned the bend into the Adak harbor – Serendipity.

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Glossary

Absorbed dose	Radiation energy deposited in tissue (usually expressed per gram or kilogram of tissue). The gray (Gy) is the Standard International (SI) unit (joules/kg).
Absorption	The process of transferring a chemical across a membrane. This can refer to the transfer of a chemical from water into microscopic organisms or from water through the gills, or it can refer to the transfer of substances from air through lung tissue into the blood stream.
Actinides	The elements from Atomic #89 (Actinium) through Atomic #103 (lawrencium). This includes uranium (U: Atomic #92) and all higher elements ("transuranics") including Plutonium (Pu) and Americium (Am).
Acute exposure	usually refers to exposure happening over a period of hours as distinguished from chronic exposure.
Alpha Particle	A particle containing two protons and two neutrons (atomic weight of 4) equivalent to a helium nucleus. Uranium, Plutonium, and Americium release alpha particles. The alpha particle has an extremely short range in tissue and it can be blocked by a piece of paper. However, they also can impart very high ionizing energy. The main risk is when the alpha particles are inhaled where they come into direct contact with lung tissue.
Anthropogenic	Not occurring in nature. Refers to elements or isotopes that are only produced through some human intervention, for example in nuclear bombs or reactors.
Atmospheric fallout	Above ground nuclear testing and nuclear accidents release radioactive materials into the atmosphere which can be transported great distances before falling back to earth either attached to microscopic particles (dry deposition) or carried by rain or snow fall (wet deposition).
Background Radiation	Radiation arising from natural sources which include cosmic radiation from outer space, natural terrestrial sources such as radium, and natural isotopes in the body. This term is used to refer to background levels of radiation in the environment (natural sources) as well as the background sources in the laboratory where samples are analyzed (both natural and artificial sources).
Bathymetry	The measurement of the depth of bodies of water.
Becquerel	Standard International (SI) Unit of radioactivity. One becquerel equals one radioactive disintegration per second. To convert becquerels to microcuries divide by 37,000.
Benthic	Pertaining to, or with the characteristics of, the benthos; also, the bottom region of a lake or sea
Beta Particle	An electron (positive or negative) emitted during decay of some isotopes. They have a short range in air and even shorter range in tissues.
Bioaccumulation	The presence of a chemical at a higher concentration in an organism compared with its food or water. The ratio of the concentration in tissue to food is called a bioconcentration factor (BF).
Biodiversity	The combined number and variety of organisms (species) that live in a particular areas.
Biota	All the plant and animal life of a particular region
Carcinogen	A substance that causes cancer. Known human carcinogens have been shown to cause cancer in people in more than one study. Probable human carcinogens have been shown to cause cancer in several types of animals and there is some data to incidate cancer in humans. Possible human carcinogens are defined by causing cancer in animals in a manner that is relevant to humans.
Centigrade-gram-second (cgs) units	A system of referring to radiation that is parallel to and convertible with the Standard International (SI) units. This uses curies, rads, and rems instead of Becquerels, Grays, and Sieverts.
Cesium	An element related to potassium and sodium which is readily absorbed by the body and distributed through all tissues. Cs-137 decays by emitting high energy gamma radiation and has a half life of about 28 years.
Chronic exposure	Usually refers to exposure happening over a period of weeks (sometimes called "subchronic") to years or for a lifetime.

