ENVIRONMENTAL ASSESSMENT FOR BRUCE RESTART: CALCULATING DOSES TO NON-HUMAN BIOTA.

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Abstract

An environmental assessment of returning Units 1 and 2 of Bruce A nuclear generating station to service from their temporary lay-up was carried out in 2005 and should be completed by mid-2006. It included an assessment of effects of environmental concentrations of radionuclides on aquatic and terrestrial biota.

A method of assessing doses to individual species of biota using data available for reference organisms was applied to conduct this assessment. This method is consistent with the draft proposals published by ICRP in November 2005.

Even though the regulatory bodies and scientific community have not achieved a full consensus on the regulatory limits on, or methodology for assessing doses to, biota, this paper demonstrates that a practical approach based on most recent research can be used successfully for the purposes of environmental assessments.

Background

The Bruce A and Bruce B nuclear generating stations are located on the eastern shore of Lake Huron north of Kincardine, Ontario. The Bruce A and Bruce B stations each consist of four CANDU® pressurized heavy water nuclear reactors. All four units of Bruce A station were shut down in late 1990s.

In 2001, Bruce Power LP (Bruce Power) took over operation of Bruce A and Bruce B from Ontario Power Generation (OPG), which is Ontario Hydro's successor, through a long-term leasing arrangement. Following the refurbishment of Bruce A Units 3 and 4 and an environmental assessment in 2002, Bruce Power subsequently returned Units 3 and 4 to service

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in January 2004 and October 2003, respectively. Both reactors have operated successfully since their restart.

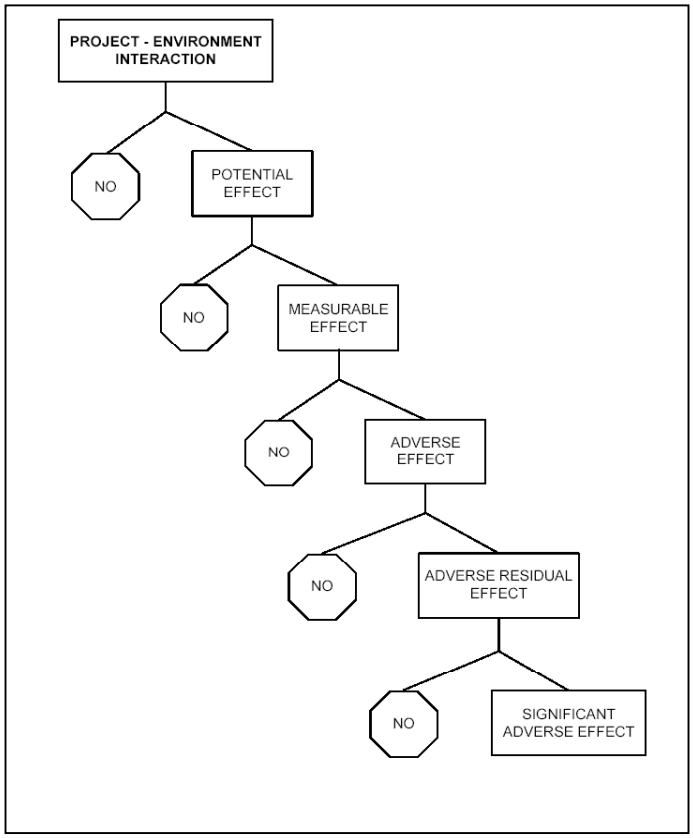
An environmental assessment of returning the remaining two Bruce A Units 1 and 2 to service from their temporary lay-up was carried out in 2005 and should be completed by mid-2006 . The Bruce A Refurbishment for life Extension and Continued Operations Project ("the project") involves implementing a series of refurbishments, upgrades and enhancements at Bruce A, improving safety while increasing electricity generation capacity and reliability for the extended life of these units and potentially Units 3 and 4. Golder Associates managed the overall assessment under a contract from Bruce Power. Nuclear Safety Solutions [Gerchikov *et. al*, 2005] carried out an assessment of the effects from radioactive releases.

Environmental Assessment Process

In accordance with the scope of the assessment, the process involved the following major steps:

- Describing the physical works and activities that constitute the project and identifying those that have a potential to interface with the environment;
- Assessing the likely environmental effects of the project, identifying mitigation measures and residual effects, and determining the significance of residual effects; and
- Conducting public and stakeholder consultation and
- Developing a follow-up programme.

