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IAEA-TECDOC-1808

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Performance of Models in Radiological Impact Assessment for Normal Operation

Report of Working Group 1 Reference Methodologies for Controlling Discharges of Routine Releases of EMRAS II Topical Heading Reference Approaches for Human Dose Assessment

Environmental Modelling for Radiation Safety (EMRAS II) Programme

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PERFORMANCE OF MODELS IN RADIOLOGICAL IMPACT ASSESSMENT FOR NORMAL OPERATION

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IAEA-TECDOC-1808

PERFORMANCE OF MODELS IN RADIOLOGICAL IMPACT ASSESSMENT FOR NORMAL OPERATION

REPORT OF WORKING GROUP 1
REFERENCE METHODOLOGIES FOR CONTROLLING
DISCHARGES OF ROUTINE RELEASES
OF EMRAS II TOPICAL HEADING
REFERENCE APPROACHES FOR HUMAN DOSE ASSESSMENT

ENVIRONMENTAL MODELLING FOR
RADIATION SAFETY (EMRAS II) PROGRAMME

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2017

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FOREWORD

Environmental assessment models are used for evaluating the radiological impact of actual and potential releases of radionuclides to the environment. They are essential tools for use in the regulatory control of routine discharges to the environment and also in planning measures to be taken in the event of accidental releases. They are also used for predicting the impact of releases which may occur far into the future, for example, from underground radioactive waste repositories. It is important to verify, to the extent possible, the reliability of the predictions of such models by a comparison with measured values in the environment or with predictions of other models.

The IAEA has been organizing programmes of international model testing since the 1980s. These programmes have contributed to a general improvement in models, in the transfer of data and in the capabilities of modellers in Member States. IAEA publications on this subject over the past three decades demonstrate the comprehensive nature of the programmes and record the associated advances which have been made.

From 2009 to 2011, the IAEA organized a programme entitled Environmental Modelling for Radiation Safety (EMRAS II), which concentrated on the improvement of environmental transfer models and the development of reference approaches to estimate the radiological impacts on humans, as well as on flora and fauna, arising from radionuclides in the environment.

Different aspects were addressed by nine working groups covering three themes: reference approaches for human dose assessment, reference approaches for biota dose assessment and approaches for assessing emergency situations. This publication describes the work of the Reference Methodologies for Controlling Discharges of Routine Releases Working Group.

The IAEA wishes to express its gratitude to all those who participated in the work of the EMRAS II programme and gratefully acknowledges the valuable contribution of T.J. Stocki (Canada), as the chair of the working group, and of A. Curti (Argentina), who assisted in the coordination and preparation of this publication. The IAEA is also grateful to R. Heling (Netherlands), who contributed significantly to the development of this publication. The IAEA officer responsible for this publication was D. Telleria of the Division of Radiation, Transport and Waste Safety.

EDITORIAL NOTE

CONTENTS

SUMMARY

Nuclear installations are designed, built, licensed and operated in order to prevent releases of radioactive materials to the environment. However, minor amounts of radioactive waste can be found in some of the gaseous or liquid effluents resulting from the normal operations and, according to International Basic Safety Standards (BSS) [1], there is a need to control and minimize the radiological impact to members of the public and the environment.

The control of the impact to public and the environment in the nuclear industry is based in the radiological protection principles of justification, dose limitation and optimization [2], which are incorporated in the IAEA Safety Standards as safety objectives and principles [3] and practical advice, in the form of requirements to governments, regulatory bodies and operators, described in the BSS [1], and technical safety guidance. Amongst those requirements, in order to control the radiological impact due to radioactive releases during normal operation, there is a need to conduct assessments that include the prospective estimation of the possible dose to members of the public.

Environmental assessment models are used for evaluating the radiological impact of actual and potential releases of radionuclides to the environment. They are essential tools for use in the regulatory control of routine discharges to the environment and also in planning measures to be taken in the event of accidental releases; they are also used for predicting the impact of releases which may occur far into the future, for example, from underground radioactive waste repositories. It is important to verify, to the extent possible, the reliability of the predictions of such models by comparison with measured values in the environment or by comparing them with the predictions of other models.

For the estimation of dose to members of the public, models which include mathematical representations of physical-chemical processes occurring in the environment are needed and different but consistent approaches can be applied by each modeller. It is important to ensure the consistency amongst the different approaches in order to provide tools for decision makers which enable similar conclusions to be reached for a similar exposure scenario, despite the possible differences in the results of the models. In order to compare different modelers' results, it is important that the exposure scenario including, for example, the radioactive source term, the location of the member of the public to be considered, the exposure pathways, and the habit data and food consumption rates necessary to run the models are agreed upon in advance. Consequently, the differences in the results are only due to the different models characteristics. The intention of this work is not to define good or bad models but to try to explain and justify, where possible, such differences. Then, decision makers can make appropriate decisions knowing the limitations in environmental modelling by, for example, making conservative assumptions and including appropriate safety margins.

This report presents the scenarios defined, the computational codes or methods used, the input parameters agreed upon and the results obtained. The majority of the input parameter values were chosen by the modellers and in many cases were taken from IAEA Safety Reports Series No. 19 (SRS 19) [4] or Canadian Standards Association (CSA) Guidelines N288.1 [5]. The idea was to standardize the parameter values used so that differences in the model characteristics could be highlighted.

1. INTRODUCTION

1.1. BACKGROUND OF THE EMRAS II PROGRAMME

The IAEA organized a programme from 2009 to 2011 entitled Environmental Modelling for Radiation Safety (EMRAS II), which concentrated on the improvement of environmental transfer models and the development of reference approaches to estimate the radiological impacts on humans, as well as on flora and fauna, arising from radionuclides in the environment.

The following topics were addressed in nine working groups:

Reference Approaches for Human Dose Assessment

- Working Group 1: Reference Methodologies for Controlling Discharges of Routine Releases
- Working Group 2: Reference Approaches to Modelling for Management and Remediation at NORM and Legacy Sites
- Working Group 3: Reference Models for Waste Disposal

Reference Approaches for Biota Dose Assessment

- Working Group 4: Biota Modelling
- Working Group 5: Wildlife Transfer Coefficient Handbook
- Working Group 6: Biota Dose Effects Modelling

Approaches for Assessing Emergency Situations

- Working Group 7: Tritium Accidents
- Working Group 8: Environmental Sensitivity
- Working Group 9: Urban Areas

The activities and the results achieved by the Working Groups are described in individual IAEA Technical Documents (IAEA-TECDOCs). This report describes the work of the Reference Methodologies for Controlling Discharges of Routine Releases Working Group.

1.2. BACKGROUND FOR EMRAS II – WORKING GROUP 1: REFERENCE METHODOLOGIES FOR CONTROLLING DISCHARGES OF ROUTINE RELEASES

The aim of Working Group 1 of the IAEA's EMRAS II Programme was to set up reference models for assessing radiological impacts from planned releases as well as existing exposure situations. The main objective was to carry out an intercomparison of methods used for assessing radiological impacts to people and the environment for three important types of exposure scenarios: atmospheric, marine and river releases. The objectives of the work are discussed in more detail in Section 1.3.

For this purpose, hypothetical exposure scenarios were defined based on information for real situations. For marine and atmospheric releases, the Scenario was partly based on the Sizewell B nuclear power station in the United Kingdom. For river releases, the Scenario was partly based on the NRU (National Research Universal) Reactor at Chalk River Laboratories. The scenarios are described in Section 2.

The following ten codes/programmes were used: CLRP, CROM, DOSAMED, DOSIS LIQUIDAS, IAEA SRS 19 methodology, IMPACT, PC-CREAM (versions 98 and 08), POSEIDON-R, RDEMO and SYMBIOSE. Descriptions of these models are presented in Section 3.

In an attempt to focus on differences in the results that were due to differences in model characteristics, the values of some parameters were fixed by the group. They were agreed upon at meetings and taken from various sources [4, 5] or were derived from the original information describing the release scenarios.

The selected radionuclides for each scenario were:

- Atmospheric discharges: ^{60}Co, ^{137}Cs, ^{131}I and ^{85}Kr;
- Marine discharges: ^{60}Co, ^{137}Cs and ^{90}Sr;
- River discharges: ^{60}Co, ^{137}Cs, ^{90}Sr, ^{131}I and ^{3}H.

