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RADIOLOGICAL ASSESSMENT FOR THE DUMPING OF RADIOACTIVE WASTES IN THE OCEANS

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Background and History

The purpose of this paper is twofold. First, the paper provides a historical review of international activities regarding radiation in the sea. Secondly, the paper provides some recommendations for future research needed for realistic dose assessment of the present and potential impact of ocean disposal and dumping operations.

Introduction

Over the last three decades or so, a number of international meetings have been convened to treat the specific problem of radioactive waste disposal into the oceans. The first of these meetings was held in 1958 at the United Nations Conference on the Law of the Sea. Immediately following, the International Atomic Energy Agency (IAEA), in the Brynielsson Report, recommended measures for ensuring that disposal of radioactive waste into the sea would not result in unacceptable hazards to man (IAEA 1961). Since that time, major changes have occurred in the philosophy and recommendations of the International Commission on Radiological Protection that are crucial to the assessments of impacts arising from this practice. Knowledge of oceanographic processes has improved markedly, providing better understanding of the physical transport process and of the pathways by which radionuclides are transported from marine dumping and disposal sites back to man. Finally, radioecology has developed to the stage where predictions of radionuclide cycling pathways and rates are possible. The IAEA report of 1961 was revised in 1983 (IAEA 1983). The IAEA has published many documents (Safety Series and Technical Documents) covering relevant areas such as oceanographic models, bioaccumulation factors, sediment distribution coefficients, and effects of ionizing radiation on organisms. The IAEA has also convened several symposia dealing with subjects related to sea disposal, such as radionuclide cycling in the marine environment, radioactive waste management, radiological and environmental protection, and environmental surveillance. Additionally, a large number of papers on these subjects have been published in the scientific literature.

The number of international and regional conventions has also increased over the same time period. One resolution of the United Nations (UN) Conference on the Human Environment, held in Stockholm in 1972, provided the stimulus for the formulation of the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Dumping Convention, 1972) which entered into force in 1975. The Convention binds participating nations to take all practical steps to prevent the pollution of the oceans through dumping of wastes which may create hazards to human health, harm living resources and marine life, damage amenities, or interfere with other legitimate use of the seas. It should be noted that the disposal of liquid wastes in coastal waters is not covered by the convention (International Maritime Organization [IMO] 1982).

The London Convention 1972 entrusts the IAEA with specific responsibilities for dumping of radioactive wastes at sea, and for making recommendations for radiological dose assessment and surveillance. In 1974, the IAEA established a Provisional Definition of High Level Wastes or other radioactive matter unsuitable for dumping at sea, and for dumping other material at sea. In this document, the IAEA made recommendations that the Contracting Parties should take fully into account in issuing permits for dumping other radioactive wastes or radioactive matter at sea. The IAEA recommendations were adopted by the London Convention 1972 in 1976, revised in 1978, and again revised in 1985 (IAEA 1986). The material deemed by the London Convention as unsuitable for dumping at sea includes irradiated reactor fuel, liquid wastes from the first extraction cycle of reprocessing irradiated fuel and solidified forms of such wastes, and any other wastes of concentrations exceeding specified quantities of alpha emitters; beta/gamma emitters with half-lives greater than one year; and tritium and beta/gamma emitters with half lives of one year or less. All other wastes with activity concentrations less than those specified shall not be dumped except in accordance with the provisions of the Convention and Recommendations.

The Derivation of the Quantitative Definition of Wastes Unsuitable for Dumping at Sea is given in Appendix 1 of IAEA Safety Series No. 78 (1986).

The maximum dumping rate into a single ocean basin of volume of at least 10^{17} m^3 shall not exceed 10^8 kg per year. While virtually all materials contain some radionuclides, it is not the intention that all materials be treated as radioactive when considering their suitability for dumping at sea. For example, sewage sludge, dredge spoils, fly ash, agricultural wastes, construction materials, vessels which are not nuclear powered, artificial reef building materials, and other such materials that have not been contaminated with radionuclides of anthropogenic origin (except global fallout from nuclear weapons testing) are not considered to be radioactive for the purposes of sea disposal.