Figure 1. Assessment of interactions between project and environmental components



Golder's assessment methodology includes a rigorous step-by-step process to demonstrate compliance with the requirements of the *Canadian Environmental Assessment Act*. Specifically, it includes a two-step approach of screening out insignificant interactions between the project and the various components of the environment, followed by a detailed assessment of remaining interactions and an assessment of significance before and after mitigation (see Figure 1). The assessment is conducted for normal operations and for malfunctions and accidents that have a reasonable probability of occurring.

In order to assess the impact of the proposed project on terrestrial and aquatic environments it was required to estimate the effects of radioactivity on Valued Ecosystem Components (VECs). VECs were identified based on the results of a public consultation and included 17 species of non-human biota.

Assessing Impact on Non-human Biota

Until recently it has been generally accepted that non-human biota is protected from radiation as long as humans are protected [ICRP, 1991]. Since the 1990s this position has been questioned [e.g Pentreath 1998, 1999, 2002].

As a result, considerable international efforts have been undertaken to develop scientifically correct and practically acceptable methodologies for assessing the possible impact on the environment from the effects of increased exposure to ionizing radiation, and, thus, to provide a basis for the protection of the non-human environment. Several relevant international documents have been prepared [e.g. UNSCEAR, 1996; IAEA, 1999]. A range of views relating to determining endpoints of concern, dosimetric issues and dose levels at which effects take place has been discussed in numerous recent publications.

In October 2005, ICRP published a draft report for consultation summarizing the previous work and outlining a concept of using reference animals and plants for radiation protection of biota [ICRP, 2005b]. This concept has been applied successfully in assessing species identified as VECs for the environmental assessment of the Bruce Power project.

Regulatory Framework

Currently, there are no internationally agreed criteria or policies that explicitly address protection of the environment from ionizing radiation, although many international agreements and statutes call for protection of biota against radiation [ICRP, 2005a]. However, there are various benchmarks available in the literature. These benchmarks are typically defined as dose levels at which populations of biota may suffer mortality, morbidity, loss of reproductive capacity or cytogenetic damage. Most notably, the Canadian Advisory Committee on Radiological Protection (ACRP) has recommended dose limits within the range of 1 to 10 mGy/d [Canadian Nuclear Safety Commission, 2002].

In the absence of agreed criteria or 'derived consideration limits' as they are called in the draft ICRP report [ICRP, 2005b], estimated doses were compared against several benchmarks, which are identified below.

Dose Assessment Approach

The following formulae were used to calculate the internal and external dose to aquatic biota:

$$(SedConc)_{nuclide} = (Water\,Conc)_{nuclide} \times CF^{sediment}_{nuclide} \times (solids\ fraction)$$

$$(Internal\,Dose)_{nuclide,organism} = (Water\,Conc)_{nuclide} \times CF^{organism}_{nuclide} \times DPUC^{internal}_{nuclide,organism}$$

$$(External\,Dose)_{nuclide,organism} = DPUC^{external}_{nuclide,organism} \times \left[(SedConc)_{nuclide} \times \left(fsed_{organism} + \frac{fsedsur_{organism}}{2} \right) + \frac{(Water\,Conc)_{nuclide} \times fwater_{organism}}{1000} \right]$$

Where:

- Sediment concentrations (*Sedconc*) are in Bq/kg dry weight;
- Water Concentrations (*WaterConc*) are in Bq/m^3 in the dissolved phase;
- Concentration Factors (*CF*s) are in m^3/kg;
- (*solids fraction*) is the fractional dry solids content of fresh sediment;
- *Dose rate per unit concentration (DPUCs)* are in μGy/h per Bq/kg fresh weight; and
- *fsed, fsedsur,* and *fwater* are the fraction of time the organism spends buried in sediment, at the sediment-water interface, and free-swimming in water, respectively.