Conductivity	Referring to the electrical property of rocks and soil; the reciprocal of resistivity (see below). Occurs mainly in the water occupying the pore space and is proportional to salinity, hence can be used in magnetotellurics to estimate salinity-depth relationship.
Conceptual Site Model	Graphic depictions of potential exposure conditions on a contaminated site illustrating sources, hazards, environmental transport, pathways and exposure routes, and receptors.
Curie	The curie is a unit used to measure a radioactivity. One curie is the amount of radioactivity in one gram of the element Radium first discovered by Madame Curie,. It is also the quantity of a radioactive material that will have 37,000,000,000 transformations in one second. Often radioactivity is expressed in smaller units like: thousandths (mCi), one millionths (uCi) or even billionths (nCi) of a curie. The relationship between Becquerel and curie is: 3.7×10^{10} Bq one curie.
Depleted uranium	The uranium that remains after enrichment has taken place is mainly U-238.
Detectable (or a "detect"):	A count value above the MDA (see MDA) includes consideration of uncertainty.
Ecosystem	A spatial unit including the air, water, soil. (abiotic components) and all the microorganisms, plants and animals living there (biotic components). Matter is recycled through a complete ecosystem, first going up the food chain and then being recycled by bacteria and fungi. Energy is dissipated through an ecosystem, being produced at the lowest level by primary producers and then being utilized at each successive step of the food chain.
Endangered Species	A species that has been determined by the U.S. Fish and Wildlife Service and/or the State of Alaska to be "Endangered" (likely to become extinct without human intervention)
Gamma Radiation	High-energy radiation emitted by many radioactive elements. These are higher energy than Xrays. They penetrate tissues readily.
Gray	The Standard International (SI) unit of radiation dose equal to 1 joule of energy deposited in 1 kg of tissue. 1 Gy = 100 rad.
Half-life	The average time required for one-half of the unstable atoms to undergo disintegration. The biological half life refers to the time required for half of the concentration to be eliminated from the body.
Isotope	An element is defined by its atomic number which refers to the number of protons in its nucleus. The atomic weight of an element can vary depending on the number of neutrons in the nucleus. Some isotopes occur naturally while others do not. Some are stable (emitting no radiation and undergoing no disintegration) whereas others are unstable and spontaneously radioactive. The different isotopes of an element generally share the same chemical and biological properties.
Linear Energy Transfer (LET)	The radiation energy that is imparted to tissue or cells by gamma radiation or by beta or alpha particles as they fly through the tissue. Gamma is low-LET compared to alpha particles (high LET) since the latter impart greater energy, causing more ionization and inducing a greater amount of damage for each strike.
Minimal Detectable Activity(MDA)	The minimum level of radioactivity that can be distinguished as exceeding the background radioactivity reaching the counter.
Neutron	An uncharged particle that occurs in the nucleus. Neutrons are also used in reactors to bombard elements and change them. Including making them undergo fission which causes the release of additional neutrons as well as energy.
Non-detectable	A radiation count value below the MDA (see MDA)
Percolation	The downward movement of soil through spaces in gravel or soil.
Plutonium(Pu)	An anthropogenic and transuranic element. Pu-238 is used in nuclear reactors. Pu-239 (produced by bombarding U-238 with neutrons) was the form used in nuclear weapons. Pu-240 is an unwanted contaminant produced during the formation of Pu-239. The two cannot be distinguished analytically by radiation measurements, but must be separated through mass spectroscopy.
Pore spaces	The space available in a soil layer for accumulation of water (called "pore water")
Porosity	Referring to the structure of the rock and soil substrate and its pore structure occupied by water. Pores may be blind or interconnected, the latter contributing to the conductivity of the subsurface.
Rad	The cgs unit of dose (equivalent to 100 ergs deposited in 1 gram of tissue. The corresponding SI unit is the Gray (1 Gy=100 rad).
Radio Activity	The number of nuclear transformations occurring in a mass of material per unit of time. The Becquerel (Bq) is the Standard International Unit of Activity measured in disintegrations/second. The Curie (Ci) is the centigrade-gram-secong (CGS) unit
Relative biological effectiveness (RBE)	Factors are used to compare the impact of different types of radiation. Alpha particles are given an RBE of 20 compared to beta emissions, to reflect the higher linear energy transfer that they can impart.

