1. INTRODUCTION

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Disclosures in the early 1990s of the dumping of radioactive wastes directly into the Arctic Ocean by agencies of the former Soviet Union (FSU) raised international concerns about the potential impacts of this dumping. The principal U.S. response to these disclosures, which were documented in a Russian-government report authored by Yablokov et al. (1993), was to fund the Arctic Nuclear Waste Assessment Program (ANWAP) in the Office of Naval Research. This program consists of a broad spectrum of projects ranging from measurement and experimental programs investigating biogeochemical processes in the Arctic Ocean to computer modeling studies examining the movement of water and ice (Morgan and Codispoti, 1995; Edson et al., 1996). Since 1995, one important element of ANWAP has been the preparation of an integrated assessment of the potential risks to Alaskan marine ecosystems and peoples posed by nuclear wastes derived from the FSU. The objective of this effort is to develop and apply a marine radiological assessment methodology that specifically addresses (1) the principal sources of nuclear wastes from the FSU that could impact the Arctic Ocean; (2) the transport of key radionuclides in the Arctic Ocean; (3) bioaccumulation of those radionuclides in marine species; (4) human dietary exposures via the consumption of fish and marine mammals; and (5) absorbed doses and associated risks for marine ecosystems and exposed human populations, with a principal emphasis on Alaskans relying on seafoods as important dietary items.

This is a prospective assessment, not undertaken to address any specific, observed human health or ecological problem in Alaska, but rather to evaluate the potential impacts from the FSU's improper disposal of nuclear materials. Completing such an effort requires a multidisciplinary team of investigators. To appropriately organize its risk-assessment effort, ANWAP in the summer of 1995 formed a Risk Assessment Integration Group (RAIG), a core group of individuals who would interact with other ANWAP investigators to obtain the relevant data and analyses. The RAIG included scientists from Lawrence Livermore National Laboratory, Pacific Northwest National Laboratory, Sandia National Laboratories, the State of Alaska, Department of Environmental Conservation, the North Slope Borough, and the Office of Naval Research (ONR). Concurrent with the initial formulation stages of the risk-assessment framework was ONR's appreciation that an important facet of the risk assessment should be communication, particularly with the native community in Alaska. An effort was made to reach out to native health associations, and to scientists and community leaders particularly knowledgeable about resources and dietary practices in North and Northwestern Alaska. In the spring of 1996, RAIG representatives traveled to Anchorage, Barrow, Kotzebue, and Nome to discuss the elements, purpose, and goals of the risk assessment and to ensure that it reflects local knowledge and interests.

1.1 Nuclear Wastes Addressed

Figure 1-1 depicts the primary sites of nuclear wastes derived from the FSU that could impact the Arctic seas.

Figure 1-1. Locations of the nuclear wastes of concern derived from the former Soviet Union.

The Kara Sea dump sites located adjacent to Novaya Zemlya have received the most scrutiny because of the amount and type of wastes discarded (including both liquid wastes and reactor vessels with and without radioactive fuel) and their proximity to the productive fisheries in the Barents Sea. The main concern with the reactor compartments and fuels disposed from 1965 to 1988 is the leaching of radionuclides to seawater and subsequent transport elsewhere in the Arctic Ocean. Another set of sites the assessment addresses are nuclear-waste ponds and reservoirs at nuclear installations situated next to the Ob and Yenisey rivers. If any of the waste reservoirs failed and released their radioactive liquids and solids to either river, a portion of the wastes would eventually discharge to the Kara Sea. The final set of wastes addressed are the liquid and solid wastes that were dumped at various locations in the Northwest Pacific Ocean as recently as 1992.

1.2 Risk-Assessment Methodology

An integrated assessment of the risk posed by a radionuclide released into the environment includes several distinct components, as shown in Figure 1-2.

The basic foundation of any risk assessment is the source-term characterization of the contaminant(s) being addressed. The basic goals of this component of an assessment are to determine the inventory (e.g., radioactivity or mass) of the contaminants available for release into the environment and to quantify time-varying release rates to the environment.

