OVERVIEW OF REPRESENTATIVE ECOLOGICAL RISK ASSESSMENTS CONDUCTED FOR SITES WITH ENHANCED RADIOACTIVITY

SENES Consultants Limited

November 2007

OVERVIEW OF REPRESENTATIVE ECOLOGICAL RISK ASSESSMENTS CONDUCTED FOR SITES WITH ENHANCED RADIOACTIVITY

Prepared for:

World Nuclear Association

Prepared by:

SENES Consultants Limited
121 Granton Drive, Unit 12
Richmond Hill, Ontario
L4B 3N4

November 2007

Printed on Recycled Paper Containing Post-Consumer Fibre

EXECUTIVE SUMMARY

Ionizing radiation is ubiquitous and all living things, human and non-human, are, and always have been, exposed to naturally occurring radiation and radioactivity. In addition, human activities have enhanced the levels of radiation and radioactivity both globally through fallout from above-ground testing of nuclear weapons and locally through release of radioactivity from activities such as mining, production of phosphate fertilizer, offshore oil and gas production and the nuclear fuel cycle among others.

Over the past ten or so years, numerous ecological risk assessments (ERAs) have been carried out for a number of sites involving enhanced radiation and radioactivity. The ERAs were done to study the potential effects of ionizing radiation on a wide variety of plants and animals - ecological receptors, generically referred to as "non-human biota". The ERAs have also been performed using a variety of approaches and using different assumptions and reference radiation dose rates. The latter serve as benchmarks for assessing potential risks to populations of non-human biota from exposure to ionizing radiation.

An overview of a selection of representative ERAs was completed for a wide range of activities and sites at various locations throughout the world. The ERAs considered in this review include studies representative over the full range of nuclear fuel cycle activities from uranium mining through nuclear power generation. Sites involving enhanced levels of naturally occurring radioactive materials (NORM), the management and disposal of radioactive wastes, and the impacts of the Chernobyl nuclear accident are also considered. Different types of ecosystems (terrestrial, freshwater and marine aquatic environments) were considered in the selection of these representative ERAs.

Selected (representative) ERAs were examined and an overview of the various studies has been provided. Based on this review some overall general observations were found:

- For the aquatic environment the non-human biota that are most likely to receive the highest doses appear to be crustaceans, molluscs and wildlife (birds and mammals) relying on the aquatic environment;
- For the terrestrial environment, the species which are expected to receive the highest doses generally appear to be vegetation, invertebrates and small mammals;
- The results showed that for normal operations of nuclear fuel cycle sites, of NORM sites and of radioactive waste management and disposal sites the potential for effects in non-human biota is low and well below reference dose rates at which adverse health effects to populations of non-human biota might be anticipated. For nuclear fuel cycle sites, this observation is strengthened by the fact that it is also valid for the sites involved in the early development of nuclear fuel cycle programs and of the related military facilities, which included both normal operations and some significant accidents;
- For those few situations where dose-rates to non-human biota are predicted to exceed the reference dose-rate at which effects on populations might be expected, the areal extent of

elevated dose rates is limited and confined to areas in, or in close proximity to, the source of radioactivity within site boundaries. The corresponding dose rates to non-human biota further away on site from the source of radioactivity or beyond the site boundaries, are below the reference dose rates; and,

- Even in the event of very high doses and dose-rates, such as those experienced following the Chernobyl accident where effects on non-human biota have been observed close to Chernobyl, populations of biota appear to recover within a reasonably short period once the radiation dose rates were reduced. Such high dose rates have not been seen for sites with controlled radioactive discharges.

Overall, the key observations from this review can be summarized as follows:

- The potential for effects on non-human biota due to exposures arising from the controlled releases of radioactivity from nuclear fuel cycle sites is low and well below reference dose rates;
- Similarly, the potential for effects on non-human biota arising from exposure to controlled releases of radioactivity from NORM sites is low and well below reference dose rates;
- For radioactive waste management and disposal sites, although higher dose rates can be sometimes found in the immediate proximity of radioactive wastes within the site boundaries, further away from the source of radioactivity or beyond the site boundaries, dose rates are below the reference dose rates; and,
- Populations of biota exposed to very high levels of radiation, arising from major accidents such as the Chernobyl accident, seem likely to recover within a reasonably short period once the source of exposure is significantly reduced or removed.

The current system of radiological protection has been based on the protection of people, assuming that if humans were adequately protected, then "*other living things are also likely to be sufficiently protected*" (ICRP 1977) or "*other species are not put at risk*" (ICRP 1991). The representative ERAs considered in this review show that the application of the current system of radiological protection, which includes a variety of standard protective practices for containing radioactive sources, controlling and limiting radioactive releases to the environment, and protecting people, have in fact also provided an adequate level of protection to populations of non-human biota.

ERAs provide additional insights to the behaviour and potential effects of enhanced level radiation and radioactivity arising from releases of radioactivity from nuclear fuel cycle sites, NORM sites, radioactive waste management and disposal sites, and from major accidents. The wide range of sites considered in this review shows that the current system of radiological protection has provided an adequate level of protection to populations of non-human biota.

TABLE OF CONTENTS

Page No.

EXECUTIVE SUMMARY ES-1

1.0 INTRODUCTION 1-1

2.0 APPROACHES TO ASSESSING RISK TO NON-HUMAN BIOTA 2-1
- 2.1 General Approach to ERA 2-1
- 2.2 Reference Radiation Dose Rates 2-2

3.0 SELECTED CASE STUDIES 3-1
- 3.1 Uranium Mining Sites 3-1
- 3.2 Nuclear Power Plants 3-3
- 3.3 Used Nuclear Fuel Reprocessing Plants 3-5
- 3.4 Management and Disposal Sites for Radioactive Wastes 3-7
- 3.5 The Chernobyl Accident 3-9
- 3.6 Sites Involving Naturally Occurring Radioactive Materials (NORM) 3-10

4.0 MAIN FINDINGS AND CONCLUSIONS 4-1

5.0 REFERENCES 4-1

APPENDIX A - OVERVIEW OF SELECTED REPRESENTATIVE ERAS A-1
- A.1 Uranium Mining Sites A-1
  - A.1.1 McArthur River A-1
  - A.1.2 McClean Lake A-3
- A.2 Nuclear Power Plants A-5
  - A.2.1 Pickering Generating Station A-5
  - A.2.2 Loire River A-8
- A.3 Used Nuclear Fuel Reprocessing Plants A-10
  - A.3.1 La Hague A-10
  - A.3.2 Marcoule A-15
  - A.3.3 Sellafield A-19
- A.4 Management and Disposal of Sites for Radioactive Wastes A-21
  - A.4.1 Hanford Site – 300 Area A-21
  - A.4.2 Bear Creek A-23
  - A.4.3 Chalk River A-25
- A.5 The Chernobyl Accident A-27
- A.6 Sites Involving Naturally Occurring Radioactive Materials (NORM) A-30
  - A.6.1 Komi A-30
  - A.6.2 Oil and Gas Off-Shore Platforms A-32

LIST OF TABLES

Page No.

2.1 Reference Radiation Dose Rates 2-3

3.1 Receptors Considered in Assessment 3-2

4.1 Overview of Ecological Risk Assessments Conducted for Radioactive Contaminants 4-3

A.1 Maximum Concentrations of Artificial and Natural Radionuclides (Marcoule Site)... A-17

LIST OF FIGURES

Page No.

A.1 Estimated Marine Biota Dose Rate for Base Case Compared to MARINA II Estimates A-13

1.0 INTRODUCTION

Ionizing radiation is ubiquitous and all living things are, and always have been, exposed to naturally occurring radiation and radioactivity. In addition, human activities have enhanced the levels of radiation and radioactivity both globally through fallout from above ground testing of nuclear weapons and locally through discharges of radioactivity to the environment from activities such as mining, offshore production of oil and gas, production of phosphate fertilizers and nuclear fuel cycle activities among others.

Traditionally, radiation protection of the environment has been based on the premise that if people are protected, then "*other living things are also likely to be sufficiently protected*" (ICRP 1977) or "*other species are not put at risk*" (ICRP 1991). Over the past decade, this view has been questioned in some situations, in part, because of increasing world-wide interest in environmental sustainability, and in part because of recognition of situations where non-human biota may be exposed but exposure to people is limited by restricted access to an area or by other protective measures. One such example is the areas within or immediately adjacent to radioactive waste management and disposal sites (IAEA 1999).

Over the past ten or so years, numerous ecological risk assessments (ERAs) have been carried out for a number of sites and situations involving enhanced radiation and radioactivity. The ERAs were done to study the potential effects of ionizing radiation on a wide variety of plants and animals - ecological receptors, generically referred to as "non-human biota". The ERAs have also been performed using a variety of approaches and using different assumptions and reference radiation dose rates. The latter serve as benchmarks for assessing potential risks to populations of non-human biota from exposure to ionizing radiation.

ERAs have been carried out for many activities and sites involving enhanced levels of radiation and radioactivity including:

- Nuclear fuel cycle sites from uranium mining to nuclear power generation;
- Sites with enhanced levels of naturally occurring radioactive materials (NORM sites); and,
- Sites associated with the management and disposal of radioactive wastes.

Finally, risks to the environment have been studied in the region around Chernobyl, the site of a major nuclear accident and other locations where the environment has been exposed to very high levels of radiation from accidental releases of radiation and radioactivity.

The ERAs have been carried out using a variety of methods; which however were often based on the exposure and dose assessment methods reported by the International Atomic Energy Agency (e.g., 2001, 1999, 1994, 1992, 1976) and the reference radiation dose-rates below which no effects on populations of biota would be expected as reported by UNSCEAR (1996). More recently, a number of national and international initiatives have been undertaken or are underway in which the methods and data for ERAs for radiation have been investigated and revised methods and data proposed. Examples of this include Environment Canada/Health Canada (2003), U.S. DOE (2002), Framework for Assessment of Environmental Impact (FASSET) (2004) and ERICA (Beresford *et al.* 2007)). A number of these initiatives also included applications of the methods to case studies from various nuclear fuel cycle activities and other situations involving enhanced levels of radiation and radioactivity.

In the spring of 2006, the World Nuclear Association (WNA) commissioned SENES to prepare an independent overview of representative ecological risk assessments (ERAs) that had been carried out throughout the world at sites with enhanced levels of radiation and radioactivity, and for a range of activities.

The objective of the review was to identify a representative set of ERAs; to compile the main findings; and to comment on the main findings and conclusions from the representative ERAs. In identifying representative ERAs for consideration, an attempt was made to include coverage of activities and sites over the full range of the nuclear fuel cycle, sites involving activities and sites involving enhanced levels of naturally occurring radioactive materials (NORM); sites associated with the management and disposal of radioactive wastes; as well as the Chernobyl nuclear accident. In carrying out this review of representative ERAs, an attempt was also made to briefly summarize the approaches and data used to perform the ERAs and the main findings and conclusions of the assessments. This report summarizes the results of that review and is organized in the following sections:

- Chapter 2 provides a brief overview of the ERA process and discusses some of the approaches taken;
- Chapter 3 provides an abbreviated synthesis of the selected ERA case studies and of their main findings and conclusions;
- Chapter 4 is a summary of the main findings and conclusions arising from the review of selected ERA case studies;
- Chapter 5 provides the references for the main text;
- Appendix A provides a more detailed overview of the (representative) ERAs examined in this study and provides additional key references relevant to individual ERAs.

2.0 APPROACHES TO ASSESSING RISK TO NON-HUMAN BIOTA

2.1 GENERAL APPROACH TO ERA

This Section provides a high-level overview of key factors involved in estimating radiation doses (dose-rates) to non-human biota and estimating consequent effects on populations of non-human biota. A number of approaches to evaluating radiological risks to non-human biota have been published and are widely used. Examples of such approaches have been outlined by IAEA (1976, 1988, 1992); US NCRP (1991); Blaylock *et al.* (1993); US DOE (2002); ICRP (2003); Jones *et al*. (2003); and FASSET (2004a,b) among others. All approaches (necessarily) involve simplifications of the actual environment. While differing in detail, there are common elements present in all of the approaches; in general terms, these include:

1) Identification and characterization of reference non-human biota to be assessed. This involves developing a conceptual model of the study area and, an understanding of the sources and routes of exposure, and the selection of representative non-human biota for assessment purposes. Given the enormous number and variability of non-human biota, it is not possible to consider all species. Thus, for example, both ICRP (2005) and FASSET (FASSET 2001; Larson 2004) have proposed the use of reference organisms selected to be representative of common ecosystems. It is important to understand that organisms considered as indicator species in a particular ERA need to be representative of the specific location and therefore, the indicator species will vary from assessment to assessment. In selecting indicator species for assessment, consideration is given to the "value" of the non-human biota to the local ecosystem.

2) Determine the concentrations of radioactivity in the environment and in non-human biota. Equilibrium models, where the radionuclides are assumed to reach equilibrium within each of the environmental compartments relevant to the assessment (for example water and fish flesh) are widely used for this purpose. Examples of such models include UNSCEAR (2000) and by the IAEA (e.g. 1994, 1992, 2001), the U.S. NCRP (1984), the (U.S. DOE (2002) and FASSET (Deliverable 5) (2003), among others.

3) A dosimetry model is used to convert exposure from both external and internal radiation to absorbed dose in non-human biota. Factors important for external dosimetry include geometrical relations between the source of the radiation and the non-human biota, the size of the non-human biota and characteristics of the radionuclides among others. Factors important to estimating dose from internal radionuclides include the fraction of emitted energy that is absorbed in the non-human biota (a function of the size of the non-human biota and the energy of the radiation(s)), the non-uniform distribution of radionuclides within a non-human biota, and a radiation weighting factor to account for the relative biological effectiveness of different kinds of radiation. Again, such considerations are well discussed in the literature (e.g., U.S. NCRP 1984;

Woodhead 1979; IAEA 1976; Pentreath and Woodhead 2001; U.S. DOE 2002 and FASSET Deliverable 3, 2003.

4) A common approach to **assessing effects** on non-human biota is the use of a screening index (SI). The SI is simply the ratio of the estimated dose rate (to an individual non-human biota) to the reference radiation dose rate, viz.

$$SI = \frac{estimated\ dose\ rate}{reference\ dose\ rate}$$

The 'reference" radiation dose rate refers here to the level below which potential health effects to populations of non-human biota are not expected. In evaluating the SI, the dose rates in the numerator and denominator would typically be expressed in terms of milliGray (mGy) per day.

This comparison assumes that the numerator and the denominator of the SI are based on a common assessment of dose relevant to the endpoint of interest (e.g., mortality, reproductive capacity). In practice, the estimated dose rates are for a uniform exposure over the whole organism. When the estimated SI is below 1, it is considered that an effect to a (population of) biota is unlikely. When an SI is estimated to be greater than 1, an effect may be possible and further more detailed evaluations are carried out to investigate whether an actual effect might be possible. Such follow-up evaluations may be iterative in nature with increasing use of site-specific information and realistic assumptions at each stage of iteration. It is evident that there are many complex factors to consider in the extrapolation from effects of dose on an individual non-human biota to a population of non-human biota. When applying the SI approach to non-human biota at the individual level, caution is therefore necessary about the interpretation of the predicted outcomes.

2.2 REFERENCE RADIATION DOSE RATES

The reference radiation dose effects levels (typically in mGy/d) developed by UNSCEAR (1996) have been the most commonly used in the denominator of the SI calculation; however, other guidance also exists, including NCRP (1991), IAEA (1992) and FASSET Deliverable 4 (2003) among others including for example Environment Canada and Health Canada (2003) and Copplestone *et al*. (2001) (See Table 2.1 for summary of selected reference dose-rates).

TABLE 2.1
REFERENCE RADIATION DOSE RATES

	IAEA 332 (1992)	NCRP 109 (1991)	UNSCEAR 1996 (1996)
Terrestrial plants	10 mGy/d	--	10 mGy/d
Terrestrial animals	1 mGy/d	--	--
Mortality		--	10 mGy/d
Reproductive		--	1 mGy/d
Aquatic organisms		10 mGy/d [4 Gy/a]	10 mGy/d

More recently, FASSET radiological database (2002), FASSET Deliverable 4 (2003) and FASSET (2004a,b) have noted that information on the effect at low dose rates (<1 mGy/h) of continuous irradiation is reasonable for plants, fish and mammals, but scarce or non-existent for other wildlife groups. Nonetheless, FASSET concluded that there were few readily observable effects at chronic dose rates below (about) 2.4 mGy/d (i.e., 100 µGy/h); this value is generally comparable to the reference dose rates shown in Table 2.1. Future evaluations may also consider the forthcoming update of the 1996 UNSCEAR report on effects of ionizing radiation on non-human biota (anticipated for 2008).