Additional requirements must be met by the appropriate national authorities in selecting of a site for dumping of packaged wastes. Two of the most important are:

- Dumping shall be restricted to those areas of the oceans between latitudes 50°N and 50°S. The area shall have an average depth greater than 4000 meters.

- The site should be located clear of the continental margin and open sea islands and not in marginal or inland seas.

Naturally-Occurring Radionuclides in the Oceans

Naturally-occurring nuclides can be measured throughout the ocean environment and are an important source of radiation for organisms, as is the case of naturally-occurring nuclides in the terrestrial environment. Primordial nuclides include those of the uranium and thorium chains such as radium-226, lead-210, polonium-210, and potassium-40. The cosmogenic nuclides include tritium and carbon-14.

In the marine environment, the dominant pathway will involve ingestion of seafoods. Fish species tend to be relatively low and only rarely greater than 10 $Bq \cdot kg^{-1}$ polonium-210. Crustacean species tend to have polonium-210 concentrations of 10-50 $Bq \cdot kg^{-1}$. Mussels and winkles have similar concentrations. An assessment of dose from all naturally-occurring radionuclides made in Project Marina (Commission of the European Communities [CEC] 1990) indicated that individuals who have high sea-food consumption rates (e.g., fish 600 $g \cdot d^{-1}$; crustaceans, mollusks and seaweed 100 $g \cdot d^{-1}$) would receive an annual dose of about 2 mSv. The overwhelming contributor to this dose would be polonium-210 from the molluscan part of the diet.

Radiation Dosimetry

Dose to Man

In order to limit radiation exposure of the general public on the basis of the constraints and conditions recommended by the International Commission on Radiological Protection (ICRP), and to limit radiation exposure to marine organisms, it is necessary to develop methods for relating the magnitude of the potential radiation source to the resultant dose. Because of the uncontrolled nature of the interactions involved in the transport of radionuclides from the source into components of the environment, there are only two points at which control can be applied for disposing of liquid radioactive wastes into coastal waters or packaged waste into deep oceans: at the point of release and at the point of exposure.

Dose can rarely be determined directly. In order to apply control at the point of release, it is necessary to first establish the relationship between doses, concentration in environmental materials, and release rates by modelling. To achieve this, a mathematical model (or set of models) is formulated from the available data or, if data are lacking, from realistically conservative (restrictive) estimates. The model must account for the physical transport, geochemical cycling, and ecological transfer of the radionuclides in order to determine, for human exposure ingestion, inhalation and external exposure (Templeton and Preston 1982, IAEA 1983).

The calculations of external, inhalation and ingestion dose are relatively simple once the concentrations in water, sediment and biological materials have been established and occupancy rates for the individuals at potential risk determined. The basic dosimetric models and parameters for human exposure have been developed by ICRP.

Intervention

ICRP Publication 60 (ICRP 1991) contains the latest recommendations of the Commission. These deal with practices that cause or increase the exposure of individuals to ionizing radiation and with interventions which reduce such exposure. Where the occurrence of exposures is foreseen, control can be applied at the source to limit the exposure. However, when high-level nuclear fuel and packaged wastes are dumped into the sea in a manner contrary to international requirements, control procedures would be difficult to apply. In this case, when a dose assessment prediction indicates that there may be exposures in the future that approach those that would cause severe effects, countermeasures may be called for. Programs of intervention need to be justified to demonstrate that they do more good than harm. Their form, scale and duration should be optimized to maximize the net benefit (ICRP 1993).

Dose to Organisms

Much attention has been given to the process required to limit the radiation exposure of the general public as recommended by ICRP. However, similar constraints have not been applied in the past to protect the environment. In this regard the National Council on Radiation Protection and Measurements (NCRP 1991) and the IAEA (1992) have suggested that the radiation dose to organisms should not exceed 1-10 $mGy \cdot d^{-1}$ (0.1-1.0 $rad \cdot d^{-1}$). They suggest that this value is appropriate because the concern is with populations of organisms, rather than with individuals, as it is with man.