An important part of the dose assessment procedure is the identification and definition of the group of individuals for which doses are to be assessed. Each modeler from each different country has their own approach and method to define the representative person (ex-critical group) and in some countries more than one approach could be applied. This is presented in Section 7 and discussed in Appendix III.

In order to collate information about the methodologies used in to control routine discharges of radionuclides to the environment, a questionnaire was distributed among the EMRAS II participants. The results of the questionnaire are discussed in Section 8 and the questionnaire form is included in Annex I for illustration.

1.3. OBJECTIVES

The overarching objective of the IAEA's activities in environmental modelling is to enhance the capabilities of Member States to simulate radionuclide transfer in the environment and, thereby, to assess exposure levels of the public in order to ensure an appropriate level of protection from the effects of ionizing radiation. Specific objectives in the areas of radioactive release assessment are:

- To test the performance of models developed for assessing the transfer of radionuclides in the environment and radiological impact on man and the environment;
- To develop and improve models for particular environments and, where appropriate, to agree on data sets that are generally applicable in environmental transfer models;
- To provide an international forum for the exchange of experience, ideas and research information.

Working Group 1 worked on methodologies to set up reference models for assessing radiological impacts from planned releases as well as existing exposure situations. The aim was to carry out an intercomparison of methods used for assessing radiological impacts to people and the environment for three important types of discharge scenarios. For this purpose, hypothetical exposure scenarios were defined based on information for real situations, the input data and parameters for the models were agreed upon and each modeler ran their own tools. The results were then compared and the conclusions, which may be used to improve the standardization and harmonization of assessment methodologies, are presented in this report.

2. THE EXPOSURE SCENARIOS

2.1. THE SIZEWELL B SCENARIO

2.1.1. Scenario description

This Scenario is partly based on the Sizewell B nuclear power station which is located in the United Kingdom.

Sizewell B is a pressurized water reactor of 1250 MW electrical power output, located on the Suffolk coast in the east of England. It started generating electricity in February 1995. "Sizewell B is co-located at the same site as Sizewell A, which has twin Magnox reactors. Sizewell A ceased generating electricity at the end of 2006" [6][1].

"The Sizewell site is located about 3 km from the villages of Leiston and Thorpeness, at 52° 13' North by 1° 37' East. Authorized discharges are made to atmosphere via stacks on the site (effective height 19 m), and to the North Sea via pipelines" [6]. A radiological habits survey was completed in 2005 [7]. The data from this survey were used as input to the Sizewell B Scenario, however, rather than use the actual radionuclides and quantities discharged, for the purposes of the EMRAS II Working Group a hypothetical inventory was considered.

2.1.2. Marine discharges

It was assumed that discharges of 1 GBq in a year of ^{137}Cs, ^{60}Co and ^{90}Sr are made from Sizewell B to the North Sea.

There is evidence of commercial fishing for a wide variety of fish and shellfish along the Suffolk coast. A habit survey conducted in 2005 has shown high rates of consumption of fish, crustaceans and molluscs with intakes of 23.0, 11.2 and 5.1 kg fresh weight per year respectively. The survey also shows that those individuals most exposed to beach sediments spend some 731 hours per year over intertidal sediments. These intake rates and occupancy factors have been used in the Sizewell B Scenario dose assessment.

The location of the exposed individuals and marine biota was assumed to be on the coast immediately adjacent to the site, which is a distance of 600 m from the site center. Consequently, for marine dispersion models based on a compartmental model approach it is assumed that both individuals and biota inhabit the nearest compartment to the site and the one into which the discharge occurs. For models which are based on a dispersing plume it was assumed that the discharge occurred immediately at the coastline and that the exposure occurred 600 m 'down-stream' of the discharge point.

Incidental intake of sediments was not recorded in the habit survey for Sizewell B but this exposure pathway has been included and the parameters used were the number of days per year that sediment intake can occur (45 days) and incidental intake of sediment per day ($3.3\ 10^{-4}$ kg dry weight per day), based on default values [5, 8].

In summary, adult committed effective doses have been calculated for exposures received during the 50th year of operation of the site. The exposure pathways considered are: ingestion of fish, crustaceans and molluscs, external exposure to intertidal sediments and inadvertent ingestion of sediments.

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[1] Publication [6] presents a summary and the preliminary results of the work done by EMRAS II Working Group 1 of EMRAS II IAEA. The present publication corresponds to the final report.

2.1.3. Atmospheric discharges

It was assumed that discharges of 1 GBq in a year of ^{85}Kr, ^{60}Co, ^{131}I and ^{137}Cs are made from Sizewell B via a 19 m stack to the atmosphere.

The habit survey [7] reports that there are 11 working farms within 5 km of the site which include 6 arable lands, 3 cattle, 1 dairy and 1 pig farm. It also notes that there is a potential site for grazing sheep and cattle (beef and dairy) 1 km from the site. In addition, there are 24 residences within 1 km of the site (11 residences 0–0.25 km, 5 residences 0.25–0.5 km and 8 residences 0.5–1.0 km) and a public house 500 m to the south of the site. Based on this information it was decided that the location of the representative person would be 300 m from the discharge point. This is also assumed to be the location of the nearest production of green vegetables, root vegetables and fruit. The production of cow milk, cow meat and sheep meat is located at 1 km from the site and all animal feed is also assumed to be produced here. The direction of these receptor locations is not required because it is assumed that the wind blows equally often in all directions and that the frequency with which different meteorological conditions occur is the same in each direction. The meteorological dispersion conditions were assumed to be Pasquill Stability Class D, 100% of the time.

From the habit survey data it is assumed that the representative person spends 7150 hours at the chosen receptor point, i.e. 300 m from the site, and of this time 20% is spent outdoors. The ingestion of each foodstuff also comes from the habit survey. In terms of fresh weight consumption the values used are; green vegetables 65.6 kg y^{-1}, root vegetables 110.9 kg y^{-1}, fruit 42.4 kg y^{-1}, cow milk 208.4 L y^{-1} and sheep meat 2.4 kg y^{-1}. For cow meat the survey reported an intake of 15.8 kg y^{-1} but this has been increased in this study to 28 kg y^{-1}.

In summary, adult committed effective doses have been calculated for exposures received during the 50th year of operation of the site. The exposure pathways considered are: inhalation of the radioactive plume, direct exposure from immersion in the plume and to material deposited on the ground, ingestion of green vegetables, root vegetables, fruit, cow milk, cow meat and sheep meat, and direct irradiation from the site (this latter dose is reported in RIFE 13 (Table A4.1) [9] to be 4.0 µSv/a). The exposure arising from inhalation of resuspended material is not considered as this is not expected to be significant during the operation of the site.

For reference, it is worth noting that the UK Environment Agency has published its own radiological assessment for Sizewell B based on the actual discharge data [10].

2.2. THE CHALK RIVER SCENARIO

2.2.1. Scenario description

Scenario C is partly based on the National Research Universal (NRU) 135 MWt Reactor at Chalk River Laboratories (CRL).The NRU is one of Canada's national science facilities. It serves 3 main roles: the generation of medical isotopes which are used to diagnose or treat over 20 million people world-wide; as the neutron source for a materials research center; and as the test bed for Atomic Energy of Canada Limited (AECL) to develop fuels for CANDU reactors. The NRU started self-sustained operation in 1957. It is fuelled by natural uranium. It does not produce electricity.

Chalk River Laboratories (CRL) is near the town of Chalk River, Canada, about 180 km north-west of Ottawa, Ontario, Canada on the banks of the Ottawa River. A radiological assessment report detailing the calculation of Derived Release Limits for AECL's Chalk River Laboratories was used to inform Scenario C [11]. In this scenario, only discharges to the river were considered. The discharge site was the CRL CA2 process sewer, which is located at 317500 5102700 in UTM (46°3'12.6756" latitude, -77°21'33.106" longitude). In this scenario, it was assumed that discharges of 1 GBq in a year of ^{60}Co, ^{137}Cs, ^{90}Sr, ^{131}I and ^{3}H are made from NRU to the Ottawa River. It was decided by the group that ^{3}H would not include organically bound tritium.