In examining the effects of ionizing radiation on non-human biota through the SI, it is important to understand that it is most common to estimate dose to individual non-human biota, and typically biota that are likely to be most exposed; however, reference dose rates are typically based on effects to a population of non-human biota, in effect, a dose averaged in some way over the population. Thus, as indicated earlier, for an SI less than 1, detrimental effects at the population level are unlikely. It is evident that there are many complex factors to consider in the extrapolation from effects of dose on an individual non-human biota to a population of non-human biota. When applying the SI approach to non-human biota at the individual level, caution is therefore necessary about the interpretation of the predicted outcomes.

ERAs are expected to continue evolve in part, based on the forthcoming update of the 1996 UNSCEAR report on effects of ionizing radiation on non-human biota (anticipated for 2008), the activities of the ICRP (especially the work of Committee 5) and further activities of the IAEA. The IAEA coordination group on the radiological protection of the environment (set in the context of a related IAEA action plan in 2004) provides a common platform for developing international harmonization practice in this area. This is an important consideration, especially in light of concerns with climate change and the need for realistic comparison of the effects of alternative energy sources, including the effects of alternatives on non-human biota.

3.0 SELECTED CASE STUDIES

In identifying representative case studies for review, an effort was made to identify ERAs across the nuclear fuel cycle sites, sites associated with enhanced levels of naturally occurring radioactive materials (NORM sites), sites associated with the management and disposal of radioactive wastes, as well as the Chernobyl nuclear accident. The activities, sites and ecological receptors considered in this review are shown in Table 3.1. Collectively, a wide range of ecological receptors has been considered in the representative case studies considered in this review.

In reviewing the ERAs, a number of factors were considered, including the nature of the activity (e.g., uranium mine, nuclear power plant, etc.), the kinds of radionuclides associated with the activity, the non-human biota considered, and corresponding level of radiation and radioactivity, the approach used to perform the ERA, the main conclusions and key references. All of the case studies discussed in this report are described either in published scientific literature or within environmental assessments that have been thoroughly peer reviewed by national and or international authorities. Additional, albeit brief, information on the various assessments is provided in Appendix A: Overview of Selected Representative ERAs. Key references for the various case studies are also provided in the appropriate section of Appendix A.

3.1 URANIUM MINING SITES

McArthur River[1]

McArthur River is a high-grade uranium mine (25% of natural uranium - U_3O_8) operated by Cameco in northern Saskatchewan, Canada. The mine has an annual production capacity of 18.7 million pounds of U_3O_8. An ERA was conducted for the uranium-series radionuclides in the receiving aquatic environment impacted by the site's radioactive discharges based on measured and predicted environmental concentrations. The approach taken generally followed IAEA/NCRP methods. A radiation weighting factor[2] of 10 for internal alpha radiation relative to gamma radiation was used as a reasonably conservative factor but an alternative radiation weighting factor of 40 were also presented for comparison purposes.

1 EcoMetrix 2005

2 A radiation weighting factor is used to account for the relative biological effectiveness of different kinds of ionizing radiation. The application of such a factor is discussed, where appropriate in the various case studies. Further information on the application of this factor to the various case studies is provided for each case study in Appendix A.

TABLE 3.1
RECEPTORS CONSIDERED IN ASSESSMENT

Facility	Aquatic Plants	Benthic Invertebrates	Fish	Soil Invertebrates	Terrestrial Plants	Aquatic Birds (ducks, swans, osprey)	Small Terrestrial Animals with Aquatic Diet (mink, beaver muskrat)	Riparian Animals (frogs, toads)	Terrestrial Birds (robin, owl, eagle)	Small Terrestrial Animals with Terrestrial Diet (mice, voles, shrew, rabbits)	Large Mammals (wolf, caribou, moose, sheep, cows)
Uranium Mine Sites											
McClean Lake	✓	✓	✓			✓	✓		✓	✓	✓
McArthur River	✓	✓	✓			✓	✓		✓	✓	✓
Nuclear Power Plants											
Loire	✓	✓(b)	✓			✓	✓				
Pickering	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓
Reprocessing Plants											
La Hague	✓(a)	✓(a)	✓(a)								
Sellafield					✓	✓				✓	✓
Marcoule	✓	✓	✓			✓					
Waste Disposal Sites											
Hanford – Area 300	✓	✓	✓		✓			✓		✓	
Bear Creek										✓	
Chalk River	✓	✓		✓	✓	✓		✓	✓	✓	
Accidents											
Chernobyl				✓	✓				✓	✓	✓
NORM											
Oil & Gas	✓(a)	✓(a)	✓(a)								
Komi				✓	✓					✓	

Notes:

(a) marine environment, all others freshwater environment

(b) includes both freshwater and marine environments

The reference dose rates used were 10 mGy/d for aquatic organisms and 1 mGy/d for terrestrial organisms.

The results showed that the only non-human biota indicator at this site that was predicted to exceed the benchmark radiological dose was a duck (scaup) with a diet of benthic organisms and sediments, primarily as a result of ingestion of Po-210. The potential radiological risk for this conservative upper bound scenario was limited to a small area near the discharge location and it was predicted to return to background levels quickly after the end of site operations. Moreover, no exceedance of the SI was predicted outside of this limited area and no potential for effects on local or regional populations are expected.

McClean Lake[3]

McClean Lake is also a uranium mine operated by AREVA Resources Canada (COGEMA) in northern Saskatchewan, Canada. The average grade is 1.7% of natural uranium (U_3O_8) and it is licensed to produce 12 million pounds of U_3O_8 annually. An ERA was conducted for the uranium-series radionuclides in the receiving aquatic environment impacted by the site's radioactive discharges based on measured and predicted environmental concentrations. The approach taken generally followed IAEA/NCRP. The primary reference dose rates used were 10 mGy/d for aquatic organisms and 1 mGy/d for terrestrial organisms. However, the assessment also considered lower benchmarks for aquatic species recommended by Canadian Nuclear Safety Commission (CNSC).

The results showed that effects on aquatic biota were not expected. Similarly, no effects were predicted for terrestrial mammals in the downstream receiving environment; however, at the upper bound estimate of concentrations, there was some potential for an effect on terrestrial species that depend on the aquatic environment within the Treated Effluent Management System (within licensed site boundaries). No potential effects on populations of non-human biota were expected outside the Treated Effluent Management System.

3.2 NUCLEAR POWER PLANTS

Pickering Generating Station[4]

Pickering Nuclear Generating Station (PNGS) is located on Lake Ontario, near Toronto, Ontario, Canada. The PNGS site includes two nuclear generation stations (2,060 MWe and 2,064 MWe) each with four CANDU reactors. A screening level ecological risk assessment was performed for regulatory compliance. A range of radionuclides in the receiving aquatic, atmospheric and terrestrial environment that is impacted by site's radioactive discharges was assessed including

[3] Cogema 2004
[4] Wismer *et al.* 2004, SENES 2000

tritium, Sr-90, Co-60 and Cs-134/137 based on measured and predicted concentration. The approach taken generally followed IAEA/NCRP. Radiation weighting factors of 3 for tritium and 1 for beta and gamma emitters were used. A benchmark of 10 mGy/d was used for all the aquatic biota and the terrestrial plants. For trumpeter swan, a species identified for special protection, a benchmark of 0.137 mGy/d was derived and used for protection of this species. For all other terrestrial biota (earthworms, birds and mammals) a benchmark of 1 mGy/d was used.

Potential effects were identified at the screening level for earthworms due to exposure to very conservative upper bound scenario based on the localized maximum concentration of tritium in groundwater and for trumpeter swan from intake of radionuclides through aquatic plants. No other potential effects were identified. However, more detailed follow-up studies have demonstrated that there is no potential for ecological effects from radiological emissions associated with PNGS (Wismer *et al.* 2004).

Loire River[5]

Between 1963 and 1999, 14 nuclear power reactors were commissioned at 5 different sites on the Loire River and its tributaries in France. The nuclear power plants are located on a stretch of the river some 350 km from its estuary. An assessment of the receiving aquatic environment (river and estuary) was conducted for two locations; the Loire River downstream of the Chinon nuclear power plant and the estuary some 350 km downstream. The assessment was done following the FASSET framework for ^{3}H, ^{14}C, ^{131}I, ^{134,137}Cs. A radiation weighting factor of 3 for low energy (<10 keV) beta radiations was used.

Dose estimates were compared to data in the FRED (FASSET Radiation Effects Database). As only sparse data were available, all activity concentrations used for dose estimation were modelled using FASSET parameters relating to equilibrium concentrations in water and sediment (K_d) and to equilibrium concentration ratios in biota and water (CR) values, as well as the estimated water concentrations. The authors note that the uncertainties in their assessment were largely associated with transfer modelling but go on to note that the estimated dose rates to freshwater organisms in the Loire River and its estuary were at least five orders of magnitude lower than those at which effects have been reported and that effects are unlikely.

In general terms, the overall conclusion from the Loire River ERA is that, notwithstanding the widespread and long standing implementation of nuclear power reactors all along the Loire River, no potential effects on populations of non-human biota from exposure to ionizing radiation are expected.

[5] Beresford and Howard 2005

3.3 USED NUCLEAR FUEL REPROCESSING PLANTS

La Hague[6]

The La Hague Used Nuclear Fuel Reprocessing facility is located in the north-west part of France, along the south shore of the English Channel. This is a major nuclear site involving a wide range of supporting nuclear facilities. Operations started in the late 1950's at La Hague and have been upgraded on several occasions over time through the addition of new facilities and the decommissioning of older facilities. The La Hague nuclear fuel reprocessing plant is currently operating. A great deal of site-specific environmental data is available to support analysis of potential effects to non-human biota.

An assessment was undertaken for non-human biota in the receiving marine environment. The radioactive discharge source terms and the related environmental transfer models covered a comprehensive list of over 90 radionuclides. The approach taken generally followed IAEA/NCRP; however, a comprehensive sensitivity analysis was also performed, including the effect of different values (radiation weighting factors) for the relative biological effectiveness of alpha radiation. Comparisons were also made to doses from natural background levels of radionuclides.

Reference dose rates of 10 mGy/day for the protection of aquatic biota (UNSCEAR 1996, IAEA 1992) as well as a range of values from 10 mGy/day up to more than 1000 mGy/d based on the FASSET dose-effect database for the protection of populations of various marine biota were used in the assessment.

The results indicate that for the base case coastal zone (Goury), which corresponds to the area where the highest concentrations were predicted and measured, the marine biota dose rates were very small (by at least 2 to 3 orders of magnitude) compared to the lowest benchmark.

Therefore, no effects on marine biota attributable to radioactive discharges to the sea from the La Hague facility would be expected.

Marcoule[7]

The Marcoule nuclear complex is a major nuclear site located on the Rhone River in Southern France. Established in 1956, various facilities have been located at the site including a used nuclear fuel reprocessing facility, nuclear research facilities, mixed oxide fuel production facility, fast breeder reactor, and other supporting facilities. The Marcoule nuclear site played a key role in support of the development of the French nuclear power program. The site also includes military facilities. The Marcoule facilities have been updated on several occasions over

[6] SENES 2003a,b,c

time through the addition of new facilities and the decommissioning of older facilities. Many facilities are still in operation the Marcoule site. However, the reprocessing plant ceased operations in 1997 and it is currently under decommissioning.

It should be emphasized that the Marcoule nuclear complex is located downstream of many nuclear power reactors and of the Tricastin nuclear complex (which is another major nuclear site) that comprises nuclear fuel conversion and enrichment plants, and nuclear power plants among others. The Rhone River has also been impacted by the Chernobyl accident.

An assessment was conducted for a large range of artificial and natural radionuclides in the receiving aquatic environment that is impacted by all of the above sources of enhanced radioactivity, based on extensive data from a series of environmental monitoring reports covering several years of annual sampling campaigns. Non-human biota dose rates were estimated generally following the IAEA/NCRP methodologies. The estimated radiation dose rates were very conservative because the calculations artificially assumed the simultaneous presence of the highest measured concentrations (at all time, all sampling locations, all samples) for each radionuclide and in each environmental medium.

The dose rate criterion was based on a review of different international guidelines (UNSCEAR 1996, IAEA 1992, NCRP 1991) – 10 mGy/d for protection of aquatic organisms and 2.5 mGy/d was used as the trigger for a more detailed evaluation of potential ecological consequences to the endemic population. It was concluded that chronic levels of artificial and natural radioactivity measured in aquatic non-human biota in the Rhone River downstream of Marcoule were unlikely to result in adverse health impacts on the categories and species of aquatic organisms studied.

In general terms, the overall conclusion of the Marcoule ERA based on monitoring data is that, notwithstanding the widespread and long standing operation of numerous nuclear facilities at Marcoule and upstream all along the Rhone River, as well as of the impact caused by the Chernobyl accident, no potential effects on populations of non-human biota from exposure to ionizing radiation are expected downstream of the Marcoule nuclear complex.

Sellafield[8]

Sellafield is one of the largest nuclear engineering centres in the world and is managed and operated by Sellafield Limited. It is located in Cumbria, United Kingdom. Established in the early 1950's, various facilities have been located at the site including two used nuclear fuel reprocessing facilities, nuclear research facilities, mixed oxide fuel production facility, and other supporting facilities. The Sellafield nuclear site played a key role in support of the development

[7] St. Pierre, Chambers, Lowe and Bontoux 1999
[8] Beresford and Howard 2005

of the British nuclear power program. The site also includes military facilities. The Sellafield facilities have been updated several times through the addition of new facilities and the decommissioning of older facilities. Many facilities are still in operation at the Sellafield site, including one reprocessing plant. Many other facilities are under decommissioning.

In 1957, the site known as Windscale experienced a significant nuclear accident, which caused significant atmospheric releases of radioactivity. An assessment of ecological risks from ionising radiation on the receiving aquatic and terrestrial environment in the vicinity of the Sellafield site was undertaken, including the sand dune and saltmarsh areas of the Drigg Coast based on measured and predicted concentration. The assessment was done following the FASSET approach. Radiation weighting factor of 10 for internally incorporated alpha radiations and 3 for low energy (<10keV) beta radiation were used.

Dose estimates were compared to data in the FRED (FASSET Radiation Effects Database). A nominal threshold for statistically significant effects in most studies was about 2.4 mGy/d (with a nominal range of perhaps 1 to 10 mGy/d). When dose estimates were compared to the FRED database, the doses received by all non-human biota organism groups considered at the Sellafield site were below the levels at which significant effects would begin to be seen, indicating no effects in small mammals and snails in the sand dune and salt marsh area that were identified as sensitive receiving aquatic and terrestrial environments for this site.

The overall conclusion that can be derived from the above is that, notwithstanding the widespread and long standing activities of a broad range of nuclear facilities at Sellafield, no potential health effects on non-human biota from exposure to ionizing radiation are expected in the vicinity of the Sellafield site.

3.4 MANAGEMENT AND DISPOSAL SITES FOR RADIOACTIVE WASTES

Hanford Site – 300 Area[9]

The 300 Area of the Hanford Site was used to produce nuclear fuel elements for the Hanford reactors. It is located just north of the city of Richland, Washington on the Columbia River and is the site of most of the research and development conducted by the U.S. Department of Energy (U.S. DOE). Approximately 27 million cubic yards of solid and diluted liquid wastes mixed with radioactive and hazardous wastes were disposed in ponds, trenches, and landfills in the 300 Area. Remediation actions, which include excavation of contaminated soil, have been selected and construction began in the summer of 1997. At the present time, all liquid waste is treated and released to the Columbia River. The selected remedy for contaminated groundwater in the

[9] Antonio, Domotor, Higley and Tiller 2003

300 Area is monitored natural attenuation, but this interim remedy is in the process of being re-evaluated.

Substantial amounts of uranium and heavy metals are present in the 300 Area liquid waste streams. An assessment was conducted following the U.S. DOE approach. The radionuclides evaluated were U-234/235/238, Sr-90 and Cs-137. For alpha radiation, a radiation weighting factor of 20 was used.

The dose rate benchmarks used by DOE were 10 mGy/d for aquatic organisms and terrestrial plants and 1 mGy/d for animals. Based on the maximum measured radionuclide concentrations, and following the US DOE approach, adverse effects were not expected.

Bear Creek[10]

Bear Creek is located within the DOE Oak Ridge Reservation (ORR). There are four major waste units and two Debris Burial Areas (DBAs) within the watershed. These areas contain hazardous and radioactive wastes derived from the Y-12 Complex. The Y-12 Plant was built in 1943 as part of the Manhattan Project, with its original mission being electromagnetic separation of uranium. Since being completed, the Y-12 Plant has also been used for chemical processing of uranium and lithium compounds as well as precision fabrication of components containing these and other materials. Wastes containing radionuclides, metals, and other chemical contaminants were disposed of at Bear Creek Valley. An assessment of waste disposal areas within the Bear Creek valley was conducted following the U.S. DOE approach. The radionuclides assessed were U-234/235/238, Cs-137, Sr-90, Th-232 and Pu-239. A radiation weighting factor of 20 was used for internally deposited alpha radiation.