An assessment (IAEA 1988) of the impact of deep-sea dumping of low-level waste on living marine resources based upon the IAEA definition indicated that mollusks living on the sea bed in the dumping area may receive about 0.1 $mGy \cdot d^{-1}$, or a dose rate which is about 2.5 times that of the background upper bound. This dose rate would result in no discernable environmental damage (Nuclear Energy Agency [NEA] 1985).

Dumping at the North East Atlantic Dump Site

Between 1948 and 1982, eight European countries conducted radioactive waste dumping operations in the Northeast Atlantic Ocean. No dumping has been conducted since 1982 in accordance with the moratorium agreed to at the London Convention 1972. The operations were conducted subject to regulations by the appropriate national authorities and within the guidelines and recommendations specified by the London Convention 1972, the NEA of the Organization of Economic and Cooperative Development (OECD), and the IAEA. Reviews of the site suitability were conducted by NEA every five years. The NEA published such a review and dose assessment (NEA 1985), as required by the *Multilateral Consultation and Surveillance Mechanism for Sea Dumping of Radioactive Wastes* (OECD 1977). The sources of radioactive waste were low-level wastes from nuclear power operations, other nuclear fuel cycle operations including reprocessing, radionuclides used in research, medicine and industry, and wastes arising from decommissioning of redundant plants and facilities. The sites utilized over the years were all below 50°N and in depths exceeding 4000 meters. The quantities of radioactive waste were about 666 TBq of alpha-emitters; 26146 TBq of beta/gamma emitters and 15474 TBq of tritium. In comparison, the United States dumped about 3.5 PBq (95 KCi) in the Atlantic and Pacific Oceans.

The radiological assessment (Templeton 1981) conducted by the multinational Coordinated Research and Surveillance Program (CRESP) for NEA followed the road-map given in Fig 1. A source term model estimating the release rate was developed because surveillance data indicated no significant concentrations in water, biota and sediment. Because of the sites' remote position from and the long time scale involved in deep-ocean dispersion models, an oceanographic model of the world's oceans was developed (Camplin and Hill 1986). The model predicted radionuclide concentrations in water and sediment as a function of time, and this data was then used to estimate individual doses to members of a critical group. The peak annual doses for past dumping practices via actual pathways were about $2x10^{-5}$ mSv. The dominant contributors to those doses were plutonium-239 and americium-241. For both the radionucides, mollusc consumption in the Antarctic by a hypothetical population was the major exposure pathway with the peak dose reached at times between 100 and 500 years after the start of dumping operations. Individual doses were also calculated for the consumption of deep-water fish from the Northeast Atlantic although no such fishery exist today. The highest individual annual dose rate from consumption of these fish was estimated to be $2x10^{-4}$ mSv at 50 years, and the major contributor was plutonium-239. The appropriate ICRP dose limit for members of the public is 1 mSv a^{-1}.

Models used to calculate concentrations of radionuclides in the ocean are described in Appendices VI and VII of the GESAMP Report (IAEA 1983) and summarized in the IAEA report entitled *The Oceanographic and Radiological*

Parts of System Included in Model	Model	Major Processes Included in Model
Canister and lining Waste form	[Waste Package] → rates of release of radionuclides into the ocean, as a function of time	Canister corrosion Degradation of package lining and caps Release of radionuclides from waste forms
Bottom sediments Benthic boundary layer (water and particulates) Open ocean (water and suspended particulates) Coastal waters	→ [Ocean Dispersion and Sedimentation] radionuclide concentrations in water and sediments, as a function of time	Diffusion and advection Interactions between radionuclides and suspended particulates and bottom sediments
Exposure pathways - seafoods, beaches, atmosphere, salt, water Dose to marine organisms	→ [Dose to Man and Organisms]	Reconcentration of radionuclides in marine organisms, beach sediments, and atmospheric aerosols/vapour Radionuclide intake and metabolism by man and organisms

Figure 1. Modelling Framework Used in Radiological Assessment (after OECD/NEA 1985b)

Basis for the Definition of High Level Wastes Unsuitable for Dumping at Sea (IAEA 1984).