Resistivity	Referring to the electrical property of rocks and soil governing the relationship between current density and the gradient of electrical potential measured on the earth's surface as measured by magnetotellurics. Resistivity is influenced by composition (mineral content, structure, grain size), porosity, water content and salinity. It is expressed in units of ohm-meter (ohms multiplied by length).
SI units	The Standard International nomenclature used in most of the world including the Becquerel (Bq), Sievert (Sv) and Gray (Gy).
Sievert (Sv)	The Standard International (SI) term for dose equivalent which takes into account the relative biological effectiveness. Equivalent to the rem. 1 Sv=100 rem.
Strontium-90	This beta-emitting isotope of strontium was a major component of fallout. It is chemically similar to calcium and when absorbed into the body is stored mainly in bone. Half life of Sr-90 is 28 years.
Threatened Species	A species that has been determined by the U.S. Fish and Wildlife Service and/or the State of Alaska to be "Endangered" (likely to become endangered without human intervention.
Threshold	The level of dose or exposure at which an effect just begins. Sub-threshold exposures generally cause no discernible effects. Even for a single individual there are different thresholds for different effects.
Transuranic elements	All elements with atomic number #93 or greater (uranium is atomic #92). Transuranic elements are anthropogenic.
Trophic Level	The different functional steps in a food chain from the primary producers that use sunlight to synthesize carbohydrates to the microscopic organisms and grazers (Herbivores) that consume the producers to the primary and secondary consumers and top level predators, and eventually the "detritovores" the digest dead matter and recycle the carbon, nitrogen, phosphorus, and other "nutrients"
Uranium 234	Occurs in very low levels in natural uranium, but at about a 1:1 activity ratios with U-238 in environmental samples. Half-life is 246 thousand years.
Uranium 236	Does not occur naturally but can be produced in reactors.
Uranium 238	This isotope comprised over 99% of naturally occurring uranium in the earth's crust. The half-life of uranium-238 is 4.5 billion years.
Uranium-235	This isotope is the main fission isotope that is used in nuclear weapons and reactors. It makes up less than 1% of natural uranium, but over 90% of super-enriched uranium used for bombs. The half-life of uranium-235 is 700 million years.

List of Abbreviations

A/PIA	Aleutian/Pribilof Island Association
ADEC	State of Alaska, Department of Environmental Conservation
AMT	Audiomagenetotelluric
AUNTS	Amchitka Underground Nuclear Test Site
CRESP	Consortium for Risk Evaluation with Stakeholder Participation
CSM	Conceptual Site Model
CTD	Conductivity, Temperature, Density
DOD	Department of Defense
DOE	Department of Energy
EIS	Environmental Impact Statements
EMC	Environmental Management
EOHSI	Environmental and Occupational Health Sciences Institute
EPA	Environmental Protection Agency
FSU	Former Soviet Union
LOI	Letter of Intent
MT	Magnetotellurics
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service
NNSA/NV	National Nuclear Security Administration, Nevada Operations Office
NOAA	National Oceanic and Atmospheric Administration
NSO	Nevada Site Office
OE	Ocean Explorer
PMP	Performance Management Plan
SNF	Spent Nuclear Fuel
USFWS	United States Fish and Wildlife Service

Executive Summary

The *Amchitka Independent Assessment Science Plan* (2003) included a complex set of geophysical and biological projects to provide the science necessary to assess whether there are currently any risks to humans and biota from radionuclides in the marine environment around Amchitka, and whether any radionuclides there could be attributable to the nuclear test shots of the 1965-1971 era. It resulted from an exchange of letters between the Governor of Alaska and the Secretary of the Department of Energy in 2000 which generated, in 2002, an agreement to request the Consortium for Risk Evaluation and Stakeholder Participation (CRESP), to develop an independent plan to study the marine environment at Amchitka Island that could be approved by diverse stakeholders.