The dose rate benchmark used by U.S. DOE was 1 mGy/d for small mammals such as mouse. The results of the assessment based on measured radionuclide concentrations and following the U.S. DOE approach showed that there is not a significant ecological risk at the site.

Chalk River[11]

The Chalk River Laboratories (CRL) site is located on the shore of the Ottawa River, 160 km northwest of Ottawa, Ontario Canada. The CRL site was established in the mid 1940s, and has a history of various nuclear operations and facilities, primarily related to research. An ERA was conducted for the site following common international practices. The radionuclides assessed were tritium, C-14, Sr-90, I-131, Cs-137, Pu-239 and Ar-41 in the receiving aquatic and terrestrial environment using measured and predicted concentrations and the IAEA and U.S. NCRP methodologies.

---

[10] Jones and Schofield 2003
[11] EcoMetrix 2005

A radiation benchmark value of 1 mGy/day was used in this assessment for all non-human biota recognizing that this is likely a conservative value for some organisms.

Conservatively estimated doses to some aquatic and terrestrial organisms within the on-site waste management areas were predicted to exceed reference dose rates; however outside of these areas, for example in the Ottawa River, doses to biota were below the benchmark. Doses to invertebrates and terrestrial plants were dominated by Sr-90 in surface soil while doses to the woodchuck were primarily due to radon inhalation in the burrow. The terrestrial receptors receiving doses above 1 mGy/d represent a few individuals within the confines of small on-site waste management facilities and are unlikely to lead to significant population level effects.

3.5 THE CHERNOBYL ACCIDENT[12]

The flora and fauna in the area around the Chernobyl nuclear power reactor site have been closely studied since the accident. The focus of this review was terrestrial non-human biota that, in the first 20 days or so following the accident, received very high doses primarily due to short-lived radionuclides (^{99}Mo, ^{132} Te/I, ^{133}Xe, ^{131}I and ^{140}Ba/La). Over the following summer and fall, the short-lived radionuclides decayed and longer lived radionuclides were distributed through the environment by various physical, chemical and biological processes. Overall, about 80% of the total radiation dose accumulated by plants and animals, of the order of 0.7 Gy, was received during the first 3 months following the accident, most of which was due to beta radiation. The deposition of beta emitting radionuclides onto plant tissues was thought to have resulted in plants receiving a larger dose than animals living in the same area.

Effects were observed in pine trees. Reproduction anomalies, stand viability and re-establishment of pine tree canopies depended on the absorbed dose. Spruce trees were observed to be more sensitive than pines with effects seen at doses as low as (about) 0.7 Gy.

Overall, the environmental response to the Chernobyl accident was a complex interaction among radiation dose, dose rate and its temporal and spatial variations, as well as the radiosensitivities of the different taxons. Both individual and population effects caused by radiation-induced cell death were observed in plants and animals; however, no adverse radiation-induced effect has been reported in plants and animals exposed to a cumulative dose of less than 0.3 Gy during the first month after the accident (corresponding roughly to a dose rate of about 30 mGy/d). In general terms, this is supportive of the current reference radiation dose rates considered protective of populations of non-human biota.

[12] EGE 2005

Following the natural reduction of exposure levels due to radionuclide decay and migration, biota populations started to recover from acute radiation effects and by the next growing season following the accident, population viability of plants and animals substantially recovered as a result of the combined effects of reproduction and immigration.

3.6 SITES INVOLVING NATURALLY OCCURRING RADIOACTIVE MATERIALS (NORM)

Komi[13]

As a result of 'radium-from-water' operations from approximately 1931 until 1950, and uranium extraction from ores in 1947 until 1956 a number of small contaminated sites were formed in the Vodnyi area within the Komi Republic (Russia). These activities led to an enhancement of naturally occurring radionuclides from the decay series of ^{232}Th and ^{238}U in soils, plants and animals. An ERA was done following the FASSET approach using a radiation weighting factor of 10 for internally incorporated alpha radiation. The range of reference dose rates from the FRED database (2.4 mGy/d to 24 mGy/d) was used.

For this ERA, the radionuclides assessed were those from the decay series of ^{232}Th and ^{238}U in the receiving terrestrial environment, i.e. in soils, plants and animals using a combination of both measured and predicted concentrations. Non-biota dose rates were estimated using the FASSET approach. However, it was noted that while FASSET provided little guidance on the application of its methodology to enhanced naturally occurring radioactivity, an attempt was made to estimate activity concentrations and subsequently dose rates "excess" over that due to natural background. Background information from a "typical European site" was used for comparison, however, it was acknowledged that this may introduce some uncertainty as levels of ^{238}U and ^{232}Th may be naturally elevated in the region above "typical" European levels. Other sites in the area, for example, Middle Timan and North Urals, have naturally enhanced radiation levels and plants and animals have adapted to live in these high radiation areas.

The results showed that for the contaminated sites in the Vodnyi area, the predominant component of radiation exposure arises from the presence of internally distributed (alpha-emitting) radionuclides. The upper end of the weighted dose rate for small mammals is above that at which significant reductions in mammalian lifespan can be expected. Radiation effects on the morbidity and reproductive capacity of rodents were reported to be observed in the field at contaminated sites in the Vodnyi area, this supported the results of the ERA. The weighted dose rates received by soil invertebrates at the Krokhal site (contaminated by discharge of radium-rich groundwater) fall in the range of about 13 to 100 mGy/d (or 540-4100 µGy/h) as reported in the ERA; various effects on soil invertebrates have been observed in the field which support the dose rate calculations.

[13] Beresford and Howard 2005

Oil and Gas Off-Shore Platforms[14]

During oil and gas production, large volumes of water, referred to as produced water, formation water or oilfield brines, are co-produced with the oil and gas and discharged into the sea, for example the North Sea from platforms on the Norwegian continental shelf. In 2003 about 135 million cubic metres of produced water was discharged to the North Sea from platforms on the Norwegian continental shelf. One issue associated with produced water is that it may contain elevated amounts of natural radionuclides, mostly radium isotopes, which have been leached from the surrounding geological material in the reservoirs. The MARINA II assessment (European Commission 2003) indicated that oil and gas industries were responsible for a large portion of alpha activity discharged in Northern European marine waters.

An ERA was conducted for the produced waters discharged as part of the routine operations at the stations. The produced waters can be enriched in radionuclides from the ^{232}Th and ^{238}U decay series, but most notably ^{226}Ra and ^{228}Ra. The assessment used a combination of measured and predicted concentrations to assess effects in the receiving marine environment. Levels of the key radionuclides in biota were estimated based on the average conditions and compared to measured data.

Non-biota dose rates were estimated using the FASSET approach. Disequilibria in the natural decay series between ^{226}Ra and ^{210}Po made the application of an aggregated dose conversion coefficient inappropriate. Doses were estimated for biota for the impact zone located at a few tens of kilometres away from the platform(s). No dose rate data are provided for locations near to the platforms where dose rates are expected to be higher. In the area assessed, dose rate values were estimated to be orders of magnitude below those for which biological effects have been observed in aquatic systems as provided in the FRED database. (At such far distances away from the sources, all of the ERAs considered in this review are also orders of magnitude below the reference dose rates.) Given that discharges from produced water includes radium-226 (and consequently polonium-210 a major contributor to dose in marine systems) there is a potential for enhanced dose rates nearer to the oil rigs, thus some additional consideration of this issue could be warranted in the future.

[14] Beresford and Howard 2005

4.0 MAIN FINDINGS AND CONCLUSIONS

An overview of representative ERAs was carried out which included: representative sites over the full range of the nuclear fuel cycle from uranium mining to nuclear power generation; sites involving enhanced levels of naturally occurring radioactive materials (NORM); sites associated with the management and disposal of radioactive wastes; as well as, the Chernobyl nuclear accident. Different types of ecosystems (terrestrial, freshwater and marine aquatic environments) were also considered in the selection of representative ERAs.

Table 4.1 summarizes the selected key information from the representative ERAs. (Further information for each ERA considered in this review is provided in Appendix A.) A number of the ERAs (e.g., Marcoule, La Hague) were supported by a great deal of measurement data on which to develop an understanding of level of radionuclides in the physical and biophysical environments. In addition, ERAs also rely on environmental models to support estimates of radionuclide concentrations in the physical and biological environments and dosimetric models for evaluating biota dose. Most of the ERAs that rely on modelling employ a number of intentionally conservative assumptions which results in an overestimate of the dose, thus it is difficult to determine whether or not actual effects are observed when reference dose rates are exceeded. Nonetheless, it is possible to draw some overall main findings and conclusions from the review as summarized below:

- For the aquatic environment the non-human biota that are most likely to receive the highest doses appear to be crustaceans, molluscs and wildlife (birds and mammals) relying on the aquatic environment;
- For the terrestrial environment, the species which are expected to receive the highest doses generally appear to be vegetation, invertebrates and small mammals;
- The results showed that for normal operations of nuclear fuel cycle sites, of NORM sites and of radioactive waste management and disposal sites, the potential for effects in non-human biota is low and well below reference dose rates at which adverse health effects to populations of non-human biota might be anticipated. For nuclear fuel cycle sites, this observation is strengthened by the fact that it is also valid for the sites involved in the early development of nuclear fuel cycle programs and of the related military facilities, which included both normal operations and some significant accidents;
- For those few situations where dose-rates to non-human biota are predicted to exceed the reference dose-rate at which effects on populations might be expected, the areal extent of elevated dose rates is limited and confined to areas within, or in close proximity to, the source of radioactivity within site boundaries. The corresponding dose rates to non-human biota further away on site from the source of radioactivity or beyond the site boundaries, are below the reference dose rates; and,

- Even in the event of very high doses and dose-rates, such as those experienced following the Chernobyl accident where effects on non-human biota have been observed close to Chernobyl, populations of biota appear to recover within a reasonably short period once the radiation dose rates were reduced. Such high dose rates have not been seen for sites with controlled radioactive discharges.

Overall, the conclusions from this review can be summarized as follows:

- The potential for effects on non-human biota due to exposures arising from the controlled releases of radioactivity from nuclear fuel cycle sites is low and well below reference dose rates;
- Similarly, the potential for effects on non-human biota arising from exposure to controlled releases of radioactivity from NORM sites is low and well below reference dose rates; and,
- For radioactive waste management and disposal sites, although higher dose rates can be sometimes found in the immediate proximity of radioactive wastes within the site boundaries, further way on site from the source of radioactivity or beyond the site boundaries, dose rates are below the reference dose rates;
- Populations of biota exposed to very high levels of radiation, arising from major accidents such as the Chernobyl accident, seem likely to recover within a reasonably short period once the source of exposure is significantly reduced or removed.

The current system of radiological protection has been based on the protection of people, assuming that if humans were adequately protected, then "*other living things are also likely to be sufficiently protected*" (ICRP 1977) or "*other species are not put at risk*" (ICRP 1991). The representative ERAs considered in this review show that the application of the current system of radiological protection, which includes a variety of standard protective practices for containing radioactive sources, controlling and limiting radioactive releases to the environment, and protecting people, have in fact also provided an adequate level of protection to populations of non-human biota.

ERAs provide additional insights to the behaviour and potential effects of enhanced level radiation and radioactivity arising from releases of radioactivity from nuclear fuel cycle sites, NORM sites, radioactive waste management and disposal sites, and from major accidents. The wide range of sites considered in this review shows that the current system of radiological protection has provided an adequate level of protection to populations of non-human biota.

TABLE 4.1
OVERVIEW OF ECOLOGICAL RISK ASSESSMENTS CONDUCTED FOR RADIOACTIVE CONTAMINANTS

Facility	Pathway of Exposure	Main Source of Exposure	Methodology	Reference Dose Rate	Assessment Method	Sensitive Ecological Receptor	Potential for Effects
Uranium Mine Sites							
McClean Lake	Aquatic discharge	internal alpha	IAEA/NCRP	UNSCEAR/ CNSC	Modelled	Duck and Muskrat	Reference dose rates exceeded only at upper bound within immediate discharge area. No potentially significant effects in receiving environment.
McArthur River	Aquatic discharge	internal alpha	IAEA/NCRP	UNSCEAR/ CNSC	Modelled	Duck	Duck (scaup) predicted to exceed benchmark (primarily ingestion of Po-210) in the area near the discharge; levels decrease quickly after discharge ceases. No potentially significant effects in receiving environment
Nuclear Power Plants							
Loire	Aquatic discharge (river and estuary)	internal beta (Cs-137 or C-14)	FASSET	FASSET	Modelled	Small terrestrial mammals with aquatic diet	No effects are expected in receiving environment.
Pickering	Aquatic, air, soil and groundwater	Internal beta (H-3)	IAEA/NCRP	UNSCEAR	Modelled	Earthworm (groundwater); Trumpeter swan (aquatic)	Initial conservative screening showed potential effects of tritium on on-site earthworms through exposure to groundwater and potential effects on trumpeter swan through intake of aquatic plants. Further investigations indicate that there are no significant ecological impacts from PNGS.
Reprocessing Plants							
La Hague	Marine discharge	Internal beta (Ru-106)	NCRP/IAEA	UNSCEAR/ FASSET	Modelled	Crustaceans and molluscs	No effects expected in marine biota from discharge.
Sellafield	Soil/ sediment	internal thorium	FASSET	FASSET	Modelled	Snails and small mammals	No effects expected in small mammals and snails in sand dunes and salt marsh areas.

TABLE 4.1(Cont'd)
OVERVIEW OF ECOLOGICAL RISK ASSESSMENTS CONDUCTED FOR RADIOACTIVE CONTAMINANTS

Facility	Pathway of Exposure	Main Source of Exposure	Methodology	Reference Dose Rate	Assessment Method	Sensitive Receptor	Potential for Effects
Marcoule	Aquatic discharges	external gamma and internal beta	NCRP/IAEA	UNSCEAR	Modelled	Molluscs and fish eating birds	No effects are expected as maximum predicted dose rates are more than a factor of 40 below reference dose rates.
Waste Disposal Sites							
Hanford – Area 300	Aquatic discharge	internal alpha/beta	DOE Graded Approach	DOE (based on NCRP/IAEA)	Modelled	Riparian mammal	No effects were expected in Columbia River.
Bear Creek	Soil	internal alpha/beta	DOE Graded Approach	DOE (based on NCRP/IAEA)	Modelled	Mouse	No effects were expected.
Chalk River	Aquatic discharge, soil	internal beta/gamma	IAEA/NCRP	UNSCEAR	Modelled	Riparian animals (snail, frog, aquatic plants) and water shrews and herons	Initial calculations indicated potential for effects on some biota in inland aquatic sites and within confines of small waste management facilities. Doses unlikely to lead to significant effects at the population level.
Accidents							
Chernobyl	Air	Internal beta (acute), beta and gamma (longer term)	Measured dose rates	N/A	Observation	Pine trees, spruce trees and invertebrates	Numerous acute adverse effects resulted from accident. Populations recovering.
NORM							
Oil & Gas	Marine discharge	internal alpha	FASSET	FASSET	Modelled	Crustaceans and molluscs	No effects expected.
Komi	Soil	internal alpha	FASSET	FASSET	Modelled/ Observation	rodents, soil invertebrates and grasses	Effects on biota have been observed at small contaminated sites within the Vodnyi area due to enhancement of naturally occurring radionuclides. Plants and animals in other areas in Komi containing naturally elevated levels of radionuclides have adapted.

5.0 REFERENCES[15]

Beresford, N.A., B.J. Howard, C.L. Barnett 2007. (ERICA) *Application of ERICA Integrated Approach: Case Study Sites.* ERICA Deliverable D10. February.

Beresford, N.A. and B.J. Howard 2005. ERICA. *Deliverable D9: Application of FASSET framework at case study sites.* Contract Number: FI6R-CT-2003-508847.

Blaylock, B.G., M.L. Frank and B.R. O'Neil 1993. *Methodology for Estimating Radiation Dose Rates to Freshwater Biota Exposed to Radionuclides in the Environment.* (ES/ER/TM-78). Oak Ridge National Laboratory, Oak Ridge TN.

Copplestone, D., S. Bielby, S.R. Jones *et al.* 2001. *Impact Assessment of Ionising Radiation on Wildlife*. R&D Publication 128. United Kingdom Environment Agency, Bristol.

Environment Canada/Health Canada 2003. *Second Priority Substances List Assessment Report (PSL2). Releases of Radionuclides from Nuclear Facilities (Impact on Non-Human Biota).* Environment Canada and Health Canada, Ottawa.

