RADIONUCLIDES IN THE MARINE ENVIRONMENT
A CRESP Science Review
Draft

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July, 2005

Objectives

1. Characterize the worldwide effort (focusing on the Northern Hemisphere), including results, to identify "background" or monitoring levels of radionuclides in marine biota and examples of related information on water and sediment.

Data and Discussion:

- ✓ Describe the various efforts in the Northern Hemisphere to characterize the marine environment. Regions include the North Pacific, Northern Europe, the polar regions of Northern Europe and the United States (northeast and northwest coastal waters). Describe the international effort to consolidate the data in a global database.
- ✓ Describe the results in a series of tables focusing on radionuclides in marine biota. Discuss the problems or limitations of such studies. Also describe data for radionuclides bioconcentration factors of various radionuclides in various biota receptors as described for marine environments.
- ✓ Describe the methods applied to estimate the degree of human risk associated with the consumption of radionuclides in biota that provide a human food source or contribute to a human food source (through the food chain) in different areas of the northern hemisphere.
- ✓ Describe the evolving role of ecological risk assessment and its current status in regional or international monitoring efforts.

This information will help the reader place the Amchitka effort, and its eventual results, in perspective of international efforts to characterize marine radionuclides. This review includes key radionuclide data tables summarizing monitoring results of key national or regional marine programs, contains a current reference list, and has been reviewed, contributed to, and co-authored by several Amchitka Study advisory and science participants. A separate summary, in a much abbreviated form, is included in the Amchitka final report and has been drafted for the purpose of supporting effective communication with a wider variety of stakeholders.

TABLE OF CONTENTS

Radionuclides in the Marine Environment
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March 14, 2005: Near Final DRAFT

1.0 Abstract

Several anthropogenic radionuclides have been detected through national, regional and international monitoring programs designed to periodically assess marine water, sediment and biota (fish, crustaceans, mollusks, algae, etc.) of the oceans and a number of seas and bays of the Northern Hemisphere. Such information, while useful for evaluating broad temporal and spatial trends in relationship to distant and local influences, can also assist in the interpretation of local marine studies by providing information on concentrations (and there variability) detected in various global marine sites. Marine biota radionuclide concentration data, in conjunction with relevant dietary intake surveys, can form the basis to assess risks to human health from seafood ingestion. Ecological risk assessment is evolving, has become an objective of several organizations (including the International Atomic Energy Association) and will likely require an agreed upon set of assumptions (i.e., a set of indicator organisms for the body of water in question and metrics of ecotoxicity) as well as basic data on seawater and sediment concentrations as well as organism-specific information including dietary patterns, food-chain bioconcentration and biomagnification, residence time, and radionuclide and organism-specific toxicity.

Current efforts are underway to consolidate marine radionuclide data from monitoring programs, published literature, and special studies in a large information database (GLOMARD) to be maintained by the International Atomic Energy Agency in Monaco. Currently, detailed radionuclide information is collected and maintained by several national and regional databases, including substantial data from many of the 15 northern-European signatories to the OSPAR

Convention, from a number of countries bordering the Pacific Ocean and its minor Seas, from countries on the Arctic Ocean, and from other monitoring efforts in the Northern Hemisphere.

The cessation of atmospheric testing by the early 1980s, accompanied by dilutional and half-life factors, have generally resulted in reduced marine environmental concentrations of Cesium-137 over the last few decades – although mobilization of sedimentary deposits continue to contribute somewhat to some environmental burdens. Technetium-99 concentrations have varied in the Irish and North Seas, primarily as a result of modulations in nuclear treatment volume through ionization separation technology developments at Sellafield's reprocessing facilities.

A number of regional dietary surveys in Ireland, England, Scotland, Norway, etc. have linked seafood radionuclide concentrations to dose and risk estimates for typical and heavy seafood consumers. The total anthropogenic radionuclide contribution to public dose through consumption of contaminated seafood is, in recent years, relatively low – resulting in only one or two percent of the composite radiation burden the public receives from all natural sources. The lifetime human cancer risks from consuming artificial radionuclides is seafood is expected to range from less than one in a million up to a few cases in a hundred thousand.

This paper places current marine biota radionuclide research – including that of Amchitka (Powers et al, 2003) - in perspective to US and international food standards and guidelines, to "background" concentrations in marine environments, and to the risks associated with natural radiation in seafood. Several aspects are addressed, including the typical range of radionuclide concentrations found internationally in marine biota, the sensitivity of a study to detect meaningful concentrations in biota, and the degree of human risks that are currently associated with marine systems that have long-standing increased levels of radionuclide contamination (i.e., the Irish Sea). The reviewed data indicates that the key surveillance systems, as well as the Amchitka

investigation, are capable of a) detecting marine biota radionuclides at concentrations that clearly meet international food standards and b) detecting low levels of human risk acceptable for seafood consumption – even at high consumption rates. This degree of sensitivity suggested for the major marine environmental surveillance systems is reassuring – but the extent to which such surveillance addresses future potential sources of emissions must be periodically re-evaluated. Our knowledge of ecological risks is evolving and is less complete, so the current interpretation that marine radionuclide contamination is generally not thought to be deleterious needs to be carefully reevaluated as new information on ecotoxicology and exposures develops in the ensuing years.

2.0 Introduction

During the last sixty years, human activity has resulted in varying degrees of contamination of the world's seas and oceans with anthropogenic radionuclides. Globally, the primary source of this contamination is fallout from over 520 atmospheric nuclear weapons tests conducted between 1945 and 1980 primarily by the United States and the former USSR - but also by the United Kingdom, France and the People's Republic of China (Gafvert, Foyn, et al, 2003; Valette-Silver and Lauenstein, 1995; Koide et al, 1985). Additional radionuclide burden to the marine environment has resulted from current and/or prior emissions from the nuclear waste reprocessing facilities at Sellafield (England), Dounreay (Scotland – facility closed in 1996), Cap de la Hague (France) and Mayak (Russia), the dumping of nuclear waste (i.e. in the Kara Sea), accidents involving nuclear facilities/reactors such as the 1986 event in the Ukraine at Chernobyl, from the accidental sinking of nuclear submarines such as the Russian vessels the Komsomolets in the Norwegian Sea and the Kursk in the Barents Sea (Matishov and Mativshov, 2004; Kronfeld-

Goharani, 2003; Gafvert, et al, 2003), and from the 1964 re-entry burn-up of a plutonium-fueled satellite (Koide et al, 1977).

The contribution of numerous underground nuclear tests - undertaken primarily beneath Pacific islands – to contamination of the marine environment is less well understood. The French government has supported research in the South Pacific by the International Atomic Energy Agency (IAEA) to assess the potential impact of 147 underground nuclear tests undertaken by France in the Mururoa and Fangataufa Atolls of French Polynesia (IAEA, 1998). Less recent research has been undertaken in the North Pacific, although that void may subsequently be addressed by current investigations of radionuclides in marine biota near three Amchitka, Alaska United States test sites, where underground detonations were performed in the late 1960s and early 1970s (CRESP, 2003).

In this science review, we highlight major national and international marine radionuclide databases that have been developed to provide a basis for comparative research and to characterize "background" or monitoring levels of radionuclides in marine biota, water and sediment. We describe concentrations typically found –in various marine biota. Furthermore, we provide examples of how marine radionuclide data is being used at national levels for risk assessment purposes. This review focuses primarily on monitoring activities in the Northern Hemisphere – the geographic area most heavily impacted by the residues of global nuclear fallout due to the location of most atmospheric tests and to relatively slow atmospheric mixing in the longitudinal plane of the earth (Livingston and Povinec, 2002).

3.0 Basis for Radionuclide Monitoring Programs

Because of the potential for radiation contamination in the food web to adversely impact human and ecological health, as well as the interest to understand the relative contributions of local

and global sources to current and future radionuclide concentrations, a number of scientific efforts have been undertaken to characterize radionuclides in the marine environment, including biota, water and sediments (Povinec, Hirose, et al, 2004; Dowdall et al, 2003; Ryan et al, 2003). To support this effort, several countries and agencies have implemented marine expeditions and in some instances have installed fixed sampling stations in order to assess and periodically track environmental concentrations of radionuclides at national or regional locations. The substantial growth in data at local, national and regional marine environments has necessitated the development of centralized international databases through which research can provide a global perspective and a basis for interpreting changes to the marine environment (GLOMARD, 2004; Povinec et al, 2004; Aoyama and Hirose, 2004; Betti et al, 2004; IAEA, 2000; Duran et al., 2004).

Environmental radionuclide marine monitoring programs have functioned primarily to assess the degree of radionuclide contamination in biota and/or media, evaluate trends over time, compare results to guidelines or environmental commitments, determine the relative attribution of potential sources, and interpret human health risk in light of seafood consumption patterns of the general population and of critical subgroups with the greatest potential for high levels of intake - such as subsistence harvesters (Ryan et al, 2003; Gafvert et al, 2003; SENES, 2003). Protection of human populations has been the primary motivation for such work, although the health of ecological receptors is an emerging international interest and may well influence future marine-based environmental exposure standards or guidelines (Copplestone et al, 2004; ICRP, 2003; ICRP, 2002; Pentreath, 1998).

Radionuclides in specific marine environments often reflect both emissions from local sources, remobilization of sediment deposits, and arrival of contaminant plumes from more distant locations. Ongoing marine monitoring programs are useful to determine the degree, significance

and trends of radionuclide pollution emitted by such sources as nuclear reprocessing plants, accidental events, the operation of nuclear submarines and nuclear power plants, impacts of off-shore oil exploration and mining activities (a potential source of naturally occurring radiation), or legacies from prior nuclear tests from distant areas of the globe. Ocean surface circulation patterns facilitate the movement of emissions from sources to receptors at distant locations. For example, radionuclide emissions from reprocessing plants at the British Nuclear Fuels' Sellafield facility in Cumbria, England and the COGEMA La Hague facility in north-west France enter the Irish Sea and the English Channel, respectively, and have been reported to migrate substantial distances through marine currents to the Norwegian Sea, the Greenland Sea, the Barents Sea and other arctic waters (Gerland et al, 2003: Frechou and Calmet, 2003; Kronfeld-Goharani, 2003; Hou et al, 2000). Ocean plume transit times from emission sources in La Hague and Sellafield to NW Greenland have been estimated to range between 9 and 16 years (Hou et al, 2000).

A large segment of the diet and economic wellbeing of populations in several radionuclide "receptor" countries, such as Norway, is derived from the sea. Radioactivity from Mayak, a Russian weapons production and reprocessing facility near the Techa River, has also contributed to distant radionuclide contamination. Its emissions include strontium-90, which have been reported to travel the Techa River to enter the Kara Sea (Kronfeld-Goharani, 2003). These and other potential radiation threats or perceptions of threat have produced substantial public and governmental commitment within a number of countries to reduce radionuclide emissions and to maintain aggressive, quality-assured, ongoing marine monitoring activities. The environmental programs often include the periodic sampling and analysis of marine water, sediment and biota for a several radionuclides of concern, as exemplified by monitoring and research derived from the OSPAR Convention.

In 1998 the signatories to the OSPAR Convention (Convention for the Protection of the Marine Environment of the North-East Atlantic) agreed to an agenda by which radioactive discharges, emissions and losses will be reduced and monitored by each of the fifteen participating countries. A major goal of OSPAR is to reduce marine radionuclide concentration increases in the North-East Atlantic region to a level "close to zero" by 2020 (Ryan, McMahon, et al, 2003). Member countries have each agreed to develop and implement ongoing monitoring programs of their respective marine environments, and participate in ongoing quality control programs. Additional monitoring efforts exist in other countries, often supported to some degree by agencies involved with radiation standards and environmental research, such the International Atomic Energy Agency (IAEA) and the National Center for Radiation Protection (NCRP). Russian research by the Murmansk Marine Biological Institute on radionuclide transfer and bioaccumulation in the Barents, Kara, Azov and Black Sea regions is such an example of national efforts – under the framework of the Russian Academy of Sciences and the Russian Fund of Fundamental Research – but also supported by grants from international agencies, such as IAEA (Matishov and Matishov, 2004).

International agencies have supported the development and maintenance of a few well designed and supported marine radionuclide databases. These databases have been designed to support a wide range of marine research and radioecology monitoring programs, important toward understanding and sustaining the long-term marine environment and its vital contributions to human and ecological health (IAEA, 200X,; NCRP, 200X).

4.0 Methods and Approaches

The programs on marine radionuclide monitoring and resulting data were identified from published literature databases, from general "online" resources, from linkages identified through international (IAEA, WHO, ICRP) and national agencies (i.e., such as the U.S. DOE, EPA, NFWS, NRC and from similar agencies in other countries), from contact with major researchers and from the references identified in recent comprehensive reviews (i.e., FASSET; MARINA II). The criteria for inclusion are:

a) at least one radionuclide is measured by defined analytic methods applied periodically to at least one type of marine biota;

b) the measures include or make available information on the number of samples (ideally, distinguishing "pooled" samples from individual samples), central tendency indicators (means, geometric means or medians), and scatter (range, standard deviation/error, distributional plot, or other indication of variability);

c) the body of water from which the biotic samples are obtained is named and the geographic area covered by the monitoring program is defined – often through global positioning system indicators;

d) the data has been published in a governmental report, the scientific literature or are accessible "on line" , via "CD", or through printed data tables; and

e) the analytic laboratories are accredited for the relevant tests and/or the analytic techniques are adequately described, supported by active quality assurance and inter-laboratory comparison programs. Programs in the Northern Hemisphere were the primary targets for this review.

Monitoring programs vary by the specific radionuclides assessed, the reported units of measurement, the analytic methods used to define concentrations, the minimum analytic detection

limits for the types/sizes of samples tested, and whether biotic findings are linked to local environmental water and/or sediment radionuclide concentrations so that bioconcentration factors can be estimated. Subsequent sections describe the basic metrics (see Appendices) used in environmental radionuclide assessments, the major marine radionuclide monitoring programs of the Northern Hemisphere identified by this review, summaries of radionuclide measurements found in marine biota (particularly marine fish) and a description of risk assessment approaches applied by Agencies to interpret the relevance of the marine data findings.

It is expected that the summarized information, which reflect the results of a large number of recent tests from Northern Hemispheric monitoring programs, may be useful for placing the results of specific, local radionuclide environmental studies in a broader perspective. It cannot be claimed that the summarized data represent true "background" levels of radionuclide concentrations in the marine environment, i.e., concentrations in pristine sites. The noted concentrations are likely influenced both directly and indirectly (i.e., remobilization of sedimentary deposits and ocean current distributions) by global fallout. Local radionuclide sources could influence the results in some monitoring studies. Biota mobility could impact the extent and time to which organisms are exposed to different environmental concentrations. A detailed review of these factors is beyond the scope of the current review. However, that being said, the range of data described in the paper should be of substantial value for comparative purposes. It summarizes (and in some cases has actually compiled) recent results – most since 1999 - of multi-national Northern Hemispheric monitoring programs that were developed to define the scope and extent of radionuclide contamination in the Hemisphere's major marine environmental systems.

Basic to interpreting the results of the monitoring systems is an understanding of the units of measure used in radionuclide environmental studies. For readers who desire to review units of radionuclide measures, Appendix 4 should be of some value..

5.0 Major Monitoring Programs and Databases

Most of the major radionuclide monitoring programs and databases (excluding the Mediterranean Sea) from the Tropic of Cancer through the arctic zones of the Northern Hemisphere are listed in tables 2. The monitoring programs periodically assess contaminants through marine expeditions and via fixed sampling site activities. These programs provide an important set of data that is maintained in the databases, which also include information from special studies, one-time voyages, and data described in the published literature.

As noted in table 2, the monitoring programs of Northern Europe include substantial efforts by Ireland, England, Scotland, France, Norway, and Russia. Additional studies have been undertaken in the waters off Iceland, Estonia, Poland, Latvia, Sweden, Finland, Belgium, the Netherlands, and in the more southern waters there have been some assessments off Spain and in the Mediterranean and adjacent seas. Periodic monitoring in the North Pacific includes such areas as the Sea of Japan, the Yellow Sea and the East China Sea. Further north there have been Pacific and Arctic seawater assessments by Japan and Russia. Information generated from these monitoring programs and other special studies is represented in the following databases.

The multinational or regional databases considered in this review are a) the HAM database (Historical Artificial Radionuclides in the Pacific Ocean and its Marginal Seas) which includes data on seawater concentrations, b) the ASPAMARD database (Asia-Pacific Marine Radioactivity Database) which includes sea water, sediment, and some biota, c) the FASSET project which includes information on seawater, sediment and biota for the North-Eastern Atlantic regions, d)

the MARINA II project for Northern European waters, e) the GLOMARD database – compiled by the IAEA in Monaco, its effort is to aggregate and make available information on radionuclides in marine environments across the globe (Aoyama and Hirose, 2003; Duran et al, 2004; Larsson, 2004; XXXXX; Nielsen and Hou, 2004), and f) RIFE, described below.

Several national monitoring programs maintain important databases. Norway has maintained, since 1997, an annual monitoring program of the Norwegian Sea, the North Sea, the Barents Sea, the Skagerrak, and selected Norwegian fjords. It data spans seawater, sediment and biota. Ireland, through its Radiological Protection Instititue of Ireland (RPII) assesses all three media. Until 2004, separate reports were generated by England and Wales, Ireland, and Scotland. Starting in 2004, covering year 2003, the Radioactivity in Food and the Environment (RIFE-8) report combines the efforts of the Food Standards Agency (England and Wales), the Scottish Environment Protection Agency – SEPA (Scotland), Environment Agency and Environment Heritage Service of Northern Ireland – and thus becomes a multinational program.

Table 2: Major Radionuclide Monitoring Programs and Related Data Integration Projects

Northern Hemisphere, Arctic and Temporate Zones

Program	Description
Nord-Cotentin Database (La Hague)	Nord-Cotentin Peninsula of the English Channel, north-west France. Radionuclides include Sr-90, Rb-87, Tc-99, Cs-137, Pu-238, 239, 240, 241, Am-241; Natural background data on Tritium, C-14, K-40, Po-210 and U-238. Data on Seawater, Sediment, and biota (crustacean, filtrating mollusks, non-filtrating mollusks, fish and algae). This program applies available data to model dose to marine biota and assess ecological risks. Its data is from a limited region of the English Channel.
RAME	Norwegian marine environment monitoring includes data from the Norwegian Sea, the North Sea, the Barents Sea, the Skagerrak, and selected fjords. Radionuclides include Cs-137,

	Cs-134, I-131, Pu-238, Am-241, Sr-90, and Co-60. Seawater, Sediment and biota samples are included in this program.
NSTP	National Status and Trends Program (Mussel Watch Project and the National Benthic Surveillance Project). 1976-78 and 1990, transuranic elements measured. 1990 survey of 36 U.S. Coastal sites for analysis of Am-241, Pu238, Pu239/40, Cs137, Ag110, Sr90, Zn65, Co60, Co58, K40 and Be7 in the mollusks Mytilus edulis (north Atlantic/Pacific) and Mytilus californianus (Pacific Coast) – as well as another mollusk in the Gulf Coast. This database has not been updated past 1990.
AMAP	The Arctic Monitoring and Assessment Programme integrates "the status and trends of the conditions of the Arctic ecosystems," it "identifies possible causes for the changing conditions", detects "emerging problems, their possible causes, and the potential risk to Arctic ecosystems, including indigenous peoples and other Arctic residents". AMAP is a working group to the Arctic Council of Ministers. The AMAP Data Centre has compiled information on ^{137}Cs in marine fish suggesting little, if any, difference in concentrations by species.
HAM	Summary of Cs-137, Sr-90, and Pu-239/40 in ocean water in Pacific Ocean and its marginal seas – published literature, Government of Japan survey reports and unpublished data.
RIFE	Data from the research monitoring programs of the UK Food Standards Agency, supplemented (in 2003) with the data from Ireland and from Scotland. This information includes a wide range of radionuclides in seawater, sediment and biota, as well as dietary intake surveys and risk assessments.
RPII (Irish database)	Radioactivity monitoring of the Irish marine environment undertaken by the Radiological Protection Institute of Ireland, consistent with the OSPAR Convention. Earliest reports are from 1982-84 time periods, through recent dates (2003). Analyses are reported for Cs-137 and other gamma emitters, and includeTc-99, Pu-238 and Pu-239/40 and Am-241 (est). Analyses are made for seawater, sediment and biota linked to ingestion pathways to estimate human health risks.
GLOMARD (IAEA-MEL Database)	Data summarized by the Marine Environment Laboratory, IAEA, Monaco. To be eventual repository of data from major monitoring programs, publications, research reports. Radionuclides in seawater, sediment, and biota will be included.
FASSET	Framework for Assessment of Environmental Impact project involved 15 organizations in 7 European countries over the

period of 2000 – 2003, under the EC 5th Framework Programme. Includes source characterization, reference organisms, environmental transfer analysis, dosimetric aspects, effects analysis, and guidance on interpretation for seven important European ecosystems – including the marine systems of the northeastern Atlantic Ocean and its marginal seas. This project included the development of reference geometries of marine organisms, a compilation of radionuclide bio-concentration factors, transfer modeling and assessment, development of a FASSET radiation effects database (FRED), and six major reports.