2.2.2. River discharges

For this scenario, it was decided that the representative person was located 8.64 km downstream in the community of Harrington Bay, which is located on the opposite site of the Ottawa River from CRL. The slope of the river is such that it descends by 2 m over 10 km. From a private communication with Adrienne Ethier from CRL, the complete full mixing distance is at Harrington Bay. In reality, the residents of Harrington Bay largely obtain their drinking water through a well water system, however for the purpose of Scenario C it was instead assumed that they get their water directly from the Ottawa River, with their intake located at 324000 5097000 (46°0'14.2668" latitude, -77°16'23.286" longitude). Based on the DRL document, additional assumptions for the residents of Harrington Bay include that they reside in this location on a full-time basis, spend 20% of their time outside, swim in the Ottawa River during the summer months, spend a fraction of their time walking on the shoreline, maintain a small garden from which they supply a fraction of their fruits and vegetables, irrigate their lawns and gardens with river water and fish in the Ottawa River for a fraction of their fish ingestion [11].

According to the DRL document, Westmeath Farm, located at 352000 5077000 (45°49'50.4228" latitude, -76°54'19.987" longitude), 53 km downstream on the same bank of the river as CRL, is the nearest farm location that could be influenced by river releases from CRL [11]. Westmeath farm includes cattle (beef and milk), chicken (poultry and eggs) and pigs (pork), although pork ingestion was not considered in this scenario. For the purpose of the scenario, it was assumed that 100% of the beef, milk, poultry and eggs ingested by residents of Harrington Bay were obtained from Westmeath Farm, although in reality this is not the case. It was also assumed all animal feed used by the Westmeath Farm is grown on site and irrigated with untreated river water and that all water for the animals came directly from the river. In order to include a wild game food source it was assumed that deer (venison) were hunted in the area near the Westmeath Farm; in this case it was assumed they feed on wild forage (not irrigated with river water) but also obtain their water from the Ottawa River, with the venison again going to residents of Harrington Bay.

The following pathways and parameters were considered in the model:

- Ingestion of drinking water (Intake rate: 840 L y^{-1});
- Ingestion of freshwater fish (Intake rate: 4.1 kg y^{-1});
- External exposure to sediment (fraction of the year: 0.02);
- External exposure to irrigated soil (garden, lawn) (fraction of the year: 0.2);
- Immersion in river water for swimming in summer months, and bathing year round (fraction of the year: 0.014);
- Incidental ingestion of sediment (Intake rate: 0.00033 kg d^{-1} during 45 d y^{-1});

- Incidental ingestion of irrigated soil (Intake rate: 0.33 kg d^{-1} during 135 d y^{-1});
- Ingestion of food from the Westmeath farm: venison (deer) (8.6 kg y^{-1}); beef (cow) (73 kg y^{-1}); milk (cow) (285 L y^{-1}); poultry (chicken) (21 kg y^{-1}) and eggs (chicken) (32 kg y^{-1});
- Ingestion of fruits (187 kg y^{-1}); above vegetables (253 kg y^{-1}) and potatoes (112 kg y^{-1}) from their personal gardens.

The full list of input parameters can be found in Appendix I. The end points were the doses from the various pathways to adult residents of Harrington Bay.

3. MODEL DESCRIPTIONS

3.1. CONCENTRATIONS LEVEL RAPID PREDICTION MODEL (CLRP)

The CLRP (Concentrations Level Rapid Prediction)[2] model, was created in 1989 as a part of research project "Long-Lived Post-Chernobyl Radioactivity and Radiation Protection Criteria for Risk Reduction" performed in cooperation with the US Environmental Protection Agency. The aim of this project was to examine the fate of long-lived radionuclides in the terrestrial ecosystem. In the years that followed, the model was intensively developed and extended for other radionuclides, especially for iodine.

The initial aim of this code was to examine the fate of some radionuclides in the ecosystem and specifically to model the transport of radionuclides through the environment to the human body. The Input Parameters Database allowed the radiological impact to be evaluated for up to 20 radionuclides of 44 elements in a single scenario, including I, Cs, Ru, Te and Sr.

All dynamic processes were described by differential formulas and are solved numerically. Radionuclide concentrations, in particular components of the terrestrial ecosystem e.g. soil, vegetation, animal tissues and animal products, are calculated as a function of time based on a calculated deposition from the atmosphere. The model considers seasonal changes in the biomass of vegetation and animal diets, and specific dates for ploughing and harvesting of crops are included. Human dietary data were included to enable calculation of time-dependent radionuclide ingestion rates as well as the critical organ content of radionuclides for seven different age groups.

The program can calculate doses from the following pathways: external (cloudshine, groundshine exposure); internal (inhalation, ingestion) and is designed to simulate many different radiological situations (chronic or acute releases) and countermeasures that affect dose such as food bans, sheltering and stable iodine prophylactics.

During the period from 1989 to 1995 a validation of the CLRP code performance for ^{137}Cs was carried out as part of a number of IAEA programmes. These included BIOMOVS (BIOspheric Model Validation Study) and BIOMOVS II, initiated by the Swedish Radiation Authority in 1985, and the programmes sponsored by the IAEA: VAMP (Validation of Model Predictions, 1988–1996) and BIOMASS (BIOsphere Modelling and ASSessment, 1996–2001).

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[2] Developer P. Krajewski (Central Laboratory for Radiological Protection) – Poland.

In 2007, a new version of the CLRP code (version 7.0) was written using Microsoft Visual Basic 6.5 for Microsoft Office Excel 2007. This was developed as an 'Add-in' application. In 2008 the CLRP code was updated to include a GIS driver to produce maps of specific zones. In addition, for EMRAS II purposes, the CLRP code parameters were set up according to SRS 19 [4]. The code performance was checked using data in Annex IV 'Example calculations' of SRS 19 [4].

3.2. CROM

CROM is a generic environmental model code developed by the CIEMAT in collaboration with the Polytechnic University of Madrid based on SRS 19 [4] with some variations from Radiation Protection 72 (RP 72) [12]. In order to estimate the radionuclide concentrations in the environmental media, the quantities and types of radionuclides to be discharged, the mode and characteristics of the discharge and the receptor points needs to be specified.

The atmospheric dispersion model is a Gaussian plume model designed to assess annual average radionuclide concentrations in air and the rate of deposition at various points in the region of interest (validated for distances <20 km) from long term releases, provided that 30 years of continuous emission and neutral atmospheric conditions are deemed appropriate [4]. The model accounts for the effects of any buildings in the vicinity of the release. The basic meteorological variables required for each individual air concentration calculation are the wind direction and the geometric mean of the wind speed at the physical height of the release point, however the height resulting from the rise of the effluent plume owing to thermal or mechanical effects is not considered. "The code allows the use of other diffusion factors, for different stability categories than D and effective heights, but does not calculate them" [6].

The surface water models account for dispersion in rivers, small and large lakes, estuaries and along the coast of seas and oceans. These models are based on analytical solutions to advection-diffusion equations describing radionuclide transport in surface water with steady state uniform flow conditions. The contamination of surface water from routine discharges to the atmosphere is considered for small and large lakes [4, 6]. All the models contain a great quantity of default values that can be used in absence of local specific information.

The terrestrial food chain models accept radionuclide sources from both the atmosphere and the hydrosphere and take account of the build-up of radionuclides on surface soil over a 30 year period:

> "The process of radioactive decay and build-up is taken into account in the estimation of the retention of radionuclides on the surfaces of vegetation and on soil, and in the assessment of the losses owing to decay that may occur during the time between harvest and vegetable consumption. The food categories considered are milk, meat and vegetables. The uptake and retention of radionuclides by aquatic biota uses selected element specific bioaccumulation factors that describe an equilibrium state between the concentration of the radionuclide in biota and water. The types of aquatic food considered are freshwater fish, marine fish and marine shellfish. The estimated radionuclide concentrations in air, soil, sediment, food and water (representative of 30 years of discharge) are combined with the annual rates of intake, occupational factors and the appropriate dose conversion coefficients to obtain the maximum effective dose in one year for the combined external and internal exposure" [6].