European Commission 2003 *MARINA II. Update of the Marina project on the radiological exposure of the European Community from radioactivity in North European marine waters.* Office for official publication of the European Communities, Luxembourg. (as cited by Beresford and Howard 2005).

Framework for Assessment of Environmental Impact (FASSET) 2004a. *Final Report. Developed Under EC 5th Framework Programme*. Contract No. FIGE-CT-2000-00102. www.erica-project.org. (2004).

Framework for Assessment of Environmental Impact (FASSET) 2004b. *Special Issue: Framework for assessment of environmental impact (FASSET) of ionising radiation in European ecosystems.* J. Radiol. Prot. 24(4A).

Framework for Assessment of Environmental Impact (FASSET) 2003. *Deliverable 3: Dosimetric Models and Data for Assessing Radiation Exposures to Biota* (G. Pröhl, ed.).

Framework for Assessment of Environmental Impact (FASSET) 2003. *Deliverable 4: Radiation Effects on Plants and Animals*, (D. Woodhead and I. Zinger, eds.).

[15] Additional selected references for case studies are provided in Appendix A.

Framework for Assessment of Environmental Impact (FASSET) 2003. *Deliverable 5: Handbook for Assessment of the Exposure of Biota to Ionising Radiation from Radionuclides in the Environment (Main Report); Appendix 1, Transfer Factors and Dose Conversion Coefficient Look-up Tables; Appendix 2, Underpinning Scientific Information (Life History Sheets, Empirical Data and Models)* (J. Brown, P. Strand, A. Hosseini *et al.*, eds.).

Framework for Assessment of Environmental Impact (FASSET) 2002. *Radiation Effects Database, Vol. 1e.* Environmental Research and Consultancy, University of Liverpool.

Framework for Assessment of Environmental Impact (FASSET) 2001. *Deliverable 1: Identification of Candidate Reference Organisms from a Radiation Exposure Pathways Perspective* (P. Strand, N. Beresford, R. Avila *et al.*, eds.).

International Atomic Energy Agency (IAEA) 2001. *Generic Models for use in Assessing the Impact of Discharges of Radioactive Substances to the Environment. Safety* Reports Series No. 19. IAEA, Vienna.

International Atomic Energy Agency (IAEA) 1999. *Protection of the Environment from the Effects of Ionizing Radiation.* A report for discussion. IAEA-TECDOC-1091. IAEA, Vienna.

International Atomic Energy Agency (IAEA) 1994. *Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments.* Technical Reports Series No. 364. IAEA, Vienna.

International Atomic Energy Agency (IAEA) 1992. *Effects of Ionizing Radiation on Plants and Animals at Levels Implied by Current Radiation Protection Standards*. Technical Reports Series No. 332. IAEA, Vienna.

International Atomic Energy Agency (IAEA)1988. *Assessing the Impact of Deep Sea Disposal of Low Level Radioactive Waste on Living Marine Resources*. Technical Reports Series No. 288. IAEA, Vienna, 1988.

International Atomic Energy Agency (IAEA)1976. *Effects of Ionizing Radiation on Aquatic Organisms and Ecosystems*. Technical Reports Series No. 172. IAEA, Vienna.

International Commission on Radiological Protection (ICRP) 2005. *Environmental Protection: the Concept and Use of Reference Animals and Plants.* Draft. Pergamon Press, Oxford.

International Commission on Radiological Protection (ICRP) 2003. *A Framework for Assessing the Impact of Ionising Radiation on Non-Human Species*. ICRP Publication 91. Pergamon Press, Oxford.

International Commission on Radiological Protection (ICRP) 1991. *1990 Recommendations of the International Commission on Radiological Protection.* ICRP Publication 60. Annals of the ICRP 21(1-3). Pergamon Press, Oxford.

International Commission on Radiological Protection (ICRP) 1977. *Recommendations of the International Commission on Radiological Protection.* ICRP Publication 26, Annals of the ICRP 1 (3), Pergamon Press, Oxford.

Jones, D., S. Domotor, K. Higley *et al.* 2003. *Principles and Issues in Radiological Ecological Risk Assessment*. J. Environ. Radioact. 66(1-2): 19-39.

Larsson, C.M. 2004. *The FASSET Framework for Assessment of Environmental Impact of Ionising Radiation in European Ecosystems--an Overview.* J. Radiol. Prot. 24(4A): A1-A12.

Marina II, Marina Update Project (MARINAII), Sazykina, T.G. and Kryshev, I.I., 2002. Assessment of the Impact of Radioactive Substances on Marine Biota of North European Waters. MARINAII, Issue 3, C6496/TR/004. Report of working subgroup D*, Commercial-in-Confidence, NNC Limited. Russia.

Pentreath, R.J. and D.S. Woodhead 2001. *A System for Protecting the Environment from Ionising Radiation: Selecting Reference Fauna and Flora, and the Possible Dose Models and Environmental Geometries that Could be Applied to Them.* Sci. Total Environ. 277(1-3): 33-43.

United States National Council on Radiation Protection and Measurements (U.S. NCRP) 1991. *Effects of Ionizing Radiation on Aquatic Organisms*. NCRP Report No. 109.

United States National Council on Radiation Protection and Measurements (U.S. NCRP) 1984. *Radiological Assessment: Predicting the Transport, Bioaccumulation and Uptake by Man of Radionuclides Released to the Environment*. NCRP Report No. 76.

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2000 *Sources and Effects of Ionising Radiation*, Report to the General Assembly, with Scientific Annexes, Volume 1 Sources, United Nations, New York.

United Nations Scientific Committee On The Effects Of Atomic Radiation (UNSCEAR) 1996. *Effects of Radiation on the Environment,* Annex to Sources and Effects of Ionizing

Radiation (Report to the General Assembly, with one Annex), Scientific Committee on the Effects of Atomic radiation, UN, New York.

United States Department of Energy (U.S. DOE) 2002. *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota*. DOE-STD-1153-2002. U.S. DOE.

Woodhead, D.S. 1979. *Methods of Dosimetry for Aquatic Organisms*. p. 43-96 in: Methodology for Assessing Impacts of Radioactivity on Aquatic Ecosystems. Technical Reports Series No. 190. IAEA, Vienna.

APPENDIX A

OVERVIEW OF SELECTED REPRESENTATIVE ERAS

APPENDIX A - OVERVIEW OF SELECTED REPRESENTATIVE ERAs

The World Nuclear Association (WNA) is interested in reviewing the main findings and conclusions of Ecological Risk Assessment (ERA) studies that have been carried out around the world in relation to radiation and radioactivity.

A review was conducted of ERAs conducted for number of studies that include a wide range of: representative sites over the full range of the nuclear fuel cycle activities: from uranium mining to nuclear power generation; sites involving enhanced levels of naturally occurring radioactive materials (NORM sites); sites associated with the management and disposal of radioactive wastes; as well as the Chernobyl nuclear accident. Brief summaries of some of the key information were made for each of the case studies including, where available:

- Nature of facility;
- Radionuclides and the environmental levels;
- Basis of analysis;
  - Species and pathways considered;
  - Approach (e.g. dose rate estimation methodology such as ERICA, U.S. DOE);
  - Concentration of radioactivity in the environment and biota (e.g. measured concentrations/doses or modelled concentration/doses);
  - Dose rate criteria;
- Conclusions (e.g., is there evidence of harm to some endpoint/species); and,
- References.

A.1 URANIUM MINING SITES

A.1.1 McArthur River

Description of Facility and Study:

McArthur River is a uranium mine operated by Cameco located in northern Saskatchewan, Canada. The high-grade ore (25% of natural uranium - U_3O_8) from McArthur River is milled at the Key Lake mill, 80 km to the south of McArthur River. The annual production capacity is 18.7 million pounds of U_3O_8 with proven and probable reserves of 389 million pounds U_3O_8. An ERA of the McArthur River mine was conducted to assess the cumulative effects of the operation from pre-production in the early 1990s through start-up in 1999 to the end of 2004 to address the influence of current and ongoing mining of McArthur River ore on the environment. Releases to air and water were included.

Radionuclides and Environmental Levels:

Uranium-238/234; Thorium-230; Radium-226; Lead-210; Polonium-210.

Upper Bound:

	Water	Sediment	Soil
U	25 µg/L	1761 mg/kg	0.498 mg/kg
Th-230	0.045 Bq/L	103 Bq/kg	29.6 Bq/kg
Ra-226	0.038 Bq/L	236 Bq/kg	29.6 Bq/kg
Pb-210	0.028 Bq/L	1458 Bq/kg	70 Bq/kg
Po-210	0.037 Bq/L	1510 Bq/kg	70.8 Bq/kg

Basis of Assessment:

Used measured and predicted concentrations in water and air along with transfer factors, based on site-specific information, to model transport. Modelling was conducted using the IMPACT computer model.

Species and Pathways:

Species were identified based on input from local groups and to ensure that all important trophic levels have been represented.

Bald Eagle
Beaver
Black Bear
Caribou - Woodland
Grouse
Lynx
Mink
Moose
Muskrat
Snowshoe Hare
Vole
Waterfowl (mallard, scaup)
Chironomid
Northern Pike
Snail
White Sucker
Lake whitefish
Lake chub
Spottail shiner

Methodology:

Total internal dose from alpha, electrons and photons were estimated using dose conversion factors (DCFs) from Amiro (1997). The external dose conversion factors due to photons and electrons were also from Amiro (1997).

Other assumptions:

- U-238 = U-238 + Th-234 for incorporated and immersion pathways.
- Rn-222 dose includes short-lived daughters.

In water, sediment, soil and tissues, Ra-226 and Rn-222 assumed to be in secular equilibrium. Terrestrial animals use incorporated, air, water, and soil/sediment DCFs.

Dose Rate Criteria:

A radiation weighting factor of 10 for alpha radiation is provided as a reasonably conservative factor but the dose values for a factor of 40 were also presented for comparison purposes.

- Aquatic Organism 10 mGy/d
- Terrestrial Organism 1 mGy/d

Conclusions:

Almost all of the predicted increases in body burdens or dose in receptors are related to the release of treated mine water. Few to no effects are predicted to result from air.

The only valued ecological component (VEC) that was predicted to exceed the benchmark radiological dose was scaup, primarily as a result of ingestion of Po-210. The radiological risk is limited to the area near the discharge point and predicted to return to background levels quickly after end of operations

The dose to benthic invertebrates (chironomid) exceeds the reference dose of 10 mGy/d only when a radiation weighting factor of 40 is assumed for alpha radiation. For the more realistic factor of 10, the reference dose is not exceeded.

Selected Key References:

EcoMetrix Incorporated 2005. *McArthur River Operation: Environmental Risk Assessment 2005.* Prepared for Cameco Corporation. December.

A.1.2 McClean Lake

Description of Facility and Study:

McClean Lake is a uranium mine operated by AREVA Resources Canada (formerly COGEMA Resources Inc.) located in northern Saskatchewan, Canada. It is licensed to produce 12 million pounds of U_3O_8 annually with 32.9 million pounds of U_3O_8 in reserves. The average grade is 1.7% U_3O_8. An ERA was conducted for a proposed open pit mine of a new high-grade ore body called Sue E. Milling will occur at the site with water treatment before discharge. Tailings will be disposed of in an existing facility. Assessment included releases to air and water.

Radionuclides and Environmental Levels:

Uranium; Thorium-230; Radium-226; Lead-210; Polonium-210

MAXIMUM IN RECEIVING ENVIRONMENT (MCCLEAN LAKE EAST)

	Water	Sediment
U	1.8-3.4 µg/L	12-32 mg/kg
Th-230	0.006-0.007 Bq/L	0.025-0.04 Bq/g
Ra-226	0.006-0.007 Bq/L	0.05-0.11 Bq/g
Pb-210	0.028-0.030 Bq/L	0.46-1.4 Bq/g
Po-210	0.006-0.007 Bq/L	0.29-0.9 Bq/g

Basis of Assessment:

Used predicted concentrations in water and air (benchmarked against measured data) along with transfer factors, based on site-specific information, to model transport. Modelling was conducted using the LAKEVIEW and INTAKE computer models.

Species and Pathways:

Bald Eagle	Snowshoe Hare
Beaver	Waterfowl (mallard, merganser, scaup)
Black Bear	Wolf
Caribou (Woodland)	Pelagic Forage Fish
Ptarmigan	Benthic Predatory Fish
Moose	Aquatic Plants
Muskrat	Benthic Invertebrates

Methodology:

Potential impacts were determined using screening index values, which are the ratios of estimated exposure levels to reference levels. Dose to aquatic receptors includes internal dose, based on predicted body concentrations, and external dose from water and sediment (where relevant). Dose to terrestrial receptors were based on internal dose, based on predicted whole-body concentrations.

	Internal Dose Factor mGy/d per Bq/g	Ext. dose factor mGy/d per Bq/g
U-238+	0.142	0.0129
Th-230	0.0658	2.25×10^{-4}
Ra-226+	0.159	0.0367
Pb-210+	6.03×10^{-3}	6.03×10^{-3}
Po-210	0.074	1.10×10^{-7}

Dose Rate Criteria:

Radiation weighting factors for alpha particles of 5, 10, 20 and 40 were used in the assessment. Sediment values were screened against Canadian Nuclear Safety Commission (CNSC) benchmarks.

- Aquatic Receptors
  - Fish 0.6 mGy/d (CNSC) and 10 mGy/d (UNSCEAR and DOE)
  - Aquatic Plants 3 mGy/d (CNSC) and 10 mGy/d (UNSCEAR and DOE)
  - Benthic 6 mGy/d (CNSC) and 10 mGy/d (UNSCEAR and DOE)
- Terrestrial Animals
  - 1 mGy/d (UNSCEAR and DOE) and 3 mGy/d (CNSC)

Conclusions:

No effects were expected for aquatic receptors. Potential effects on muskrat, mallard and scaup were predicted based on the upper bound estimate only within the Sink/Vulture Treated Effluent Management System (S/V TEMS). No effects were predicted for downstream of the S/V TEMS. The overall assessment of the project, based on the results of the calculations and receptor prevalence and potential for exposure, indicates that the potential for adverse effects are not significant.

Selected Key References:

COGEMA Resources Inc. 2004. *McClean Lake Operation – Sue E Project Environmental Impact Statement. Main Document.* November.

A.2 NUCLEAR POWER PLANTS

A.2.1 Pickering Generating Station

Nature of Facility and Study:

Pickering Nuclear Generating Station (PNGS) is located on the northern shoreline of Lake Ontario, east of Toronto, Ontario, Canada. The PNGS site includes two nuclear generation stations (2,060 MWe and 2,064 MWe) each with four CANDU reactors, housed in one building with a common shoreline surface intake and separate cooling water shoreline surface discharge. The other major facilities include switchyards, transformer stations and a used fuel dry storage facility (Wismer *et al.* 2004). A screening level ecological risk assessment was performed for regulatory compliance.

Radionuclides and Environmental Levels:

Estimated end-of pipe concentrations or monitored concentrations at receptor locations used in the assessment are provided in the following table (SENES 2000).

CONCENTRATIONS USED IN PICKERING ENVIRONMENTAL RISK ASSESSMENT

	Water (Bq/L)	Air (Bq/m^3)			Groundwater (Bq/L)	Soil* (Bq/kg)
		Site 1	Site 2	Site 3		
H-3	2780	659.45	36.04	81.26	7E+06	4.81E+07
C-14	0.481	0.116	0.0766	0.481	2368	
Cr-51	11.1					
Mn-54	0.74					
Fe-59	0.666					
Co-58	0.255					
Co-60	0.0851					452
Zn-65	0.296					
Sr-89	6.29					
Sr-90+	0.274	4.09E-05	3.16E-06	9.55E-06		1.85
Zr-95+	0.999					
Nb-95	0.962					
Ru-103	0.370					
Ru-106+	0.814					
Sb-124	1.44					
Sb-125	3.03					
I-131	0.144	2.27E-04	8.52E-06	1.26E-05		
Cs-134	0.00326					18.5
Cs-137+	0.00444				1.48	28.5
Ba-140+	0.555					
Ce-141	2.78					
Ce-144+	1.52					
Eu-152	0.144					
Eu-154	0.152					
Gd-153	1.96					

* Also used measured gamma rates.

Basis of Assessment:

The methodology used in the PNGS Screening ERA follows standard scientific procedures for pathways analysis and contaminant uptake by biota for the different stressors being assessed. Potential environmental impacts were measured in terms of screening indices, which are the ratios of estimated exposure levels to levels or concentrations deemed unlikely to have a significant ecological effect.