For terrestrial biota:

$$(Soil\ Conc)_{nuclide} = (Air\ Conc)_{nuclide} \times CF^{soil}_{nuclide} \qquad (for\ H-3,\ C-14\ \&\ S-35)$$

$$(Internal\ Dose)_{nuclide,organism} = (Air\ Conc)_{nuclide} \times CF^{organism}_{nuclide} \times DPUC^{internal}_{nuclide,organism}$$

$$(Soil\ Conc)_{nuclide} = (Soil\ Conc\ (dry))_{nuclide} \times (solids\ fraction) \qquad (for\ other\ nuclides)$$

$$(Internal\ Dose)_{nuclide,organism} = (Soil\ Conc)_{nuclide} \times CF^{organism}_{nuclide} \times DPUC^{internal}_{nuclide,organism}$$

$$(External\ Dose)_{nuclide,organism} = DPUC^{external}_{nuclide,organism} \times$$
$$(SoilConc)_{nuclide} \times \left[(fsoil_{organism} + fsoilsur_{organism} / 2) + (reducn)_{radiationtype} \times fair_{organism}\right]$$

Where:

- Air concentrations (*AirConc*) for ^{3}H, ^{14}C and noble gases are in Bq/m^3, and the soil concentrations (*SoilConc*) for the other nuclides are in Bq/kg dry weight;
- Concentration Factors (*CF*s) for ^{3}H and ^{14}C are in Bq/kg (fresh weight) of soil or organism per Bq/m^3 in air, and for the other nuclides are in Bq/kg (fresh weight) per Bq/kg (dry weight) of soil;
- (*solids fraction*) is the fractional dry solids content of fresh soil;
- *DPUCs* are in μGy/h per Bq/kg fresh weight;
- *reducn* = 0.25 in this work (for high energy beta and gamma ray photons) [UK Environment Agency, 2003]; and,
- *fsoil, fsoilsur,* and *fair* are the fraction of time the organism spends buried in soil, at the soil-air interface, and above the soil surface, respectively.

Thus, in order to calculate doses to biota it is necessary to:

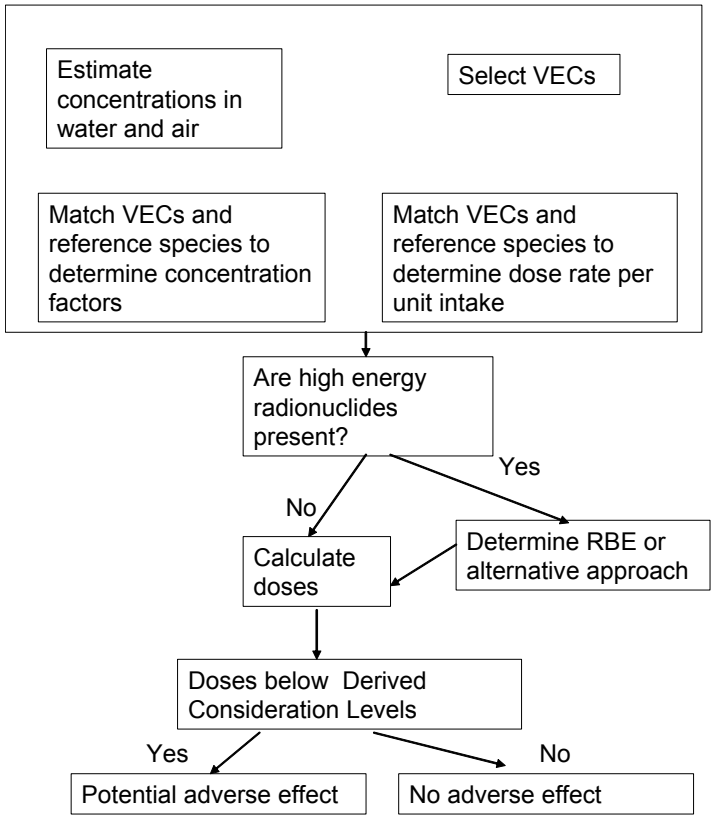
1. Estimate or, in the case of baseline values, measure radionuclide concentrations in water and air;

2. Derive dose rate per unit concentration values and concentration factors for each radionuclide-organism pair; and

3. Collate information on the organism's habits.

Since 2000, the international FASSET project has collated a wealth of data and proposed dose factors for unit internal and external radionuclide concentrations for a variety of species dimensions and geometries [Williams, 2004]. For aquatic organisms, the most comprehensive set of dose rate per unit concentration values for both external and internal exposure for most of the radionuclides has been reported by [Vives i Batlle *et. al.,* 2004]. For terrestrial fauna, similar calculations have been undertaken by [Taranenko *et al.*, 2004]. Although the method for determining impact from high-energy alpha-emitters by using the relative biological effectiveness factor (RBE) or alternative approaches is still been actively discussed in the scientific community, this has not been a concern for the assessment of the effects of the Bruce Power project.