Dumping and Disposal in the Barents and Kara Seas

In 1991, information about the Soviet Union's practice of dumping radioactive waste in the Arctic Seas became available from the international organization *Greenpeace*. This material was presented to the London Convention 1972 so that the IAEA could correct its inventory of radioactivity dumped into the world's seas as required by the London Convention 1972. In 1992 the President of the Russian Federation convened a Commission on Matters Related to Radioactive Waste Disposal at Sea. This Commission reported to the President in 1993 (Yablokov et al, 1993). The Commission's report suggests that the total amount of solid radioactive waste dumped into the Northern Arctic Seas was about 903 TBq (24 kCi) of which 0.0007 TBq (0.2 Ci) was dumped into the Baltic; 3.7 TBq (100 Ci) in the White Sea; 450 TBq (12 kCi) into the Barents Sea; and 315 TBq (8500 Ci) into the Kara Sea. The composition of these wastes included small ships, barges, packaged wastes and redundant equipment. Liquid radioactive wastes discharged into the Barents and Kara Seas and the Ara Bay were about 651 TBq (17600 Ci). The quantity of spent nuclear fuel (predominantly fission products and actinides) expressed as strontium-90 equivalents, was about 1704 TBq (4600 kCi). This material was dumped in protected packages and in nuclear submarines.

The IAEA was requested by the Contracting Parties to the London Convention 1972 to pursue a program to assess the risks to human health and the environment. The IAEA was to examine possible remedial actions related to the dumped wastes and to advise on whether they were necessary and justified. In 1993 the IAEA, with the Norwegian Radiation Protection Authority and the Scientific Production Association-TYPHOON of the Russian Federation, organized an international meeting to initiate this program. The main objectives of the meeting were 1) to review available information relevant to the dumping of radioactive wastes into the Barents and Kara Seas and 2) to launch an international four-year program entitled the International Arctic Seas Assessment Project (IASAP) for assessing the existing and possible future radiological and environmental impacts of the dumping and for examining whether remedial actions are necessary. Information in the Yablokov Report

(1993) and the results of the joint Norwegian-Russian Federation cruise to the Barents and Kara Seas in 1992 were not available at that time. Dose assessments conducted by the Russian Federation for man and organisms were presented. It was assumed that the radioactivity, and hence doses, received from consumption of fish from the Barents Sea originated from Sellafield (UK) and Cap de la Hague (France).

As a result of congressional action, the United States has also initiated a comparable assessment program through the U.S. Navy Office of Naval Research. This program will likely be coordinated with IAEA towards achieving the objectives of IASAP.

Research Needs

A dose assessment of the present and potential impact of the disposal and dumping operations conducted in the Barents and Kara Seas is extremely complex. Not only are we dealing with high-level radioactive wastes as nuclear fuel in reactors but also with activation products in the dumped structures, other packaged waste of indeterminate composition, and liquid wastes from naval operations. This material has been dumped in relatively shallow waters on the shelf surrounding the island of Novaya Zemlya. While the surveillance data today does not suggest a significant contribution from these sources, the potential for releases in the future needs to be examined in great detail. First, we must establish whether leaving the high-level wastes in their present placement presents any risk to man or marine organisms. Secondly, if a risk has been demonstrated, we must determine what intervention will be necessary to reduce that risk. To complicate matters, we not only have an identified contribution in the Barents Sea from the radionuclides discharged from chemical reprocessing plants at Sellafield (UK) and Cap de la Hague (France), but we have contributions to the Kara Sea from actual and potential releases from the military weapons complexes in the watersheds(~5 million km^2) of the Ob and Yenesi Rivers. Research needs are shown below by category.

<u>Source Terms and Release Rates</u>

- The initial needs are for detailed information on the radionuclide composition of the reactor fuel in the dumped reactors and the composition of the activation products in the dumped submarines and in the packaged wastes. In order to develop release rates from these modules, including the furfural matrix around the reactor cores, corrosion rates under Arctic conditions are essential for the variety of materials.

- Information will be required on past and present quantities and composition of the input from the major rivers entering the Barents and Kara Seas. Because of the potential for increased releases in the future from the reactor and from reprocessing and waste disposal sites in these watersheds, some predictive modelling will be required.

- The objective of this task is to develop 1) an inventory of the dumped materials, 2) a realistic release rate model for the packaged dumped waste including that for the reactor fuel, and 3) a screening model for the potential contributions from the Kara and Barents Seas watersheds.