A screening methodology was also applied to derive generic No-Effects Concentrations (NECs) for the abiotic environment. Sample NECs were estimated for a series of radionuclides and representative biota. For each radionuclide and each biota, the concentration in air, water, sediment and soil corresponding to a selected dose limit were calculated. The lowest value for each radionuclide for each of the base environmental media was selected as a generic NEC. These generic NECs can be applied at a variety of sites (Garisto *et al.* 2005).

Indicator Species Included:

Fish (alewife, smallmouth bass, northern pike, brown bullhead, round whitefish, white sucker), aquatic plants, bottom-feeding invertebrates, amphibians (northern leopard frog), terrestrial invertebrates (earthworms), birds (lesser scaup, double-crested cormorant, trumpeter swan, ringbilled gull, great-horned owl), mammals (muskrat, red fox, meadow vole) and livestock and pets (dairy cow, poultry, dog, cat).

Pathways Considered:

- Fish: surface water and sediment through ingestion of water, plankton, other fish and benthos, immersion in water and exposure to sediment.
- Amphibians: surface water and sediment through ingestion of water and aquatic invertebrates, immersion in water and exposure to sediment.
- Aquatic invertebrates: surface water and sediment through ingestion of water and plankton, immersion in water and exposure to sediment.
- Aquatic plants: surface water through uptake and immersion in water.
- Terrestrial invertebrates: soil and groundwater through ingestion of soil and immersion in soil.
- Terrestrial plants and crops: soil, through uptake and exposure to soil.
- Birds: air and surface water through ingestion of water, fish, benthos, terrestrial vegetation, aquatic vegetation and rodents, inhalation and immersion in air.
- Mammals: surface water, air and soil through ingestion of water, fish, terrestrial vegetation, aquatic vegetation and rodents, inhalation, immersion in air and exposure to soil.
- Livestock: air and soil through ingestion of vegetation and inhalation.

Methodology:

The dose rate estimates followed the method recommended by IAEA (1992) and UNSCEAR (1996). Radiation weighting factors of 3 for tritium and 1 for beta and gamma emitters were used (UNSCEAR 1996). Thyroid dose was included in the dosimetry of terrestrial biota (SENES 2000).

Dose Rate Criteria:

A benchmark of 10 mGy/d was used for all the aquatic biota and the terrestrial plants. For trumpeter swan, a species identified for special protection, a benchmark of 0.137 mGy/d was used and for other terrestrial biota (earthworm, birds and mammals) a benchmark of 1 mGy/d was used (SENES 2000).

Conclusion:

Potential effect of tritium on earthworm through intake of/ exposure to groundwater and a potential for an effect on trumpeter swan from all radionuclides combined, through intake of aquatic plants, was estimated. No other effects were identified. More refined calculations and further data acquisition were deemed necessary. Also, a new monitoring study was recommended to measure exposure, uptake and potential effects of multiple stressors on the biota. The results of further investigations indicate that there are no significant ecological impacts from radiological and chemical emissions associated with PNGS emissions (Garisto *et al.* 2005).

Selected Key References:

Garisto, N.C., S.L. Fernandes, M. Monabbati, D. Brown and F. Bajurny. 2005. *Screening "No-Effect Concentrations" for Radionuclides in the Abiotic Environment from a Generic Ecological Risk Perspective: Derivation and Application for the Pickering Nuclear Site.* Proceeding from the 2nd International Conference on Radioactivity in the Environment. 2-6 October 2005. Nice, France.

SENES Consultants Limited. 2000. *Ecological Risk Assessment of Pickering Nuclear, Phase (ii) Supporting Document.* Prepared for Ontario Power Generation. September.

Wismer, D.A., N.C. Garisto and F. J. Bajurny. 2004. *Application of ecological risk assessment to establish non-human environmental protection at nuclear generating stations in Ontario, Canada.* Radioprotection, Suppl. 1, vol. 39.

A.2.2 Loire River

Description of Facility and Study:

Between 1963 and 1999, 14 nuclear reactors were commissioned at 5 different sites on the Loire River and its tributaries in France. The Loire River, the longest river in France, is considered one of the last 'wild' rivers in Europe. The Loire provides a habitat to 103 plant species of natural heritage interest and 107 nationally protected animal species. The nuclear power plants are located on a stretch of the river some 350 km from its estuary.

Two locations are discussed: the Loire River downstream of the Chinon nuclear power plant and the estuary.

Radionuclides and Environmental Levels:

Nuclear power plants are not allowed to release α emitters into the environment. Data available are for β and γ emitters (^{54}Mn, ^{58}Co, ^{60}Co, ^{110m}Ag, ^{63}Ni, ^{123m}Te, ^{124}Sb, ^{125}Sb, ^{131}I, ^{134}Cs, ^{137}Cs, ^{3}H and ^{14}C). Of the radionuclides released into the Loire River only seven are covered by the FASSET framework. Five radionuclides were found to have enough information and be relevant to the assessment of chronic exposure - ^{3}H, ^{14}C, ^{131}I, ^{134,137}Cs.

ESTIMATED CONCENTRATIONS NEAR CHINON (USING FASSET APPROACH)

Radioisotope	Mean water concentration (Bq m^{-3})	Mean sediment concentration (Bq kg^{-3})	Concentration in aquatic plants (Bq kg^{-3})	Concentration in fish (Bq kg^{-3})
^{14}C	42	0.21	0.21	0.21
^{131}I	0.23	2.30×10^{-3}	4.60×10^{-2}	9.2×10^{-3}
^{134}Cs	0.36	0.36	0.36	3.6-4.3
^{137}Cs	0.98	0.98	0.98	9.8-12

WATER CONCENTRATIONS IN ESTUARY

Radioisotope	Estimated average concentrations (Bq m^{-3})	Measured concentrations	
		Mean (Bq m^{-3})	Max (Bq m^{-3})
^{3}H	5210	8500	2.1×10^{4}
^{14}C	7.67	4.8*	6.0*
^{131}I	4.17×10^{-2}	4.7×10^{-2}	0.18
^{134}Cs	6.54×10^{-2}	3.0×10^{-2}	3.0×10^{-2}
^{137}Cs	0.18	0.18	0.61

Basis of Assessment:

The assessment was done following the FASSET approach. Concentrations in the environment were estimated using FASSET and benchmarked against measured data and estimated concentrations using other approaches (CRESCENDO). For the Loire River, given the sparse data available, all activity concentrations used to estimate doses were modelled using FASSET sediment-water partition coefficients (K_d) and biota-environment concentration ratios (CR), as well as the estimated water concentrations. For the estuary measured water activity concentrations were available. Dose rates were estimated assuming using both marine and freshwater transfer parameters from the FASSET framework. Absorbed dose is estimated using dose conversion coefficients (DCC) to estimate internal dose rate and external dose rates, on the basis of media activity concentrations.

Species and Pathways:

FASSET uses reference organisms. The Loire River and its estuary represent the final receiving ecosystem (before the ocean) and are respectively analogous to the freshwater and brackish water ecosystems of the FASSET framework. The reference organisms included are: bacteria, phytoplankton, zooplankton, mollusc, worm, vascular plant, pelagic fish, bird, macroalgae, benthic fish, crustacean and mammal.

Methodology:

The assessment followed the FASSET approach. DCCs are provided for a range of geometries and sizes selected to be representative of the reference organisms. A radiation weighting factor of 3 for low energy (<10keV) beta radiations was used.

Dose Rate Criteria:

A review of available radiation effects data was performed within the FASSET project and the information organised into a database (FRED – the FASSET Radiation Effects Database). The database includes approximately 25,000 data entries from more than 1,000 references. It was found that was generally insufficient information on chronic low dose rates. The FRED database does not distinguish between marine and freshwater biota.

Conclusions:

The estimated dose rates to freshwater organisms in the Loire River and its estuary are at least five orders of magnitude lower than those at which effects have been reported. The main contribution to total estimated dose rates is internal radiocaesium exposure. The highest estimated dose rates were for mammals (3.7×10^{-3} μGy h^{-1} at Loire River and 5.7×10^{-4} μGy h^{-1} in the estuary). If marine transfer parameters are used for the assessment of the estuary, internal doses from ^{14}C contribute the greatest to total dose rates and the highest dose rate rises to 7×10^{-3} μGy h^{-1} for mammals and birds.

Overall, since the highest estimated dose rates are 5 orders of magnitude below the threshold for statistical effects suggested within FASSET a certain amount of confidence can be placed in the conclusion that effects due to discharges from the Loire River NPPs are unlikely.

Selected Key References:

Beresford, N.A. and B.J. Howard 2005. ERICA. *Deliverable D9: Application of FASSET framework at case study sites.* Contract Number: FI6R-CT-2003-508847.

A.3 USED NUCLEAR FUEL REPROCESSING PLANTS

A.3.1 La Hague

Description of Facility and Study:

The La Hague used nuclear fuel reprocessing facility is located in the north-west part of France, on the north-west tip of the Nord-Cotentin Peninsula, along the south shore of the English Channel. This is a major nuclear site involving a wide range of supporting nuclear facilities. Operations started in the late 1950's at La Hague and have been upgraded on several occasions over time through the addition of new facilities and the decommissioning of older facilities. The La Hague nuclear fuel reprocessing plant is currently operating.

Sea currents in the La Hague area are very strong, among the most intense in Europe, especially at the north-west tip of the peninsula, where the off-shore discharge pipe outfall of the La Hague facility is located. Because of the strong sea currents, marine biota tend to concentrate and flourish in rocky areas along the peninsula coast, which offer protection. Away from the coast, this protection is reduced, especially in sandy and muddy areas where it can be more difficult for biota to stay and survive. Sessile algae are particularly important along the coast and are a key part of the habitat structure for many organisms. A number of important food species such as lobsters, crabs, whelks, scallops, squid, and fish are also present along the coast.

Radionuclides and Environmental Levels:
The radioactive discharge source terms derived by the Nord-Cotentin Radioecology Group (GRNC) and the related environmental transfer models covered a comprehensive list of over 90 radionuclides.

Basis of Assessment:
The assessment was largely based on the results of the comprehensive environmental studies conducted by the Nord-Cotentin Radioecology Group (GRNC), which provided a very large knowledge base of environmental measurements (of sea water, sediment and marine biota) and environmental transfer models for radionuclides in the La Hague coastal area (GRNC 1999a, GRNC 1999b).

Species and Pathways:
In general terms, the first step was to develop a conceptual model for the Nord-Cotentin Peninsula coastal area. The conceptual model for the marine coastal environment identified various biota categories and defined representative biota species ("reference biota") for each biota category; namely, crustaceans, filtrating molluscs, non-filtrating molluscs, round fish, flat fish and algae.

Methodology:
The base case assessment was carried out for a reference location (Goury), which in general had the highest radionuclide concentrations along the coast. Dose rates for marine biota were estimated using the IAEA dose assessment model which included geometry factors and occupancy factors to account for body sizes, and habits of the region-specific organisms, respectively. Both the internal dose rates from the radionuclide concentrations in the organisms and the external dose rates from the radionuclide concentrations of the media in which the organism lives (i.e. water and sediments) were estimated. A uniform radionuclide distribution was assumed in the organisms and in environmental media. Crustaceans, filtrating molluscs, and non-filtrating molluscs were assumed to spend all of their time in sediment. This is very conservative since these organisms tend to live at the sediment/water interface with some time away from the sediments. Flat fish were assumed to spend half of their time in the water column

and the other half in sediment. This is very conservative since flat fish do spend a significant amount of time away from the sediments. Round fish and algae were assumed to spend all their lives in the water column.

For the base case coastal zone (Goury), the marine biota dose rates were very small (by at least 2 to 3 orders of magnitude) compared to the lowest generic guidance values for the protection of populations of marine biota (Figure A.1). Since the radionuclide concentrations in biota, water and sediments for other coastal locations are lower than from Goury, the dose rates to biota in other coastal regions are also expected to be lower. The highest dose rate determined for the base case was estimated for filtrating molluscs and the radionuclide contributing the most to dose rate was ^{106}Rh. The results from this study were compared to those from the MARINA II report (Sazykina and Kryshev 2002), which also provided estimates of the dose rate to various marine organisms in the Cap de La Hague coastal area.

A number of sensitivity analyses were performed and compared to an assessment of the base case reference location (Goury). The base case dose rate estimates were expressed in units of absorbed dose but did not account for the differences in radiation weighting factors that account for the relative biological effectiveness of alpha, beta and gamma radiations developed using the U.S. NCRP dose estimation methodology (Blaylock, Frank and O'Neil 1993). Included in the sensitivity analyses performed in this study, were an evaluation of alternative radiation weighting factors for internally deposited alpha emitters and comparison with alternative approaches to dose estimation, in particular, the approach used by the U.K. Environmental Agency (Copplestone and Bielby 2001) and in the MARINA II report (Sazykina and Kryshev 2002). In addition, doses from background levels of radioactivity (both natural and man-made, but excluding contributions from the La Hague facility itself) were also estimated. For man-made radiation other than from La Hague (e.g. from past nuclear weapon test fallout), the assessment included contributions: from ^{3}H, ^{14}C, ^{60}Co, ^{90}Sr(+Y), ^{106}Ru(+Rh), ^{125}Sb, ^{129}I, ^{131}I, ^{134}Cs, ^{137}Cs(+Ba), ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, and ^{241}Am were. For natural radioactivity, ^{3}H, ^{14}C, ^{40}K, ^{210}Po and ^{238}U were considered.

Dose Rate Criteria:

The radiation dose rates to marine biota in the study area were estimated and compared to guidance values for the protection of populations of marine biota. The reference guidance values for this assessment were based on generic criteria published by international organizations (e.g. UNSCEAR 1996, IAEA 1992, NCRP 1991) and on applicable data from the FASSET database on biological effects of ionizing radiation on non-human biota (FASSET Deliverable 4, 2003). A range of generic dose-effect guidance values (from about 0.01 to 10 Gy/d) were developed from the FASSET dose-effect database (FASSET 2002) for the protection of populations of marine biota, and from the conventional international generic guidance values of 10 mGy/day for the protection of biota.

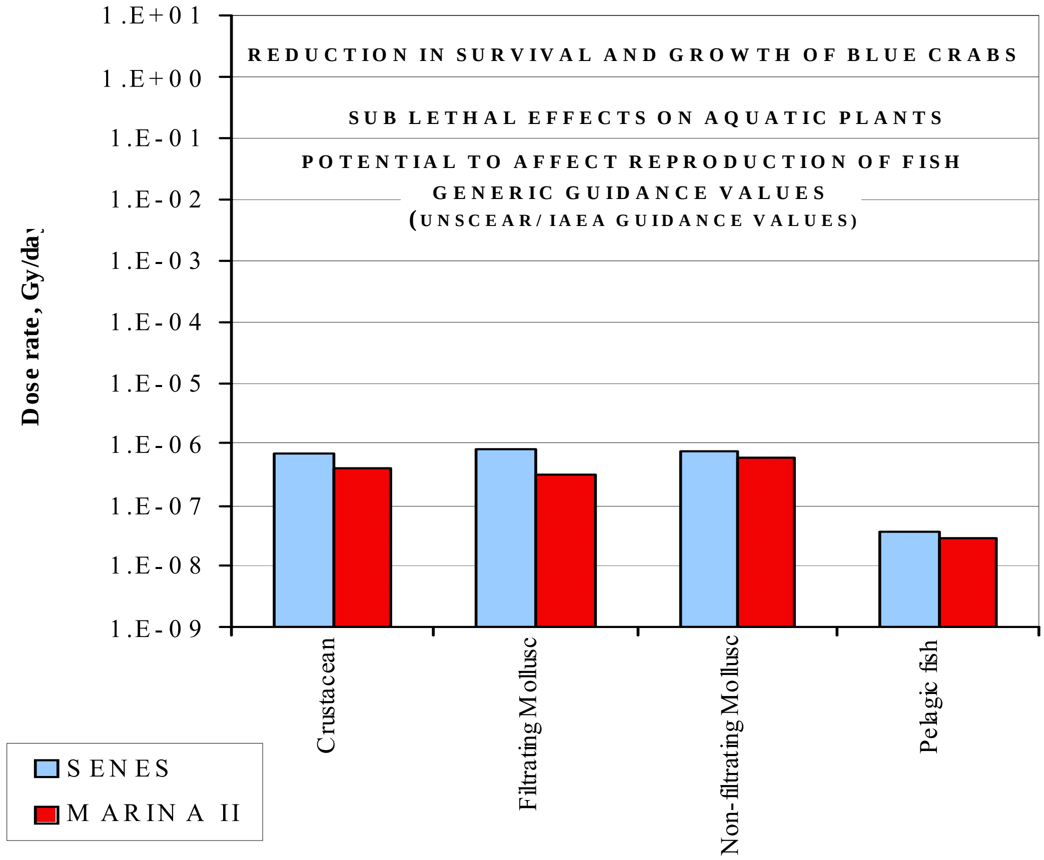

Figure A.1. Estimated Marine Biota Dose Rate for Base Case Compared to MARINA II Estimates. For comparison purposes, the base case estimate from SENES (2003) uses a radiation weighting factor of 20 for alpha emitters, as was used in MARINA II (Sazykina and Kryshev 2002).