MARINA II Collates marine radioactivity data after 1985 in North European waters, including North-East Atlantic and contributory seas. Radionuclides included are: ^{210}Pu, ^{137}Cs, ^{99}Tc, ^{90}Sr, ^{238}Pu, $^{239+240}$Pu, ^{241}Am, ^{129}I, ^{60}Co,^{3}H, and ^{106}Ru.

BNFL database Includes 26 consecutive annual data reports (as of 2002 report) on "radioactive discharges and disposals, monitoring of the environment, and radiological impact" of BNFL operations in the UK. Radionuclide data on tritium, C-14, Co-60, Sr-90, Zr-96, Nb-96, Tc-99, Ru-106, I-129, Cs-134, Cs-137, Pu (alpha) and Am-241 is provided for fish, mollusks, crustaceans, and seaweed for waterways potentially impacted by BNFS operations in UK. In addition are coastal radiation surveys, and inland impact analyses (i.e., milk, tap water, vegetables, lakes).

HELCOM database

Monitoring data of Baltic Sea since 1984 by (or supported by) member states to the Helsinki Commission (HELCOM): Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia, and Sweden. Annual data on radionuclides in water, sediment, fish, aquatic pelagic and benthic animals of the Baltic Sea are entered into the HELCOM database. Cesium-137 and Strontium-90 are most frequently tested. Laboratories include Riso National Laboratory (Denmark), Federal Maritime and Hydrographic Agency (Germany), Swedish Radiation Protection Institute, Radiation and Nuclear Safety Authority (Finland), Central Laboratory for Radiological Protection (Poland), and V.G. Khlopin Radium Institute (Russia).

ERICA Started in mid-2004, it is an outgrowth of FASSET and will develop an "integrated approach to scientific, managerial, social issues concerned with the environmental effects of contaminants emitting ionizing radiation, with emphasis on biota and ecosystems." ERICA will develop risk tools, risk characterization methodologies, case-studies (including Sellafield marine releases of radionuclides). and guidance on decision-making involving stakeholder issues.

7.0 Standards for Human Consumption of Radionuclides

Some of the earliest public radiation protection guidelines for consumption in the United States were developed in 1961, prior to the development of the nuclear industry. The guidelines were derived by applying approximately 3% to NCRP's occupational exposure guidelines, and were developed for I-131, Sr-90, Sr-89, Cs-137, Ba-140, Tritium, and Ru-106 (Davistownmuseum).

In 1982, the US Food and Drug Administration (FDA) developed recommendations regarding accidental radiation contamination of food products, which were replaced by Recommendations for State and Local Agencies in 1998 (FDA, 1998). Recently, guidance levels have been developed jointly in the codex alimentarius commission of the World Health Organization and the Food and Agriculture Organization of the United Nations for radionuclides in foods "destined for human consumption and traded internationally" (Codex, 2004). Within the United States there has been an expansion of the 1998 Recommendations by the U.S. FDA for application to "domestic food in interstate commerce or food offered for import into the United States" (FDA, 2004).

The proposed international guideline levels for radionuclides in imported foods, as described in the 2004 codex alimentarius (table 3) are based on the intervention level of about 1 mSv per year. It is considered that food that does not exceed the Guideline Levels "should be considered as safe for human consumption." While these limits were designed to protect against risks that could occur from a major contamination event (i.e., a major radionuclide release, such as at Chernobyl), and are intended to assure food safety for at least a one year timeframe after a recognized incident, they can also be applied for longer time frames and are general acceptance criteria for food in international trade.

Table 3: Guideline Levels (Bq/kg) for Radionuclides in Foods

Radionuclides	Guideline Level (Bq/kg)
Pu-238, 239,240, Am-241	1
Sr-90, Ru-106, I-129, I-131, U-235	100
S-35, Co-60, Sr-89, Ru-103, Cs-134, Cs-137, Ce-144, Ir-192	1,000
H-3, C-14, Tc-99	10,000

Note: The Guideline Level is for the total radionuclides in each noted group.

While not all radionuclides are included in the Guideline Levels, the list is considered sufficient since it includes those most relevant to the food chain and those most important biologically in either accidental or intentional environmental releases. The Guideline Level for the radionuclide groups are addressed independently (i.e., the H-3, C-14, Tc-99 group guideline value is 10,000 Bq/kg, regardless of what is found in the other groups). However, there is addition of concentrations within in the same group, such that radiation contributions of Cs-134, Cs-137 and other same group radionuclides would be combined and their total should be less than the stated guideline level for that group, i.e., 1,000 Bq/kg for the group to which Cs belongs. The assumed annual intake of food for adults is 550 kg and for infants is 200 kg (includes food and milk). It is also assumed that imported foods comprise no more than 10% of the total diet.

The estimated exposure for individual consumers is derived from the following formula: E = GL X M(a) X dC(a) X IPF, where E is the average mSv of internal dose, where GL is the Guideline level in Bq/kg, M(a) is the age-dependent mass of food consumed (kg) per year, dC(a) is the age-dependent ingestion dose coefficient (mSv/Bq), and IPF is the import/production factor – assumed at 10% (or less). As per the example noted in ANNEX 2, Appendix XXII of the codex alimentarius commission report of April, 2004, the Cs-137 dose estimation to adults and to infants from applying the 1000 Bq/kg Guideline Level would be as follows:

Adult: E = 1000 Bq/kg X 550 kg/yr X 1.3E-05 mSv/Bq X 0.1 = 0.7 mSv/yr

Infant: E = 1000 Bq/kg X 200kg/yr X 2.1E-05 mSv/Bq X 0.1 = 0.4 mSv/yr

It should be noted that each of the values is less than the 1 mSv/yr standard.

The documentation for the USFDA Guidance Levels for radionuclides in foods used domestically and in those imported were recently published, and are consistent with those values reported in a prior 1998 FDA publication (FDA, 2004; FDA, 1998). The committed effective dose basis of the Guidance is 5 mSv, with an associated lifetime total cancer mortality risk of about 2.25E-4 (approximately 1 in 4400) or less. The FDA values are derived from the most limiting diets based upon the radionuclide in question and the most susceptible population age group – taking into consideration age groups 3 months, 1 year, 5 years, 10 years, 15 years and adult. A summary of the FDA Derived Intervention Levels (DIRs) is demonstrated in table 4.

Table 4: FDA Derived Intervention Levels (Bq/kg)

Radionuclide Group	Derived Intervention Level(Bq/kg)
Sr-90	160
I-131	170
Cs 134+137 total	1200
Ru*-103	6800
Ru-106	450
Pu + Am group total	2

*Ru 103 and 106 values are summed and divided by their DIRs with the total ratio DIR set a 1.

The FDA also performs market basket assessments of radionuclides in food products, as part of if its Total Diet Study program of the U.S. food consumer (FDA, 2001). The data is compiled for the total US population, as well as for fourteen age and sex subgroups. Dietary exposure is computed by multiplying the concentrations found in 280 different foods in the survey by the amount consumed of each type of food. While the minimal analytical reporting limits of radionuclides are meant to be well below derived intervention levels, it is important to recognize their importance – since values below the reporting limits are considered zero by the Agency. The

Agency has therefore essentially set, through the sensitivity of its radionuclide analytical program, a food concentration below which there is no level of concern, i.e., a value indistinguishable from zero.

The FDA minimal analytical reporting limits for some of the key radionuclides in food are as follows: 90Sr = 0.1 Bq/kg; 137Cs = 5 Bq/kg; 241Am = 200 Bq/kg. The radionuclide monitoring of US foods by FDA measures contaminants at levels sensitive enough for the purpose of assessing the public's Total Diet Intake. The analytical reporting limits differ from, but are related to detection limits (see next section).

8.0 Detection Levels of Radionuclides in Marine Monitoring Programs

Environmental radionuclide monitoring programs must be supported by sufficient laboratory capability to measure samples at concentrations that are distinguishable from background, given a certain counting system, sample analytic counting uncertainty, counting time and sample size. This potential capacity is called the minimum detectable amount or activity (MDA). The MDA is a function of a counting system's inherent assessment capability, the radionuclide being tested, and the theoretical sample size. It is independent from what concentrations are actually found in analysis of collected samples. The MDA is "the value that one can legitimately advertise that one can measure with reasonable assurance" (Strom, 1998).

For example, if the environmental monitoring program is designed to detect potential exposures in fish at a concentration that could produce a certain level of risk of cancer in a heavy fish consuming public, then back calculations must be undertaken in advance of field studies to determine the concentrations of a substance that must be detectable in a given counting system for certain types of samples. Given the concentrations that must be detectable, the laboratory

determines the sample and analytical requirements needed to assure that the laboratory procedures and equipment will have the capability to ascertain certain Minimum Detection Activities or MDAs for the radionuclide in question in a given medium (i.e., Cs-137 at 4 E -05 Bq/kg-wet weight of edible fish flesh).

The process by which one systematically computes the MDA for a particular measurement process of radionuclide analysis of a radionuclide has been described in a classic work of nearly 40 years ago (Currie, 1968). The detection limit was defined by Currie as "the true net signal level that may be expected a priori to lead to detection." The detection limit is contrasted to the critical level and the determination limit. The "critical level" is defined as "the signal level above which an observed instrument response may be reliably recognized as 'detected'." The "determination level" is another signal level, but this time is at a level above which "a quantitative measurement can be performed with a stated relative uncertainty." Furthermore, some laboratories or institutions utilize the concept of laboratory "minimum reporting levels" or MRLs – which are based on "the radiological significance of a particular concentration of activity" rather than just the technical capability of measuring it (RIFE-8, 2003). MRLs are used to help render results more transparent when taking into consideration data from laboratories with different detection limits. MRLs are above the detection limit, but at concentrations below which there is thought to be no meaningful risk potential, i.e., measures considered indistinguishable from zero in terms of information content value. FDA converts food contaminant levels less than the reporting level to zero in its calculations.

The MDA (as per Currie) can be computed as follows:

$$MDA = \frac{(\text{Std Dev of background}) + 2.71}{(T)(Y)(E)(M)(K)}$$

Where: Std Dev = the standard deviation of the background counts;
T = the counting time (in seconds) per sample
Y = the radiation yield per disintegration
E = the absolute detector efficiency
M = sample size in grams
K = the unit conversions (from counts per second to pCi, etc.)

As can be noted from the above equation, the MDA (sometimes called MDL) level will be higher, that is will be less sensitive, if the background radiation count has high scatter or less certainty (i.e., higher standard deviation). One could potentially reduce the background levels and standard deviations by performing analyses in laboratories with low background radiation levels, such as lead-shielded environments or underground counting laboratories (IAEA, 2004). The MDA can also be reduced by increasing counting times and the sample size – as well as utilizing large volume HPGe detectors with higher relative efficiency. Given the specific radionuclide, the radiation yield per disintegration and the unit conversions are set values over which the investigator has no control.

The MDLs from a number of national laboratories from Norway, Ireland, Japan, and Hong Kong are shown (table 5) for Cesium-137 in fish. These minimum detection limits are all listed in Bq/kg – wet weight. Unfortunately, not all laboratories report both sample size and analytic time data, so direct comparisons of the potential capabilities of the laboratories to achieve similar MDLs cannot be noted from the table. The data ranges from the least sensitive level of about 11 Bq/kg, derived from a portable sodium iodide detector system applied to 0.2 kg fish samples, to a much higher level of sensitivity at 0.06 Bq/kg, accomplished for 2 kg samples analyzed through a system of four high purity germanium detectors. In general, HPGe technologies commonly have environmental monitoring laboratory MDLs for Cesium-137 in fish in the range of 0.4 to 0.1

Bq/kg. Portable sodium iodide detectors have, as expected, less sensitive MDAs, with levels at about 11 Bq/kg.

Table 5: Minimum Detection Limits for Cesium-137 in Marine Fish Environmental Monitoring

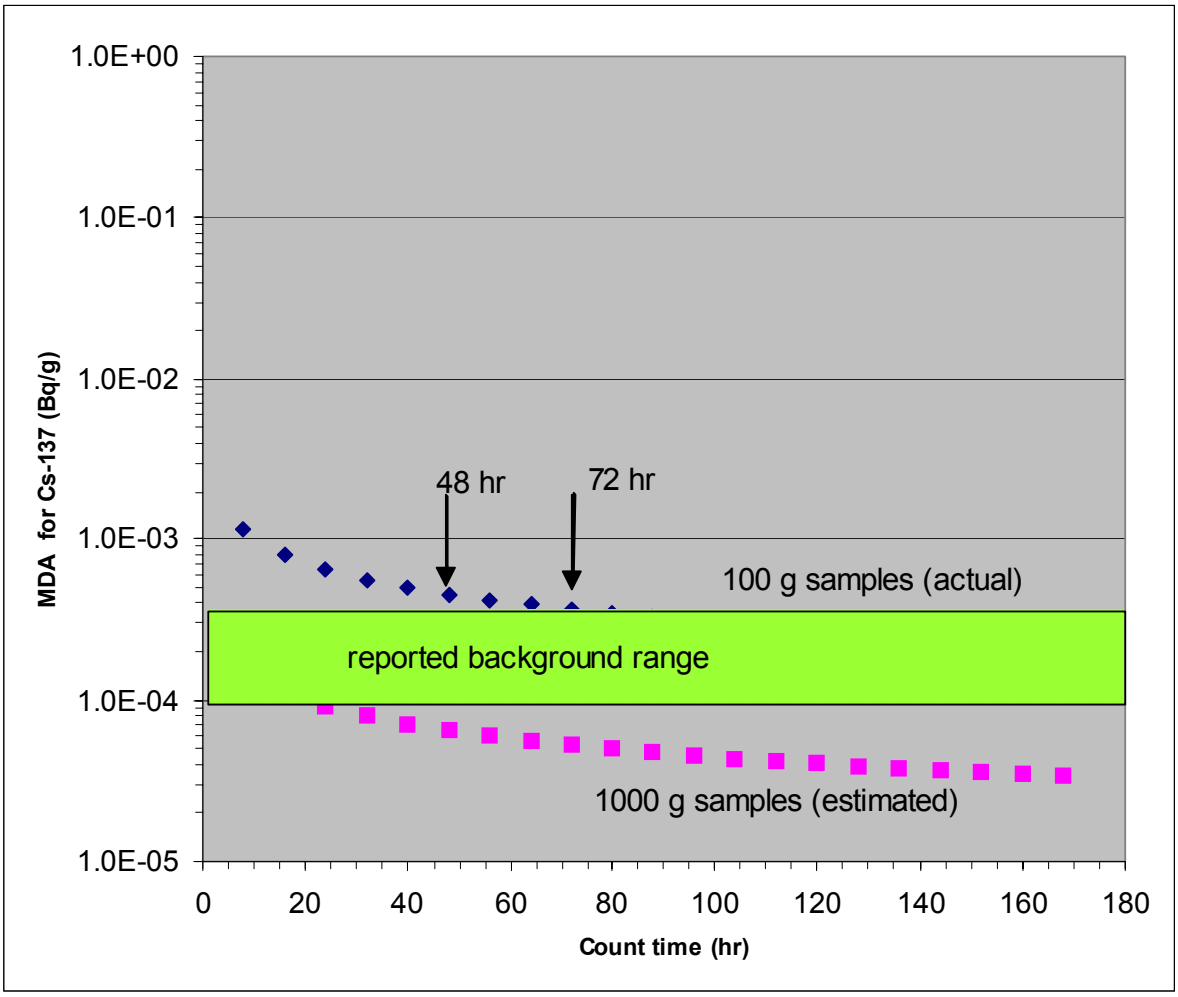
Findings from National and other Laboratories. Data on Analyses of Marine Fish

Laboratory	Sample size	Analysis Time	Detection Limit Bq/kg	Average Conc. Bq/kg	Reference
Norwegian Radiation Protection Authority	up to 5 kg	2 days	0.2 to 0.4 - ww	0.2 to 0.4 (general findings)	Gafvert et al, 2003
Comment: NRPA low-level, HPGe detectors are in low-background lab and have relative efficiencies of 23% to 40%. IMR (The Institute of Marine Research) lab gamma counters include an extra-low background HPGe detector with 60% relative efficiency, electrostat cooling systems and 10cm lead shielding. FWHM=1.9 keV at 1332 keV.					
Norwegian Food Control Authority	0.5 kg dried muscle	2-3 days	0.1		Gafvert et al, 2003
Comment: EG&G Ortec GEM (p-type) detector with 45% relative efficiency.					
Directorate of Fisheries (Tromso) **- local office (Norway)**	0.2 kg fresh muscle	Not stated	11		Gafvert et al, 2003
Comment: Canberra series 10 portable NaI detector					
Radiation Protection Institute of Ireland	Not stated muscle	Not stated	0.3	0.8	Ryan et al, 2003
Comment: High resolution gamma spectrometyr using high purity germanium detectors. Typical uncertainties are about 15%.					
Japan Chemical Analysis Center	4 kg muscle	Not stated	0.7 lowest values	0.8	JCAC, No. 139, 2004
Japan Nuclear Cycle Development Institute	Not stated	Not stated	Not stated lowest values 7 E -5	0.1	Shinohara 2003
Hong Kong Observatory	2 kg	20 hours	0.06	0.08 (averages of only detectables	Li & Young 2003
Comment: Gamma spectrometry system with 4 high purity germanium detectors. Canberra Genie-2000 software used.					

MDAs from the Hong Kong Observatory laboratories (table 6) are shown again for Cesium-137 – but also for Strontium-90, Plutonium-239, tritium and Iodine-131 in both fish/shellfish and seaweed. Relatively large samples of fish were used (2 kg) for Cesium-137 analyses, and the MDA was at the low end of levels noted in other laboratories, at 0.06 Bq/kg-ww.

Limits of detection for Cs-137 were defined, as a function of counting time and biota sample size (100 gram and 1000 gram samples) for the ongoing Amchitka study (Powers et al, 2003; Kosson and Stabin, 2005). A comparison of the detection limits to international food standards for consumption and risk based thresholds was made, to assure that the analyses would be planned to have sufficient sensitivity to detect concentrations of relevance to public health. As noted (graph 1), the analytic system would be able to detected Cs-137 at 0.4 Bq/kg with 72 hour determinations for 100 gram biota samples, and much lower concentrations for selected 1000 gram sub-samples with shorter counting times. In all cases, the anticipated sensitivity would be substantially below the requirements of the proposed international food standards (WHO, FAO, 2004) and risk-based thresholds for high consuming subsistence fishers.

Graph 1: Detection Limits, Sample Size and Counting Times for Cs-137 in Amchitka biota



Reference: Kosson and Stabin, 2005.