<u>Concentration and Distribution of Radionuclides in the Arctic</u>

The objective of the task is to:

- Assemble and analyze all data on concentrations of radionuclides, water, sediment and biota from the Arctic Ocean.

- Predict the present and future contribution to the Arctic Seas from the low-level liquid effluents from European reprocessing plants.

<u>Transport of Radionuclides in the Arctic Oceans</u>

- The present state of knowledge on the oceanography of the area needs to be reviewed. Some simple models have been developed, but data needs should be assessed and composite models developed. These models should include the geochemical interaction between radionuclides and suspended sediments and bottom sediments.

- The role of ice scour on sediments and packaged wastes and ice pack development on dispersion needs to be considered. This determination is particularly important in the Kara Sea.

- The objective of this task must be to provide a definitive model to provide output on the concentrations of radionuclides in seawater and sediments, both spatially and temporally.

Ecological Characteristics and Bioaccumulation

- The Arctic marine ecosystem is clearly very different from that found in the more temperate Atlantic and Pacific Oceans (Fig 2). Differences in biological productivity, energy transfer, metabolic physiologic rates, and rates of bioaccumulation present a challenge to the radioecological community. We have little evidence, for instance, that the bioaccumulation factors presently used, can be relied upon in an Arctic assessment. There is an essential need to review the existing data and develop appropriate sampling strategies to obtain reliable parameters for use in this assessment. Some radionuclides of interest in this assessment are already present in the Arctic environment from weapons test fallout or from the European discharges from reprocessing plants. A limited surveillance program may be useful to determine the distributions of the radionuclides and their interrelationships with sediment and biota to determine whether they are markedly different from those found in more temperate regions.

- The objective of this task is to provide, based upon the output from the Oceanographic Model, a data base on the predicted concentrations of radionuclides in all significant Arctic food-chain pathways.

Pathways Analyses

The design of effective and economical assessments depends heavily on identifying those critical groups which are representative of the individuals expected to receive the highest doses, and those critical radionuclides and exposure pathways which are responsible for most of the dose received by critical groups (Templeton 1981). Furthermore, information will be required