Figure 2. Algorithm for assessing impact of radioactivity on biota



Whereas dose factors for reference organisms are readily available from the FASSET documentation, concentration factors are not provided. However, such concentration factors have been provided for a wide variety of reference organism types by [Environment Agency, 2003]. As these concentration ratios have been developed in the context of screening calculations for key organisms, they are considered particularly appropriate to VECs.

It was therefore necessary to match individual species, which were identified as VECs for the environmental assessment, with reference organisms for which dose assessment data are available. The matching was carried out on the basis of species dimensions for internal or external doses and on the basis of type and habitat for concentration factors. Once this had been completed there was sufficient information to estimate doses.

The main steps which were made to determine whether there were significant adverse effects from radiation on biota are illustrated in Figure 2.

Results

The results are summarized in Table 1 and Figures 3 and 4. It can be seen that dose rates predicted for the conditions when the refurbished units are operational are significantly below all benchmark criteria considered by several authors as well as international and national regulatory bodies. ICRP benchmark criteria are called "Derived Consideration Limits" [ICRP, 2005b].

Table 1. Comparison Of Estimated Dose Rate (mGy/d) To Benchmarks – Operations Phase Conditions

			Bench marks				
Source	**Calculated for Bruce EA 2005**	**ACRP**	**IAEA**	**UNSCEAR**	**Thompson**	**USA DOE**	**Thorne et. al.**
Species	**Dose Rate**						
Sago Pondweed (Aquatic Plant)	0.0023	1 to 10	10	10		10	10
Diporeia (Benthic Invertebrate)	0.0052	1 to 10	10	10	2.5	10	10
Deepwater Sculpin (Benthic Fish)	0.0134	1 to 10	10	10	1.25	10	10
Spottail Shiner (Pelagic Fish)	0.0124	1 to 10	10	10	1.25	10	10
Smallmouth Bass (Pelagic Fish)	0.0149	1 to 10	10	10	1.25	10	10
Lake Whitefish (Benthic Fish)	0.0149	1 to 10	10	10	1.25	10	10
Brook Trout (Pelagic Fish)	0.0133	1 to 10	10	10	1.25	10	10
Double-crested Cormorant (Aquatic Bird)	0.0059	1 to 10	10	1	1.25	10	10
Mallard (Aquatic Bird)	0.0217	1 to 10	10	1	1.25	10	10
Eastern White Cedar (Terrestrial Plant)	0.2476	1 to 10	10	10		10	10
Bald Eagle (Terrestrial Bird)	0.1337	1 to 10	1	1	1.25	1	10
Yellow Warbler (Terrestrial Bird)	0.1337	1 to 10	1	1	1.25	1	10
White-tailed Deer (Terrestrial Mammal)	0.1433	1 to 10	1	1	0.25	1	10
Muskrat (Terrestrial Mammal)	0.1433	1 to 10	1	1	0.25	1	10
Meadow Vole (Terrestrial Mammal)	0.1433	1 to 10	1	1	0.25	1	10
Midland painted turtle (Amphibian)	0.0021	1 to 10	1	1	0.25	1	10
Northern leopard frog (Amphibian)	0.0022	1 to 10	1	1	0.25	1	10