Table 6a outlines the MDAs at the Hong Kong Observatory for a few radionuclides in seawater (suspended particulates) and seabed sediment from four sampling locations in the eastern coastal waters of Hong Kong: , Basalt Island, Tai Long Wan, Waglan Island and Port Island. The sediment MDAs for 137Cs are comparable to the "typical" sediment laboratory MDA of 1.5 E-04 Bq/g reported by South Korean investigators at Kyungpook, Pukyong and Daegu National Universities of South Korea and the Korea Institute of Nuclear Safety (Park, Lin et al, 2004).

Table 6: Minimum Detection Activity (MDA) Hong Kong – Seaweed and Shellfish

Hong Kong Environmental Monitoring. Hong Kong Observatory, 2003

Radionuclide	Data for Fish, Shellfish			Data for Seaweed		
	Sample size	Counting Time	Bq/kg-ww MDA	Sample Size	Counting time	Bq/kg-dw MDA
Cesium-137	2 kg	20 hours	0.06	0.5 kg	6 hours	2
Strontium-90	2 kg	8 hours	0.003	0.1 kg	8 hours	0.05
Plutonium-239	0.5 kg	61 hours	0.003	0.03 kg	61 hours	0.01
Tritium	0.01 kg	10 hours	4	.02 kg	10 hours	2
Iodine-131	2 kg	20 hours	0.03	0.5 kg	5.5 hours	1

Reference: Hong Kong Observatory, technical Report No. 23, "Summary of Envornmental Radiation Monitoring in Hong Kong, 2003. Li SW and Yeung KC.

Table 6a: Minimum Detection Activity (MDA) Hong Kong – Marine Water and Sediments

Hong Kong Environmental Monitoring. Marine Water and Sediment

Radionuclide	Seawater Suspended Particulates			Sea Sediments		
	Sample size	Counting time	Bq/l MDA	Sample size	Counting Time	Bq/g-dw MDA
Iodine-131	4 liters	15.3 hrs	1.00E-02	2 kg	5.5 hrs	4.00E-04
Cesium-137	4 liters	15.3 hrs	2.00E-02	2 kg	5.5 hrs	5.00E-04
Strontium-90	3 liters	8.3 hrs	2.00E-03			
Plutonium-239	2 liters	61 hrs	3.00E-04	.005 kg	61 hrs	2.00E-04

Note: Strontium-90 analyses: background level 1 CPM, 75% counting efficiency, and 90% chemical recovery.
Plutonium-239 analysis: 20% counting efficiency and 50% chemical recovery.
Reference: Hong Kong Observatory, technical Report No. 23, "Summary of Environmental Radiation Monitoring in Hong Kong, 2003. Li SW and Yeung KC.

Detection limits can be influenced by a number of factors, including the sensitivity of the analytic instrument, the size of the sample, the counting time duration, background count rates, the influence of radiochemical separation and concentration techniques. Detection limits will vary in relation to the previously noted factors, and will often change within the same laboratory at different times or with different laboratory setups or calibrations. Some guidance on what one might expect for "typical" limits of detection in the analytic testing for a variety of radionuclides in different marine media are outlined in a recent report (Jones, Simmonds et al, 2004) and are noted below for a few radionuclides (table 7). These values, of course, are not specific to a particular study and will be expected to vary by the relevant study conditions.

Table 7: Radionuclide Typical Detection Limits

Analysis of the Marine Environment

Radionuclide	Fish Bq/kg-ww	Crustacea Bq/kg-ww	Molluscs Bq/kg-ww	Seaweed Bq/kg-ww	Sediment Bq/kg-dw	Seawater Bq/m^3
^{90}Sr	0.1		0.1	0.1		
^{99}Tc		0.08		0.08		0.00005
^{137}Cs	0.1	0.1	0.1	0.1	0.4	0.0001
$^{239+40}Pu$		0.0001.	0.0001		0.0001	
^{241}Am		0.0001	0.0001		0.0001	

Reference: (adapted from) Jones, Simmonds et al, 2004.

The MDA for 129 I in biological samples has recently been described using direct gamma-X spectrometry, with sub-samples as small as 20 mg (Frechou and Calmet, 2003). The detection limit was noted as 0.5 Bq/kg. The technique was advocated by the authors as "a simple and fast I-129 activity measurement technique to monitor environmental samples and to select the most efficient and representative bio-indicators to assess the I-129 environmental contamination levels." The gamma-X spectrometry analysis is now routinely applied on a monthly surveillance basis of the English Channel and to the North East Atlantic Ocean coast of France to several seaweed species: Fucus serratus, Fucus vesiculosus and Ascophyllum nodosum – as well as to a variety of foodstuff (Frechou and Calmet, 2003). Other more demanding measurement procedures, such as Accelerator Mass Spectrometry and Radiochemical Neutron Activation Analysis, have been previously used for the detection of low level I-129. Radiochemical Neutron Activation Analysis has been reported to have a detection limit of 10^9 atoms of I-129 for 40 g seaweed samples (Hou et al, 2000).

A common difficulty associated with the low concentrations assessed in environmental radionuclide monitoring is how to report and statistically deal with results below the detection limits. Data reporting options noted (Royal Society of Chemistry, 2001) to have been used by

various investigators to describe results below the study detection limits include: a) not detected, i.e., nd; b) less than the detection level, i.e., <dl; c) assigning an arbitrary value of ½ of the detection level, i.e., ½ dl; or d) list the result with its uncertainty expressed as the 95% confidence level. The last option is to be preferred, since "it provides the most information" and can the data can be incorporated in statistical assessments (Royal Society of Chemistry, 2001). Data from some monitoring programs, such as individual samples from the UK Food Standards Agency, are routinely reported with results and uncertainty. Frequently, however, average sample values are often reported as below a given detection level or are simply excluded from data tables if the average is below the detection level. It is this type of inconsistency in the reporting of radionuclide monitoring data that makes it difficult to compare and assess results from various monitoring programs.

9.0 Monitoring Program Data: Radionuclide Concentrations in Biota

There are a number of approaches that can be used to display the results of radionuclide environmental monitoring programs of the oceans and seas of the northern hemisphere. The basic data consists of radionuclide (Cesium-137, Strontium-90, etc.), environmental compartment (ie, surface water, sediment, biota), general type of biota (fish, mollusk, crustacean, seaweed), specific type of biota (including scientific name), body of water (i.e. Arctic Ocean, Kara Sea, Baltic Sea, etc.), and geographic convention categories of location. Data can be sorted by country or region, and can be displayed using geospatial mapping. The results of monitoring can be influenced by technical aspects, such as sampling schemes, sample sizes, analytic procedures, and detection limits for various radionuclides in various environmental media.

The approach used in this report is two-fold. First, marine biota radionuclide data will be summarized and reviewed separately by body of water, including key national or regional coastal

areas (i.e., Atlantic and Pacific Coasts of the mainland United States; Japan's sea environment – Sea of Japan and Coastal NW Pacific, etc.). A list of the bodies of water considered in this report, and their major country shorelines, is outlined in Appendix 1. This method of describing data will permit reviews of biota from major oceans and seas as well as their surrounding countries or regions – and will provide a place in the report where a description of local potential sources of radionuclides can be considered. The second approach summarizes the radionuclide information for marine fish in a single composite table (see table YX) – where ranges of concentrations of the most commonly measured radionuclides can be visualized for the Northern Hemisphere. These approaches should provide the reader with increased clarity and a comprehensive assessment.

9.1 United States Marine Biota Concentrations

Coastal Atlantic and Pacific Oceans

Within the United States, radionuclides in bivalves were last surveyed in 1990, and reported in a 1995 publication (Valette-Silver,1995). Data include Sr-90., Cs-137, Pu-238, Pu-239,240 and Am-241 concentrations for bivalves collected on the East and West Coasts of the United States. Gulf Coast data is also collected but is not summarized in this review. The results, summarized in Tables 8 and 9, display the average values (for above detection limit samples) and their SD, median, range and individual composite results. Only 4 of the 14 East Coast samples had Cs-137 values above the detection limit, with the lowest reported concentration being 74 uBq/g – dw. West Coast samples had higher Cs values, with 12 of 17 samples being above detection, the lowest reported value being 0.11 Bq/kg-dw.

Table 8: Radionuclides in Bivalves – East Coast

Mussels and Oysters of Unites States. National Status and Trends Program, NOAA, 1990 data
Ref: Valette-Silver and Lauenstein, 1995. Data in Bq/kg dry-weight.

E Coast	Sr-90	Cs-137	Pu-238	Pu-239/40	Am-241
Ave	0.2	0.140	0.006	0.016	0.006
SD	0.25	0.060	0.006	0.016	0.003
# samples	14	14	14	14	14
Median	0.087	0.150	0.005	0.011	0.007
Range	0.02-0.69	<dl – 0.195	<dl -0.020	0.001-0.047	<dl-0.009
#>dl	14	4	13	14	14
Data Set	0.056	<	0.005	0.047	0.006
	0.027	0.192	0.002	0.012	0.001
	0.027	0.195	0.002	0.027	0.008
	0.026	<	0.003	0.015	0.007
	0.032	0.103	0.001	0.001	0.001
	0.181	<	0.020	0.012	0.009
	0.503	<	<	0.046	0.008
	0.124	<	0.005	0.002	<
	0.017	<	0.004	0.002	0.008
	0.209	0.074	0.005	0.008	0.0005
	0.733	<	0.002	0.029	0.007
	0.117	<	0.013	0.004	NA
	0.037	<	0.005	0.011	0.007
	0.692	<	0.016	0.004	0.005

Note: usually 300g dry soft tissue(about 180-200 mussels) per composite sample per site Ave, SD, Median all stated as reported in publication, with conversion to Bq/kg-dw.
Adapted from: Valette-Silver NJ, Lauenstein GG (1995). Radionuclide Concentrations in Bivalves Collected along the Coastal United States. Marine Pollution Bulletin 30, 320-331.

Table 9: Radionuclides in Bivalves – West Coast

Mussels and oysters of the United States. National Status and Trends Program, NOAA, 1990 data. Ref: Valette-Silver and Lauenstein, 1995. Data in Bq/kg dry-weight.

West Coast	Sr-90	Cs-137	Pu-238	Pu-239/40	Am-241
Ave	0.170	0.250	0.003	0.012	0.036
SD	0.470	0.100	0.003	0.008	0.031
# sampes	17	17	16	16	17
Median	0.050	0.270	0.002	0.011	0.024
Range	0.023-1.994	<dl -0.400	<dl -0.012	0.001-0.027	0.002-0.090
#>dl	17	12	14	16	17
Data set	0.027	0.400	0.003	0.008	0.012
	0.031	0.360	0.002	0.005	0.070
	0.061	0.295	0.003	0.002	0.007
	0.050	<	0.002	0.001	0.005
	0.069	0.189	0.002	0.027	0.087
	0.023	0.112	<	0.011	0.019
	0.051	<	<	0.006	0.068
	0.027	0.322	0.003	0.007	0.002

0.045	<	0.001	0.016	0.024
0.051	0.118	0.002	0.018	0.065
0.032	0.177	0.002	0.017	0.053
0.045	0.313	0.012	0.015	0.045
1.994	0.122	0.002	0.021	0.090
0.172	<	NA	NA	0.050
0.144	0.268	0.003	0.024	0.013
0.028	0.280	0.002	0.009	0.007
0.076	<	0.009	0.010	0.005

Note: usually 300g dry soft tissue(about 180-200 mussels) per composite sample per site. Adapted from: Valette-Silver NJ, Lauenstein GG (1995). Radionuclide Concentrations in Bivalves Collected along the Coastal United States. Marine Pollution Bulletin 30, 320-331.

9.12 Seawater

Plutonium isotopic characterization was undertaken in the Gulf of Maine (Dai et al, 2001). This research was unique in that it was designed to assess Pu isotopic data as well as size-fractionation. A three-stage thermal ionization mass spectrometer (TIMS) analysis was applied to discern specific plutonium isotopes (Pu-239, Pu-240, Pu-241) and a cross-flow ultra-filtration membrane assessed size-fractionation. Plutonium results from seawater samples at 1, 65 and 200 meters depth (table 10) demonstrate that, up to 200 meters, plutonium concentrations increase with sample depth – with Pu-239 increasing from 3.98 uBq/kg at the surface to about 8.15 uBq/kg at 200 meters. The study detection limit for Pu-239 and 240 is 0.02 uBq/m3. Four liter samples were analyzed for soluble plutonium fractions and 1.5 kg of retained filter fractions were used for size determinations. The researchers indicate that the Pu-240/Pu-239 ratios in the surface (0.1892) and at other depths are consistent with a global fallout radionuclide source.

Table 10: Plutonium isotopes in Seawater of the Gulf of Maine

Results in mBq/m^3 (standard deviation) by depth. Reference: Dai, Buesseler, Kelley, et al, 2001

Radionuclide	*1 meter*	*65 meters*	*200 meters*
Pu-239	3.98(.05)	5.58(.08)	8.15(.08)
Pu 240/239 ratio	0.1892	0.1808	0.1837
Pu 241/239 ratio	NA	0.0026	0.0025

NA = not available

Dai, MH., Busseler KO, Kelley JM, et al. Size fractionated plutonium isotopes in a coastal environment. Journal of environmental radioactivity 53(2001) 9-25

9.2 Japan Marine Biota Concentrations

Sea of Japan and NW Pacific Ocean

The Japan Chemical Analysis Center performs an annual radioactivity survey in Japan of a wide range of media, including concentrations in tea, soil, fresh water, airborne dust, rain, vegetables, milk, freshwater fish, and – most importantly for this review – seawater, sea sediment, sea weed, sea fish and shellfish. The marine environment is assessed for Sr-90 and Cs-137. Biota ample sizes are from 3 to 5 kg sea fish, and 3 to 5 kg of shellfish and seaweed. The Sr-90 and Cs-137 data for sea fish (table 11, selected fish) are reported in the units of Bq/kg-wet. Data in the original report (not shown here) are also computed as Bq/g Calcium for Sr-90 and Bq/g potassium for Cs-137. Limits of detection limit data are not discussed in the JCAC reports.

Table 11: Cesium-137 and Strontium-90 in Sea Fish of Japan

Source: Radioactivity Survey Data in Japan. Japan Chemical Analysis Center. Reports 138 (2003) and 139 (2004). Data in Bq/kg-ww and (SD)

Marine Fish	^{90}**Sr**	^{90}**Sr**	^{137}**Cs**	^{137}**Cs**
Report Year	**2003**	**2004**	**2003**	**2004**
Ammodyt.personatus (sand lance)	.017(.007)	.000(.005)	.054(.008)	.035(.007)
Branchiostegus sp. (tilefish)	.010(.006)	.013(.005)	.12(.010)	.12(.010)
Hexagrammos otakii (fat greenling)	.010(.006)	.000(.006)	.10(.009)	.13(.010)
Oncorhynchus keta (salmon)	.006(.005)	.01(.006)	.084(.009)	.074(.009)
Pleuronectidae (righteye flounder)				
Sea of Japan (ave)	.004(.005)	.002(.004)	.094(.009)	.068(.008)
Pacific	.003(.005)	.016(.007)	.077(.008)	.054(.008)
Sardinops sp. (sardine)	.005(.005)	.000(.004)	.038(.007)	.052(.007)
Sebastes inermis (darkbanded rockfish)	.007(.005)	.014(.007)	.13(.011)	.11(.010)
Sebastiscus marm. (marbled rockfish)	.020(.006)	.039(.009)	.051(.009)	.079(.009)

Note: data adapted from Radioactivity Survey Data in Japan. Environmental and Dietary Materials. Japan Chemical Analysis Center, Chiba, Japan. Reports 138(2003) and 139 (2004).

The five types of shellfish included in the Japan Chemical Analysis Center Radioactivity Surveys (table 12) of 2003 and 2004 are the Japanese littleneck (Tapes philippinarum), Yezo scallop (*Patinopecten yessoensis*), Japanese oyster (*Crassostrea gigas*), blue mussel (*Mytilus edulis*), and horned turban (*Turbo Batillus cornutus*).

The strontium values in the shellfish are low and generally not significantly different from zero. Shellfish cesium-137 concentrations are higher than those of strontium, with the greatest cesium values found in the Yezo scallop in both 2003 and 2004.

Table 12: Cesium-137 and Stronium-90 in Shellfish of Japan

Source: Radioactivity survey Data in Japan. Japan Chemical Analysis Center. Reports 138 (2003) and 139 (2004). Data in Bq/kg-ww and (SD).

Marine Shellfish	^{90}**Sr**	^{90}**Sr**	^{137}**Cs**	^{137}**Cs**
Report Year	**2003**	**2004**	**2003**	**2004**
Crassostrea gigas (Japanese oyster)	.000(.007)	.017(.013)	.010(.007)	.01(.007)
Mytilus edulis (blue mussel)	.000(.005)	.000(.006)	.011(.005)	.011(.005)
Patinopecten yesso. (Yezo scallop)	.005(.006)	.006(.006)	.019(.005)	.024(.005)
Tapes philippinarum (Japanese littleneck)	.008(.008)	.005(.005)	.015(.006)	.012(.005)
Turbo (Batillus) corn. (horned turban)	.013(.008)	.008(.008)	.018(.007)	.02(.008)

Note: data adapted from Radioactivity Survey Data in Japan. Japan Chemical Analysis Center, Chiba, Japan. Reports 138(2003) and 139 (2004). Where data was collected from multiple sites, average values are reported.

Other environmental radiological monitoring efforts specifically assess the control of potential local radiation sources. For example, a recent report (Shinohara, 2004) describes concentrations of Sr-90, Zr/Nb-95, Ru-106, Cs-134, Cs-137, Ce-144, and Pu-239,240 in marine fish, shellfish, and seaweed in the Pacific Ocean offshore from a Japanese reprocessing plant and in distant control sites (see table 13). With the exception of cesium-137 in fish, Pu-239,240 in

seaweed, and both Pu-239,240 and Cs-137 in shellfish, the other radionuclides were below the level of analytic detection in samples off-shore from the plant and in the control area samples. The offshore and control sample concentrations (compared vertically in the table) are very similar.

Table 13: Cesium-137 and Pu-239, 240 Concentrations in Biota

Samples from the Pacific Ocean. Offshore from Tokai(Japan) Reprocessing Plant vs Comparison Site 20km further north. Data in Bq/kg-ww.

	Fish	*Shellfish*	*Seaweed*
Cs-137			
offshore			
Mean	0.11	0.058	< detect
(variance)	0.0008	0.0006	
# samples	40	80	
control			
Mean	0.12	0.063	< detect
(variance)	0.001	0.0006	
# samples	40	40	
Pu-239,40			
offshore			
Mean	< detect	0.0021	0.0036
(variance)		8.00E-08	2.20E-06
# samples		33	80
control			
Mean	< detect	0.002	0.0034
(variance)		2.90E-09	2.20E-06
# samples		40	40

Reference: Shinhara K. Asessment of radiological effects on the regional environment de to the operation of the Tokai reprocessing Plant. Journal of Environmental Radioactivity 72(2004) 299-322.

Specific monitoring for strontium-90 and cesium-137 in the seaweed Undaria pinnatifida is performed as part of the annual radioactivity survey of environmental and dietary materials by the Japan Chemical Analysis Center. As can be noted from the data (table 14), the data are remarkably stable for Sr-90, with the averages during the two years being essentially identical (0.024Bq/kg-wet and 0.030 vs 0.031Bq/kg Ca). The Cs-137 data also was very consistent, though not to the same extent.

Table 14: Radionuclides in Japanese Marine Seaweed

Strontium-90 and Cesium-137. Sample dates: April 2001-March 2003. Seaweed: *Undaria pinnatifida.* Data in Bq/kg wet, Bq/kg Ca & K.

	Strontium-90 Data		Cesium-137 Data	
	Bq/kg-wet	**Bq/kg Ca**	**Bq/kg-wet**	**Bq/kg K**
# Sampling sites/yr	9	9	9	9
April 2001-Mar 2002				
Average	0.024	0.030	0.015	0.002
Standard Dev.	.0153	0.020	0.008	0.001
April 2002-Mar 2003				
Average	0.024	0.031	0.018	0.004
Standard Dev.	0.013	0.020	0.009	0.003

References: Japan Chemical Analysis Center, Radioactivity Survey Data in Japan environmental and dietary Material, reports 138 (2003) and 139 (2004).