The dose conversion coefficients for internal exposure are taken from the Safety Series No. 115[3] [13] while for external exposure they have been calculated based on the coefficients and equations given in the Federal Guidance Report No. 12 [14]. The model takes into account external gamma dose rates from radionuclides due to cloud immersion, soil and sediments deposition and water submersion (for gamma and beta exposure). The effective doses from external exposure and radionuclide intakes are calculated for the six age categories recommended by the IAEA [13] and ICRP [2].

3.3. DOSAMED

DOSAMED is a code developed by the Nuclear Regulatory Authority (ARN) in 1989 for assessing doses in the critical group due to atmospheric routine releases during normal operation of radioactive and nuclear facilities. It is based on the models presented in SRS 19 [4] and is applicable to every radionuclide of interest, from the radiological point of view, except for ^{3}H and ^{14}C; and for the critical groups of different facilities.

The updated DOSAMED version in 2011 has the possibility of splitting the critical group location into foodstuff production site and foodstuff consumption site. The model considers the following critical exposure pathways:

- Inhalation;
- External exposure due to surface contaminated owing to air deposition;
- Submersion in air;
- Ingestion of green and root vegetables, fruit, cow meat and cow milk.

DOSAMED code includes databases with the following parameters, which can be modified by the operator:

- Transfer parameter and dose coefficients for every radionuclide;
- Atmospheric dispersion factors for every critical group location, for vegetables production site and the milk and meat production site;
- Consumption rates for critical exposure pathways;
- Breathing rate.

The other parameters used by the source code are selected by default. Two age groups are considered for estimating annual dose to the critical group:

- 1 year old (infant);
- Adults.

3.4. DOSIS LIQUIDAS

DOSIS LIQUIDAS is a model used by the Nuclear Regulatory Authority for the critical group dose assessment due to routine liquid radioactive releases. It is appropriate for modelling radioactive discharges to rivers and lakes during normal operations. It is based on SRS 19 generic environmental models [4] and assumes complete mixing in the receptor surface water body.

[3] This Safety Series has been superseded by IAEA Safety Standards Series No. GSR Part 3 [1].

The following critical exposure pathways are considered:

- Internal exposure due to drinking water ingestion;
- Internal exposure due to fish ingestion;
- External exposure from activity in shore/beach sediment;
- External exposure from immersion.

The dose estimation is performed taking into account parameters describing the surface water reception body such as: the annual river flow rate, concentration of suspended sediment and the effective accumulation time of the shore/beach sediment. Other necessary parameters are ingestion rates and exposure time during working/playing over contaminated sediments and swimming/taking baths.

It is possible to change all parameters, including transfer and dose conversion factors.

3.5. IAEA SAFETY REPORTS SERIES NO. 19 (SRS 19)

IAEA Safety Reports Series No. 19 (SRS 19) [4] is a method published by the IAEA which comprises generic models for use in assessing the impact of discharges of radioactive substances to the environment. SRS 19 [4] provides simple spreadsheet-based methods for calculating doses arising from radioactive discharges into the environment. A generic environmental screening methodology takes account of dilution and dispersion of discharges into the environment.

A Gaussian plume model is applied to assess the dispersion of long term atmospheric releases. As the plume moves downwind, removal by radioactive decay and depletion by dry and wet deposition is considered.

For aquatic releases to a river or to a sea, the generic methodology is based on analytical solutions to advection–diffusion equations describing radionuclide transport in surface waters with steady state, uniform, flow conditions.

For ingestion of radionuclides, terrestrial and aquatic food chain models are used to estimate activity concentrations in various environmental materials, i.e. human food crops and animal produce, including milk and meat. A compartment model is used to estimate concentrations in linked compartments.

The estimation of total individual doses needs dosimetric, habit and other data as input. The estimation covers external doses from airborne radionuclides and from deposited activity, and inhalation and ingestion due to intake of radionuclides.

The dose coefficients of the inhalation and ingestion pathways are applied with the values presented in various ICRP publications [15–18]. The dose coefficients for external exposures, including submersion in noble gases, radioactive deposits on ground surfaces, and sea-shore activities are applied with the values from the Federal Guidance Report [14].

3.6. INTEGRATED MODEL FOR THE PROBABILISTIC ASSESSMENT OF CONTAMINANT TRANSPORT (IMPACT)

The Integrated Model for the Probabilistic Assessment of Contaminant Transport (IMPACT) model (EcoMetrix Inc.) is based on Canadian Standard Association (CSA) Standard N288.1 [5]. Both IMPACT and the N288.1 standard are used to calculate Derived Release Limits (DRL) for nuclear facilities, but can also be used to estimate annual doses to public through the use of models which represent the transfer of radioactive material across the

environment to humans. The version of IMPACT used calculates individual doses to a selected human receptor. It does not calculate collective doses. The IMPACT model is intended for the case of routine releases (i.e. steady state conditions) and not for acute or accidental releases. Both atmospheric and aquatic releases are allowed. Aquatic releases may be to a lake, river, pond or marine environment. Atmospheric releases are modelled using a Gaussian plume model. Aquatic releases are modelled as a plume based on the 1986 report by Gorman [19] for marine releases, and NCRP 123 [20] for river releases.

IMPACT allows the user to build exposure pathways as appropriate for the selected human receptor. Exposure pathways may include: Immersion in air; Inhalation of air; External exposure to soil; Incidental ingestion of soil; Ingestion of terrestrial plant produce; Ingestion of terrestrial animal produce; Ingestion of aquatic animal produce; Ingestion of aquatic plant produce; External exposure to sediment; Incidental ingestion of sediment; Ingestion of water; and Immersion in water. IMPACT allows for interactions between each of the compartments along these pathways. For instance, ingestion of water, feed and soil by a cow can be taken into account when calculating the concentration in meat. At any point in these pathways, monitors can be setup to determine the concentration in a compartment of interest. In addition to the options pre-supplied in IMPACT, the user is also able to develop and describe their own compartments. For instance, the user may need to develop an option for a type of wild game not accounted for in the pre-supplied options.

3.7. CONSEQUENCES OF RELEASES TO THE ENVIRONMENT: ASSESSMENT METHODOLOGY (PC-CREAM)

PC-CREAM (Consequences of Releases to the Environment: Assessment Methodology) is a suite of models and data for assessing the radiological consequences of routine aerial and liquid radioactive releases for members of the population of concern. The new version of PC-CREAM is known as PC-CREAM 08 and is based solidly on its predecessor, PC-CREAM 98.

PC-CREAM 08 can be divided into two main parts: a set of ‘Models’ that predict the transfer of radionuclides through the environment and calculate environmental concentrations; and ‘ASSESSOR’ which calculates effective doses based on the results of the models. Details of the models and data are given in the accompanying methodology report [21].

Models

PLUME is the atmospheric dispersion model used within PC-CREAM 08. It is a Gaussian plume model [22] and is used to calculate activity concentrations in air, deposition rates and external gamma dose rates from radionuclides in the cloud at various distances downwind of the release point (inhalation of the radioactive plume and gamma rays from cloudshine).

RESUS, is the model to estimate resuspension used within PC-CREAM 08. The model is based on a formula derived using data following Chernobyl [21] and can be used to estimate activity concentrations in air arising from the resuspension of previously deposited radionuclides (inhalation of the resuspended activity).

GRANIS models external exposure to gamma radiation from radionuclides deposited on the ground (groundshine gamma rays) [21].

FARMLAND is a suite of compartmental models that can be used to predict the transfer of radionuclides into terrestrial foods following deposition onto the ground (ingestion of food) [21].

DORIS is the marine dispersion model used in PC-CREAM 08 and is based closely on the MARINA II model [23]. This compartmental model can be used to predict the activity concentrations in sea water, sediments and marine biota (ingestion of marine biota, sediment beta and gamma, inhalation of seaspray).

PC-CREAM 08 includes two models for calculating the dispersion of radionuclides released to rivers [21], a simple dilution model and a time dependent compartmental model (ingestion of fish and water, beta particles and gamma rays from sediment).

ASSESSOR

Once activity concentrations in environmental media have been calculated using the various models they can be used in ASSESSOR to calculate effective doses. These include individual and collective doses from discharges to the atmosphere and sea and individual doses from discharges into rivers. The results of the models are combined with actual discharge rates, site specific data, habit data and dose coefficients to calculate effective doses for various exposure pathways.