Amchitka was the site of three underground nuclear tests: *Long Shot* (80 kilotons in 1965), *Milrow* (about 1000 kilotons in 1969), and *Cannikin* (about 5000 kilotons in 1971, the largest U.S. underground test). Questions exist about whether radionuclides from these tests could be entering the sea, whether they pose a hazard, and how this should be monitored over time. The data generated by the geophysical and biological expeditions were used to examine the safety of the foods, impact on marine ecosystems, to reduce the uncertainty in the groundwater and risk assessment models, and to provide information to develop future biomonitoring and long-term stewardship plans at Amchitka. Amchitka, located in the Aleutians between the Bering Sea and the North Paific, is one of 129 DOE sites requiring long-term stewardship, and is surely the most remote. CRESP was not tasked to perform risk assessments, or to develop the longterm stewardship plan itself.

The initial design of the *Science Plan*, refinement of the research objectives and protocols, and execution of the research involved an iterative process with a range of stakeholders, including residents of Unalaska, Nikolski, Atka, and Adak, Alaska Department of Environmental Conservation, U.S. Fish & Wildlife Service, and the Department of Energy. Only a portion of that *Science Plan* was funded, and the findings reported here are the results from the funded portion. CRESP researchers conducted three expeditions in the summer of 2004 to gather geophysical and biological data. The biologic expedition included a team from the Aleut communities, recruited by the Aleutian/Pribilof Island Association, to ensure that subsistence fishing/hunting practices were represented.

There were two main areas of study: geophysical and biological. The geophysical tasks included: review of prior oceanographic data and geological information, enhanced bathymetry data, studies to examine whether there is evidence of freshwater discharge into the ocean floor, whether there is accumulation of sediment, and evidence for the depth of the fresh-salt water interface in the groundwater below each test shot. Both the geophysical and the biological sampling were designed to maximize the possibility of detecting release of radionuclides to the marine environment from the test sites.

The CRESP study of radionuclides in biota in the marine environment around Amchitka and at Kiska (a carefully-selected reference site) had several key features: 1) It sampled marine biota from seabirds nesting on the island surface and the coast, and marine algae, invertebrates and fish from the intertidal zone to 90 foot depth, and fish from a commercial-type trawl survey. 2) It collected organisms at several trophic levels, from primary producers, through filter-feeders and grazers, to low and high level predators. 3) It collected samples from adjacent to all three test shots and Kiska, 4) It included 17 transects and 47 stations at depths ranging from 15 feet to 90 feet, and 5) It included the collection of fish by Aleuts, scientist divers, scientist fishermen, and a fisheries biologist on a NOAA trawler. Sampling was as balanced as possible, attempting to obtain each species in transects from each of the three test shots and at Kiska. Time, adverse weather, and non-uniform distribution of organisms, precluded a completely balanced design. Nonetheless, the CRESP collection is one of the most complete for one relatively small region, at one point in time.

Similarly, appropriate species and tissues were analyzed for a wide range of radionuclides of interest because of human and ecological health, and for understanding the possible source. A multi-level program for radionuclide analysis that incorporated extensive quality assurance was developed and carried out from August 2004 to the present. Since the source term radionuclide composition (that is, what radionuclides are or were expected actually to be in the test cavities after the test shots) remains classified, CRESP had to use a variety of sources to arrive at its selection of which radionuclides to analyze. These included Cs-137, Eu-152, Co-60, Am-241, Pu-238, Pu-239,240, U-234, U-235, U-236, U-238, Sr-90, I-129, and Tc-99. Most studies of radionuclides examine a far more limited range of biota and radionuclides, although some of these studies are longitudinal and thus provide information on radionuclide levels over time. The CRESP study, although completed in a single year (2004), provides a baseline for long-term monitoring.

The main conclusions from our studies are:

1. There is a wide range of biota in the benthic and intertidal habitats around Amchitka that could be at risk if radionuclides seeped into the marine environment at significant levels.

2. Some of the biota that could be exposed are sedentary, while others are more mobile. There is a potential for bioaccumulation and biomagnification up the food chain, if there were contaminated seepage in the future.