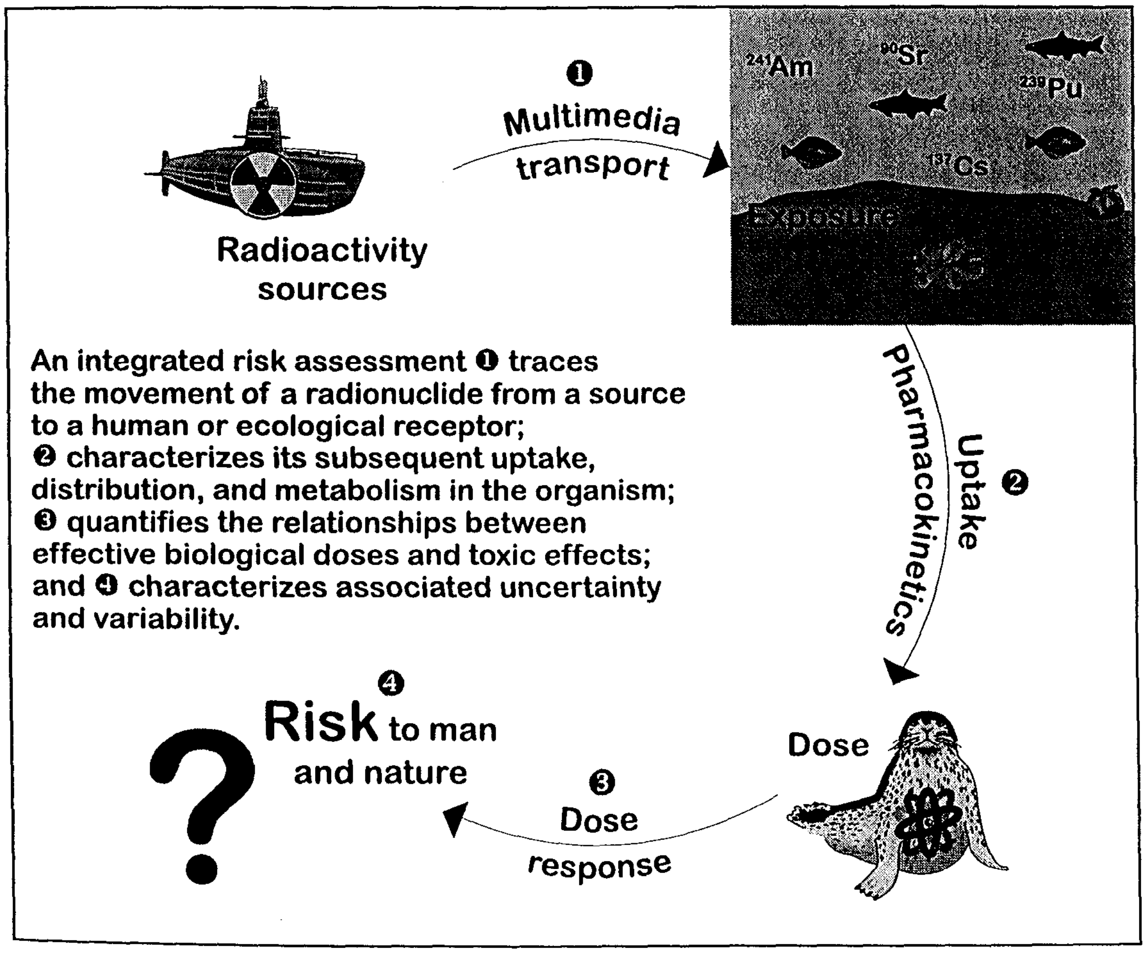

Figure 1-2. Overview of the basic risk-assessment methodology.