9.22 Seawater

A substantial amount of data has been collected on seawater in the Sea of Japan and in the North Pacific near Japan (table 15). For the purposes of this review, we will focus on information from the ASPAMARD (Asia-Pacific Marine Radioactivity Database), the HAM (Historical Artificial Radionuclides in the Pacific Ocean and its Marginal Seas) database, the GLOMARD (Global Marine Radioactivity) database, and annual surveillance reports (Radioactivity Survey Data in Japan) from the Japan Chemical Analysis Center, and will also include information from seven sampling cruises in the Japan Sea between 1997 and 2000 (Ito et al, 2003). While some overlap in database information is to be expected, we have avoided redundancy from the Japan Chemical Analysis Center data by only including the most recent two reports (2003 and 2004) – timeframes not included in the other published databases.

Table 15: Surface Water Cesium-137 and Plutonium-239, 240

Surface Water Cesium-137 and Plutonium 239, 240: Sea of Japan and NW Pacific Ocean. Data from ASPAMARD, HAM, GLOMARD databases. Japan Chemical Analysis Center reports and Japan Sea cruise samples (Ito et al, 2003).

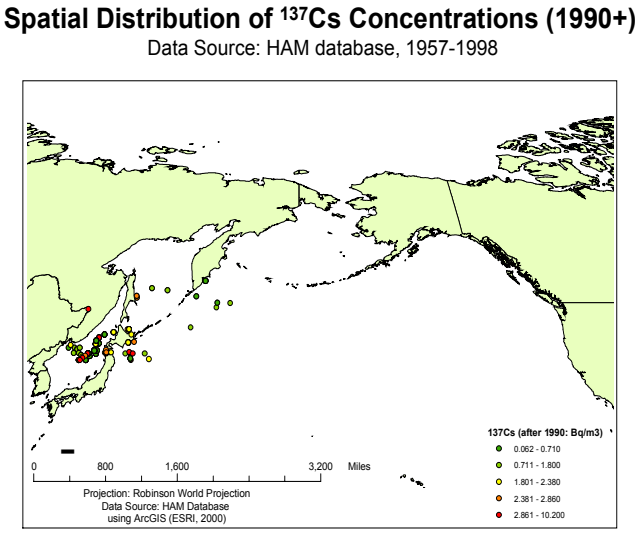
		^{137}Cs			$^{239+240}$Pu	
	#samples	**mean Bq/m^3**	**SD**	**#samples**	**mean mBq/m^3**	**SD**
ASPAMARD (1995-2001)	168 (# of sites)	*2.7*	1	261	*5.9** *median	0.8-1.4** **92%
GLOMARD (1996-2000)						
Sea of Japan	44	*2.8*	0.5	30	*6.6*	2.5
NW Pacific	30	*2.4*	0.5	6	*3.8*	2.4
HAM						
NW Pacific(1997)		2.1	0.9		2	1.5
Japan Chem Center - 2003 Report						
NW Pacific	9	1.74	0.41			
Sea of Japan	5	2.04	0.38			
- 2004 Report						
NW Pacific	9	1.91	0.48			
Sea of Japan	5	2.1	0.29			
Japan Sea Cruises (Ito et al, 2003)						
Northern Japan Sea	4	2.58	0.26			
South Japan Sea	6	2.62	1.14	1	<.04	
Total Japan Sea	10	2.6	0.89			

HAM: Hirose K, Aoyama M. Present background levels of surface ^{137}Cs and ^{239,240}Pu concentrations in the Pacific. Journal of Environmental Radioacitivity 69(2003) 53-60.
GLOMARD: Povinec P, Hirose K, Honda T et al. Spatial distribution of ^{3}H, ^{90}Sr, ^{137}Cs and 239,240Pu in surface waters of the Pacific and Indian Oceans -GLOMARD database. Journal of Environmental Radioacitivity 76(2004)113-37.
ASPAMARD: Duran EB, Povince PP, Fowler SW, et al. ^{137}Cs and $^{239+240}$Pu levels in the Asia-Pacific regional seas. Journal of Environmental Radioacitivity 76 (2004) 139-160.
Japan Sea Cruises: Ito T, Aramaki T, Kitamura T, et al. Anthropogenic radionuclides in the Japan Sea: their distributions and transport process. Journal of Environmental Radioactivity (2003):68, 249-267.
Radioactivity Survey Data in Japan, Japan Chemical Analysis Center, reports 138,139.

The HAM database provides a substantial summary of published and governmental reports regarding seawater monitoring of the North Pacific Ocean (primarily northwest) and its seas. The HAM database was recently made available (personal communication: Aoyama, 2004) for analysis and plotting (Vyas and Mun, 2004). Surface seawater Cesium-137 data from 1990-1998 is

geographically pictured for the Sea of Japan, the Sea of Okhotsk, and the Northern region of the Pacific Ocean (figure 1) – applying a lower latitude range limit of 40 degrees.

Figure 1: Cesium-137 in the North Pacific Surface Water, HAM database



It should be noted that the highest cesium-137 concentrations identified in HAM for the Northern (above 40 degrees) Pacific region and its seas are in the Sea of Japan (up to 2.9-10.2 Bq/m^3) and in the Pacific Ocean off the Northern coast of Japan. The database contains no samples the represent the Aleutian Chain of islands, and few recent samples from the Sea of Okhotsk. Similar sampling patterns exist for strontium-90 (figure 2) and for plutonium-239 and 240 (figure 3), not unexpected since voyages for sampling usually collect specimens for a broad range of radionuclide assessments.

Figure 2: Strontium-90 in the North Pacific Surface Water, HAM database

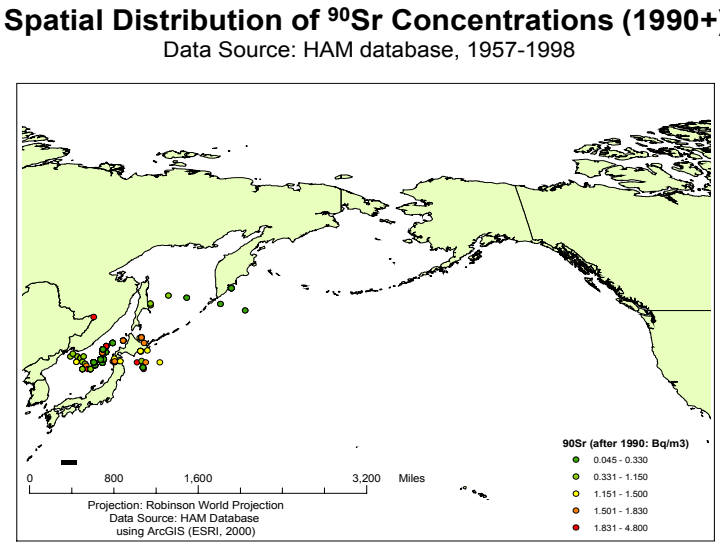
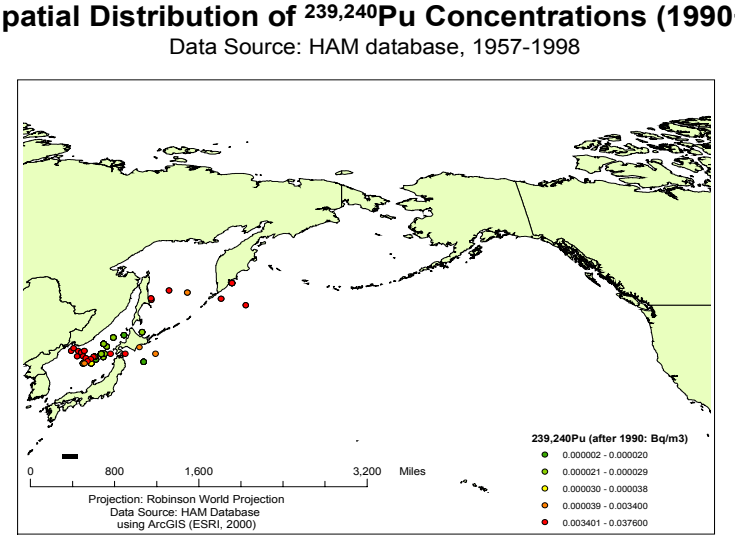


Figure 3: Plutonium 239 and 240 in the North Pacific Surface Water, HAM database



A summary of average marine surface water concentrations for Cs-137, Sr-90, Pu-239 and 240, and tritium – extracted from the WOMARS Project and from GLOMARD, is provided for two recent time intervals (table 16). There is substantial consistency of values, with a suggestion of some decreases in Sr-90 and Pu-139,240. Only one set of comparable tritium data is available from each time

period, and it shows lower concentrations, decreasing from 165 Bq/m^3 in 1991-1995 in Upstream Kuroshio Currents to 136 Bq/m^3 in the more recent 1996-2000 period.

Table 16: Surface Water Average Radionuclide Values, Pacific Ocean, 1991-95; 1996-2000

Pacific Ocean	Cs-137 Bq/m^3	Sr-90 Bq/m^3	Pu-239/40 mBq/m^3	Tritium Bq/m^3
1991-1995 Data				
Japan/East Sea	2.7 (0.5)	1.8 (0.4)	8.5 (5.8)	330 (70)
Subarctic Pacific, N40+	2.3 (0.6)	1.8 (2.7)	5.3 (5.0)	210 (70)
Upstream, Kuroshio Currents, N25-40	2.7 (0.6)	1.7 (0.5)	5.5 (2.4)	165 (12)
Downstream, Kuroshio Currents, N25-40	2.8 (0.5)	1.41 (0.07)	0.71(0.13)	177 (12)
Upstream, N Equatorial/Calif Currents,N5-25	2.3 (0.3)	1.12 (0.15)	1.7 (0.7)	112 (17)
Downstream, N Equatorial Current	2.7 (0.6)	1.61 (0.18)	3.4 (1.4)	NA
1996-2000				
Japan/East Sea	2.8 (0.5)	1.6 (0.3)	6.6 (2.5)	NA
Subarctic Pacific, N40+	2.0 (0.5)	1.3 (0.3)	7.8 (8.7)	NA
Upstream, Kuroshio Currents, N25-40	2.4 (0.5)	1.6 (0.3)	3.8 (2.4)	136 (8)
Downstream, Kuroshio Currents, N25-40	NA	NA	NA	NA
Upstream, N Equatorial/Calif. Currents, N5-25	NA	NA	NA	NA
Downstream, N Equatorial Current, N5-25	2.4 (0.4)	1.5 (0.09)	2.4 (0.7)	109 (7)
( ) = 1 standard deviation		N = Degrees Latitude		

Source of 1996-2000 data, WOMARS project, Povince, Livingston, Shima et al, 2003. Source of 1991-1995 data: GLOMARD database, Povinec, Hirose, Honda et al, 2004. Note: all data is decay-corrected to Jan 1, 2000

9.23 Sediment

Data on sediments vary considerably by location of sampling, since local depositions can influence concentrations, as well as whether surface or deeper core samples are assessed. In the following table (table 17), a range of sediment data has been assembled for the North Asian Pacific Ocean region (Povinec, Fowler et al, 2004).

Table 17: Radionuclides in Sediment Samples in North-Asian Pacific Ocean

All data is decay-corrected to March 2001 9ASPAMARD). Surface sediment (0 to 2cm) concentrations by latitude.

	Cesium-137 Data (Bq/kg dry w)		Plutonium-239/40 Data (Bq/kg dry w)	
	Range	Median	Range	Median

Latitude				
40-45N	0.6-23.4	1.7	0.1-2.7	0.2
35-40N	0.5-14.9	9.7	0.1-3.7	2.2
30-35N	1.4-4.5	1.8	0.1-0.4	0.2
25-30N	0.2-0.4	0.3	0.02-0.5	0.1
20-25N	0.1-3.9	1.4	NA	NA
15-20N	0.9-1.9	1.2	NA	NA
10-15N	0.6-3.4	1.2	0.03-0.1	0.1

Source: Duran, Povinec, Fowler, et al, 2004. ASPAMARD = Asia-Pacific Marine Radioactivity Database. Countries included = Australia, Bangladesh, China, India, Indonesia, Republic of Korea, Malaysia, Pakistan, Philippines, Sri Lanka, Thailand and Vietnam.
NA = data not available.

Sediment data more specific for the Sea of Japan and for the North Pacific near the Japanese coast are displayed in the following table (18).

Table 18: Radionuclides in Japanese Marine Sediments

Strontium-90 and Cesium-137 data. Sample dates: April 2001-March 2003

Sea of Japan	**Sr-90**	**Cs-137**
April 2002-March 2003		
# sample sites	5	5
Ave Conc (Bq/kg-dw)	0.638	6.45
April 2001-March 2002		
# sample sites	5	5
Ave Conc (Bq/kg-dw)	0.396	2.08
N Pacific, Japan Coast		
April 2002-March 2003		
# sample sites	9	9
Ave Conc (Bq/kg-dw)	0.043	1.10
April 2001-March 2002		
# sample sites	9	9
Ave Conc (Bq/kg-dw)	0.043	1.31

References: Japan chemical analysis center, radioactivity survey Data in Japan. Reports 138 (Oct. 2003) and 139 (Aug. 2004).

9.3 Hong Kong Marine Biota Concentrations

South China Sea

The Hong Kong Observatory performs annual environmental monitoring on sea fish, shellfish and four species of seaweed (Ulva lactuca, enteromorpha prolifera, porphyra dentate, and sargassum hemiphyllum) for radionuclides, including plutonium 239, tritium, strontium-90, carbon-14, iodine-131, cesium-137 and potassium 40. Radionuclide monitoring data in 2002 and 2003 (table 16) show that Cs-137, Sr-90 and Tritium were all found at measurable concentrations in Hong Kong area marine fish – with positive results of Cs-137 in the hair tail fish for both years tested. No Pu-239 concentration was found above the detection limit, so it is omitted from table 19.

Table 19: Radionuclides in Marine Fish

Hong Kong Environmental Monitoring. Hong Kong Observatory, 2003-03. Data from samples with Measurable Activity.

	Fish	Cs-137 (Bq/kg)	Sr-90 (Bq/kg)	Tritium (Bq/kg)
2003				
	Nemipterus japonicus (Melon coat)	0.04	0.007	0.9
	Trichiurus haumela (Hair tail)	0.1		
	Platycephalus inducus (Bartail flathead)			1.4
2002				
	Nemipterus japonicus (Melon coat)		0.01	
	Trichiurus haumela (Hair tail)	0.1	0.014	
	Platycephalus inducus (Bartail flathead)			1.3

References: Li SW and Yeung KC, Hong Kong Observatory, Summary of Environmental Monitoring in Hong Kong 2003. Technical Report No. 23, 2004.
Hong Kong Observatory. Environmental Radiation Monitoring in Hong Kong. Technical Report No. 22, Annual Report 2002. May 2003.

Radionuclide data in shellfish, gastropod and cuttlefish, as well as seaweed, are also analyzed annually by the Hong Kong Observatory and data are summarized for 2003 (table 20). Cesium-137 was not measurable in any of the seaweed or shellfish samples. Sr-90 was found at higher levels in seaweed than in shellfish – reflecting the known differences in concentration factors by organism for different elements (see Section 11.1: Concentration Factors).

Table 20: Hong Kong Environmental Radionuclide Monitoring Data

Hong Kong Observatory 2003. Average (range) in Seaweed & Shellfish

Seaweed	**Tritium** Bq/kg	**Sr-90** Bq/kg	**Cs-137** Bq/kg	**Pu-239** Bq/kg	**K-40** Bq/kg
Ulva lactuca (Sea lettuce)		0.118 (.078-0.16)			
Enteromorpha prolifera (Sea hair)	1.90	.046			
Porphyra dentate (Red algae)		0.279			
Sargassum hemiphyllum (Brown algae)		0.277 (0.209-0.345)		0.05	
Shellfish/other					
Tapes philippinarum (clam)	1.00	0.012			
Perna viridis (Green-lipped mussel)	0.95 (0.02-0.1)	0.0065 (0.006-0.007)			
Portunus sanguinolentus (Three-spotted crab)		0.008 (0.005-0.010)			
Babylonia formosae (Gastropod)	0.90				
Sepia spp (Cuttlefish)	1.40				

Reference: Hong Kong Observatory Technical Report No. 23, "Summary of environmental Monitoring in Hong Kong 2003, Li SW and Yeung KC.

9.32 Seawater

All samples of seawater (and particulates suspended in seawater) assessed for Pu-239, Sr-90, I-131 and Cs-137 were below the level of detection in the Hong Kong laboratories. Potassium-40 concentrations were below detection limits in suspended particulates, but data on upper, middle and lower level samples off of four Japanese island areas is provided (table 21).

Table 21: Potassium-40 in Hong Kong Seawater

Hong Kong Seawater Radionuclide Datasheet: HK Observatory. Technical Report No.22, Annual Report 2002. Bq/m^3 Concentration.

Seawater sample site	K40 in:	Upper	Middle	Lower Level
Waglan Island		11,500	12,800	11,900
Basalt Island		11,400	10,800	12,300
Tai Long Wan		11,000	12,400	13,500
Port Island		10,400	12,900	11,700
	Average	11,100	12,200	12,400
	Overall Average: 11,900 Bq/m^3			

Reference: Hong Kong Observatory, Environmental Radiation Monitoring in Hong Kong. Technical Report No.22, Annual Report 2002, published May 2003.

9.33 Sediment

The sediment concentrations of radionuclides are shown for intertidal upper and lower layers and for the seabed in the Hong Kong marine environment (table 22). Where concentrations were less than detection limits (designated by <), one half of the detection limit was used in calculating average values of a data column.

Table 22: Hong Kong Environmental Radionuclide Monitoring.

Hong Kong environmental Radionuclide Monitoring. Hong Kong Observatory, 2002. Concentrations in intertidal and seabed sediments. Average concentrations in Bq/kg-dw (range).

Intertidal		**Pu-239**	**K-40**	**Cs-137**
upper-layer				
		0.22	531	0.50
		0.07	523	0.90
		0.18	510	0.70
		<0.17	482	0.50
		0.14	351	1.00
		0.07.	316	0.90
		0.06	361	1.20
		<0.29	321	1.00
		0.17	618	0.50
		<0.11	568	0.40
		<0.20	516	0.40
		<0.15	533	0.50
	Average	0.11	469	0.71
lower-layer		**Pu-239**	**K-40**	**Cs-137**
		<0,11	548	0.90
		0,16	548	0.80
		0.18	782	0.80
		0.13	510	0.50
		0.19	340	1.20
		<0.08	353	1.00
		<0.09	393	1.20
		0.15	359	0.90
		<0.26	576	0.40
		<0.15	613	0.70
		<0.20	503	0.40
		<0.21	538	0.40
	Average	0.11	505	0.77
Seabed		**Pu-239**	**K-40**	**Cs-137**
		0.57	299	0.80
		0.66	325	1.00
		0.50	418	0.70
		<0.55	458	0.50
	Average	0.50	375	0.75

Note: Averages with < detection limit are calculated using 0.5 of the specific detection limit.

Reference: Hong Kong Observatory, Environmental Monitoring Technical Report No.22, 2002.

9.4. Arctic and related Seas

(Barents Sea, Norwegian Sea, Greenland Sea, Baffin Bay, Beaufort Sea, East Siberian Sea, Chukchi Sea, Kara Sea, Pechora Sea)

The Arctic region has been, and continues to be assessed, because of its number of anthropogenic sources of radionuclides that have contributed to, and could potentially contribute in the future, to contamination of this area. The myriad of sources include waste releases from Western European (Dounreay, Sellafield, Cap de la Hague) and Russian (Mayak) fuel reprocessing plants, nuclear power plants (at least nine in the Arctic region: 2 Finland, 4 Sweden, 3 Russian) and nuclear reactor dumping in the Kara Sea of nuclear submarine and icebreaker compartments with (n=7) and without (n=6) spent nuclear fuel (Jennson et al, 2004). Radionuclide sources to the Arctic region also include releases carried via rivers or bays from the Siberian Chemical Combine and from the Mining and Chemical Industrial Complex of Zheleznogorsk, from the accidental sinking of nuclear ocean vessels (Kursk, etc.) and aircraft (Thule accident), and from the accident at Chernobyl. Overarching all of these potential sources has been the global impact of nuclear tests – the largest of which was a 50 Mt atmospheric test at Novaya Zemlya in 1961.