3.8. POSEIDON-R

The POSEIDON-R (POSEIDON/RODOS) model is a modified version of the original POSEIDON-PC software for individual and collective dose assessments for routine and emergency releases to the marine environment from both atmospheric fallout and direct discharges into the marine environment [24–27]. The direct releases are from rivers, land-to-water, or from coastal nuclear installations. POSEIDON-R is able to assess accidental releases from sources placed at any place of the calculation domain and any depth, including the seabed. The model is a component of the Realtime Online DecisiOn support System for nuclear emergencies (RODOS).

POSEIDON-R is compartment model that includes a radionuclide transport module, a food chain module and a dose module to predict individual and collective doses from seafood consumption and several other pathways. The model is able to describe the water transport both in horizontal and in vertical directions. The suspended particle transfer between 3-D boxes in the vertical direction is taken into account. Three compartments are used to represent bottom sediment (top, middle and bottom) and several vertical boxes can represent the water column. The POSEIDON/RODOS model calculates time-dependent radionuclide concentrations in basin compartments taking into account advection and diffusion, radioactive decay, radionuclide interaction with suspended and seabed sediments, time-dependent radionuclide concentrations in top and middle sediment layers and time-dependent radionuclide concentrations in biota. The progeny of long-lived radionuclides is taken into account; very short-lived daughter products are assumed to be in equilibrium with the long lived parent radionuclide in the water phase and in the biota in terms of concentration, and are included in the dose module with a dose conversion coefficient including the short lived progeny. In the case when equilibrium is not likely, the decay products are modelled separately.

In the POSEIDON-R model concentrations in marine food-stuffs used for dose estimation can be calculated in two ways, which can be chosen by the user:

(a) The equilibrium approach, the traditional Concentration Ratio approach (CR) assuming equilibrium between radioactivity in the water and in the biota, which is applicable for releases with a smooth dynamics; or

(b) Dynamical food chain model BURN, by which the radionuclide transfer through the entire food chain is calculated [26].

This second choice is preferable for accidental releases with sharp rise of radionuclide activity concentration. By grouping the marine organisms in a limited number of classes based on the trophic level and types of species, and by grouping the radionuclides into a limited number of classes associated with the dominating tissue in which a radionuclide accumulates preferably, the number of input parameters is kept rather limited. The marine organisms are grouped into phytoplankton, zooplankton, fishes (two types: piscivorous and non-piscivorous), crustaceans, and molluscs. Standard sets of input parameters are used to avoid the necessity to collect site specific parameters for a large number of different species and for each possible radionuclide.

POSEIDON-R calculates individual and collective doses resulting from ingestion of marine products and other pathways: exposure to beach bottom sediments, swimming, boating and inhalation of sea spray and resuspended sediments.

3.9. RDEMO

"The code RDEMO is a deterministic computing program model used for the estimation of the radiological consequences from radioactive discharges into the atmosphere and hydrosphere during normal and abnormal operation" [6] of Nuclear Power Plant Mochovce, company Slovenské elektrárne:

> "Program set RDEMO includes programs for preparation of input data files, calculation programs and programs for graphic and printed outputs. Program set RD (Radiological Doses) was developed by company VUJE Trnava for nuclear power plants in Slovak republic and Czech Republic. The RD code has been validated by Expert Commission of SUJB Czech republic. Moreover, RDEMO has been validated also by comparison with the code NRC Dose" [6].

The mathematical model of the transfer of radioactive substances to humans and their dose uses a compartment model based on the concentration coefficient method. The following radiation pathways are considered: atmosphere, hydrosphere and food chains. Calculation of radioactive substances transfer via food chains uses the concentration coefficients method subject to balanced concentration of radioactive substances in environmental elements. Only Cs transfer to pork uses a dynamic model. Calculation of the dispersion of substances in the atmosphere uses the Gaussian model of atmospheric diffusion. Diffusion parameters were used from the atmosphere stability categorization according to Pasquill–Uhlig. The calculation in hydrosphere only considers surface water effects.

Calculation requires a large amount of input data contained in databases in the form of input data files. Databases contain input local data characterizing affected data within 60 km radius around NPP Mochovce, i.e. demographic data, data regarding production and consumption of agricultural food, hydrologic parameters of the river Hron, various coefficients, discharge of radioactive substances to atmosphere and hydrosphere and meteorological data.

The program enables calculation of annual individual effective and equivalent doses or 50 (70) year commitments of effective doses for six age categories (0–1, 1–2, 2–7, 7–12, 12–17, more than 17 years of age); for six calculated body organs (gonads, bone marrow, lungs, thyroid gland, alimentary tract and skin) and for the whole body; for ten irradiation pathways (from atmosphere: external radiation caused by the cloud and deposit, internal radiation caused by inhalation from the cloud and ingestion of food contaminated by atmospheric fall-out; from hydrosphere: external radiation from swimming and sailing and from

contaminated bank sediments and from staying on irrigated land, internal radiation from ingestion of contaminated potable water and ingestion of contaminated fish and ingestion of food contaminated by irrigations). The program also calculates collective effective doses for all zones and regional dose. RDEMO also determines critical exposure pathway, critical radionuclide and critical zone or critical population group.

3.10. SYMBIOSE

SYMBIOSE is a simulation platform for assessing the fate and transport of pollutants in environmental systems, and their impact on humans [6, 28, 29]. It is flexible enough to deal with a wide range of situations, from simplified generic studies to more realistic spatially-distributed and site-specific assessments [30]. This platform, co-funded by IRSN (Institut de Radioprotection et de Sûreté Nucléaire, France) and EDF (Electricité de France), is to be used as a reference tool for assessing doses induced by radioactive releases from nuclear facilities under accidental, decommissioning or normal operating conditions, including waste disposal facilities. SYMBIOSE offers various numerical solvers dealing with possibly complex system dynamics, and functions in either a deterministic or probabilistic mode.

Environmental models in SYMBIOSE address media such as atmospheric, terrestrial, freshwater and marine systems, as well as major transfer processes at their interfaces. Hundreds of components and interactions are accounted for in the system, most of which are modelled using a mechanistic approach (i.e. with physically-based parameterizations). When possible, alternative modelling approaches, of varying complexity, are provided. Specific models have been designed to deal with hydrogen, carbon and chlorine, which are based on a non-equilibrium approach.

Pollutant transport in the atmosphere is modelled either by a Gaussian plume model or is externalized by interfacing SYMBIOSE to an external software. Pollutant transport in the river is modelled by the Casteaur box model [31]. Transport in the sea is modelled either by a simple dilution model or the model described in SRS 19 [4].

The dose calculations are performed for individuals of the population and take account of various standard exposure pathways, each depending on spatial scenarios describing the use of the environment: internal exposure due to ingestion of foodstuff (terrestrial, freshwater or marine) and accidentally ingested stuff, internal exposure due to inhalation (in the plume and of resuspended material), external exposure (to radioactive material in the plume and dispersed in terrestrial, freshwater or marine compartments man uses in diverse activities).

4. DIFFERENT METHODS OF CALCULATION BY MODELLERS

The following software/models were used to perform the three Scenario exercises:

- Sizewell B Atmospheric releases: CLRP, CROM, DOSAMED, IAEA-SRS 19, IMPACT, PC-CREAM 98, PC-CREAM 08-Modeller 1 and PC-CREAM 08-Modeller 2, RDEMO and SYMBIOSE;
- Sizewell B Marine releases: CROM, IAEA-SRS 19, IMPACT, PC-CREAM 08-Modeller 2, POSEIDON and SYMBIOSE;
- Chalk River releases: CLRP, CROM, DOSIS LIQUIDAS, IAEA-SRS 19, IMPACT, PC-CREAM 08-Modeller 2, RDEMO and SYMBIOSE.

5. INPUT PARAMETERS

The input parameters used in the analysis for each Scenario, i.e. Sizewell B Atmospheric releases, Sizewell B Marine releases and Chalk River releases are summarized in Appendix I.

The radionuclides considered in each Scenario are shown in Table 1 and Table 2 shows the model type of dilution used in each code and Scenario.