Conclusions:

The contributions from man-made background radionuclides (other than from the La Hague facility) to the dose rates were also found to be very low in comparison to those from the natural radionuclides, for which most of the dose came from ^{210}Po. The highest radiation dose rate from natural and man-made background was estimated for crustaceans and molluscs, respectively. The dose rates estimated from background levels of radiation (i.e. natural and man-made radionuclides) were higher, by about 1 to 2 orders of magnitude, than the base case dose rates predicted for the discharges from the La Hague facility.

Overall, the assessment showed that the predicted dose rates to marine biota attributable to radioactive discharges to the sea from the La Hague facility are small, well below comparison guidance levels at which deleterious and observable health effects to populations of marine biota might be expected and well below dose rates from background radioactivity in the region.

Selected Key References:

Chambers, D.B., E. Muller, S. St Pierre *et al.* 2003. *Assessment of Marine Biota Doses Arising from the Radioactive Sea Discharges of the COGEMA La Hague Facility.* Presented in International Conference on the Protection of the Environment from the Effects of Ionizing Radiation, Stockholm, October.

Compagnie Generale Des Matieres Nucleaires (COGEMA) 1996. Dossier d'Enquête Publique – La Hague – Etude d'impact.

Copplestone, D., S. Bielby, S.R. Jones, D. Patton, P. Daniel, and I. Gize 2001. *Impact Assessment of Ionising Radiation on Wildlife,* UK Environment Agency, R&D Publication 128, Bristol, UK.

Groupe Radioecologie Nord-Cotentin a, (GRNC) Groupe de Travail nº2, Revue Critique des mesures dans l'environnement Tome 1-2, France (1999).

Groupe Radioecologie Nord-Cotentin b, (GRNC) Groupe de travail nº3, Modèles de transfert des radionucléides dans l'environnement, France (1999).

Marina II, Marina Update Project, MARINA II, Sazykina, T.G. and Kryshev, I.I. 2002. *Assessment of the Impact of Radioactive Substances on Marine Biota of North European Waters*. MARINA II, Issue 3, C6496/TR/004. Report of working subgroup D*, Commercial-in-Confidence, NNC Limited. Russia.

SENES Consultants Limited (SENES) 2003a. *Assessment of Marine Biota Doses Arising from the Radioactive Sea Discharges of the COGEMA La Hague Facility, Final Report, Vol. I: Executive Summary and Consensus Appraisal of the Study.*

SENES Consultants limited (SENES) 2003b. *Assessment of Marine Biota Doses Arising from the Radioactive Sea Discharges of the COGEMA La Hague Facility, Final Report, Vol. II: Main Report.*

SENES Consultants Limited (SENES) 2003c. *Assessment of Marine Biota Doses Arising from the Radioactive Sea Discharges of the COGEMA La Hague Facility, Final Report, Vol. III: Appendices.*

A.3.2 Marcoule

Description of Facility and Study:

The Marcoule nuclear complex is located on the Rhone River in Southern France. Since 1956, various facilities have been located at the site. The first industrial and military plutonium experiments took place in Marcoule. In 1973, the Phénix prototype fast breeder reactor started up. Starting in 1995 Melox produced a mixed oxide fuel production facility using plutonium from La Hague. A fuel reprocessing facility, nuclear research facilities and other supporting facilities are also located on the site. The Marcoule facilities have been updated on several occasions over time through the addition of new facilities and the decommissioning of older facilities. Many facilities are still in operation the Marcoule site. However, the reprocessing plant ceased operations in 1997 and it is currently under decommissioning.

Radionuclides and Environmental Levels:

Artificial radioactivity in the Rhone River aquatic environment is associated with controlled radioactive releases from the complex. An assessment was conducted for artificial and natural radionuclides. Detailed radioecological data have been collected from the site and the maximum measured values are summarized in the Table A.1.

Basis of Assessment:

A conservative approach was taken to determine concentration in aquatic media (water, sediments and aquatic organisms). Extensive data had been collected from the site. The analyses included gross (total) alpha, gross (total) beta analysis, gamma spectrometry, alpha spectroscopy, ^{3}H analysis, ^{90}Sr analysis and uranium fluorimetry. To infill data gaps, where appropriate, assumptions were made regarding the levels of some radionuclides based on equilibrium. Measured data were used where available and simple transport models were used to estimate other concentrations (e.g. fish-eating bird).

Species and Pathways:

The selected species include submerged aquatic plants (phanerogam), non-bottom feeding fish, bottom-feeding fish, molluscs and fish-eating birds.

Methodology:

Measured radionuclide concentrations were assumed to be uniformly dispersed in the aquatic media to estimate the absorbed (whole body) dose rates. Simple theoretical expressions for typical shapes and sizes of biota were used to estimate internal and external dose rates following the application of the "Point Source Dose Distribution" methodology. Curves provided by Blaylock *et al.* (1993), NCRP (1991) and IAEA (1976) relating absorbed fraction as a function of radiation energy were used.

The implication of different radiation weighting factors for alpha radiations was discussed.

Dose Rate Criteria:

Several international guidelines (UNSCEAR 1996, IAEA 1992, NCRP 1991) were reviewed. The discussion considered a level of 400 µGy/h for protection of aquatic organisms and 100 µGy/h was used as the trigger for a more detailed evaluation of potential ecological consequences to the endemic population.

Conclusions:

The maximum dose rate for artificial radionuclides was about 0.03 mGy/d (or 1.3 µGy/h) for molluscs. External dose was important for aquatic plants, bottom-feeding fish and molluscs. For fish-eating birds 95% of the dose was attributable to internal dose. The three most significant radionuclides were ^{134}Cs, $^{137}Cs+^{137}Ba$, and $^{106}Ru+^{106}Rh$.

The highest dose rate for natural radionuclides was 0.12 mGy/d (or 5 µGy/h) for fish-eating birds, primarily due to internal dose. The three natural radionuclides with the most significant contribution on the dose rates were ^{214}Bi, ^{214}Po and ^{40}K, with ^{40}K being the largest contributor.

It was concluded that chronic levels of artificial and natural radioactivity measured in aquatic media downstream of Marcoule are unlikely to result in adverse health impacts on the categories and species of aquatic organisms studied. A more detailed evaluation of the dose rates does not appear warranted.

Selected Key References:

St-Pierre, S. D.B. Chambers, L.M. Lowe and J.G. Bontoux 1999. *Screening Level Dose Assessment of Aquatic Biota Downstream of the Marcoule Nuclear Complex in Southern France.* Health Physics. Volume 77, Number 3. pp313-321.

Table A.1: Maximum Concentrations of Artificial and Natural Radionuclides (Marcoule Site)

Artificial Radionuclides	Water (mBq L^{-1})		Sediment (Bq kg^{-1} dry)		Submerged Aquatic Plants[a] (Bq kg^{-1} dry)		Non-Bottom-Feeding Fish[a] (Bq kg^{-1} fresh)		Bottom-Feeding Fish[a] (Bq kg^{-1} fresh)		Mollusca (Bq kg^{-1} fresh)		Fish-eating birds (Bq kg^{-1} fresh)	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Fission Products:														
^{144}Ce + ^{144}Pr	--[b]	--	6.0	109	19.5	280	1.49	1.5	--	--	1.00	1.00	0.01	0.04
^{134}Cs	0.002	9	0.6	210	0.5	68	0.10	4.1	0.10	1.28	0.27	27.00	1.99	271.68
^{137}Cs + ^{137m}Ba	0.008	88	1.0	2080	2.0	588	0.11	29.6	0.20	10.30	3.28	57.00	2.42	2166.85
^{152}Eu	--	--	--	--	--	--	--	--	--	--	--	--	--	--
^{155}Eu	--	--	--	--	--	--	--	--	--	--	--	--	--	--
^{129}I	--	--	--	--	2.2	4.5	1.62	1.62	--	--	0.37	4.64	32.26	107.55
^{131}I	--	--	0.37	1.1	4.9	11.8	--	--	--	--	--	--	--	--
^{95}Nb	--	--	--	--	7.0	7.0	--	--	--	--	--	--	--	--
^{103}Ru	--	--	--	--	--	--	--	--	--	--	--	--	--	--
^{106}Ru + ^{106}Rh	0.068	2600	1.3	2320	20.3	4160	1.20	25.6	5.23	5.23	3.00	293	0.09	6.61
^{125}Sb	0.009	7.2	1.0	44	1.4	40	0.35	1.42	--	--	-.74	8.1	0.28	3.75
^{90}Sr + ^{90}Y	0.006	160	11	600	2.1	279	2.0	16.9	1.88	1.88	44.5	96.9	31.5	887
^{99}Tc	--	--	--	--	--	--	--	--	--	--	--	--	--	--
^{95}Zr	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Activation Products:														
^{110m}Ag + ^{110}Ag	22.9	96.5	0.37	27	1.2	83	0.29	1.25	0.15	0.15	0.37	0.70	0.015	0.22
^{57}Co	--	--	--	--	0.3	1.0	--	--	--	--	--	--	--	--
^{58}Co	--	--	0.37	13	2.2	194	0.22	0.88	--	--	0.30	6.0	0.12	1.60
^{60}Co	1.4	25.2	0.80	159										
^{54}Mn	0.07	11.6	0.37	78	1.5	1300	0.20	2.41	0.30	0.51	0.37	177	0.07	2.80
^{65}Zn	--	--	5.0	40	--	--	--	--	--	--	--	--	--	--
Transuranic Elements:														
^{241}Am	0.04	5.0	0.058	50	0.020	6.2	0.001	0.018	0.001	0.001	0.09	0.27	0.00005	0.003
^{243}Am + ^{239}Np	--	--	0.13	0.40	0.073	1.1	--	--	--	--	--	--	--	--
^{243}Cm + ^{244}Cm	--	--	0.21	0.40	0.062	1.1	--	--	--	--	--	--	--	--
^{238}Pu	0.018	0.070	0.017	18.2	0.007	1.7	0.006	0.006	0.003	0.003	1.03	1.86	0.0003	0.001
^{239}Pu + ^{240}Pu	0.033	0.095	0.090	50.6	0.002	5.2	0.001	0.28	--	--	--	--	0.00004	0.051
Tritium:														
^{3}H: Bq L^{-1}	22000	56000	--	--	--	--	--	--	--	--	--	--	--	--
Interstitial Water: Bq L^{-1}	--	--	6.3	16.2	--	--	--	--	--	--	--	--	46	1498
Combustion Water: Bq L^{-1}	--	--	31.7	13400	7.4	297	33	1155	222	867	--	--	--	--
OBT (Organically bound ^{3}H)	--	--	0.3	27.8	0.17	0.88	0.70	2.0	7.8	7.8	--	--	--	--
Tritium (Organic Matter): Bq kg^{-1}	--	--	20.0	8600	2.5	113	19	450	251	643	--	--	--	--
Tritium (Dry Matter): Bq kg^{-1}	--	--	0.2	107	8.4	39	44	131	528	528	--	--	--	--

Table A.1: Maximum Concentrations of Artificial and Natural Radionuclides (Marcoule Site) (Cont'd)

Natural Radionuclides	Water (mBq L^{-1})		Sediment (Bq kg^{-1} dry)		Submerged Aquatic Plants[a] (Bq kg^{-1} dry)		Non-Bottom-Feeding Fish[a] (Bq kg^{-1} fresh)		Bottom-Feeding Fish[a] (Bq kg^{-1} fresh)		Mollusca (Bq kg^{-1} fresh)		Fish-eating birds (Bq kg^{-1} fresh)	
	Min.	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**
^{238}U decay series:														
^{238}U	0.90	80	4.7	100	5.7	79.6	0.10	1.10	0.009	0.63	0.09	8.0	0.10	3.65
^{234}Th	0.90	80	4.7	100	5.7	79.6	0.10	1.10	0.009	0.63	0.09	8.0	0.00	0.00
^{239}Pa	0.90	80	4.7	100	5.7	79.6	0.10	1.10	0.009	0.63	0.09	8.0	0.00	0.00
^{234}U	0.90	80	4.8	20.5	5.3	48.2	0.11	0.64	0.009	0.63	0.09	8.0	0.11	2.12
^{230}Th	0.90	80	4.8	20.5	5.3	48.2	0.11	0.64	0.009	0.63	0.09	8.0	0.00	0.02
^{226}Ra	0.90	80	4.8	82.6	6.1	57.4	0.16	2.22	0.009	2.07	0.09	37.2	1.7	79.8
^{222}Rn	0.90	80	4.8	82.6	6.1	57.4	0.16	2.22	0.009	2.07	0.09	37.2	-	-
^{218}Po	0.90	80	4.8	82.6	6.1	57.4	0.16	2.22	0.009	2.07	0.09	37.2	0.00	0.00
^{214}Pb	0.90	80	4.8	82.6	6.1	57.4	0.16	2.22	0.009	2.07	0.09	37.2	0.00	0.01
^{214}Bi	0.90	80	4.8	82.6	6.1	57.4	0.16	2.22	0.009	2.07	0.09	37.2	0.00	0.00
^{214}Po	0.90	80	4.8	82.6	6.1	57.4	0.16	2.22	0.009	2.07	0.09	37.2	0.00	0.00
^{210}Pb	15	50	11	370	1.1	67.1	0.35	8.30	0.51	2.07	0.09	37.2	3.5	274
^{210}Bi	15	50	11	370	1.1	67.1	0.35	8.30	0.51	2.07	0.09	37.2	0.01	0.75
^{210}Po	15	50	11	370	1.1	67.1	0.35	8.30	0.51	2.07	0.09	37.2	0.19	14.8
^{232}Th decay series:														
^{232}Th	13	67	3	70	1.7	54.0	0.31	2.01	0.39	0.85	6.50	33.5	0.00	0.07
^{228}Ra	13	67	3	70	1.7	54.0	0.31	2.01	0.39	0.85	6.50	33.5	3.1	68.1
^{228}Ac	13	67	3	70	1.7	54.0	0.31	2.01	0.39	0.85	6.50	33.5	0.00	0.00
^{228}Th	13	67	3	70	1.7	54.0	0.30	2.56	0.39	1.28	1.85	33.5	0.00	0.09
^{224}Ra	13	67	3	70	1.7	54.0	0.30	2.56	0.39	1.28	1.85	33.5	0.05	1.3
^{220}Rn	13	67	3	70	1.7	54.0	0.30	2.56	0.39	1.28	1.85	33.5	-	-
^{216}Po	13	67	3	70	1.7	54.0	0.30	2.56	0.39	1.28	1.85	33.5	0.00	0.00
^{212}Pb	13	67	3	70	1.7	54.0	0.30	2.56	0.39	1.28	1.85	33.5	0.00	0.00
^{212}Bi	13	67	3	70	1.7	54.0	0.30	2.56	0.39	1.28	1.85	33.5	0.00	0.00
^{208}Tl (36%)	4.7	24	1.1	25.2	0.6	19.4	0.11	0.92	0.31	0.46	0.67	12.1	0.00	0.00
^{212}Po (64%)	8.3	43	1.9	44.8	1.1	34.6	0.19	1.64	0.39	0.82	1.18	21.4	0.00	0.00
Potassium: ^{40}K	1.0	1480	14.7	772	104	2790	18	362	66	96	8	31.8	223	14965
Beryllium: ^{7}Be	-	-	4.1	59.6	14.8	121	1.7	5.9	2.8	2.8	2.6	23.5	0.075	0.87

a Composite results from the reference studies (see text) for each category of organism defined by the species shown in Table 1.

b Measurements from reference studies below detection limits (variable with study and media) shown as "--".

A.3.3 Sellafield

Description of Facility and Study:

Sellafield is one of the largest nuclear engineering centres in the world and is managed and operated by Sellafield Limited. It is located in Cumbria, United Kingdom. Established in the early 1950's, various facilities have been located at the site including two used nuclear fuel reprocessing facilities, nuclear research facilities, mixed oxide fuel production facility, and other supporting facilities. In 1957, the site known as Windscale experienced a significant nuclear accident, which caused significant atmospheric releases of radioactivity.

The Sellafield nuclear site played a key role in support of the development of the British nuclear power program. The site also includes military facilities. The Sellafield facilities have been updated several times through the addition of new facilities and the decommissioning of older facilities. Many facilities are still in operation at the Sellafield site, including one reprocessing plant. Many other facilities are under decommissioning.