9.41 Biota

Various types of fish, as reported by the Arctic Monitoring and Assessment Programme (Jensson et al, 2004), show similar concentrations of Cesium-137 – ranging from a low mean of 0.09 Bq/kg-ww in Dab to a high of slightly above 0.3 Bq/kg-ww in Shorthorn sculpin and Flounder (table 23). It should be noted that Dab were mostly obtained from Icelandic waters with generally low Cs-137 concentrations.

Table 23: Concentrations of Cesium-137 in Arctic Marine Fish

1995-2000 Data, in Bq/kg-ww

Fish Type	# samples	ave conc. Bq/kg-ww	SD
Haddock *(Melanogrammus aeglefinus)*	65	0.25	0.11
Cod (*Gadus* spp.)	394	0.22	0.08
Shorthorn sculpin (*Myoxocephalus scorpius*)	10	0.31	0.16
Flounder *(Platichthys flesus)*	6	0.33	00.6
Capelin *(Mallotus villosus)*	3	0.16	0.08
Dab *(Limanda limanda)*	247	0.09	0.03

Source: Jensson, Strand et al, AMAP, 2004

9.42 Seawater

Cs-137 Concentrations of Cs-137 in surface seawater samples from the Norwegian Sea in the year 2000 range from 1.7 to 8.5 Bq/m3 (Gafert et al, 2003). The concentrations appear to be higher in the lower region of the Norwegian Sea (table 24). Cesium-137 concentrations from the Arctic Ocean near the Norwegian territory of Svalbard are similar to those of the northern aspects of the Norwegian Sea (table 23).

Technetium-99 concentrations are clearly lower in the Svalbard region of the Arctic Ocean than in either region of the Norwegian Sea. It should be noted that Techneticium-99 results as a beta decay product of ^{99}Mo during nuclear reactions. It has a half-life of 213,000 years and over 200 TBq (note: T is "tera" or 10^{12}) of it has been estimated to have been released to the environment, with about 85% from nuclear fuel reprocessing plants and 15% from nuclear weapons testing (Dowdall, Gwynn, Selnaes et al, 2003). The transport pathway of ^{99}Tc from the

Enhanced Actinide Removal Plant (EARP) at Sellefield, UK to the Irish Sea, the North Sea and then via the Norwegian Coastal Current to the Norwegian Sea and other Arctic waters has been thought to take about three or four years of transit time (Brown et al, 1998). The Norwegian Radiation Protection Authority has continued to monitor technetium as a priority marine pollutant.

Concentrations of Cs-137, Pu-239/40 and Sr-90 in seawater of many Northern European marine environments are summarized in table 25.

Table 24: Norwegian and Arctic Surface Sea Water Data

Cesium-137 and Technetium-99, in Bq/m^3. Samples from Year 2000

		Norwegian Sea		***Arctic Sea***
		Upper	Lower	
Cesium-137	Average	3	6.1	2.8
	Std Dev	0.8	2	1.2
	n =	7	7	9
Technetium-99	Average	1.2	1.4	0.3
	Std Dev	0.3	0.2	0.1
	n =	7	8	6

Note: The Norwegian Sea "Upper" is between 65 and 70 N Latitude and 0 and 25 degrees Longitude. The Norwegian Sea"Lower" is between 60 and 65 N Latitude and 0 and 25 degrees Longitude. The Arctic Sea samples were above 70 N Latitude and 0 and 25 degrees Longitude.
Reference: Gafvert T, Foyn L, Brungot AL, et al. Radioactivity in the Marine Environment 2000 and 2001, Results from the Norwegian Monitoring Programme (RAME), StralevernRapport 2003:8, Norwegian Radiation Protection Authority, 2003.

Table 25: Radionuclides in Surface Water, Northern European Seas

Data from the Murmansk Marine Biological Institute, Russia. Range of concentrations, Bq/m^3, 1992-1994

Sea/Ocean	Cesium-137	Plutonium239/40	Strontium 90
Norwegian Sea	3-28		
Barents Sea	2-15	4-8	
White Sea	11-15	10-11	
Kara Sea	2-12	2-8	
Laptev Sea	1-13		3.7-6.6
Greenland Sea	1.7-5.4*	2.1-7.1	1.0-2.0
Arctic Ocean	1-15		

References: Matishov and Matishov, 2004

* Dahlgaard et al, 2004.

9.43 Sediment

The sea sediment concentrations of Cesium-137 from the Svalbard and the Fram Strait regions of the Norwegian Arctic Ocean are summarized in Bq/kg-dw in table 26. These samples, which include surface and subsequent sequential one or two centimeter interval sections, were collected between May and August of 2000. These samples do not demonstrate a particular pattern of concentration gradient (direct or indirect) by sediment core depth.

Table 26: Cesium-137 Concentrations in Norwegian Arctic Ocean Sediments

Data collected in2000 and reported in Bq/kg-dw

Location	Ocean Depth	Sediment Depth	Bq/kg-dw Ave; (SD)
Fram Strait	2239 m	0-1 cm	6.7 (.3)
		1-2 cm	7.7 (.5)
		2-3 cm	7.7 (.5)
Fram Strait	1284 m	0-1 cm	4.2 (.3)
		1-2 cm	1.7 (.4)
		2-3 cm	2.8 (.2)
Fram Strait	173	0-1 cm	6.3 (.4)
		1-2 cm	6.9 (.4)
		2-3 cm	5.8 (.3)
Svalbard	?	0-1 cm	2.5 (.1)
		2-4 cm	2.3 (.2)

Reference: Gafvert T, Foyn L, Brungot AL et al. Radioactivity in the Marine Environment 2000 and 2001, Results from the Norwegian National Monitoring Programme (RAME), StralevernRapport 2003:8, Norwegian Radiation Protection Authority, 2003

Table 27: Radionuclides in Marine Sediments: N. European Seas

Radionuclides in Marine Sediments N. European Seas. Data from Murmansk Marine Biological Institute, Russia. Concentrations in Bq/kg-dw, 1990 decade.

Sea/Ocean	^{137}Cs	^{134}Cs	$^{239/240}$Pu	^{238}Pu	^{90}Sr	^{41}K

Norwegian Sea			0.7-1.6			
Barents Sea	0.2-11*		0.5-3.2	<.02-0.14	0.11-0.74	
White Sea	1-60	0.9-1.5			1-4	
Kara Sea	0.6-73.6		0.2-5.7	<0.02-0.1	0.5-3.5***	12.8-21.4
Leptev Sea	1.6-13					
Pechora Sea**	3.3-11.6		0.76-1.65			

Reference: Matishov & Matishov 2004
*Barent Sea data excludes high concentrations found near Novaya Zemlya test areas, where concentrations reach 910 Bq/m^2
**Pechora Sea data excludes concentrations within 100 km of Chernaya Bay, site of previous Soviet Union underwater nuclear tests.
***One of the 17 composite samples was less than detection level and is not included in this summary.

9.5 North Atlantic Region

North Sea, Irish Sea, Celtic Sea, Baltic Sea, English Channel, North Atlantic.

Information on the North Atlantic Region reviewed in this section is substantial. The following set of tables provides a summary of radionuclide concentrations, with data presented in averages, ranges, or averages with standard deviations – depending upon the availability of data for analyses.

9.51 Biota

The average cesium values (table 28) were highest in cod, at about 1.5 Bq/kg, while plaice, mackerel and whiting concentrations were about the same, ranging from 0.3 to 0.5 Bq/kg. Most fish composite values were above the limit of detection. Mollusks concentrations were generally lower than those for cod, but similar to the other fish, while crustaceans values were somewhere between cod and the other fish. It should be noted that the presented concentrations are slight underestimates, in that the few non-detects were considered zero in the computations. This approach was applied since the actual levels of detection were not available.

Fish cesium-137 concentrations, as derived from substantial (nearly 4400 fish) marine surveys reported by the Norwegian Radiation Protection Authority (table 28b), show little variation by most of the northern sites tested. The weighted (by pooled sample size) fish concentrations in the Barents, North and Norwegian seas were 0.27, 0.24 and 0.35 Bq/kg-ww, respectively. The fewer number of pooled samples from Skagerrak had concentrations three to four times higher, at 1.08 Bq/kg. It should be noted that the percentage of non-detects was similar for both the Barents and North Seas, at around 5%, considerably less than the 35% non-detects in Norwegian Sea fish samples. All of the Skagerrak samples exceeded detection limits.

While the majority of the samples came from three types of fish - cod (n=61), haddock (n=14) or saith (n=12) - wide variations in concentrations were not seen across the wider spectrum of fish. The highest concentration, at 2.2 Bq/kg, in this data set was from a single pooled sample of horse mackerel. The horse mackerel were from the Skagerrak and Kategatt areas, often influenced by outflows of higher Baltic Sea cesium concentrations. Excluding single pooled sample results, the highest concentrations (0.7 to 0.9 Bq/kg) were seen in sprat, whiting and Atlantic herring – and each of these types of fish were distributed across three of the marine locations. Most of the other fish concentrations ranged only between 0.1 and 0.3 Bq/kg.

Cod had the greatest proportion (42%) of the pooled samples. It was harvested from three locations, the Barents, North and Norwegian Seas, and its cesium-137 concentration averaged 0.3 Bq/kg-ww. Cod appears to be a good indicator for fish biomonitoring, at least in northern European waters, since it can be harvested in sufficient numbers, provides adequate sample mass for radionuclide analyses, and because it reflects the mid to upper range of concentrations found in other fish living in the same bodies of water from which it was collected. The upper cesium-137

concentrations found in cod from the Barents, North and Norwegian Seas were 0.40, 0.32 and 0.56 Bq/kg – values exceeded by very few other fish for those bodies of water.

Table 28: Cesium-137 Concentrations in Irish Sea Fish

Cesium-137 Concentrations in Irish Sea Fish, 2000-2001. Data in Bq/kg-ww

	Cod	Plaice	Mackerel	Whiting
# Composites	44	42	39	42
Average Conc.	1.52	0.34	0.31	0.47
Standard Dev.	1.49	0.28	0.56	0.43
# > detection	44	35	36	42

One extreme outlier value exists in each Mackerel and Whiting data set. Re-analysis of the same sets without the outliers finds:

Analysis without single outlier/fish-type

	Mackerel	Whiting
# composites	38	41
Average Conc.	0.22	0.41
Standard Deviation	0.16	0.19

Data abstracted from: ryan TP, McMahon CA, Dowdall A, et al. Radioactivity monitoring of the Irish marine environment 2000 and 2001. The Radiological Protection Institute of Ireland (RPII), 2003.

Table 28a: Cesium-137 Concentrations in Irish Mollusks and Crustaceans, 2000-2001

	Mollusks Bq/kg	Crustaceans Bq/kg
# Composites	18	24
Average Concentration	0.26	0.62
Standard Deviation	0.20	0.74
# below detection	1	5

Data summarized from: Ryan RP, McMahon CA, Dowdall A, et al. Radioactivity monitoring of the Irish marine environment 2000 and 2001. The radiological Protection Institute of Ireland (RPII), 2003.

Table 28b: Pooled Fish Samples Analyzed by the Norwegian Radiation Protection Authority

Number of Pooled Samples by Sea, Average Concentration and % Non-detect Cesium-137 measured in Bq/kg.

	Barents	*North*	*Norwegian*	*Skagerrak*	*Total #*	Weighted *Ave Conc**	*% nd*
Atlantic Salmon	2		2		4	0.28	0%

Atlantic Herring	2		2	3	7	0.62	0%
Blue Whiting			3		3	0.27	67%
Blackmouthed dogfish			1		1	0.69	0%
Cat-fish	1		1		2	0.13	100%
Cod	47	2	12		61	0.3	0%
Dab		1		1	2	0.25	0%
European plaice	1		1		2	0.15	50%
Golden redfish	1				1	0.09	0%
Greater argentine			1		1	0.14	100%
Haddock	10	2	1	1	14	0.16	0%
Horse mackerel				1	1	2.2	0%
Lemon sole	1	1	1		3	0.21	33%
Ling			1		1	0.65	0%
Lumpsucker		1			1	0.1	100%
Long rough dab	5				5	0.25	0%
Mackerel			2		2	0.14	50%
Norway pout		1	4		5	0.15	80%
Norway redfish		2	1		3	0.15	33%
Rabbitfish			2		2	0.2	100%
Round ray			1		1	0.15	100%
Saithe	7	1	4		12	0.3	16%
Spotted catfish		1			1	0.2	0%
Sprat	1	2		1	4	0.7	0%
Torsk			2		2	0.28	0%
Whiting		1	2	1	4	0.9	0%
Witch			1		1	0.13	100%
Total # Sample Pools	78	17	43	8	146		
Wtd. Concen. Bq/kg	0.27	0.24	0.35	1.08	0.32		
% Non-detects	5.10%	5.40%	34.90%	0%	13.70%		

Note: the 146 pooled samples contained 4379 fish. Eleven other pooled samples with undefined number of fish were not included in this summary.
Reference: Data extracted and analyzed from: Gafvert T, Foyn L, Brungot Al, et al. Radioactivity in the marine environment 2000 and 2001, Norwegian Radiation national Monitoring Programme, 2003.

9.52 Seawater

Table 29: Surface Sea Water Radionuclide Concentrations: N. European Seas and English Channel

Averages Estimates or ranges, 2000-2002

	Cs-137	Sr-90	Pu-239/40	Tritium	Tc-99	Am-241
	Bq/m^3	Bq/m^3	mBq/m^3	Bq/m^3	Bq/m^3	mBq/m^3
English Channel, Goury,France	3.5	1.36	7.5	293	7	6
English Channel, general	<4	2.0-10	3.0-40		60	
North Sea General	2 to 8	5.0-30	3.0-40	3-4,000	5.0-10	
Skagerak/Kateegat	15 to 60		<10.0		0.4-0.5	

Western English Channel	1 to 3			to 30,000		
Irish Sea and Scottish Waters	10 to 45	10 to 35	2.1	to 23,000	0.2-0.6	<1.4 - 5.4
Irish Sea: Wylfa area				to 18,000		
Sellafield Coast	200		2-4,000			160-560
Irish Sea: Coastline	2 to 35	up to 400	600-2000		nd - 23	44-500
Irish Sea: Offshore	9 to 35		100-700		14 - 30	10-110
Baltic Sea	50					
Arctic/North Atlantic	5	<3 to <9	1		0.02-0.2	

References: RIFE_8, 2003; SENES, 2003. NRPB, CEFAS and Enviros, 2004. MARINA II, 2004 (Arctic and North Atlantic Oceans, Baltic Sea, Skagerrak and Kattegat – upper range data); and RPII, 2003.
Note:background tritium in continental waters before nuclear explosion era, 200-900 Bq/m^3 (ref: UNSCEAR, 1982). Sr-90 values of 200-400 were annual meansnear nuclear reprocessing plant BNFL.
I-129 in Baltic Sea, averages 3mB/m^3. Tc-99 North Atlantic background is considered to be 0.005 Bq/m^3. MARINA II, Annex B Pu-238 in English Channel, Goury, France: 4mBq/ m^3 at Irish Sea and Scotland: 0.5mBq/m^3 . PU-241 in English Channel, Goury, France: 0.2 Bq/ m^3

9.53 Sediment

Table 30: Irish Sea Sediment Cesium-137 Concentration, 2000-2001

Data in Bq/kg, dry weight

	Coastline Sediments		Offshore Sediments	
	2000	2001	2000	2001
# samples	17	14	9	3
Average	5.9	7.6	29.6	54.7
SD	4.4	3.6	32.6	21.9

Reference: Ryan et al, Radiological Protection Institute of Ireland (RPII) April, 2003.

9.6 Comprehensive Overview of Radionuclides in Marine Fish

The concentrations of cesium-137 in fish has been, as noted in the previous sections, rather extensively studied in various marine environments. Table 30a summarizes the data, by type of fish, within ten marine locations within the Northern Hemisphere for which substantial data has been gathered. The first eight locations all have reasonably similar concentrations within fish, with data on cod being represented in six of the eight locations and having a rather tight two-fold range in average concentrations from 0.2 to 0.38 Bq/kg-ww. In contrast, much higher average cesium-137 concentrations in cod, 6.44 to 8.86 Bq/kg-ww, are found in both the Irish and Baltic seas – areas that have been more impacted by nuclear reprocessing facilities (Sellafield for the Irish Sea) and by fallout from Chernobyl (Baltic Sea).

Table 30a: Cesium-137 concentrations in representative marine fish

Cesium-137 Representative Marine Fish Concentrations (Bq/kg-ww)

Data primarily from 1999 through 2003

Single concentration numbers are average values

Location/Sea	Species	Concentration	# (pooled)	Reference
Japan	Tilefish	0.12	2	Japan Chemical Analysis
	Greenling	0.12	2	Center, 2003
	Flounder	0.07	12	
	Rockfish	0.09	4	
	Mackerel (various)	0.12	18	
Arctic	Sculpin	0.3	10	Jensson et al, 2004
	Flounder	0.3	6	Matishov&Matishov, 2004
	Cod	0.2	394	
	Haddock	0.3	65	
Hong Kong	Melon Coat	0.04		Li and Yeung, 2003
	Hair Tail	0.1		
Barents Sea	Cod	0.29	53	Gafvert et al, 2003
	Haddock	0.2	10	CEFAS, 2003&2004
				Ryan et al, 2003
North Sea	Cod	0.38	21	CEFAS, 2003 & 2004
	Haddock	0.2	10	Gafvert et al, 2003
	Plaice	0.21	19	
Norwegian	Cod	0.32	20	Gafvert et al, 2003
	Saithe	0.27 to 0.64		CEFAS, 2003& 2004
	Mackerel	0.14	4	Ryan et al, 2003
N. Atlantic	Cod	0.28	3	CEFAS, 2003&2004
	Plaice	0.36	3	Gafvert et a;. 2003
	Haddock	0.47	3	
	Mackerel	0.09	5	
Channel	Cod	0.2	8	CEFAS, 2003&2004
	Plaice	0.06	16	
	Mackerel	0.19	8	
Irish	Cod	6.44	75	Ryan et al, 2003
	Plaice	3.77	60	CEFAS, 2003&2004
	Mackerel	0.31	39	
	Flounder	11.0	19	
	Haddock	1.1	10	
Baltic	Cod	8.86	7	CEFAS, 2003&2004

Information of the concentrations of other radionuclides in marine fish, as well as the US FDA minimum reporting levels and derived intervention levels (DILs) and international CODEX recommended limits, are shown in table 30b. The radionuclide concentrations of many of the northern hemispheric locations are summarized under one heading and are contrasted with findings from the somewhat more contaminated (yet still acceptable for commercial fishing) Irish Sea. While concentrations of individual radionuclides in fish are not easily compared to general food guidelines, which often are set on a group of radionuclides, it is apparent that the average concentrations found are nearly all cases only a trace percent of acceptable values. The concentrations in fish that equate with estimated cancer morbidity risks of from one in 10,000 to one in a million to consumers of 100 kg of fish per year are noted in table 30b. For example, an average concentration of cesium-137 in fish of 14 Bq/kg-ww, consumed at 100 kg per year, might present a one in ten thousand risk of increased cancer morbidity. The fish concentrations of cesium-137 in the northern hemisphere are, with the possible exception of the Irish Sea, 50 to 300 times lower than 14 Bq/kg. More information on procedures for estimating cancer risks is described in the next section.