5.1. SELECTION OF THE REPRESENTATIVE PERSON FOR THE 3 EXPOSURE SCENARIOS

In order to avoid differences in the results caused by the selection of the representative person performed by each modeller, it was decided to fix the main characteristics and parameters that describe the representative person for the 3 exposure Scenarios (see the Sizewell B Scenario description (atmospheric and marine releases) in Section 2.1, and Chalk River Scenario description in Section 2.2). These common input parameters were chosen based on the survey data from Sizewell B NPP [8], the DRL document for the National Research Universal Reactor at Chalk River Laboratories [11] and international recommendations. It was expected that by fixing input parameters characterizing the representative person, this would help to understand differences in dose estimates which were caused by the model characteristics.

TABLE 1. RADIONUCLIDES CONSIDERED IN EACH SCENARIO

	Scenario		
	Sizewell B – Atmospheric	**Sizewell B – Marine**	**Chalk River**
Radionuclides	^{60}Co, ^{137}Cs, ^{131}I, ^{85}Kr	^{60}Co, ^{137}Cs, ^{90}Sr	^{60}Co, ^{137}Cs, ^{90}Sr, ^{131}I, ^{3}H

TABLE 2. BASIC TYPES OF DILUTION MODELS IN THE CODES

Model	**Scenario**		
	Sizewell B – Atmospheric	**Sizewell B–Marine**	**Chalk River**
CLRP	Gaussian	N/A	SRS 19$^{(1)}$ approach [4]
CROM	Gaussian	SRS 19$^{(1)}$ approach [4]	Gaussian Plume
DOSAMED	Gaussian	N/A	N/A
DOSIS LIQUIDAS	N/A	N/A	SRS 19$^{(1)}$ approach [4]
IAEA SRS 19	Gaussian	SRS 19$^{(1)}$ approach [4]	SRS 19$^{(1)}$ approach [4]
IMPACT	Gaussian	Plume model based on Gorman [19]	NCRP 123$^{(2)}$ [20]
PC-CREAM 98	Gaussian	N/A	N/A
PC-CREAM 08	Gaussian	Box model (based on EC Marina II model)	Box model
POSEIDON-R	N/A	Box model	N/A
RDEMO	Gaussian	N/A	Simple dilution model
SYMBIOSE	Gaussian	SRS 19$^{(1)}$ approach [4]	Box model

NOTES:

$^{(1)}$ SRS 19 models are based on steady state vertically average advection-diffusion equations.

$^{(2)}$ NCRP 123 models are based on an analytical solution to the advection-diffusion equations. The rivers are divided into 4 regions based on the degree of radionuclide mixing within a river cross section:

- River region 1, area where complete mixing in the vertical and lateral direction is not achieved.
- Region 2, the area where complete mixing in the vertical direction is achieved but complete mixing in the lateral direction across the river is not yet occurred.
- Region 3, area where complete mixing is achieved.
- Region 4, area near the bank of the river opposite from the bank where radionuclide release occurs.

6. RESULTS AND DISCUSSION

The results of the EMRAS II WG1 exercise are shown in Figures 1–15 where the estimated effective doses (µSv/a) to the representative person for the three discharge scenarios are presented. In order to calculate these doses participants used different dose assessment codes and in one case the same code was used by two different modellers. Figures 1–3 present total effective doses obtained from each model broken down by radionuclide. This enables a broad comparison to be made between models and it can be seen that some codes are in general more conservative than others, however, this depends on the type of discharge, the radionuclide and, as will be seen in later figures, the exposure pathway considered. For Sizewell B Atmospheric releases, the CLRP model gives higher doses for all radionuclides, and this is discussed further in Section 6.3. For Sizewell B Marine releases, the differences in results are explained by the fact that different model types for dilution and transport were used. For the Chalk River releases there is some agreement between models regarding activity concentrations in water although model predictions tend to diverge when irrigation and uptake by crops and animals is considered.

Figures 4–15 present doses as a function of pathway for specific radionuclides released in each discharge scenario. The dose results are expressed in µSv per year and represent the total effective dose to the representative person from each radionuclide. For Sizewell B Atmospheric releases the results from the CLRP model have been removed from Figures 4–7 due to large differences with other results. In addition, results from the DOSAMED model have also been removed from Figures 4–6 because doses for every exposure pathway considered are not available for this model. Details of the doses calculated are also presented in tabular form in Appendix II.

It can be observed that in general there is an acceptable agreement among the results in most of the figures, even though the contribution to the total effective dose of each exposure pathway can differ significantly.

6.1. GENERAL ANALYSIS

Table 2 above presents a general view of the basic types of dispersion model included in the different dose assessment codes for each of the discharge scenarios.

It can be seen that for the Sizewell B atmospheric release scenario, all codes include an implementation of the basic type of dispersion model, i.e. the Gaussian plume model.

For the Sizewell B marine release scenario, three basic model types for dilution and transport were used: models based on solutions to steady state, vertically averaged advection-diffusion equations; a Gaussian plume model; and a box model with first order kinetics (i.e. a fixed fraction of the box inventory is transferred in unit time).

In the case of the Chalk River release scenario, five different models were used: models based on solutions to steady state, vertically averaged advection-diffusion equations; the Gaussian Plume model; a box model with first order kinetics; a simple dilution model; and a combination of these.

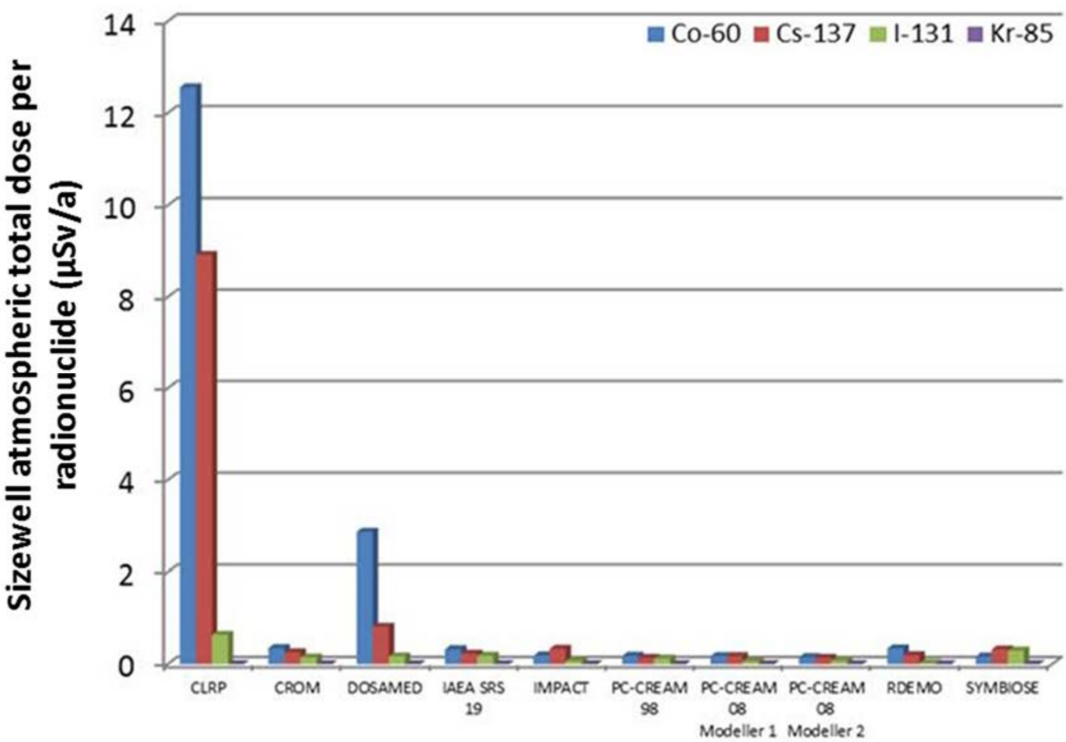

FIG. 1. Sizewell B Atmospheric – total dose (µSv/a) – all radionuclides.