An assessment of ecological risks from ionising radiation on the receiving aquatic and terrestrial environment in the vicinity of the Sellafield site was undertaken, including the sand dune and saltmarsh areas of the Drigg Coast based on measured and predicted concentration. The assessment was done following the FASSET approach. Radiation weighting factors of 10 for internally incorporated alpha radiations and 3 for low energy (<10keV) beta radiations were used.

The results of the assessment for the Drigg Coast are summarized in this case study.

Radionuclide and Environmental Levels:

Radionuclide activity concentrations (Bq kg^{-1} fw) in soils/sediments used in the assessment of the effects of ionising radiation on biota at Drigg coast are provided in the table below.

Radionuclide	Soil/sediment concentration	
	Saltmarsh	Sand dunes
^{40}K	539	384
^{106}Ru	1150	5.0
^{134}Cs	18.4	2.5
^{137}Cs	6590	341
^{210}Pb	-	25.4
^{226}Ra	172	22.3
^{227}Th	91500	9.4
^{228}Th	354	38.0
^{230}Th	1040	101
^{234}Th	20400	21.7
^{235}U	-	1.2
^{238}Pu	352	34.0
$^{239+240}Pu$	1860	165
^{241}Am	1600	177
^{237}Np	3.0	-

Basis of Assessment:

The assessment was done following the FASSET approach. Measured soil activity levels were used along with concentration ratios (CR) to predict biota concentrations. These were benchmarked against measured data. Absorbed dose is estimated using dose conversion coefficients (DCC) to estimate internal dose rate and external dose rates, on the basis of media activity concentrations. DCCs are provided for a range of geometries and sizes selected to be representative of the reference organisms.

Species and Pathways:

FASSET uses reference organisms. The assumptions made regarding these organisms are:

- Vole and field mouse are represented by the mouse reference organism;
- Shrew is represented by the weasel reference organism;
- All vegetation types assessed are represented by the herb reference organism;
- Sheep are represented by the roe deer reference organism;
- Greylag goose, widgeon and mallard are represented by the herbivorous bird reference organism;
- Shell duck, black headed gull, great and lesser black backed gulls, curlew, bar-tailed godwit and curlew are represented by the carnivorous bird reference organism.

No adequate reference organisms could be found to represent the reptiles, amphibians, butterflies, moths, and the lichen and bryophyte flora found at Drigg coast.

Methodology:

The assessment followed the FASSET approach. DCCs are provided for a range of geometries and sizes selected to be representative of the reference organisms. Radiation weighting factors of 10 for internally incorporated alpha radiations and 3 for low energy (<10keV) beta radiations are recommended.

Dose Rate Criteria:

A review of available radiation effects data was performed within the FASSET project and the information organised into a database (FRED – the FASSET Radiation Effects Database). The database includes approximately 25,000 data entries from more than 1,000 references. The threshold for statistically significant effects in most studies was about 0.1 mGy h^{-1} (i.e. 2.4 mGy d^{-1}); responses then increased progressively with increasing dose rate usually becoming very clear at dose rates >1 mGy h^{-1} over a large fraction of a lifespan.

Conclusions:

Radiation dose rates to small mammals in the salt marsh system ranged from 2.3 to 46 μGy h^{-1} (weighted). Radiation dose rates to small mammals in the sand dunes were about 0.5 μGy h^{-1} (weighted). The majority of the dose originates from isotopes of thorium, which are of natural origin. Radiation dose rates to vegetation were about 0.1 μGy h^{-1}; those to soil fauna ranged from 1 to 10 μGy h^{-1} (weighted), with gastropods (snails) receiving the highest doses.

When compared to the FRED database, the doses received by all organism groups were below the levels at which significant effects would begin to be seen (typically, about 100 μGy h^{-1}).

Several recommendations were made for the development of the FASSET methodology within ERICA including: DCC for internal radioactivity in plants, filling in gaps, limitations of reference organisms, and include additional radionuclides.

Selected Key References:

Beresford, N.A. and B.J. Howard 2005. ERICA. *Deliverable D9: Application of FASSET framework at case study sites.* Contract Number: FI6R-CT-2003-508847.

A.4 MANAGEMENT AND DISPOSAL OF SITES FOR RADIOACTIVE WASTES

A.4.1 Hanford Site – 300 Area

Description of Facility:

The 300 Area of the Hanford Site is located just north of the city of Richland, Washington. This area borders the Columbia River and covers 1.5 km^2. The U.S. DOE fabricated fuel for nuclear reactors in the 300 Area and utilized other 300 Area facilities for research and development purposes. The site contains approximately 220 facilities and 70 soil waste sites, including solid and liquid waste disposal areas and soil contamination areas. The site also contains 32 miles of contaminated underground piping. The disposal areas and plumes of contaminated groundwater cover approximately 1.6 square miles. Approximately 27 million cubic yards of solid and diluted liquid wastes mixed with radioactive and hazardous wastes were disposed in ponds, trenches, and landfills in the 300 Area. Liquids percolated through the soil into the groundwater and the Columbia River

Remedies, which include excavation of contaminated soil, have been selected and construction began in the summer of 1997. As of June 2005, approximately 720,000 tons of contaminated soil and debris have been removed from the area and sent to the Environmental Restoration Disposal Facility. Additional remedial work is being undertaken. The selected remedy for contaminated groundwater in the 300 Area is monitored natural attenuation, but this interim remedy is in the process of being re-evaluated.

Substantial amounts of uranium and heavy metals, such as copper, are present in the 300 Area liquid waste streams. At the present time, all liquid waste is treated and released to the Columbia River.

A number of contaminants are present in groundwater at the 300 Area. Sampling locations selected for this study were centred near historic riverbank spring discharges and the contaminants of concern were primarily known groundwater contaminants (i.e., radionuclides).

Radionuclides and Environmental Levels:

Samples were collected from water, sediment, riparian and aquatic vegetation, fish, molluscs, crustaceans, aquatic insects and mice.

MAXIMUM RADIONUCLIDE CONCENTRATIONS MEASURED IN WATER AND SEDIMENT

Radionuclide	Water (Bq/m^3)	Sediment (Bq/kg)
Sr-90	7.5	0.96
Cs-137		8.5
U-234	2000	100
U-235	83	3.8
U-238	1800	91

Basis of Assessment:

Follows U.S. DOE Graded Approach and uses RESRAD-BIOTA.

Species and Pathways:

The Graded Approach includes Biota Concentration Guides (BCGs) derived for aquatic animal, riparian animal, terrestrial plant, and terrestrial animal reference organisms.

Methodology:

The U.S. DOE (2000) benchmarks for radionuclides are very conservative, and meant for screening purposes. They are focused on riparian or terrestrial wildlife receptors, utilize upper end pathways parameters, and assume complete absorption of both internal and external radiations of all types.

External and internal dose coefficients (DCs) are derived in the DOE Graded Approach and a radiation weighting factor of 20 is used for alpha radiation. In the investigation, a radiation weighting factor of 10 was also considered. The effect of size-specific radiation dose-factors was also investigated with RESRAD-BIOTA.

Dose Rate Criteria:

10 mGy/d for aquatic organisms; 10 mGy/d for terrestrial plants; 1 mGy/d for animals.

Conclusions:

Based on the maximum measured radionuclide concentrations the results did not exceed the screening index thus adverse effects are not expected. Uranium was the major contributor to radiological dose for both water and sediment pathways.

Although the maximum measured water and sediment data collected passed the initial screen, site-specific screening and assessment calculations were performed to test the DOE evaluation framework and the RESRAD-BIOTA code. The site-specific screen indicated no potential issues. The biggest contribution was still uranium isotopes in water, but the limiting organism was a riparian animal.

Selected Key References:

Antonio, E.J., S.L. Domotor, K.A. Higley and B.L. Tiller 2003. *The U.S. Department of Energy's Regulatory and Evaluation Framework for Demonstrating Radiation Protection of the Environment: Implementation at the Hanford Site.* (Submitted to IAEA for October 2003 Conference).

A.4.2 Bear Creek

Description of Facility:

Bear Creek is approximately 12.5 km long and is within the DOE Oak Ridge Reservation (ORR). This area contains waste derived from the Y-12 Complex. The Y-12 Plant was built in 1943 as part of the Manhattan Project, with its original mission being electromagnetic separation of uranium. Since being completed, the Y-12 Plant has also been used for chemical processing of uranium and lithium compounds as well as precision fabrication of components containing these and other materials. Wastes containing radionuclides, metals, chlorinated solvents, oils, coolants, polychlorinated biphenyls (PCBs), and others were disposed of at Bear Creek Valley. There are four major waste units and two Debris Burial Areas (DBAs) within the Bear Creek watershed. These areas contain hazardous and radioactive wastes derived from the Y-12 Complex.

Radionuclides and Environmental Levels:

Concentrations in soil (upper 4 inches), maximum and average, were used. Data from several locations in the Bear Creek watershed were used. Soil concentrations are used with limits for soil.

	Soil Concentration (Bq/g)	
	Highest Maximum (Road Side DBA – Undiluted)	**Highest Average (Bone Yard / Burn Yard)**
Cesium-137	0.18	
Plutonium-239	0.007	
Strontium-90		0.01
Technetium-99	2.8	0.81
Thorium-232	0.1	0.02
Uranium-234	60.9	3.5
Uranium-235	0.27	0.08
Uranium-238	9.4	5.5

Note: Concentrations converted from pCi/g provided in original reference

The Bone Yard / Burn Yard (BYBY) includes a previously capped hazardous waste disposal area. Subsurface discharges of radioactivity were detected via beta- and gamma- radiation surveys. The purpose of the DBAs was disposal of uranium- and thorium- containing waste.

Basis of Assessment:
Follows U.S. DOE Graded Approach and uses the RAD-BCG calculator.

Species and Pathways:
Mouse (white-footed deer mouse) selected as receptor of concern based on previous formal base line ecological risk assessment (BERA).

Methodology:
The U.S. DOE (2000) benchmarks for radionuclides are very conservative, and meant for screening purposes. They are focused on riparian or terrestrial wildlife receptors, utilize upper end pathways parameters, and assume complete absorption of both internal and external radiations of all types.

External and internal dose coefficients (DCs) are derived in the U.S. DOE Graded Approach and a radiation weighting factor of 20 is used for alpha radiation.

Dose Rate Criteria:
0.1 Rad/d (1 mGy/d)

Conclusions:
There are measurable levels in the soil; however, these do not pose a significant ecological risk. The primary radionuclides contributing to the dose are U-238, U-234 as well as Sr-90 in the case of the generic approach taken for the Bone Yard/Burn Yard and Cs-137 for the Road Site DBA.

Selected Key References:

Jones, D.S. and P.A. Schofield 2003. *Implementation and Validation of a DOE Standardized Screening Method for Evaluating Radiation Impacts to Biota at Long-Term Stewardship Sites.* U.S. Department of Energy, Oak Ridge National Laboratory. ORNL/TM-2003/76.

A.4.3 Chalk River

Description of Facility:

The Chalk River Laboratories (CRL) site is located in Renfrew County, Ontario, Canada on the shore of the Ottawa River, 160 km northwest of Ottawa. The site has a total area of about 4000 ha. The CRL site was established in the mid 1940s, and has a history of various nuclear operations and facilities, primarily related to research. Most of the nuclear and associated support facilities and buildings on the site are located within a relatively small industrial plant site area adjacent to the Ottawa River near the southeast end of the property. Various waste management areas for radioactive and non-radioactive wastes are located within the CRL property.

Radionuclides and Environmental Levels:

Radionuclide screening concentrations in water, sediment and soil were compared to screening benchmark values developed by the Oak Ridge National Laboratories (Blaylock *et al.*, 1993; Bechtel Jacobs, 1998), with corrections made to the parameterization of sediment-water partition coefficients (K_d) and bioconcentration factors (BCF), as well as the screening benchmarks provided by U.S. Department of Energy (DOE, 2000). Radionuclides were generally identified on the basis of the DOE benchmark and DOE water and sediment screening values for protection of aquatic life, and riparian wildlife. Radionuclides in soil were compared to the ORNL sediment values (no values available specifically for soil) and the DOE soil values for protection of terrestrial biota.

Basis of Assessment:

Radionuclides in air were compared to benchmarks derived from IAEA (1992) for H-3, C-14, Sr-90, I-131, Cs-137, and Pu-239, from Holford (1988) for Ar-41, and from Gorman (1986) for mixed fission product noble gases. Concentrations in air were mainly estimated values, since there is limited monitoring of these concentrations within the site.

Concentrations of contaminants were gathered from available site monitoring data (effluents, site surface water, groundwater, sediments and soils) and were estimated from recent loading data for releases to both air and water. The data are contained in annual performance and monitoring reports, as well as special investigation reports. The radionuclides in effluents are often reported as loadings and thus the concentration values were often estimates.

Species and Pathways:

Aquatic organisms such as snails, frogs, aquatic plants, fish, water shrew, blue heron, terrestrial plants, worms, robins and wood chucks were considered in the assessment.

Methodology:

This Ecological Effects Review (EER) follows available ERA guidance from the CCME (1996) and the U.S. EPA (1998). The approaches outlined in these documents are quite similar, notwithstanding some minor differences in terminology; however, neither document specifically addresses radionuclide issues. With respect to radionuclide risk assessment, common international practices are followed.

Dose Rate Criteria:

For radiation doses to biota levels of 1 to 10 mGy/day (40 to 400 µGy/h) have been widely used as benchmark values for possible reproduction or survival effects on individuals, but no measurable effects at the population level. A radiation benchmark value of 1 mGy/day (40 µGy/h) was used in this assessment for all organisms, recognizing that this is likely a conservative value for some.

Conclusions:

The results show that at most locations around the CRL site, radiation doses were below the benchmark value. However, some radiation doses exceed the benchmark value for aquatic organisms in at various locations (South Swamp and East Swamp in West Swamp and at Perch Lake Inlet 1). The aquatic organisms that may experience such doses include frogs, small fish, snails, aquatic plants, and riparian plants. Water shrews and great blue herons may also exceed the 40 µGy/h benchmark, if they are resident at the specified location; however, this is an unlikely scenario. It is unlikely that radiation effects on the local aquatic populations could be seen outside these areas.

Aquatic biota in the Ottawa River are predicted to all receive average and maximum doses below 1 mGy/d. Radiation doses terrestrial valued ecosystem components (VECs) within or near the Waste Management Areas are predicted to exceed 1 mGy/d under average conditions in two areas for invertebrates, plants, shrew, robin, woodchuck.

Doses to invertebrates and terrestrial plants inside of the waste management areas were predicted to be greater than 1 mGy/d with dose dominated by Sr- 90 in surface soil. Home range and habitat factors limit exposure to other terrestrial receptors at this site. In the waste management area containing Port Hope waste soil, the woodchuck was predicted to receive a dose of 51 mGy/d due to radon inhalation in the burrow. This dose is above 1 mGy/d; however, the literature suggests that doses in burrowing mammals may routinely exceed 1 mGy/d. In all other cases, doses in terrestrial biota within or adjacent to waste management areas were predicted to be below 1 mGy/d. The terrestrial VECs receiving doses above 1 mGy/d represent a few individuals within the confines of small waste management facilities. These doses are unlikely to lead to significant effects at the population level.

Based on this initial assessment, recommendations are developed either for more detailed ERA involving gathering of additional site information, or for an ongoing EEM program.

Selected Key References:

Advisory Committee on Radiological Protection (ACRP) 2002. *The Protection of Nonhuman Biota from Ionizing Radiation*. Report to the Canadian Nuclear Safety Commission. INFO-0730. June.

Bechtel Jacobs 1998. *Radiological Benchmarks for Screening Contaminants of Potential Concern for Effects in Aquatic Biota at Oak Ridge National Laboratory*. BJC/OR-80. Prepared by Bechtel Jacobs Company for the U.S. Department of Energy.

EcoMetrix Incorporated 2005. *Ecological Effects Review of Chalk River Laboratories.* Prepared for Atomic Energy of Canada Limited. January.

A.5 THE CHERNOBYL ACCIDENT

A great deal of scientific information concerning the effects of ionizing radiation has been developed from studies of non-human biota in the area surrounding the Chernobyl nuclear power plant. UNSCEAR 2000 provides a convenient summary of the results of studies up to 2000. The more recent report of the Chernobyl forum (EGE 2005) provides the most recent comprehensive overview of the Chernobyl data. The Chernobyl Forum arose from an initiative of the International Atomic Energy Agency (IAEA) in co-operation with the Food and Agriculture Organisation (FAO), the United Nations Office for Coordination of Humanitarian Affairs (OCHA), the United Nations Development Programme (UNDP), the United Nations Environment Programme (UNEP), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the World Health Organisation (WHO), and the World Bank, as well as the competent authorities of Belarus, the Russian Federation, and Ukraine. The work of the Chernobyl Forum has been accomplished by two expert groups: the Expert Group on Environment (EGE) and the Expert Group on Health (EGH).