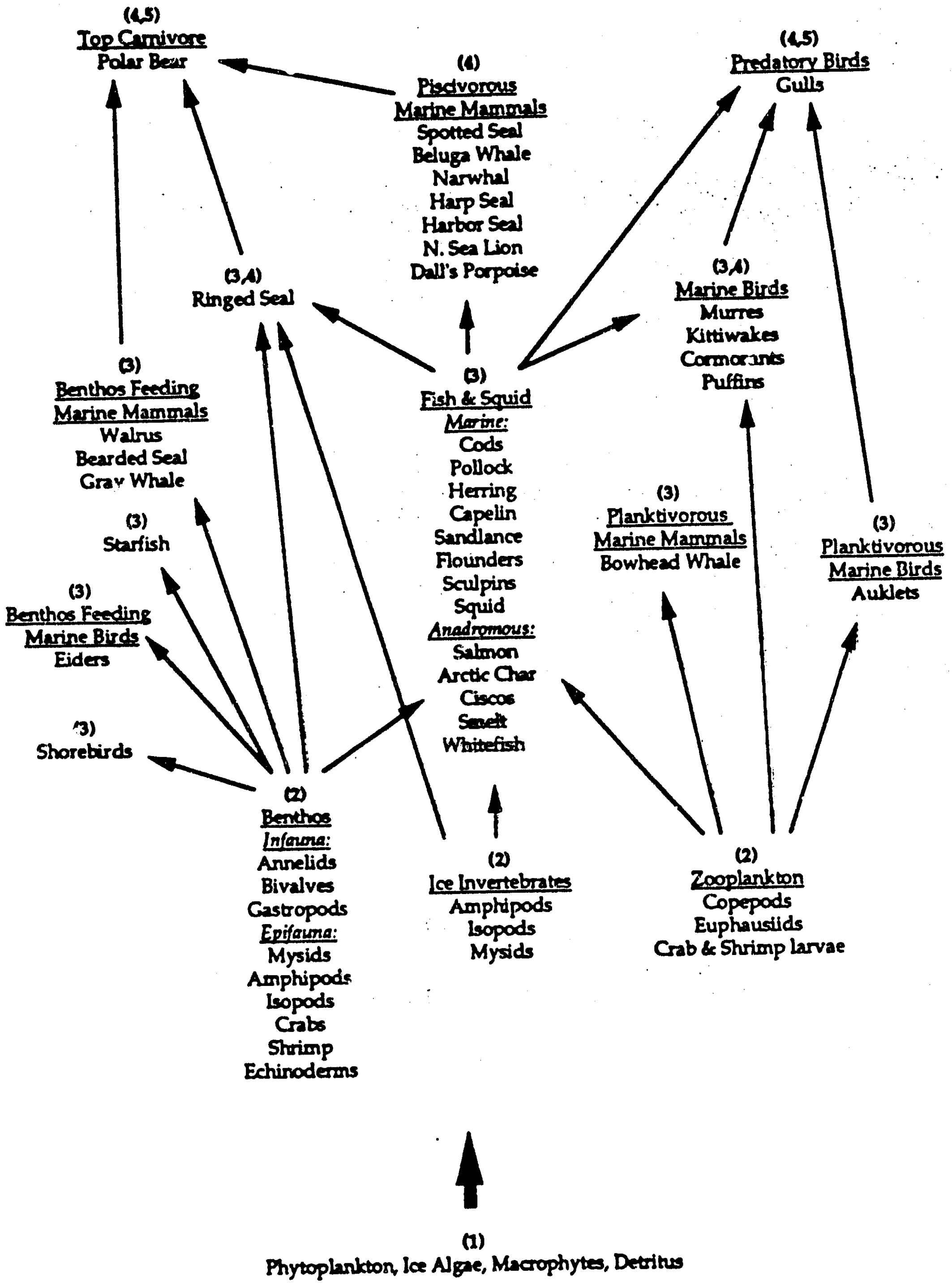

Fig. 2. Generalized composite food web of the Arctic marine ecosystem. The number in parenthesis indicates trophic level in ascending order. Examples of each major category of biota are also listed. (Paul Becker. 1993. IAPRC. Anchorage, AL)

on the pathways responsible for significant collective dose commitments. These may not necessarily be the same as those which are important with respect to the exposure of individuals, and their additional pathways will have to be taken into account. When applying ICRP or national dose limits, it is necessary to ensure beyond a reasonable doubt that the dose to the most exposed individuals is within the dose limits. Therefore, the working, eating and recreational habits of the local populations and populations at some distance from the site must be identified. These studies should include items listed below.

- The type and amounts of ingested marine sea-food derived from specific areas should be estimated. As can be seen from Fig 2, intensive radioecological studies will be necessary to elucidate food chain relationships and seasonal food consumption by humans, over a wide selection of mammals, fish and invertebrates.

- The majority of the indigenous peoples of the Arctic Rim depend heavily upon the arctic tundra environment for food. Because these terrestrial animals and plants have been shown to have elevated levels of fallout and natural radionuclides, their contribution needs to be factored into the dose assessment.

- For external dose calculations, it is necessary to estimate the number of hours spent handling fishing gear at sea and on the beach, and the number of hours spent on the beach and on the ice at work and for recreation.

- Consumption and occupancy rates derived from habit surveys of an identified critical group are not normally distributed. These variations can be accounted for by applying the appropriate dose limit for individual members of the public to the weighted mean dose equivalent for the group.

- A dose integration and assessment group should be established early in the assessment project. This group should lay out the project road-map.

Experience has shown that this group needs to identify the objectives of the assessment and provide guidelines to the source term, oceanographic, geochemical, ecological and human factors groups on the scope and type of information required. Without this input, the input data to the integration and assessment group may be inadequate and/or inappropriate. This group should initiate screening studies to assist in defining the major radionuclides and pathways.

- Studies on alternative countermeasures to reduce the potential for radiation exposures from radioactivity dumped and disposed of in the Barents and Kara Seas should be initiated. With this in hand, a strategy for intervention should be developed.

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