Table 30b: comparative concentrations of radionuclides in marine fish

Key Values for Radionuclides in Marine Fish
All Concentrations in Bq/kg-ww

	Bq/kg in fish					Cancer morb risk at 100 Kg fish eaten/yr	
Radionuclide	Northern Hemisphere	Irish Sea	FDA Minimum reporting levels	FDA DIL	Codex	CA 10^{-4}	CA 10^{-6}
Cs-137	.04 to .33	0.31 to 11	5	1200[e]	1,000[b]	14	0.14
Sr-90	.007 to.01	.003 to.027	0.1	160	100[c]	8	0.08
Tc-99	.05 (crab) 0.75 (mus) 2.2 to 41.5 (lobster)	0.05 to 5.8			10,000[d]	132	1.32
I-129		.005 to 1.6			100[c]	3	0.03
Am-241	0.0012	.0001 to .23	200	2[a]	1[a]	4	0.04
U-238	.008 to.015					6	0.06
Pu-238	8.5 E-6 to 5.4 E-5	.0001 to .02		2[a]	1[a]	3	0.03
Pu-239/40	.0003 to .07	1.3 E-5		2[a]	1[a]	3	0.03

U-235	0.0035 to 0.0046	100[c]

Notes:
[a] = totals for Am + Pu groups
[b] = totals for S-35, C0-60, Sr-89, Ru-103, Cs-134, Cs-137, Ce-144 and Ir-192
[c] = totals for Sr-90, Ru-106, I-129, !-131, U-235
[d] = totals for H-3, C-14, Tc-99
[e] = Cs-134, Cs-137

FDA minimum reporting levels are the minimum concentrations reported in FDA food surveys for the noted radionuclides. Lower values are reported as zero.

FDA DIL: FDA derived intervention levels (Bq/kg), are guidance levels for radionuclides in food that is used domestically in the United States and for foods imported into the United States. These concentrations are developed based upon the most susceptible age groups and are approximately equivalent to a 1 in 4400 cancer mortality risk over a lifetime. They assume a shorter term exposure (one or a few years)

Codex: The Codex alimentarus is the proposed international guideline (WHO and the Food and Agriculture Organization of the United Nations) for radionuclides in food. These are food safety values, intended to screen food sources as acceptable for consumption for at least a one year timeframe.

Cancer risks are lifetime estimates of cancer morbidity, assuming heavy seafood consumption of 100 kg/year (average values for general populations are 14 kg/year).

10.0 Human Risk Assessments: Ingestion of Radionuclides in Marine Biota

The comprehensive assessment of human risk from radionuclides in the marine environment would take into consideration potential external exposure pathways (i.e., dose rate and time spent near external sources, such as beaches or contaminated fishermens' nets), inhalation of resuspended contaminated soil and sediment, and - the focus of this review - ingestion of marine foodstuff, including fish, mollusks and crustaceans. In order to assess reasonable estimates of population seafood ingestion dose and cancer risks, it is necessary to have dietary consumption data from site-specific surveys for the seafood types under consideration. Data is required for both the general seafood consuming population as well as for potential critical groups, i.e., those likely to have the highest rates of seafood ingestion. In addition, an average value is needed for radionuclide concentrations for each type of radionuclide by each category of seafood consumed.

Average radionuclide consumption values can then be computed per food category and summated according to the dietary patterns of the typical and high rate seafood consumer – across the time period being considered (usually per year). Conversion from Bq/kg consumed for each radionuclide measured is converted to dose in Sv/Bq or, if more convenient in data display or use in uSv/Bq, by application of dose coefficient factors (DCFs) as developed by ICRP (ICRP, 1996).

The series of steps involved in the development of public radiation dose estimates (and risks) from the ingestion of radionuclides in marine foodstuff (Figure Y) depict the various types of data that are required to accomplish this task. Some degree of uncertainty is introduced in nearly every step of the dose assessment process, and attempts to minimize or manage it are numerous, including the appropriate design of the assessment study, the sampling process, the laboratory analyses, the definition of the major pathways of exposure for the public – including design of dietary surveys, minimizing errors in radiation dosimetry and the application of procedures for data analyses. Some radionuclide sample analyses might result in non-detected concentrations, and different approaches exist on how to handle such results, ranging from assuming zero, mid-point of detection limit or detection limit for non-detected samples. Each approach can be used, and, depending upon the scenario, can be justified. There is a tendency to err in the direction of providing an additional margin of pubic health protection by somewhat over-estimating exposure (and risk) by assigning some value (either 50% or 100% of the non-detect value) when a few samples of a sample set are non-detects.

FIGURE Y (TO BE DEVELOPED)

10.1 Marine Seafood Ingestion Risk Assessment – Examples

10.11 United Kingdom

A substantial set of information exists on UK seafood consumption and radionuclide concentrations. The following tables (tables 31 and 32) show the components and results of the

calculation of radionuclide dose in heavy seafood consumers in NE Ireland. As noted in the tables, these heavy seafood consumers eat 73 Kg of fish and 3.65 kg of both crustaceans and of mollusks per year. These values, while quite high, are not the highest seen in surveys of UK populations (see Appendix 3).

Table 31:Radionuclide Dose Calculation for Heavy Seafood Consumers

North East Ireland, 2000. Heavy Consumer Diet: Fish, 73Kg; Crustaceans, 3.65Kg; Molluscs, 3.65 Kg

Radionuclide	Seafood	Ave Activity Conc *Bq/kg*	Bq/yr	DCF uSv/Bq	uSv/yr
Technetium-99	Fish	0.4	29.2	6.40E-04	0.002
	Crustaceans	85	310.25	6.40E-04	0.199
	Molluscs	24	87.6	6.40E-04	0.056
Cesium-137	Fish	0.7	51.1	1.30E-02	0.664
	Crustaceans	1	3.65	1.30E-02	0.047
	Molluscs	0.4	1.46	1.30E-02	0.019
Plutonium-238	Fish	0.0001	0.0073	2.30E-01	0.007
	Crustaceans	0.0026	0.0095	2.30E-01	0.002
	Molluscs	0.016	0.0584	2.30E-01	0.013
Plutonium-239+240	Fish	0.0002	0.013	2.50E-01	0.003
	Crustaceans	0.014	0.051	2.50E-01	0.013
	Molluscs	0.095	0.347	2.50E-01	0.087
Americium-241	Fish	0.0002	0.015	2.00E-01	0.003
	Crustaceans	0.022	0.08	2.00E-01	0.016
	Molluscs	0.043	0.157	2.00E-01	0.031
				Annual Dose, uSv	*1.162*

Calculated from data in: Ryan et al. Radioactivity monitoring of the Irish marine environment, 2000 and 2001, The Radiological Protection Institute of Ireland, 2003.

Table 32: Radionuclides in North East Ireland Seafood for Heavy Consumers

Data Summary by Radionuclide and Seafood. Data in uSy per year.

	Fish	Crustacea	Molluscs	Totals	% Total
^{99}Tc	0.002	0.199	0.056	0.257	22.10%
^{137}Cs	0.664	0.047	0.019	0.73	62.80%
^{238}Pu	0.007	0.002	0.013	0.022	1.90%
^{239,240}Pu	0.003	0.013	0.087	0.103	8.90%
^{241}Am	0.003	0.016	0.031	0.05	4.30%

Totals	0.679	0.277	0.206	1.162
% Totals	58.40%	23.80%	17.70%	100%

Calculated from data in: Ryan et al, Radiological Protection Institute of Ireland, 2003.

10.2 Natural vs Anthropogenic Radionuclides: North East Irish Sea Dose Estimate

In order to estimate total annual radionuclide consumption from seafood for a population, it is necessary to discern the dietary intake of the component seafoods. The Radiological Protection Institute of Ireland uses, for its own risk assessments, two generic seafood eating models: the typical seafood consumer (40 g of fish, 2.5 g crustaceans and 2.5 g mollusks per day) and the heavy seafood consumer (200 g of fish, 10 g of crustaceans and 10 g of mollusks per day) (Ryan et al, 2003). Converted to annual intake, the data becomes: typical consumer (14.8 kg/yr fish; 0.9 kg crustaceans and 0.9 kg mollusks) and heavy seafood consumer (73 kg/ yr fish; 3.65 kg crustaceans and 3.65 kg mollusks). The following set of tables (tables 33-36) summarizes estimates of natural radionuclide dose from consumption of seafood in NE Ireland, utilizing the described "typical" and "heavy" consumer patterns. It should be noted that there are estimates for seafood dietary intake for several countries and regions, with a few sites of the UK summarized in Appendix 3.

10.21 Typical Consumption Pattern: Fish, Crustaceans, Molluscs

Table 33: Natural Radionuclide Dose Ingested by Typical Consumer of Fish

Based on RIFE diet survey of NE Ireland. Radionuclide Concentrations from the RIFE-8 Study

Fish: consumption at 14.6 Kg/yr

	Bq/kg	Bq/yr	uSv/Bq	uSv/yr	%total uSv
^{210}Pb	0.025	0.365	6.91E-01	0.252	4.71
^{210}Po	0.28	4.088	1.2	4.906	91.79
^{226}Ra	0.04	0.584	2.80E-01	0.164	3.06
^{228}Th	0.005	0.073	1.43E-01	0.01	0.19
^{230}Th	0.001	0.015	2.10E-01	0.003	0.06
^{232}Th	0.001	0.015	2.30E-01	0.003	0.06
^{234}U	0.005	0.073	4.90E-02	0.004	0.07

^{238}U	0.004	0.058	4.84E-02	0.003	0.06
Totals		5.271		5.345	100

Table 34 Natural Radionuclides in Seafood: Typical Consumption, Crustacean

Based on RIFE diet survey of NE Ireland. Radionuclide Concentrations from the RIFE-8 study.

Crustacean: consumption at 2.5 Kg/yr

	Bq/kg	Bq/yr	uSv/Bq	uSv/yr	%total uSv
^{210}Pb	0.08	0.2	6.91E-01	0.138	0.87
^{210}Po	5.2	13	1.2	15.6	98.89
^{226}Ra	0.03	0.075	2.80E-01	0.021	0.13
^{228}Th	0.01	0.025	1.43E-01	0.004	0.02
^{230}Th	0.003	0.008	2.10E-01	0.002	0.01
^{232}Th	0.003	0.003	2.30E-01	0.001	0
^{234}U	0.04	0.1	4.90E-02	0.005	0.03
^{238}U	0.035	0.088	4.84E-02	0.004	0.02
Totals		13.499		15.775	99.97

Table 35 Natural Radionuclides in Seafood: Typical Consumption, Mollusk

Based on RIFE diet survey of NE Ireland. Radionuclide Concentrations from the RIFE-8 study.

Mollusk: consumption at 2.5 kg/yr

	Bq/kg	Bq/yr	uSv/Bq	uSv/yr	%total uSv
^{210}Pb	0.69	1.725	6.91E-01	1.192	3.96
^{210}Po	9.4	23.5	1.2	28.2	93.78
^{226}Ra	0.08	0.2	2.80E-01	0.056	0.19
^{228}Th	0.37	0.925	1.43E-01	0.132	0.44
^{230}Th	0.19	0.475	2.10E-01	0.1	0.33
^{232}Th	0.28	0.7	2.30E-01	0.161	0.54
^{234}U	0.99	2.475	4.90E-02	0.121	0.4
^{238}U	0.89	2.225	4.84E-02	0.108	0.36
Totals	12.89	32.225		30.07	100

Table 36 Natural Radionuclides in Seafood: Typical Consumption, Total

Based on RIFE diet survey of NE Ireland. Radionuclide Concentrations from the RIFE-9 study.

	Fish	**Crustacea**	**Mollusks**	**Total**	**% of Total**
	uSv/yr	uSv/yr	uSv/yr	uSv/yr	
^{210}Pb	0.252	0.138	1.192	*1.582*	3.09
^{210}Po	4.906	15.6	28.2	*48.706*	95.15

^{226}Ra	0.164	0.021	0.056	*0.241*	0.47
^{228}Th	0.01	0.004	0.132	*0.146*	0.29
^{230}Th	0.003	0.002	0.1	*0.105*	0.21
^{232}Th	0.003	0.001	0.161	*0.165*	0.32
^{234}U	0.004	0.005	0.121	*0.13*	0.25
^{238}U	0.003	0.004	0.108	*0.115*	0.22
Totals	5.345	15.775	30.07	*51.19*	100

10.22 Heavy Seafood Consumer: Fish, Crustaceans and Mollusks

The process by which an estimation of the committed effective radionuclide dose for the heavy seafood consumer is determined is identical to that applied previously to describe the Typical Consumer. The only difference is a larger quantity of seafood consumed, both in total and by food type. By applying the NE Ireland consumption estimates for seafood, as defined by the Radiological Protection Institute of Ireland (Ryan et al, 2003), to the average activity concentration (in Bq/kg) of each radionuclide in fish, crustaceans and mollusks, one arrives at the radionuclide and food-specific Bq/yr contribution. Then applying the dose conversion factor (in uSv/Bq), a total uSv/yr dose for each radionuclide and seafood category is obtained, as previously shown. of the Polonium-210 contributes 94.5% of the total natural radionuclide dose in heavy seafood consumers in North East Ireland (table 37).

Table 37: Annual Consumption of Radionuclides by the Heavy Seafood Consumer

North East Ireland, 2000-2001, Average Annual Diet: Fish, 73kg; Crustaceans, 3.65kg; Mollusks, 3.65kg. Committed Effective Dose in uSv per Year.

	Fish	**Crustacea**	**Molluscs**	**Totals**
^{210} Pb	1.26	0.2	1.74	3.2
^{210} Po	24.53	22.78	41.17	88.48
^{226} Ra	0.82	0.03	0.08	0.93
^{228} Th	0.05	0.01	0.19	0.25
^{230} Th	0.015	0.002	0.146	0.163
^{232} Th	0.017	0.001	0.235	0.253
^{234} U	0.018	0.007	0.177	0.202
^{238} U	0.014	0.006	0.156	0.176
Totals	26.724	23.036	43.894	93.654

Data received from: Ryan et al, Radioactivity monitoring of the Irish marine environment, 2000 and 2001; The Radiological Protection Institute of Ireland (RPII-03/3), April, 2003.

10.23 Comparison: Natural and Anthropogenic Radionuclide Doses and Risks

There are several approaches by which one may assess the relative importance of man-made radionuclides in the human diet. One approach, of course, is human risk assessment – usually focusing on cancer incidence or cancer mortality. That approach is reviewed in a subsequent section. Another method is comparative. That is, it seeks to determine what proportion of the total burden of radionuclides in the diet come from man-made sources versus the dose that nature serves us. If that proportion of the total dose evolving from our own activities is very low, then in the "scheme of things" it would not seem very important as a current contributor to the overall radionuclide dietary concern. The next table (table 38) condenses and summarizes information that has already been provided in this report, but with the intent of directly comparing nature to man as primary radionuclide contributors to our food supply. The data is again derived from the NE Ireland population, since information on dietary intake, natural and man made radionuclide concentrations is readily available.

Table 38: Comparison: Natural and Anthropogenic Radionuclides

Dietary Doses in Heavy Seafood Consumers. North East Ireland, 2000

	Natural Source		Anthropogenic Source	
	Total uSv	Major Radionuclide	Total uSv	Major Radionuclide
Fish	26.72	^{210} Po (24.5 uSv)	0.68	^{137} Cs (0.66 uSv)
Crustacean	23.04	^{210} Po (22.8 uSv)	0.28	^{99} Tc (0.20 uSv)
Mollusks	43.89	^{210} Po (41.2 uSv)	0.21	^{239,240}Pu (.09 uSv)
Total	93.65		1.17	

Data derived from: Ryan et al, Radiological Protection Institute of Ireland, 2003.

As can be readily seen from the previous table, natural sources of radionuclides vastly predominate the radiation load of the seafood diet of heavy seafood consumers in Ireland. Natural

levels total nearly 100 times greater than man-made sources. This is particularly important for the target site, since the Irish Sea has been the recipient of radionuclide pollutant loads from Sellafield, and has greater anthropogenic concentrations of radionuclides than the Arctic and North Pacific Oceans, as well as several important seas of the northern hemispheres.

10.24 Cancer Mortality Risks of Radionuclides in Seafood: ICRP vs EPA

The degree of cancer mortality risk associated with the consumption of seafood is commonly estimated through application of a methodology advocated by the International Commission on Radiological Protection (ICRP, 1991). In this approach, the total committed effective dose (TCED), in Sv or uSv, is computed for the typical and heavy consumer of the product. The dose is the average activity concentration of each radionuclide (in Bq/kg) in a food times the annual quantity consumption of the food in question (kg/yr) times the dose conversion factor for the radionuclide (Sv/Bq). The product is the number of Seiverts consumed in that food product per year for that radionuclide. The summation across all radionuclides for all food products considered (i.e., fish, crustaceans and mollusks) result in the total committed effective dose for that set of food products.

We will continue with the example of the typical and heavy seafood consumer model of NE Ireland that was developed in previous sections (10.11-10.23). As previously shown (table 38), the NE Ireland heavy seafood consumer has an annual total committed effective dose of 93.65 uSv from eating naturally occurring radionuclides in seafood and a total of about 1.17 uSv from anthropogenic radionuclide contaminants in the same seafood. ICRP has defined the cancer mortality risk of about 4.5 to 5.0 E-02 per Sv consumed (ICRP, 1991; Ryan et al, 2003). This level of risk, which is based on the use of an effective dose, assumes that “the equivalent dose is fairly uniform over the whole body” and it does not deal with possible influences of competing causes of

death – which could be of relevance in radionuclides with long biological and physical half lives. However, regardless of these modest limitations, the ICRP approach is the international approach used for estimating radiogenic cancer risks. By applying the cancer mortality risk per Sv to the estimated number of Sv consumed in seafood, the incremental cancer risk from seafood can be computed. The results of this computation, based upon a one year heavy diet of seafood in NE Ireland containing a background level of natural radionuclides, is an estimate of overall incremental risk of approximately 5.5 cancer deaths per million heavy seafood consumers over their predicted lifetimes (table 39). Nearly 80% of the cancer mortality risk from natural radionuclide components is attributed to Polonium-210, followed by about 16% from Uranium-238. If this diet were consumed annually, then an accumulation of natural radionuclides would result (tempered by biological and physical half-life considerations) such that the lifetime cancer risk would increase.

Table 39:Cancer Mortality Risks of Heavy Seafood Consumers, NE Ireland (2000-2001)

Risks of Natural Radionuclides Consumed, Using ICRP Publication 60 (1991). Risk is a product of "effective dose" and "fatality probability coefficient"

	Fish uSv/yr	Crustacea uSv/yr	Mollusks uSv/yr	Totals uSv/yr	CA death risk/uSv	Total CA risk
Pb-210	1.26	0.2	1.74	3.2	5.00E-08	1.60E-07
Po-210	24.53	22.78	41.17	88.48	5.00E-08	4.42E-06
Ra-226	0.82	0.03	0.08	0.93	5.00E-08	4.65E-08
Th-228	0.05	0.01	0.19	0.25	5.00E-08	1.25E-08
Th-230	0.015	0.002	0.146	0.163	5.00E-08	8.15E-09
Th-232	0.017	0.001	0.235	0.253	5.00E-08	1.27E-08
U-234	0.018	0.007	0.177	0.202	5.00E-08	1.01E-08
U-238	0.014	0.006	0.156	0.176	5.00E-08	8.80E-07
Totals	26.724	23.036	43.894	93.654		5.55E-06

Risks computed assuming cancer mortality risk of 5E-08 per uSv (or 5E-02 per uSv), and multiplying the effective dose components (or the sum of the components as the total effective committed dose) by the cancer probability coefficient (cancer mortality risk estimate).