Figure 3. Impact on terrestrial biota

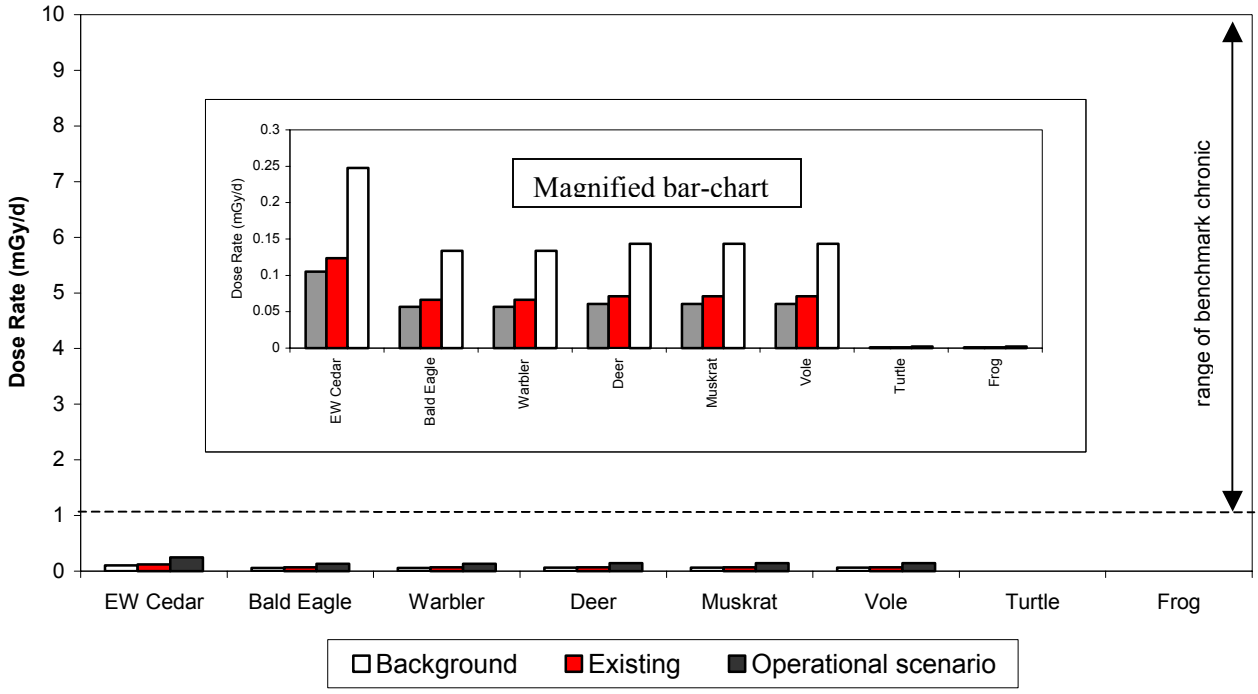
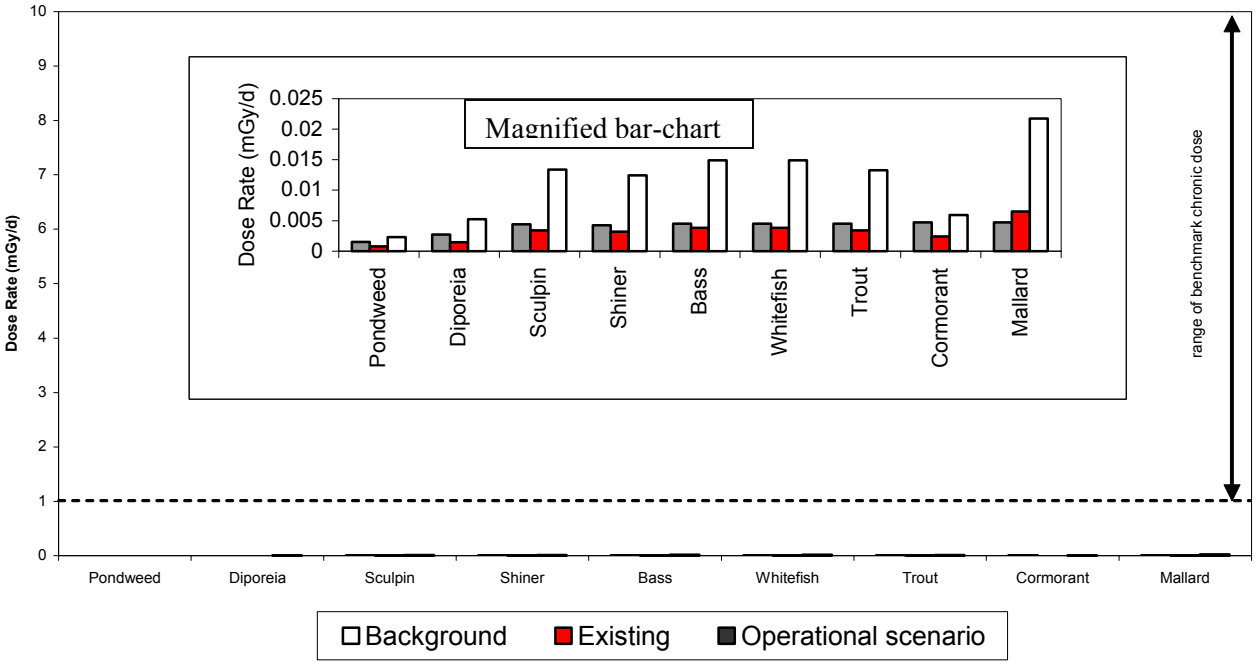