3. None of the marine organisms tested had radiation levels that would pose a threat to humans, and all results are well below published human health food safety standards and guidelines.

4. The levels of radionuclides measured in biota are within the range found in biota from other marine environments in the Northern Hemisphere, and are far below levels found in known contaminated marine areas such as the Irish Sea. They are also below any levels known to impact organisms or ecosytems.

5. The levels of Eu-152, Co-60, Sr-90, I-129, and Tc-99 were all or almost all below the minimum detection activity (MDA) levels, which, in turn, were ten times or more lower than food safety standards and guidelines. Several organisms had accumulated Am-241 to just above the MDA, but there was no pattern with respect to species, trophic level, or island. Cs-137, plutonium and uranium isotopes were found more widespread.

6. For most radionuclides, there were no significant differences between Amchitka and Kiska (the reference site) in either the number of values above the MDAs, or in the average concentrations. The number of Cs-137 levels above the MDA was significantly higher in large fish at Kiska than at Amchitka, and the number of Pu-239,240 levels above the MDA was significantly higher in kelp at Amchitka than at Kiska. However, in both cases, the differences in concentration were small, the levels were within the ranges published for other studied marine environments in the Northern Hemisphere, and the levels were well below human health food safety standards and guidelines. Moreover, the detectable levels at Amchitka were distributed among areas adjacent to all three test sites, and could not be attributable to a single test site.

7. There were differences among species in the levels of some radionuclides: high trophic level predators had higher Cs-137 levels than others lower on the food chain, and primary producers (algae) had significantly higher levels of Pu-239,240 than all others. These findings are consistent with the findings in other scientific studies in that they indicate that fish bioaccumulate cesium from the food chain and algae takes up plutonium at a rate many times higher than do other biota.

8. Substantial localized discharge of freshwater through the ocean floor within the study area was not indicated based on ocean floor salinity measurements. Thus, no specific preferential pathway (i.e., large freshwater flow through geologic faults) for contaminant migration along with fresh groundwater from test shots was found.

9. Large areas of the ocean floor in the region of the *Cannikin* and *Long Shot* test sites have significant sediment accumulations. Sediments typically have the potential to accumulate specific contaminants, supporting the need to monitor sedentary biota that may uptake contaminants present in sediment deposits.

10. Geophysical investigations indicate that all three test shots were within the transition zone between fresh and salt groundwater, and that greater subsurface pore volume was present than assumed by earlier studies, suggesting very long travel times for any contaminant migration from the test shots to the marine environment.

11. Hence, the CRESP expedition did not find either geophysical or biological evidence of recent or current radionuclide migration into the marine environment from the Amchitka test shots. The nature and spatial pattern of detectable radionuclides, do not suggest that they are attributable to the Amchitka test shots. Some additional information about where the island's own fresh water intersects the sea water in which the island sits has increased the ability for scientists to predict where and when fresh groundwater discharge and, therefore possibly contaminated seeps, will occur at Amchitka beyond what was available from earlier modeling.

12. A combination of sedentary and mobile organisms at different trophic levels would be ideal for a continued biomonitoring program at Amchitka, largely because different radionuclide isotopes concentrate at different nodes on the food chain. Because of the differences in accumulation of Cs-137 in high level predators (i.e. fish), and of the Pu-239,240 in primary producers (i.e. algae), more than one species group would always be needed to serve as bioindicators of future radionuclide exposure near Amchitka.

Overall, our geophysical and biological analyses did not find evidence of risk from radionuclides from the consumption of marine foods, nor indication of any current radionuclide contaminated migration into the marine environment from the Amchitka test shots. Our data are useful in reducing the uncertainties in the groundwater models and risk assessments, to indicate that there are species at multiple trophic levels that would be at risk if there were contaminated seepage from the test shots, and to provide insights for selecting bioindicators for a monitoring plan for the future and a baseline useful for comparison in any future biomonitoring.