International Commission on Radiological Protection (ICRP), 1991. 1990 recommendations of the International Commission on Radiological Protection. Annals of the ICRP, 21 (1-3), Publication No. 60

International Commission on Radiological Protection (ICRP), 1996. Conversion Age-dependent doses to members of the public from intakes of radionuclides: Part 5, compilation of ingestion and inhalation coefficients. Annals of the ICRP, 26(1), Publication No.72

It is instructive to apply an alternative cancer mortality risk approach to the exact same NE Ireland heavy seafood consumer population to note the degree of variability in results. The US Environmental Protection Agency (USEPA) developed a somewhat different approach to estimating environmental cancer risks. In its Federal Guidance Report No. 13, titled Cancer Risk Coefficients for Environmental Exposure to Radionuclides (EPA, 1999), the Agency has developed risk coefficients for ingestion of radionuclides in food. The food consumption patterns, age and gender demographics, and information on age-gender mortality by major causes were considered in estimating causes of death that would compete with potential radiogenic mortality. This approach has also incorporated some newer data on the non-uniform distribution of thorium-232 in vivo, as well as more recently developed low-LET radio-biologic effect estimates for leukemia and breast cancer. In the EPA dietary intake model, however, the Agency assumes that there is 100% contamination of the total food supply with the radionuclide, and therefore 1.2 kg of contaminated food are ingested daily by the population. This assumption of a 438 kg annual ingestion of contaminated foodstuff contrasts with the total heavy consumer of radionuclides in seafood for NE Ireland, where a total of about 80 kg (73 kg fish and 7 kg of crustaceans and mollusks) are consumed.

Table 40 shows the application of the EPA model to NE Ireland heavy seafood consumers. Notice that the cancer mortality risks are provided per Bq of the specific radionuclide consumed. The differences in the total degree of cancer mortality risk between the EPA and ICRP approaches are not that substantial, with the EPA risk being about 40% lower – but not that different considering the variations likely in international demographics, survivorship and competing causes of death.

Table 40: Cancer Mortality Risks of Heavy Seafood Consumers, NE Ireland Data

Risks of Natural Radionuclides Consumed, Using EPA Coeffcients. Risks computed per Bq of Radionuclide Consumed.

	Fish Bq/yr	Crustacea Bq/yr	Mollusks Bq/yr	Total Bq/yr	CA death risk/Bq	Total Ca risk
Pb-210	1.8	0.292	2.519	4.611	2.31E-08	1.07E-07
Po-210	20.44	18.98	34.31	73.73	4.44E-08	3.27E-06
Ra-226	2.92	0.11	0.292	3.322	9.56E-09	3.18E-08
Th-228	0.365	0.037	1.351	1.753	2.46E-09	4.31E-09
Th-230	0.075	0.012	0.694	0.781	2.16E-09	1.69E-09
Th-232	0.075	0.004	1.022	1.101	2.45E-09	2.70E-09
U-234	0.365	0.146	3.614	4.125	1.66E-09	6.84E-09
U-238	0.29	0.128	3.249	3.667	1.51E-09	5.54E-09
Totals				93.09		3.43E-06

Risks computed using coefficients in: EPA Cancer Risk Coefficients for Environmental Exposure to Radionuclides, Federal Guidance Report No. 13, September, 1999 (EPA 402-R-99-001).

Of interest is the relatively low cancer mortality risk attributable to anthropogenic radionuclides in the seafood diet compared natural ones. While mortality risks of 3.4 (EPA model) to 5.6 (ICRP model) in a million heavy seafood consumers per year are estimated from natural radionuclides, the risks of the same ingested food from man-made radionuclides are only about 1% of the natural radionuclides, ranging from 6 to 7 per *hundred million* per year (table 41).

Table 41: Cancer Mortality Risks of Heavy Seafood Consumers, NE Ireland

Anthropogenic Radionuclide Risks: epa vs ICRP Models. Comparison of EPA and ICRP Cancer Mortality Risks.

		EPA CA Mortality		ICRP CA Mortality	
	Bq/yr	Deaths/Bq	Risk	uSv/yr	Risk
Tc-99	427.1	6.17E-11	2.63E-08	0.257	1.29E-08
Cs-137	56.2	6.88E-10	3.87E-08	0.73	3.65E-08
Pu-238	0.1	3.50E-09	2.80E-10	0.022	1.10E-09
Pu-239+40	0.4	3.63E-09	1.48E-09	0.103	5.14E-09
Am-241	0.3	2.56E-09	6.45E-10	0.05	2.50E-09
Total CA Mortality Risk:			**6.74E-08**	1.162	**5.81E-08**

References: Federal Guidance Report No. 13, September, 1999 (EPA 402-R-99-001).
International Commission on Radiological Protection (ICRP), 1991. 1990 recommendations of the International Commission on Radiological Protection. Annals of the ICRP, 21 (1-3), Publication No. 60.

International Commission on Radiological Protection (ICRP), 1996. Age-dependent doses to members of the public from intakes of radionuclides: Part 5, compilation of ingestion and inhalation coefficients. Annals of the ICRP, 26 (1), Publication No. 72.

11.0 Ecological Risk Assessments from Marine Radionuclides

There has been a recent recognition that the previous model regarding environmental protection, i.e., the "belief that the standard of environmental control needed to protect humans will ensure that other species are not put at risk" (Coppleston et al, 2004; ICRP, 1991) is not necessarily a protective approach for the ecological environment. In this section we will only briefly review selected aspects of this complex issue, including the preferential sequestration of environmental radionuclides in certain biota (i.e., concentration factors), the selection of representative marine biota around which data can be developed and protective approaches developed, the debate regarding what to measure (and protect) as metrics of ecological health, and a summary of a recent European evaluation of the scientific literature on radionuclide marine ecotoxicology – in the quest for "acceptable exposure limits".

11.1 Concentration Factors – indicators of biological uptake

Radionuclides in marine water columns tend to concentrate to varying degrees in organisms living in such columns. The degree of preferential passage (transfer and uptake) of dissolved or particulate-linked radionuclides from water columns to biota is characterized, at least to some extend, by the Concentration Factor (CF) concept. The CF for a marine organism is the ratio of the concentration of a radionuclide in that organism to its concentration in its marine water environment under conditions of equilibrium. In natural settings, the state of equilibrium is usually assumed – since it can best be assured only under artificial laboratory conditions. The CF, while widely used, does have a number of limitations. A recent review cited several criticisms of the approach, including that the CF does not provide insight on how biological uptake occurs (i.e., mechanisms or processes), has limited supporting data for many radionuclide/organism

combinations, and is less supported for estimating higher trophic-level organisms since it is difficult to characterize complex food chain accumulation with a single ratio (FASSET,2003). Furthermore, the CF approach can be human-centric or eco-centric, that is, it can focus on concentration considerations most important to human health (i.e., concentrations in human-edible sections of human-edible organisms) or considerations most important to other components of the ecosystem that are not directly a part of the human food chain.

A recent summary provides an excellent overview of CFs by generic category of marine organism (FASSET, 2003). Some data extracted from that work are shown in the following table (table 42). Concentrations of 10,000 to over 100,000 fold exist in at least one of the phytoplankton, macoalgea, zooplankton, mollusks or crustacean families for several radionuclides, including Pu, Am, Po, Tc, and Pb. In contrast, the concentration factor for strontium is 10 or less in all of the categories of organism, and the elements cesium and uranium are reported to have concentration factors less than 100, also in all categories. Some elements have wide ranges of concentration, depending upon the organism. For example, iodine concentrates over 1000 fold in macroalgae and in zooplankton, but is noted concentrated to a great extent in such marine biota as mollusks, crustaceans or fish.

Table 42: Marine Organism concentration Factors of Radionuclides

IAEA Techdoc 247: FASSET, 2003

CF:	> 10^5	>10^4,<10^5	>10^3,<10^4	>10^2,<10^3	>10, <10^2	10 or less
Phytoplankton	Pu, Am	Pb,Po		I	Cs,Tc,U	Sr
Macroalgae		Tc	I,Am,Pu	Pb,Po	Cs,U	Sr
Zooplankton		Po	I,,Am,Pu	Pb	Cs,U,Tc	Sr
Mollusca		Pb,Po	Pu	Am,Tc	Cs,U	Sr,I
Crustaceans		Pb,Po		Am,Pu,Tc	Cs	Sr,I,U

Fish	Po	Pb	Am,Pu,Tc, Cs	Sr,I,U

Data adapted from FASSET, Deliverable 5, Appendix 2, October, 2003.

It is important to consider the potential for certain radionuclides to exhibit a preferential concentration within specific organ systems – since such data could provide information useful for the early markers of contamination. For example, Tc-99 is found at concentrations 10 to 1000 times higher in the green gland of the European lobster than in its muscle (FASSET, 2003). Measures of Tc-99 in this organ could, therefore, provide a more sensitive indicator of environmental contamination than might data from whole lobsters or edible muscle samples. Some data, from studies on organisms in their natural environments, on comparative organ concentrations for selected radionuclides in certain marine organisms are noted in table 43.

Table 43: Organ Concentration Factors for Radionuclides in European Marine Organisms

Organ and Radionuclide Specific Concentration Factors. CF= concentration organ/seawater

	Muscle	**Hepatopancreas**	**Shell**	**Bone or Exoskeleton**
Lobster	Tc=5000	Tc=1400	Tc=1100	
Crab	Tc=20	Tc=160		
Shrimp	Sr=15	Po=2E+4	Sr=25 Po=3E+3	
Molluscs	Cs=3 to10 Po=2E+3 Pu=800	Po=7E+4	Cs=2 to 5 Po=1E+4 Pu=2E+3	Po=3E+4
Fish	Cs=100 Sr=4	Po=3E+5		
Seabird	Cs=400	Cs=500		

Data summarized from: FASSET, Deliverable 5, Appendix 2, October, 2003.

An additional set of information has been compiled by FASSET for experimental studies undertaken in controlled environments. The advantages of such studies include assuring that equilibrium conditions are met and that the biota survive in relatively non-competitive conditions, there is the disadvantage of not being able to simulate "real life" exposure complexes (currents, sediments, organic loads, etc.) nor typical ecologic food chains characteristic of a region. However, the results of such studies are still of value and are summarized in the next table.

Table 44: Concentration Factors for marine biota from Experimental Studies

	Whole	Muscle	Hepatopancreas	Shell	Exoskeleton
Algae (brown)	Am=380 Cs=4 Tc=10500				
Crab	Am=145	Am=5 Pu=6.5	Am=5 Pu=2		Am=240 Pu=70
Shrimp	Po=150 Pb=675	P0=40 Pb=40	Po=640 Pb=610		Po=290 Pb=1775
Mollusks	Am=265 Cs=8 I=5	Np=14		Np=47 I=3	
Fish	Cs=3				

FASSET, Deliverable 5, Appendix 2, 2003.

Information from CF estimates can be used in both directions, that is, if actual sampling data is available on biota for specific radionuclides, then estimates of marine water concentrations can be made by applying the CF. Conversely, if the only sampling data available is on seawater radionuclide concentrations, then CFs may be useful to estimate the range of concentrations that might be expected in various types of marine life – taking into account the various caveats previously discussed about the CF. To be sure, there are a number of factors that may influence the actual CF, including specific biota, temperature and dissolved organic matter in seawater, region of

the marine environment and other issues. Despite these complications, there is still wide use of the CF in marine investigations, supplemented by major advances in marine ecosystem modeling of release, transport and uptake mechanisms.

11.2 Reference Marine Biota

For human radiation protection, there is the concept of the *reference man* (or woman), which is used to develop dosimetric models, comparative data, and risk assessments. There has been a major interest in developing an analogous concept, *reference organisms,* to be developed and applied in order to coordinate the collection of comparative data and to assess our deffectiveness at protecting the environment. An early step in the process of defining the extent and consequence of radionuclide exposure to marine biota, is to standardize, for comparative purposes, a relatively small set of organisms that are typically found in major marine environments and have, from an exposure perspective, "radioecological sensitivity" (Strand et al, FASSET Deliverable 1, 2001). FASSET uses the term "radioecological sensitivity" as an indication that certain organisms are indicators of high exposure to radionuclides due to either their proximity to contaminated sediment (i.e., the organisms habitat and feeding habits), their ability to bioconcentrate radionuclides (increase internal exposure, i.e., dose), or their top predator position in the foodchain which leads to biomagnification (i.e., increasing concentrations higher up the foodchain) of radionuclides. This information, coupled with ecological relevance and the availability of dose-response relationships, have formed the basis of the development of a set of reference organisms (table 45). Because of the focus of our review, only information relevant to the marine environment has been considered from the FASSET reports.

Table 45: Environmental Reference Organisms as indicators of Marine Radiation

Rationale for inclusion as priority

Marine Organisms	Water Column	Sediment	External Conc.	High Bioconcentration
Bacteria		Yes	alpha part.	
Worm		Yes	beta-gam	potential
Bivalve Molluscs		Yes	beta-gam	^{106}Ru, ^{210}Po, ^{239}Pu,^{241}Am
Gastropod Molluscs			"	" " "
Crustaceans		Yes	beta-gam	^{99}Tc, ^{210}Po
Phytoplankton (microalgae)	Yes			^{210}Po, ^{226}Ra, ^{239}Pu
Zooplankton	Yes			^{210}Po
Macroalgae(seaweed)	Yes			^{99}Tc, ^{106}Ru, ^{129}I
Fish	Yes	Yes	beta-gam	^{137}Cs Plus biomagnification
Vascular plants	Yes		beta-gam	^{226}Ra, ^{238}U
Mammals	Yes	Yes		Particle reactives + alphas
Wading Birds	Yes	Yes	beta-gam	Particle reactives + alphas

Reference: Adapted from FASSET, Deliverable 1: Identification of candidate reference organisms from a radiation exposure pathways perspective, (Strand et al, ed) November 2001.

FASSET researchers have reviewed environmental dosimetry (organisms with high dose rates), exposure pathways (maximally exposed organisms for specific radionuclides in certain marine environments) and assessment of environmental effects (radiosensitivity, ecological sensitivity and importance) to develop a set of reference organisms for the marine (and other) environment. They limited their focus to a subset of twenty radionuclides and their principal radioisotopes (table 46), selected because of the type of their radiation emission, their environmental mobility and biological uptake, their importance from a regulatory standpoint (hazardous waste, etc.), and because there is sufficient data available for assessment purposes.

Table 46: Key Radionuclides considered in determination of Reference Organisms

Mammal

Radionuclide (element group)	**Mobility**	**Radiation half life**	**Biologic half life***	**Key Radioisotopes**
H	High	12 y	days	Tritium
C	High	5.6E3 y	days	^{14}C
K	High	1.3E9 y	weeks	^{40}K
Cl	Moderate	3.01E5 y		^{36}Cl
Ni	Low	96 y		^{63}Ni
		7.5E4 y		^{59}Ni
Sr	High	50.5 d	years	^{89}Sr
		28.5 y		^{90}Sr
Nb	Low	2.03E4 y		^{94}Nb
Tc	High	2.13E5 y	days	^{99}Tc
Ru	High	368 d	days	^{106}Ru
I	High	1.57E7 y	wks-mos	^{129}I
		8.04 d		^{131}I
Cs	High	2.06 y	wks-mos	^{134}Cs
		30 y		^{137}Cs
		2.0E5 y		^{135}Cs
Po	High	138 d	weeks	^{210}Po
Pb	High	22 y	years	^{210}Pb
Ra	Moderate	1.6E3 y	years	^{226}Ra
Th (Actinide series)	Very low	18.7 d	years	^{227}Th
		1.9 y		^{228}Th
		7.7E4 y		^{230}Th
		25.5 h		^{231}Th
		1.4E10 y		^{232}Th
		24.1 d		^{234T}h
U (Actinide series)	Low-mod.	2.45E5 y	months	^{234}U
		7.04E8 y		^{235}U
		4.47E9 y		^{238}U
Pu (Actinide series)	Very low	88 y	years	^{238}Pu
		2.4E5 y		^{239}Pu
		6.5E3 y		^{240}Pu
		14.4 y		^{241}Pu
Am (Actinide series)	Very low	4.32E2 y	years	^{241}Am
Np (Actinide series)	Very low	2.1E6 y	years	^{237}Np
Cm (Actinide series)	Very low	163 d	years	^{242}Cm
		28.5 y		^{243}Cm
		18.1 y		^{244}Cm

*for the element, not specific for the isotope
Source: FASSET, Deliverable 1: Identification of candidate reference organisms from a radiation exposure pathways perspective. (Strand et al, eds), November 2001.

11.3 Marine biota ecological metrics: What to Measure?

11.4 Marine biota radio-ecotoxicology: Current Status

This section summarizes the key findings of a recent comprehensive review of the literature under the European Commission's Framework for Assessment of Environmental Impact (FASSET), included in the FASSET Radiation Effects Database or FRED (FASSET, 2004). The data set included acute and chronic experimental studies addressing morbidity, mortality, reduced reproductive success and mutation in 16 wildlife groups – including fish, crustaceans, mollusks, aquatic invertebrates, aquatic plants, zooplankton, birds, amphibians, mammals, and others. Of particular relevance to the current review were the chronic and acute studies on fish. A total of 110 studies were represented in the chronic fish study database (an over-count, since a study – for the purposes of this report – was recorded separately for each of one to four endpoints that it might address). Sixty-nine of those studies specifically assessed dose-response data, while 41 studied background incidence of the events. Only the morbidity and reproductive capacity studies covered a wide range of dose-rates, while mutation studies were primarily at high dose-levels and very few studies were available for chronic mortality studies (table 46a).

Table 46a: Chronic Fish Radiotoxicity Studies Summarized in FASSET Toxicity Database

Number of Studies Reported in FASSET					
Dose-rate (uGy/hr)	**Morbidity**	**Mortality**	**Reproductive**	**Mutation**	**Totals**
Background	9	4	21	7	41
<99.9	2	0	6	0	8
100-199.9	2	1	2	1	6
200-499.9	1	0	5	0	6
500-	1	0	5	0	6

999.9					
1,000-1,999.9	1	0	6	0	7
2,000-4,999	3	0	4	1	8
5,000-9,999	2	0	6	2	10
>10,000	4	0	10	4	18
Totals	25	5	65	15	110

Reference: FASSET, Deliverable 4, Radiation Effects on Plants and Animals. June 2, 2003. (adapted from)

Chronic irradiation of fish at rates 100 to 1000 uGy/h have been found to reduce measures of sperm generation, testicular mass, fecundity (i.e., embryo survivorship into an entity living separate from its parents) and spawning (table 46b). Depletion of spermatogonia results when dose rates of 5000 to 10,000 uG/h are applied.

Table 46b: Effects of Chronic Irradiation on Fish Toxicity

Summary: Effects of chronic Irradiation on Fish. Studies with Gamma Radiation Exposure

Reproduction Endpoint		
Dose-rate (uGy/h)	**Species**	**Outcomes Noted**
1E2 to1E3	Plaice;Medaka:Roach	Reduced sperm, testes mass, fecundity, and delayed spawning
1-5E3	Eelpout, Rainbow Trout, Plaice, Medaka, Guppy,	Reduced sperm, testes mass, fertility, male courtship, spermatogonia
5E3-1E4	Medaka	Depletion of spermatogonia
1-5E4	Medaka, Guppy	Sterility, vertebral anomalies, larvacidal
Morbidity Endpoint		
1-5E3	Medaka(?)	Reduced immune response
Mortality Endpoint		
>5E4	Guppy	Parental irradiation - no offspring impact

Reference: FASSET, Final Report. May 2004 (Section 4).

To help place these dose-rates into some perspective, the typical human receives somewhere between 0.3 and 0.5 uG/h from all sources of radiation, including terrestrial, cosmic, medical and other sources. The FASSET report suggests that a no-adverse-effect level has been characterized

for some key endpoints in fish. For example, "chronic exposures at dose rates up to 4 mGy h^{-1} of developing embryos (most sensitive stage) will not have significant effects on subsequent growth" and, while based upon rather limited studies, that "dose rates < 4mGy h^{-1} at any life stage are unlikely to affect survival" (FASSET, 2004). The FASSET report also indicates that there is "little consistent, significant evidence for effects on reproductive capacity at dose rates <0.2 mGy h^{-1} ", but that there is, as in other vertebrates, probably no threshold for some endpoints – such as genetic toxicity markers. It should be noted that the 4 mGy/hour no-observed-effect levels described for embryonic growth and for survival (of any life stage) is a substantial absorbed dose. It is equivalent to 400 mrad / hour, or, on a chronic annual basis is 350 rad. Furthermore, there is little evidence for significant fish reproductive capacity adverse effects below 0.2 mGy hr^{-1}, which if continued for one year is equivalent to about 17.5 rad.