The ANWAP assessment focuses exclusively on direct releases to ocean waters or riverine releases that end up in ocean waters. Next, measurements and/or models help determine the transport and fate of the radionuclides in the environment. An important output of the transport component of the assessment is the prediction of the spatial and temporal distributions of radionuclide concentrations in ocean waters. Once the radionuclide concentrations in environmental media are determined, the RAIG analyzes the mechanisms that bring marine organisms and humans in contact with the contaminants. For humans the dominant pathway of exposure to marine contaminants is the ingestion of seafoods, while for marine organisms pathways include the intake of foods and sediment, immersion, and direct uptake from water. The RAIG translates exposures to a radionuclide to internal doses to body tissues and organs using models that simulate its uptake, distribution, retention, and elimination. Dose-response functions are then used to relate biologically effective doses to toxic endpoints. Finally, sensitivity and uncertainty analyses are performed to guide the interpretation of the predicted risks.

1.3 Scope of the Risk Assessment

The risk assessment begins with a characterization of existing and potential sources of radionuclides in the Arctic Ocean and the Northwest Pacific Ocean (Section 2 of this report). As background information, the RAIG discusses both natural and anthropogenic sources of radionuclides in seawater (e.g., radionuclides from the uranium decay chains and nuclear testing and processing facilities). Of special interest is an analysis of the various sources of radionuclides detected in Arctic waters, including nuclear-weapons testing, the Chernobyl accident, and nuclear installations such as the fuel-reprocessing facilities at Sellafield, United Kingdom, and La Hague, France. Following the analysis of previously existing sources of radionuclides, the RAIG reviews information on the inventories of various nuclear wastes dumped by the FSU in ocean waters and stored at inland locations in Russia. Next, the team conducts a screening-level analysis to identify which of the radionuclides from the FSU sources are potentially the most important from a risk standpoint, based on their inventories, transport in Arctic waters, and possible subsequent human exposures and doses. The RAIG then estimates the source-term inputs of the key radionuclides to the Arctic seas from Russian dump sites in the Kara Sea. Estimates of release rates for the wastes at the Kara Sea dump sites rely on models and supporting data from the International Arctic Seas Assessment Project (IASAP), sponsored by the International Atomic Energy Agency (IAEA).

Another source of nuclear waste is radioactive liquid wastes stored in reservoirs and ponds at nuclear-weapons facilities in the Russian interior adjacent to the Ob and Yenisey rivers. The RAIG summarizes information available on those sources and presents simple release scenarios for subsequent analysis. Finally, FSU agencies dumped solid and liquid nuclear wastes in the Northwest Pacific. Unlike the Kara Sea, however, most of the dumping evidently occurred as liquid wastes, but radioactively contaminated solid wastes also exist on the sea bottom. The team estimates the magnitude of such sources.

Results of the source-term analyses serve as the primary inputs to computer models that simulate the transport of the various radionuclides in the Arctic Ocean (Section 3). The transport models predict the concentrations of radionuclides in the Arctic seas resulting from the simulated releases of radionuclides from the dumpsites in the Kara Sea and liquid-waste disposal sites located within the drainage areas of the Ob and Yenisey rivers. Section 4 is devoted to the development of bioconcentration factors (BCFs) that relate the predicted concentrations of the key radionuclides dissolved in seawater with the associated levels in fish and marine mammals. Section 5 provides a brief overview of Arctic marine systems and their food webs, primarily emphasizing species of ecological significance and economic importance. The RAIG assesses the potential of radiological effects on marine organisms by comparing dose rates reported to produce significant detrimental effects on mortality, sterility, and fertility in radiosensitive species to those dose rates predicted from the release of FSU-waste radionuclides, using worst-case scenarios, and to those from measured values of anthropogenic and naturally occurring radionuclides.

Section 6 presents the results of the health-risk assessment for Alaskan populations whose diet includes significant amounts of fish and marine mammals derived from the Arctic Ocean. Because the dietary habits of native populations vary considerably, the RAIG has developed two different approaches for estimating dietary exposures to radionuclides. The first approach defines reference diets that reflect the food intakes typical of people living in Alaskan coastal villages. The team then uses these reference intakes with measured or estimated concentrations of radionuclides in the individual dietary items and with appropriate dose-conversion factors to estimate radiation doses. As an alternative, it presents a technique for constructing an individual's personal dietary dose using information on the average daily intakes of seafoods and unit dose-conversion factors for the seafoods (i.e., radiation dose incurred from consuming a specified amount of a given seafood item each year).