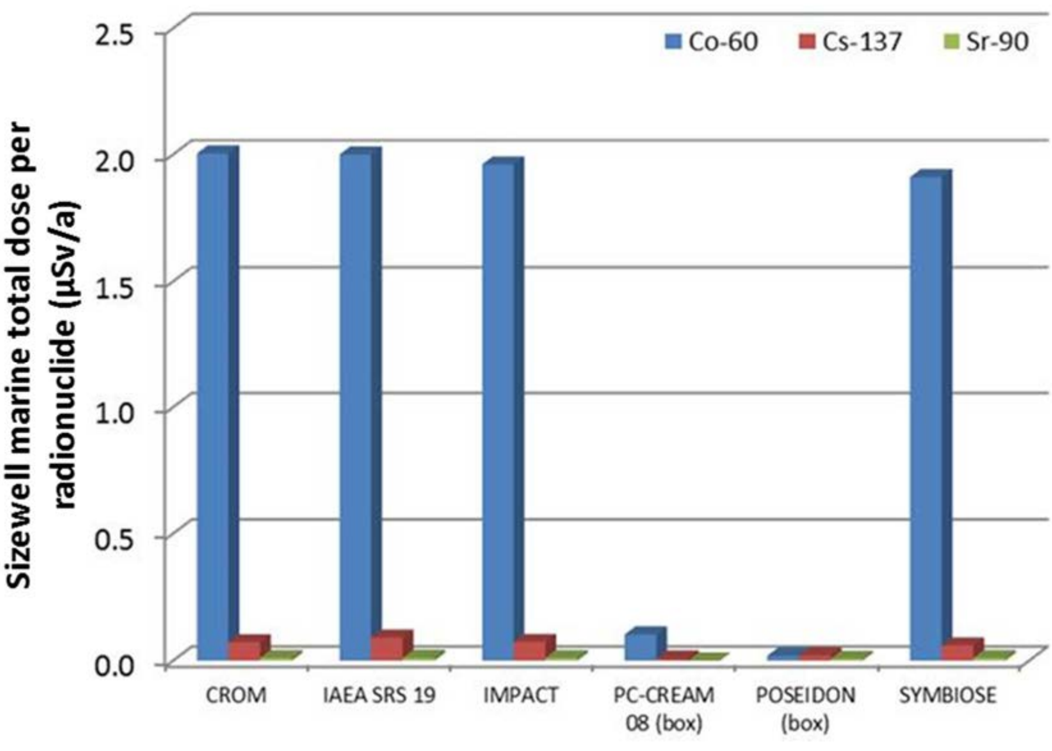

FIG. 2. Sizewell B Marine –total dose (µSv/a) – all radionuclides.

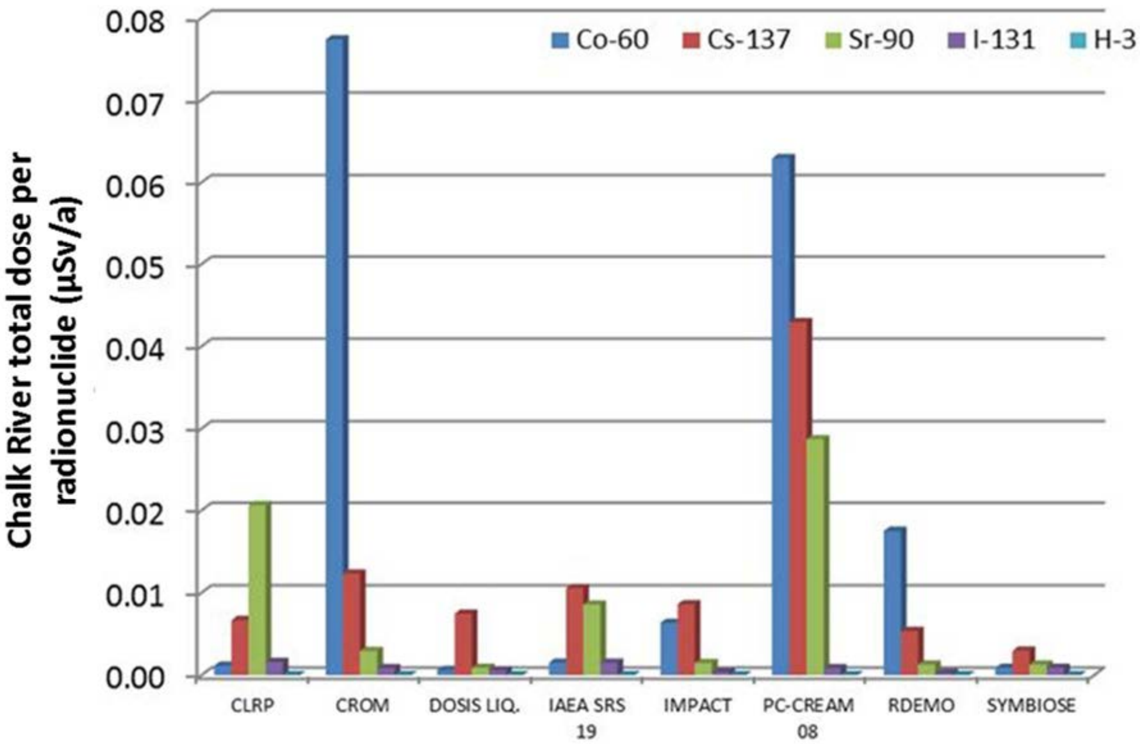

FIG. 3. Chalk River –total dose (µSv/a) – all radionuclides.

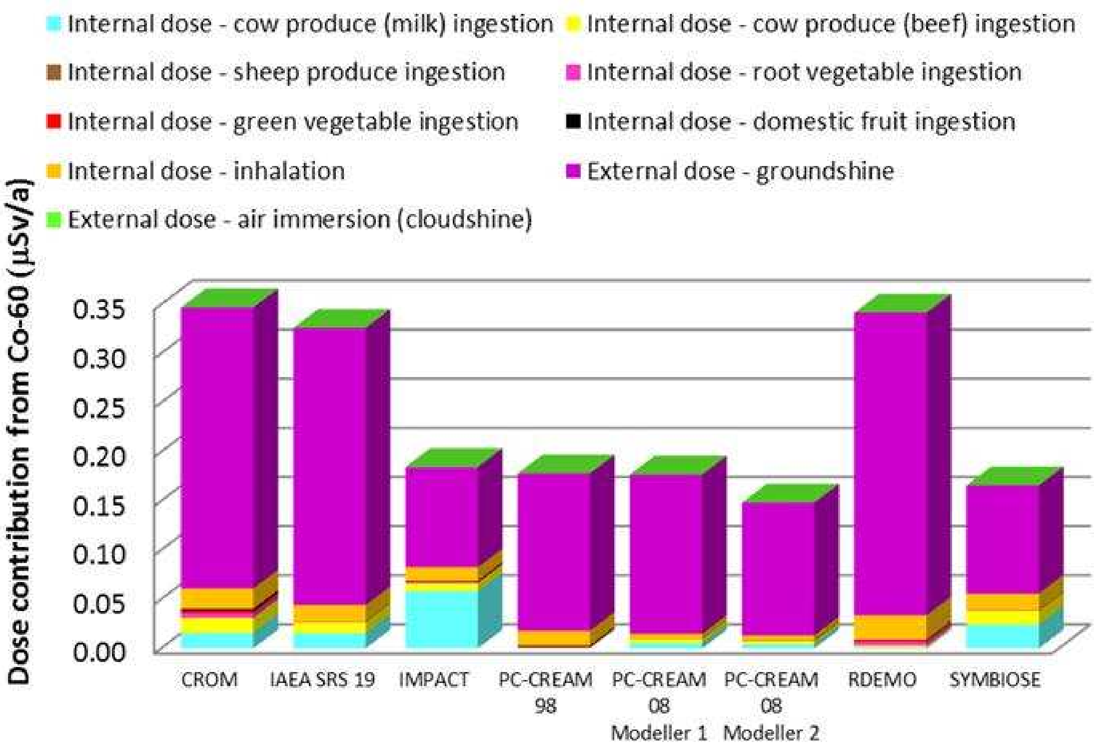

FIG. 4. Sizewell B atmospheric – total dose (µSv/a) – ^{60}Co.