12.0 Implications and Conclusions

This review documents the average radionuclide concentrations and their degree of variation from recent studies of the marine environment (including biota) of the northern hemisphere. For example, average concentrations of cesium-137 in mollusks demonstrate about a twenty-fold range, from a low of 1.4 to 1.7E-05 from samples from the USA Atlantic Coast and the Sea of Japan to values of about 2.6E-04 from those in the Irish Sea, while fish populations, whose mobility might allow greater integration of dose from multiple sources, have slightly less variability (tables 8, 12, 28a). Knowledge of the average concentrations and their degree of variation, either by geographical location or temporally at the same location, should support investigators in their quest to distinguish perturbations of "background" values from those that might occur from locally contaminated conditions. Furthermore, this type of data will assist in determining whether locally found values are consistent with those found in other marine

environments/biota that are deemed acceptable as commercial and subsistence sources of human seafood.

A second finding addresses the degree of human health risk that one might expect from varying degrees of contamination of the marine environment with radionuclides. A very useful example is the expected human risk associated with consumption of marine biota from the Irish Sea, which has substantially higher contamination with Cs-137 and Tc-99 due to the reprocessing facility at Sellefield than does the north Pacific and many other large bodies of marine environments. It is important to note that with the current levels of Irish Sea contamination (the concentrations have dropped over the last two decades) the human health risks are estimated to be very low - less than 1 in 10 million - even in the high seafood consumer populations. Furthermore, the annual dietary doses (over 90 uSv) of a typical heavy seafood consumer from radiation of natural sources (polonium and other natural radionuclides), dwarfs the contributions from anthropogenic sources (about 1 uSv). This information should be useful in the broad interpretation of results from specific special studies or surveillance from other locations (such as the Amchitka study and others) – and should provide data and concepts useful in communications with the public. It should not, however, provide license for increasing the radionuclide load in marine waters.

Finally, marine monitoring systems need to be designed to detect radionuclide contamination at levels sufficient to protect the public health. This does not mean that every study must be designed and supported to detect the lowest possible concentrations. To be sure, there have been great advances in low level measurements, such as the new and unique International Atomic Energy Agency's Underground Counting Laboratory which is designed at the depth of the equivalent of 30 meters underwater, has double lead shielding, anticosmic plastic scintillation

detectors, an anticompton gamma-spectrometer and a low-background liquid scintillation spectrometer Quantulus. Most environmental radiation research and monitoring programs do not require the extraordinary degree of sensitivity, sophistication and expense incorporated into the IAEA laboratory. However, modern, effective environmental radiation assessments and monitoring systems should be able to detect the concentration levels in biota that, when coupled with population consumption patterns, could present potential doses and risks relevant to the public's health and/or to adherence to food regulations. Dose levels of contamination that could reach risks of public health concern (such as between 1E-4 to 1E-6 risk of cancer) should be detectable, as also should concentrations relevant to international food radiation safety standards. Surveillance or studies must be able to determine if radionuclide concentrations in seafood harvested at a location are, or are not, acceptable to be sold in the international commercial marketplace. And finally, the risks of the most potentially exposed populations – such as subsistence harvesters – need to be carefully assessed and be acceptable.

The current report has demonstrated that the reviewed programs are sufficient to detect cesium-137 concentrations at levels substantially below the new WHO and FAO recommended international food standards. In addition, the detection limits for Cs-137 demonstrated in modern laboratory systems (including those in the current Amchitka study) are sufficient to protect even the high consuming members of the public, to potential human health risks (between one-in-ten thousand and one-in-a million) from current cesium-137 and other anthropogenic radionuclides in marine seafood. Protective regulations and data on ecological risks from radiation are less well defined. The current movement in international environmental organizations to recognize the need for, and to develop, guidelines for representative marine organisms is welcome and much needed. A recent comprehensive review of radionuclide toxicology information for marine organisms

(FASSET, Deliverable 4, 2003) indicates that the rates of radiation exposure found to increase risks to key markers of toxicity, i.e., morbidity, mortality, reproductive capacity or mutation, tend to be orders of magnitude greater than the concentrations currently found in marine biota (as reviewed in this document). As future studies are accomplished on more marine organisms, and the ability to interpret ecological information expands beyond the individual organism, we will be better equipped to interpret with greater conviction the broader ecological implications of radionuclides in our marine environment.

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Appendix 1: Bodies of Water and Associated Countries

Table 47: Bodies of Water and Associated Countries

Body of Water	Bordering Countries
Arctic Ocean/Seas	
Baffin Bay	Greenland, Canada

Beaufort Sea	Canada, United States
Chukchi Sea	Russia, United States
East Siberian Sea	Russia
Greenland Sea	Greenland
Kara Sea	Russia
Laptev Sea	Russia
Pechora Sea	Russia
White Sea	Russia
Norwegian Sea	Norway, Iceland, Scotland
Atlantic Ocean/Seas	
Baltic Sea	Sweden (Gulf of Bothnia: Finland & Sweden), Finland, Russia, Estonia, Latvia, Lithuania, Poland, Germany, Denmark.
Celtic Sea	England, Ireland, Wales
English Channel	England, France, Belgium
Hudson Bay	Canada
Irish Sea	England, Ireland, Wales
Labrador Sea	Canada
North Sea	Norway, England, Scotland, Denmark, Germany, Netherlands, Belgium
U.S Atlantic Coast	United States
Pacific Ocean/Seas	
Bering Sea	United States, Russia
East China Sea	Japan, China, South Korea, North Korea
Okhotsk Sea	Japan, Russia
Sea of Japan	Japan, South Korea, North Korea, Russia/Siberia
N.Pacific, Japan	Japan
N.Pacific, U.S.	United States
Yellow Sea	China, South Korea

Appendix 2: Radionuclide Ratios as Indicators of Source

Most marine environments have, to one degree or another, received radionuclide intrusion from local, regional and global conditions. While absolute concentrations of each radionuclide are necessary to assess the magnitude of contamination and its trends, the source of the contamination may be elucidated through the assessment of certain ratios (isotopic or elemental) – and shifts in those ratios over time may have significance regarding the relative importance (emergence or fading) of one source versus another. It is for these reasons that radionuclide ratios have been used by many investigators and agencies as potential indicators of the source - regardless of whether the analyses be of atmospheric, terrestrial or marine environments.

Analyses of aerosols, ice core and soil samples indicate that the global fallout mean value for $^{240}Pu/^{239}Pu$ is about 0.18 (Hirose, Igarashi et al, 2003). The fallout ratios from different nuclear test sites vary, however, with ratios of 0.21 to 0.36 in the soil of the Pacific Test Site in the Bikini Atolls being substantially different from the 0.035 ratios of the Russian Semipalatinsk and U.S. Nevada Test Sites. While ratios may be a tool or indicator of recent sources of plutonium, interpretation of these types of ratios may be "a very complex affair", even when investigating relatively "simple" situations, such as the range of sedimentary residues at the marine site of a single accident (Dahlgaard et al, 2001).

While all marine environments (more so in the northern hemisphere) have sustained radionuclide pollution from global fallout, and many (particularly European) waterways have received Chernobyl depositions, some bodies of water are impacted more intensely by close sources and/or those that are channeled across substantial distances through currents or other mechanisms. Nearly every sea, ocean or bay in the northern hemisphere has some anthropogenic radionuclide contamination – and all have natural radionuclides.

The Barents and Kara Sea components of the Arctic Ocean have been influenced by contamination from Russian industry emissions emptied to Siberian rivers, by releases from nuclear reprocessing facilities in Western Europe and potentially from dumped radioactive wastes and sunken nuclear submarines and icebreakers in the Kara Sea (Sazykina and Kryshev, 1997). The Irish Sea has been most impacted by the radionuclides from the Sellafield nuclear reprocessing plant located in Cumbria, UK. – with the plutonium and americium contamination from Sellafield estimated at well over 100 times that accumulated from atmospheric nuclear test fallout (Ryan et al, 1999). The French Channel's most important source of radionuclides has been the water and gaseous discharges from the La Hague nuclear fuel reprocessing facility (Frechou

and Calmet, 2003). The Sea of Japan radionuclide contamination is thought to be primarily from global fallout, although several studies have been undertaken regarding potential releases from previously dumped radioactive wastes by the former USSR in the northern section of the Sea in the Peter the Great Bay area (Hirose, Miyao et al, 2002; Livingson, Povinec et al, 2001). The key anthropogenic sources to the Pacific Ocean and its marginal seas are from global and close-in nuclear test fallout – with some less degree of nuclear facility releases (Hirose and Aoyama, 2003).

Radionuclide ratio data has been used to plot trends and to assess potential contributions of sources to environmental media contamination. It should be noted that the feasibility of using radionuclide and isotopic ratios depends upon the ability to detect the contaminants in analyzed samples. This is not always feasible, given the low concentrations expected in certain media for certain radionuclides. The following table (table 48) provides some of the reported marine radionuclide ratios and the interpretation of the findings provided in the original publications.

Table 48: Radionuclide Ratios in Marine Environment and their Implications

Contrast	Refer.	Media	Water site	Ratio	Interpretation
^{129}I / ^{127}I	Frechou & Calmet 2003	Seaweed	Europe French Channel	*Postulated* <1E-08	Global fallout
				>1E-07	Industrial discharge
				Actual	
		C. crispus (low value)		7E-07 to	Industrial discharge
		F. humbricalis (high value)		3.00E-05	(La Hague processing plant)
$^{240}Pu/^{239}Pu$					
	Buesseler 1997	Coral	N Pacific	<0.19	Global fallout
				>0.20	Close-in fallout
		Surface sediment	N Pacific	0.18-0.19	Global fallout
				>0.20	Close-in fallout
$^{238}Pu/^{239,240}Pu$	Dahlgaard et al, 2004	Sediment	Baffin Bay	0.014	Thule accident site

$^{241}Am/^{239,240}Pu$		Sediment	Baffin Bay	0.13	
$^{241}Am/^{239,240}Pu$		Molluscs	Baffin Bay	0.63	
$^{241}Am/^{239,240}Pu$		Crustacea	Baffin Bay	0.22	
	Dahlgaard et al, 2001				
$^{240}Pu/^{239}Pu$ atoms		Sediment	Baffin Bay	.027-.057	Thule accident site
		Sediment	Global estimate	0.18	Global fallout
		Sediment	Irish Sea	0.25	Sellafield discharges
$^{238}Pu/^{239,40}Pu$	Ryan et al 1999	Seaweed	NE Irish Sea	0.19	Sellafield
			W Irish Sea	0.17	Sellafield
					Global = 0.033

The long-lived plutonium isotopes, ^{239}Pu and ^{240}Pu, have been used as isotopic metrics of nuclear-weapons fallout, with their proportionate presence in the marine environment reflecting at least partly the type of weapon tested, i.e., its yield and its design, as well as whether the test was atmospheric or surface-based (Buesseler, 1997). For example, surface-based testing on atolls in the Pacific would incorporate calcium hydroxide from the coral matrix. Upon re-entry into the sea, the calcium component of the calcium hydroxide-plutonium complex would interact with seawater magnesium ions "to form a shell of insoluble magnesium hydroxide on the fallout particle" (Buesseler, 1997). This is in clear distinction from global fallout from atmospheric tests, where there is no interaction with compounds on the earth's surface. In atmospheric tests, "Pu is carried by sub-micron-sized particles that are composed primarily of iron-oxides" (Buesseler, 1997). It can therefore be noted that the physical/chemical forms of plutonium residing in marine waters will differ based upon whether they originated from atoll-land based tests (i.e., Pacific Proving Grounds) or from atmospheric based tests. The 240Pu/239Pu ratio is increased (>0.20 ratio) in the relatively insoluble Pacific Proving Grounds fallout compared to that of the more soluble stratospheric global fallout (0.18-0.19 ratio) (Buesseler, 1997). The influence of type of fallout and its relative insolubility have resulted in increased 240Pu/239Pu ratios in sediments and subsurface waters in the Pacific Proving Grounds area in the NW Pacific.

In 1968 a US B52, carrying four atomic bombs, crashed in frozen Baffin Bay after leaving from Thule Air Base in Northwest Greenland. This tragic incident provided investigators specific research material (see Table 48) by which the diagnostic or attributive value of radionuclide ratios could be assessed in an environmental setting (Dahlgaard, Eriksson, et al, 2001). The site was last sampled in 1997. It is interesting to note that plutonium in the surface sediment (0-3 cm) was not readily taken up by inhabiting benthic organisms such as bivalves, snails and starfish, with biotic concentrations one or two orders of magnitude lower in those organisms than in the surface sediment. Furthermore, little transfer of plutonium occurred to surface waters or to brown algae, *Fucus disticus*. The ratios of $^{240}Pu/^{239}Pu$ varied over two fold, from 0.027 to 0.057. This degree of variation indicated to the investigators that the plutonium originated from at least two different sources and suggests the complexity of assigning source apportionment even in relatively uncomplicated crash scenarios. Also involved in such analyses is the dynamic nature and ingrowth from relatively short-lived radionuclides. The ^{241}Pu isotope has a half-life of only 14.4 years and decays to 241Am. Thus, the ratios present at the time of the crash, nearly 30 years prior to the 1997 sampling, would be influenced by half-life considerations – one of the more predictable components of such complex assessments of marine source attribution.

Assessment of plutonium ratios in the Irish Sea and its biota have been made to determine the degree and direction of contaminant influence of the Sellafield nuclear fuel reprocessing plant. The Sellafield outfall pipe has been estimated to have discharged, between 1952 and 1992, 271 kg of plutonium and 4.25 kg of americium to the Irish Sea (Ryan, Dowdall, et al, 1999). Seaweed such *Fucus vesiculosu*s, has been studied to determine both the geographical distribution of plutonium in the Irish Sea as well as source attribution. Seaweed from the Irish Sea coast has been assessed for ^{238} Pu and $^{239,240}Pu$ four times over a 10 to15 year time frame, permitting an analysis

of trends. The $^{238}Pu/^{239,240}Pu$ ratios, as well as their absolute values, were assessed. While the activity concentrations of plutonium have generally decreased, the 238Pu/239,240Pu ratios have either remained high (0.218 and 0.19 in NE Coast for 1986 and 1996) or have risen (0.05 to 0.17 on West Coast) in seaweed from the Irish Sea. The investigators concluded form this data that "an increasing fraction of plutonium available to Fucus vesiculosus is currently of Sellafield origin" (Ryan, Dowdall, et al, 1999). Ratio data was clearly important in forming such judgments, since the decreasing total plutonium activity concentrations may not have suggested such an attribution.

Appendix 3:UK Dietary Survey Data for Seafood Consumption (RIFE-8)

Table 49: UK Dietary Survey Data for Seafood Consumption (RIFE-8)

Site of Survey	*Date*	*Fish(kg.yr)*	*Crustaceans(kg/yr)*	*Mollusc(kg/yr)s*
Bradwell	1999	44	3.1	6.5
Channel Islands	1997	62	30	60
Chapelcross	2000	20	12	3
Dunreay	1999	19	14	2.2
Dungeness	1999	59	17	15
Hartlepool	2002	32	15	12
Heysham	2001	36	18	19
Hinkley Point	2000	43	9.8	1.8
Hunterston	2001	29	22	2
Isle of man	?	100	20	20
Norther Ireland	2000	99	34	7.7
North Wales	?	100	20	20
Rosyth	1999	21	6.6	5.6
Sellafield (fishing comm.)	2002	51	16	29
Sizewell	2001	40	8.4	6.4
Springfields	2000	42	15	10
Torness	2001	41	17	5.9
Winfrith	1987	77	26	3.9
Wylfa	1988	94	23	1.8

Reference: CEFIS, Radioactivity in Food and the Environment, Appendix 4, 2002 (RIFE-8)

Appendix 4

5.0 Radionuclide Measures

Key Environmental Radiation Units

The units of measurement frequently applied in radionuclide monitoring programs constitute a scientific jargon that is not fully understood by the public. This section is meant to provide a brief description and interpretation of the commonly used units in order to aid the general reader to better understand the monitoring data presented in this report. This review focuses on the major international units (SI) of measure for ionizing radiation – the becquerel (Bq), gray (Gy) and sievert (Sv) – all of which are used in marine environmental studies. We also define the units frequently used in U.S. studies, including the curie (Ci), rad and rem. A comparison of the terms is outlined in table 1.

Table 1: Major International and U.S. Units of Radiation Measurement

Measure	International Unit(SI)	U.S. Unit	Conversion(SI/US)
Radioactivity	Becquerel	Curie(Ci)	3.7 billion Bq per Ci 1 Bq=27 pCi
Aborted dose	Gray(Gy)	rad	1 Gy=100 rad 0.01 Gy=10mgy=1rad 1 uGy=0.1 mrad
Radiation dose equivalent	Sievert(Sv)	rem	1Sv=100 rem 0.01 Sv=10mSv=1 rem 1 uSv= 0.1mrem

The becquerel (Bq) unit is the international unit of radioactivity and is not specific to the type of radioactivity. It simply describes the gross amount of radioactivity emitted from – and therefore indicative of radiation within - a sample as measured by the amount of radioactive decay detected in one second. One Bq of radioactive material produces 1 atomic-disintegration or transition per second. The Bq is a small unit compared to the U.S. metric, the curie (Ci). One Ci is the amount of radioactive material needed to generate 37 billion disintegrations (i.e., 3.7E 10 disintegrations) per second, or the number of disintegrations produced in one second by one gram of radium. Therefore, one Ci is equal to 37 billion Bq. The Bq unit is a useful metric for describing the low level radioactivity typically found in environmental monitoring studies of the marine environment. Radioactivity in marine biota is usually reported in Bq per kg wet-weight (ww) sample, i.e., Bq / kg-ww. Sample results for seawater are usually reported in Bq per volume, i.e., Bq/m3 or its equivalent of mBq / ml. Sediment radiation, which could vary a great deal by water content, is usually characterized by unit dry-weight (dw), i.e., Bq/kg-dw.

The gray (Gy) international metric indicates the radiation absorbed dose. It is a measure of the amount of energy that whatever is being emitted imparts on the recipient. The physics equivalence of 1 Gy is 1 Joule of energy absorbed per kilogram in the receptors tissue. In marine environmental studies, where absorbed doses are typically low, the centi-gray (cGy) or micro-gray (uGy) units are often used.

The sievert (Sv) is the radiation dose equivalent and is designed to address the potential for imparting biological effects. It is obtained after standardizing the absorbed dose (Gy) by the relative biologic effectiveness (RBE) or quality factor (QF) for the type of radiation. The Sv measure results from multiplying the Gy dose by the RBE for the specific type of radiation involved. One Sv is the amount of radiation, after adjusting for radiation type, equal to the

biological effect of 1 Gy of gamma rays. An RBE of 1 is used for gamma rays and beta particle positrons, while it can be up to 20 for alpha particles, depending upon energy levels. The Sv integrates the type of radiation and its dose (Gy) into equivalent biological units of impact. Thus, when one attempts to characterize biological risk from radiation exposure, the Sv - or fractional units of the Sv, such as the uSv - is the ultimate unit of interest. The Sv equivalent in United States units is 100 rem.

The British Broadcasting Company (BBC) has provided an illustrative boxing analogy to contrast what is intended by the three international radiation measures (BBC, 2004). It depicts, for the public, the qualitative differences between Bq, Gy and Sv as:

Bq: " a measure of how many punches are thrown without regard to whether they are roundhouses, hooks, jabs, or even if they connect at all."

Gy: "a unit that measures whether the punch is a strong uppercut or just a little jab. However, the gray wouldn't show the cumulative effect of something like 100 jabs to the exact same spot on the cheekbone versus one hard punch to the solar plexus"

Sv: "useful in determining the likelihood that (the boxer) might suffer some long-term damage as a result of this pummeling." "In short, a Sv is the most useful but complicated and subjective unit for measuring radiation effects on people."