There were three distinct phases of radiation exposure associated with the Chernobyl accident. UNSCEAR (2000) and EGE (2005) suggest that it is important to look at the effects of the Chernobyl accident within these corresponding time periods. In the first 20 days, radiation exposures were essentially acute due to the large quantities of short-lived radionuclides present in the passing cloud of contamination (^{99}Mo, ^{132}Te/I, ^{133}Xe, ^{131}I and ^{140}Ba/La). Most of these short-lived, highly radioactive isotopes deposited onto plant and ground surfaces and resulted in γ-irradiation of up to 20 Gy d^{-1}. However, for surface tissues and small biological targets (e.g., mature needles and growing buds of pine trees), there was a considerable additional dose rate from the β-radiation of the deposited radionuclides. High exposures to the thyroids of vertebrate animals also occurred during the first days/weeks following the accident from the inhalation and ingestion of radioactive iodine isotopes or their radioactive precursors.

The second phase of radiation exposure extended through the summer and autumn of 1986, during which time the short-lived radionuclides decayed and longer-lived radionuclides were transported to different components of the environment by physical, chemical and biological processes. Dose rates at the soil surface declined to much less than 10% of the initial values due to radioactive decay of the short-lived isotopes (EGE 2005). According to EGE (2005), approximately 80% of the total radiation dose accumulated by plants and animals was received within 3 months of the accident, and over 95% of this was due to β-radiation. The total cumulative dose in the first month from β- and γ-radiation was estimated to be 0.5 ± 0.2 Gy, and 0.6 and 0.7 Gy at the end of the second and third months, respectively.

The EGE (2005) report also defined a third (and continuing) phase of radiation exposure with chronic dose rates less than 1% of the initial values and derived mainly from ^{137}Cs contamination. With time, the decay of the short-lived radionuclides and the migration of much of the remaining ^{137}Cs into the soil have meant that the contributions to the total radiation exposure from the β- and γ-radiations have tended to become more comparable. (EGE 2005) notes that balance depends on the degree of bioaccumulation of ^{137}Cs in organisms and the behaviour of the organism in relation to the main source of external exposure from the soil.

Within the 30-km zone of Chernobyl, deposition of total beta activity and associated doses to plants were sufficient to cause short-term sterility and reduction in productivity of some species (Prister 1999). By August 1986, crops that had been sown prior to the accident began to emerge and growth and development problems[16] were observed in plants growing in fields with contamination densities resulting in (initial) estimates of dose rates to plants of the order of 300 mGy d^{-1}. According to Prister (1999), the deposition of β-emitting contamination onto plant tissues resulted in their receiving a significantly larger dose than animals living in the same environment. It is of interest to note that large, apparent, inconsistencies in dose-response observations occurred when the beta-irradiation component was not appropriately accounted for.

Reproduction anomalies, stand viability, and re-establishment of pine-tree canopies, were dependent on absorbed dose. Acute irradiation of *Pinus silvestris* at doses of 0.5 Gy caused detectable cytogenetic damage; at >1 Gy growth rates were reduced and morphological damage occurred; and at >2 Gy the reproductive abilities of trees were altered. Doses of less than 0.1 Gy

[16] Spot necroses on leaves, withered tips of leaves, inhibition of photosynthesis, transpiration and metabolite synthesis were detected, as well as an increased incidence of chromosome aberrations in meristem cells.

did not cause any visible damage to the trees. The radiosensitivity of spruce trees was observed to be greater than that of pines. At absorbed doses as low as 0.7 to 1 Gy, spruce trees had malformed needles, buds, and shoot growth. Of the absorbed dose to critical parts of trees, 90% was due to β-irradiation from the deposited radionuclides and 10% to γ-irradiation. As early as 1987, recovery processes were evident in the surviving tree canopies and young forests were re-established in the same place as the perished trees by replanting via reclamation efforts.

Within two months after the accident, the numbers of invertebrates in the litter layer of forests 3 to 7 km from the nuclear reactor were reduced by a factor of 30, and reproduction was strongly impacted (larvae and nymphs were absent). Doses of approximately 30 Gy (estimated from TLDs placed in the soil) had catastrophic effects on the invertebrate community, causing mortality of eggs and early life stages, as well as reproductive failure in adults. Within a year, reproduction of invertebrates in the forest litter resumed, due in part to the migration of invertebrates from less contaminated sites. After 2.5 years, the ratio of young to adult invertebrates in the litter layer, as well as the total mass of invertebrates per unit area, were no different from control sites; however, species diversity remained markedly lower.

The EGE (2005) report also noted that after the accident, the agricultural fields still yielded domesticated produce for a number of years, and many animal species, especially rodents and wild boars, consumed the abandoned cereal crops, potatoes and grasses as an additional source of forage. This advantage, along with the special reserve regulations established in the exclusion zone (e.g., a ban on hunting), tended to compensate for the adverse biological effects of radiation, and promoted an increase in the populations of wild animals, including game mammals (wild boars, roe deer, red deer, elk, wolfs, foxes, hares, beaver, etc.) and bird species (black grouse, ducks, etc). In addition, the Chernobyl Exclusion Zone has become a breeding area of white-tailed eagle, spotted eagle, eagle owl, crane and black stork.

The EGE (2005) reached a number of conclusions based on their evaluation of the Chernobyl data, including:

- Irradiation from radionuclides released from the Chernobyl accident caused numerous acute adverse effects in the non-human biota located in areas of higher exposure, i.e., up to a distance of few tens of kilometres from the release point. Beyond the exclusion zone, no acute radiation-induced effects on non-human biota were reported.
- The environmental response to the Chernobyl accident was a complex interaction among radiation dose, dose rate and its temporal and spatial variations, as well as the radiosensitivities of the different taxons. Both individual and population effects caused by radiation-induced cell death have been observed in plants and animals as follows:
  - Increased mortality of coniferous plants, soil invertebrates and mammals;
  - Reproductive losses in plants and animals;
  - Chronic radiation sickness of animals (mammals, birds, etc.).

- No adverse radiation-induced effect has been reported in plants and animals exposed to a cumulative dose of less than 0.3 Gy during the first month after the accident.
- Following the natural reduction of exposure levels due to radionuclide decay and migration, populations have been recovering from acute radiation effects. Population viability of plants and animals substantially recovered as a result of the combined effects of reproduction and immigration.
- The acute radiobiological effects observed in the Chernobyl accident area are consistent with radiobiological data obtained in experimental studies or observed in natural conditions in other areas affected by ionizing radiation. Thus, rapidly developing cell systems such as meristems of plants and insect larva were predominantly affected by radiation. At the organism level, young plants and animals were found to be more sensitive to acute effects of radiation.
- Genetic effects of radiation, in both somatic and germ cells were observed in plants and animals of the exclusion zone during the first few years after the Chernobyl accident. Both in the exclusion zone and beyond, different anomalies attributable to radiation continue to be reported from experimental studies performed on plants and animals; however the detrimental biological significance is not known.
- The recovery of affected biota in the exclusion zone has been confounded by the overriding response to the removal of human activities, e.g., termination of agricultural and industrial activities accompanied with the environmental pollution in the more affected areas. As a result, populations of many plants and animals have eventually expanded, and the present environmental conditions have positive effect on the biota in the exclusion zone.

Selected Key References:

Expert Group on Environment (EGE) 2005. *Environmental Consequences of the Chernobyl Accident and Their Remediation: Twenty Years of Experience*. Report of the Chernobyl Forum Expert Group “Environment”. STI/PUB/1239. IAEA, Vienna.

Prister, B.S. 1999. *Consequences of the Accident at the Chernobyl NPP for Agriculture of Ukraine.* Center of Privatisation and Economic Reform, Kiev, 1999. (In Russian).

A.6 SITES INVOLVING NATURALLY OCCURRING RADIOACTIVE MATERIALS (NORM)

A.6.1 Komi

Description of Facility and Study:

Industrial operations the Vodnyi area within the Komi Republic (Russia), have led an enhancement of naturally occurring radionuclides from the decay series of ^{232}Th and ^{238}U in soils, plants and animals. The area was originally associated with oil production with refineries, in Vodnyi from 1931 to 1950 radium was extracted from groundwater and from 1947-1956, there was also uranium and radium extraction from imported ores. The Vodnyi area comprises of a number of small contaminated sites.

Radionuclides and Environmental Levels:

Activity concentrations of uranium-thorium series radionuclides in soil from different locations within contaminated sites in the Vodnyi area of Komi (Bq kg^{-1} dw).

Radionuclide	Radionuclide activity concentration (Bq kg^{-1} dw)		
	Krokhal	Obzhig	Otvally
^{238}U	<4 - 48	950 - 2300	700 - 3600
^{234}Th	<4 - 48	950 - 2300	700 - 3600
^{234}U	<6 - 44	960 - 1200	860
^{230}Th	220 - 2600	6400 - 240000	61000
^{226}Ra	8200 - 68000	7000 - 14000	35000 - 82000
^{210}Pb	3400 - 26000	8400 - 10000	41000 - 48000
^{210}Po	3400 - 26000	8400 - 10000	41000 - 48000
^{232}Th	18 – 27	22	24
^{228}Th	1500 - 4100	10000	3900

Basis of Assessment:

The assessment was done following the FASSET approach. Using soil data: (i) activity concentrations in reference biota were predicted by application of appropriate FASSET concentration ratios (CRs), (ii) external dose rates to reference biota through the application of appropriate external dose conversion coefficients (DCCs) and (iii) effects for selected organisms using the FRED database. Each of these predictions was then compared with actual measurements and observations made in the field.

Species and Pathways:

FASSET uses reference organisms. The reference organisms used in this assessment include soil invertebrates, grass, shrub, detritivore, small herbivore mammal, burrowing mammal and carnivorous mammal.

Methodology:

The assessment followed the FASSET approach. DCCs are provided for a range of geometries and sizes selected to be representative of the reference organisms. A radiation weighting factor of 10 for internally incorporated alpha radiations was recommended.

Dose Rate Criteria:

A review of available radiation effects data was performed within the FASSET project and the information organised into a database (FRED – the FASSET Radiation Effects Database). Significant effects were observed above dose rates of 100 µGy h^{-1} in the FRED database with a "clear" effect occurring at 1 mGy h^{-1}.

Conclusions:

The overwhelmingly predominant component of radiation exposure arises from the presence of internally distributed (alpha-emitting) radionuclides. The upper end of the weighted dose rate for small mammals is above 1,000 μGy h^{-1} at which significant reductions in mammalian lifespan can be expected. Radiation effects on the morbidity and reproductive capacity of rodents were observed in the field at contaminated sites in the Vondnyi area of Komi.

The weighted dose rates received by soil invertebrates at the Krokhal site (contaminated by discharge of radium-rich groundwater) estimated using the FASSET methodology fall in the range 540-4,100 μGy h^{-1}. Studies at the Krokhal site, Vodnyi and its environs, have reported various effects on soil invertebrates.

A limited number of studies have been conducted involving the observation of effects on tufted vetch (*Vicia cracca*). However, the FASSET methodology does not allow the estimation of internal doses to plants. Effects include reduced survival and cytogentic effects including a greater number of variable mitosis and anaphases with aberrations in irradiated populations compared to controls. It is noted however, that mortality effects observed may be due to the chemical toxicity of species such as uranium rather than exposure to ionising radiation.

At other locations in the Komi area, Middle Timan and North Urals, the background levels of radioactivity are naturally enhanced. Plants and animals have adapted to live in these high radiation areas although the ERA framework would suggest a potential concern.

Selected Key References:

Beresford, N.A. and B.J. Howard 2005. ERICA. Deliverable D9: Application of FASSET framework at case study sites. Contract Number: FI6R-CT-2003-508847.

Beresford, N.A., B.J. Howard, C.L. Barnett 2007. (ERICA) *Application of ERICA Integrated Approach: Case Study Sites.* ERICA Deliverable D10. February.

A.6.2 Oil and Gas Off-Shore Platforms

Description of Facility and Study

In recent years, the focus on discharges of natural radioactivity from non-nuclear industries has increased. During oil and gas exploitation, large volumes of water (referred to as produced water, formation water or oilfield brines) are co-produced with the oil and gas and discharged into the sea. The MARINA II assessment (European Commission 2003) suggested oil and gas industries were responsible for a large portion of alpha activity discharged in Northern European marine waters.

In 2003, about 135 million m^3 of produced water was discharged to the North Sea from platforms on the Norwegian continental shelf. One issue associated with produced water is that it may contain elevated amounts of natural radionuclides, mostly radium isotopes, which have been leached from the surrounding geological material in the reservoirs.

Radionuclides and Environmental Levels:

ACTIVITY CONCENTRATIONS OF RADIONUCLIDES IN SEAWATER (EMPIRICAL DATA)

Radionuclide	Area		
	Impact zone mean concentration (range)	**North Sea mean concentration (range)**	**Background range in concentration**
Ra-226	1.6 (1.4-2.5) Bq m^{-3}	(1.5-8.5) Bq m^{-3}	1.3-3.1 Bq m^{-3}
Ra-228	n/d	1 Bq m^{-3}	0.04-3.7 Bq m^{-3}
Po-210	n/d	0.8 Bq m^{-3}	0.19-3.7 Bq m^{-3}
Pb-210	n/d	0.72 Bq m^{-3}	0.4-5.0 Bq m^{-3}

The impact zone is taken to be an area within a few 10s of km from the oil platforms.

Sediment concentrations were estimated using a sediment-water partitioning (K_d) approach. The following table summarizes the "excess" activity concentrations in the near impact zone of ^{226}Ra, ^{228}Ra, ^{210}Pb and ^{210}Po in water and sediments derived from anthropogenic activity alone.

Radionuclide	Seawater activity concentration* (mBq L^{-1})	Sediment activity concentration (Bq kg^{-1} dw)**
^{226}Ra	1	2
^{228}Ra	1	2
^{210}Pb	0.15	15
^{210}Po	0.15	3000

* assumed filtered

** exchangeable activity assumed to represent the total sediment-associated activity arising from the discharge

Basis of Assessment:

The assessment was done following the FASSET approach. Water concentrations were used along with concentration ratios (CR) to predict biota concentrations. These were benchmarked against empirical (measured) biota data. Absorbed dose was estimated using dose conversion coefficients (DCC) to estimate internal dose rate. DCCs were provided for a range of geometries and sizes selected to be representative of the reference organisms. Disequilibria in the natural decay series between ^{226}Ra and ^{214}Po made the application of an aggregated DCC inappropriate.

Species and Pathways:

FASSET uses reference organisms. The subset of the FASSET suite of reference organisms suitable for application in this marine case study includes phytoplankton, mollusc, crustaceans (pelagic-zooplankton and benthic) and fish.

Methodology:

The assessment followed the FASSET approach. A radiation weighting factor of 10 for internally incorporated alpha radiation was used. FASSET provides no guidance for the application of the environmental impact methodology to cases where technologically enhanced naturally occurring radioactive material (TENORM) forms the focus of the study.

Dose Rate Criteria:

A review of available radiation effects data was performed within the FASSET project and the information organised into a database (FRED – the FASSET Radiation Effects Database). For example, morbidity effects have been observed on fish/fish eggs (arguably the most sensitive truly-aquatic reference organism) at dose rates as low as 8.3 μGy h^{-1}.

Conclusions:

Using the FASSET methodology an internal dose rate of 0.03 μGy h^{-1} from excess Ra isotopes for all biota groups has been derived reflecting the fact that (i) most of the dose is derived from the weighted alpha component of ^{226}Ra and daughters (therefore the effect of a variable geometry is negligible) and (ii) all biota have the same CR value and therefore the same (predicted) body concentration of ^{226}Ra. Further analyses demonstrates that the predicted excess dose rate is in most cases < 20% of that arising from the occurrence of natural radionuclide in the marine environment. The dose rate excesses are orders of magnitude below those for which biological effects have been observed in aquatic systems.

Selected Key References:

Alexahin, R.M., S.V. Fesenko and N.I. Sanzharov 1996. *Serious Radiation Accidents And The Radiological Impact On Agriculture*. Radiat. Prot. Dosim. 64: 37-42.

Beresford, N.A. and B.J. Howard 2005. ERICA. *Deliverable D9: Application of FASSET Framework at Case Study Sites.* Contract Number: FI6R-CT-2003-508847.

European Commission 2003 *MARINA II. Update of the Marina project on the radiological exposure of the European Community from radioactivity in North European marine waters.* Office for official publication of the European Communities, Luxembourg. (as cited by Beresford and Howard 2005).