Figure 4. Impact on aquatic biota



Conclusion

A method of assessing doses to individual species of biota using data available for reference organisms was used in the environmental assessment of the Bruce A Refurbishment for Life Extension and Continued Operations Project. This method is consistent with the draft proposals published by ICRP in November 2005. It has been demonstrated that the dose assessment and concentration factor data available in the recently published literature are sufficient for such an assessment.

The regulatory bodies and scientific community have not achieved a full consensus on regulatory limits and methodology for assessing the impact on non-human biota. Nevertheless for levels and types of environmental radioactivity resulting from nuclear power plants it is possible to assess the likelihood of consequences using the data and criteria, which have a high level of confidence.

It has been demonstrated that environmental concentrations of radioactivity following restart and continued operation of all reactor units at Bruce A are not likely to result in any significant adverse effects on terrestrial or aquatic biota.

References

Canadian Nuclear Safety Commission (CNSC). 2002. *Protection of Non-Human Biota from Ionizing Radiation.* INFO- 0730. Prepared by ACRP. August 22.

Gerchikov M, Peng J, Badi K, Thorne M. 2005. *Radiation and Radioactivity Technical Support Document – Bruce A Refurbishment for Life Extension and Continued Operations Environmental Assessment.*

International Atomic Energy Agency (IAEA). 1992. *Effects of Ionizing Radiation on Plants and Animals at Levels Implied by Current Radiation Protection Standards*.

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

ICRP. 2005a. *2005 Recommendations of the International Commission on Radiation Protection (Draft for consultation).*

ICRP. 2005b. *The Concept and Use of Reference Animals and Plants for the Purposes of Environmental Protection (Draft for consultation).*

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

Pentreath R.J. 1998. *Radiological protection criteria for the natural environment*. Radiat Prot Dosim. 1998; 75:175-179.

Pentreath R.J. 1999. *A system for radiological protection of the environment: some initial thoughts and ideas*. J. Radiol. Prot. 19, 117-128.

Pentreath R. J. 2002. *Radiation protection of people and the environment: developing a common approach* J. Radiol. Prot. 22, 1-12.

V Taranenko, G Pröhl and J M Gómez-Ros. 2004. *Absorbed dose rate conversion coefficients for reference terrestrial biota for external photon and internal exposures.* J. of Radiol. Prot., Vol. 24, No. 4A, pp. A35-A62.

Thompson, P.M. 1999. *Assessment programme to fulfill the commitments of the nuclear safety commission*, Proceedings of the Second International Symposium on Ionizing Radiation and the Environment. Ottawa.

Thorne M,, Kelly M, Rees JH, Sanchez-Friera P, Calvez M.. 2002. *A Model for Evaluating Radiological Impacts on Organisms other than Man.* J. Radiol. Prot., 22, pp. 249-277

UK Environment Agency. 2003. *Habitats Regulations for Stage 3 Assessments: Radioactive Substances Authorisations, R&D Technical Report P3-101/SP1a*, Bristol, BS10 6BF, UK.

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). 1996. *Sources and Effects of Ionizing Radiation*. Report to the General Assembly, with Scientific Annex. United Nations Publication, ISBN 92-1-142219-1.

United States National Commission on Radiological Protection and Measurement (NCRP). 1991. *Effects of Ionizing Radiation of Aquatic Organisms*. NCRP Report 109.

Vives i Batlle et.al. 2004. *A method for calculation of dose per unit concentration values for aquatic biota*. J. Radiol. Prot., Vol. 24, No. 4A, pp. A13-A34.

Williams. 2004. *Special Issue: Framework for Assessment of Environmental Impact (FASSET) of Ionising Radiation in European Ecosystems*. J. Radiol. Prot., Vol. 24, No. 4A.