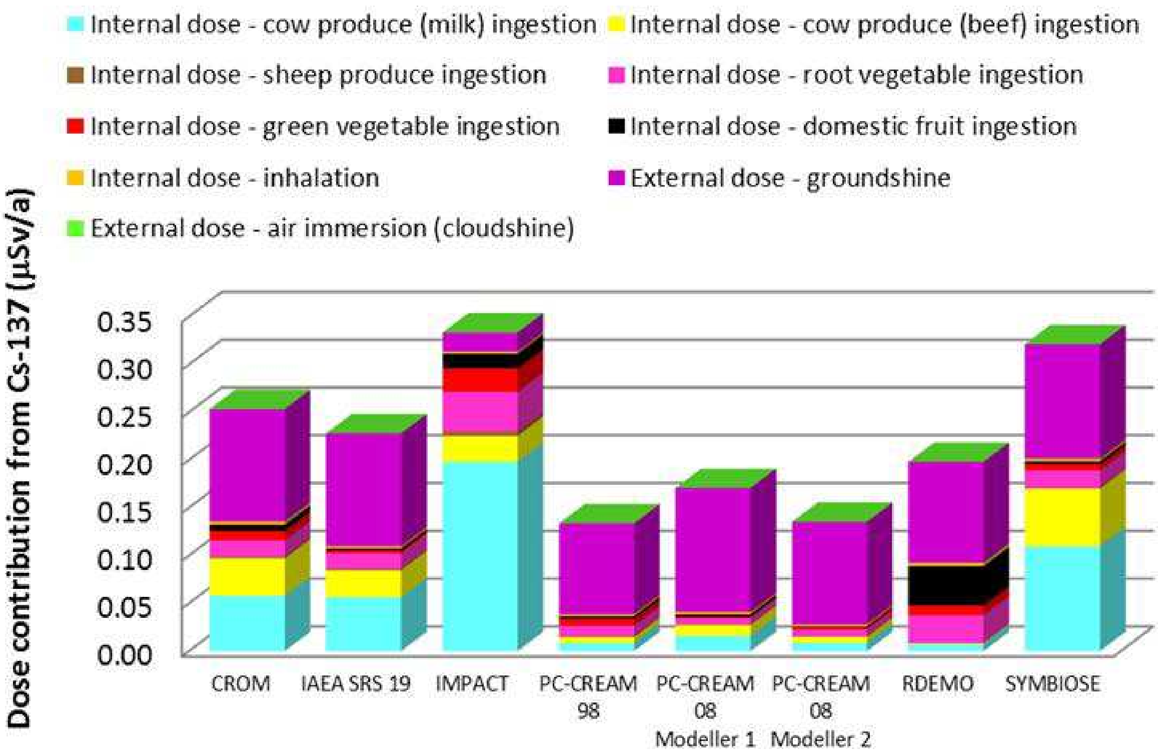

FIG. 5. Sizewell B atmospheric – total dose (µSv/a) – ^{137}Cs.

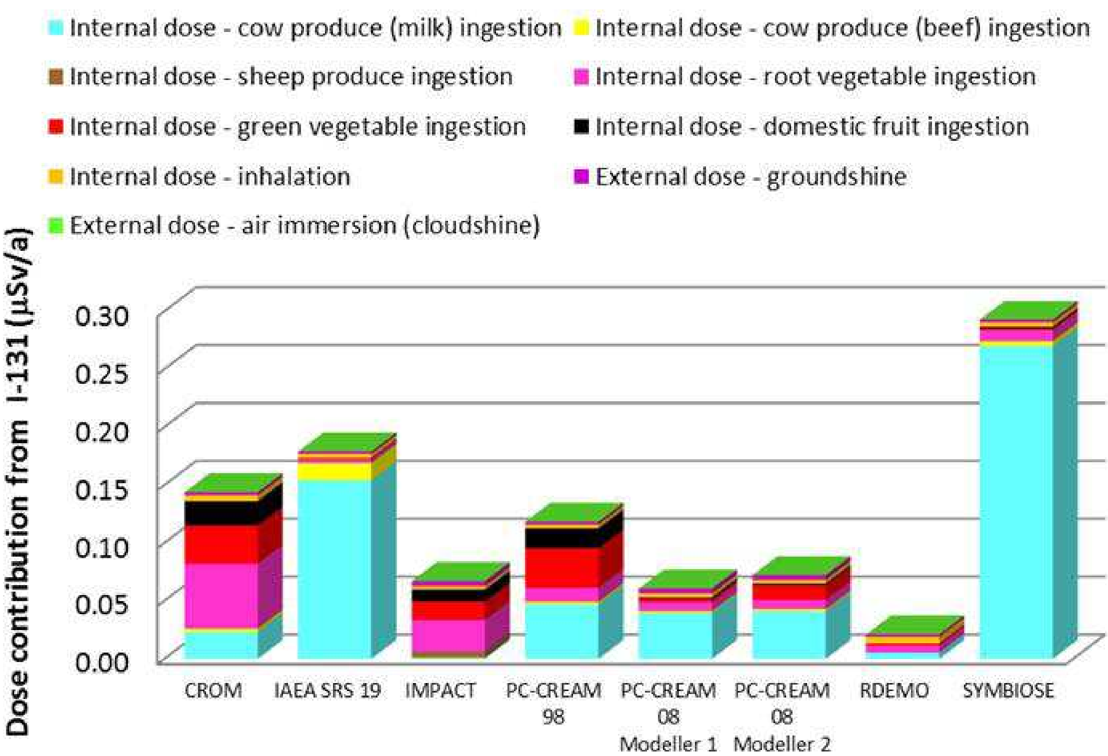

FIG. 6. Sizewell B atmospheric – total dose (µSv/a) – ^{131}I.

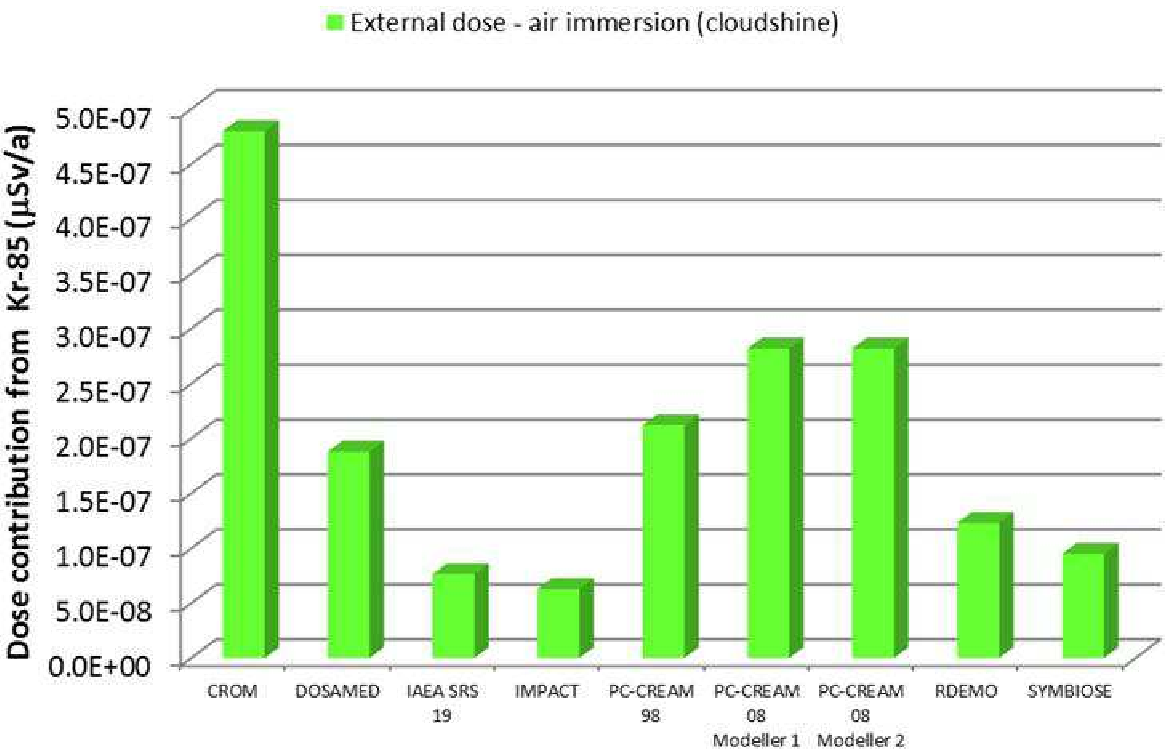

FIG. 7. Sizewell B atmospheric – total dose (µSv/a) – ^{85}Kr.

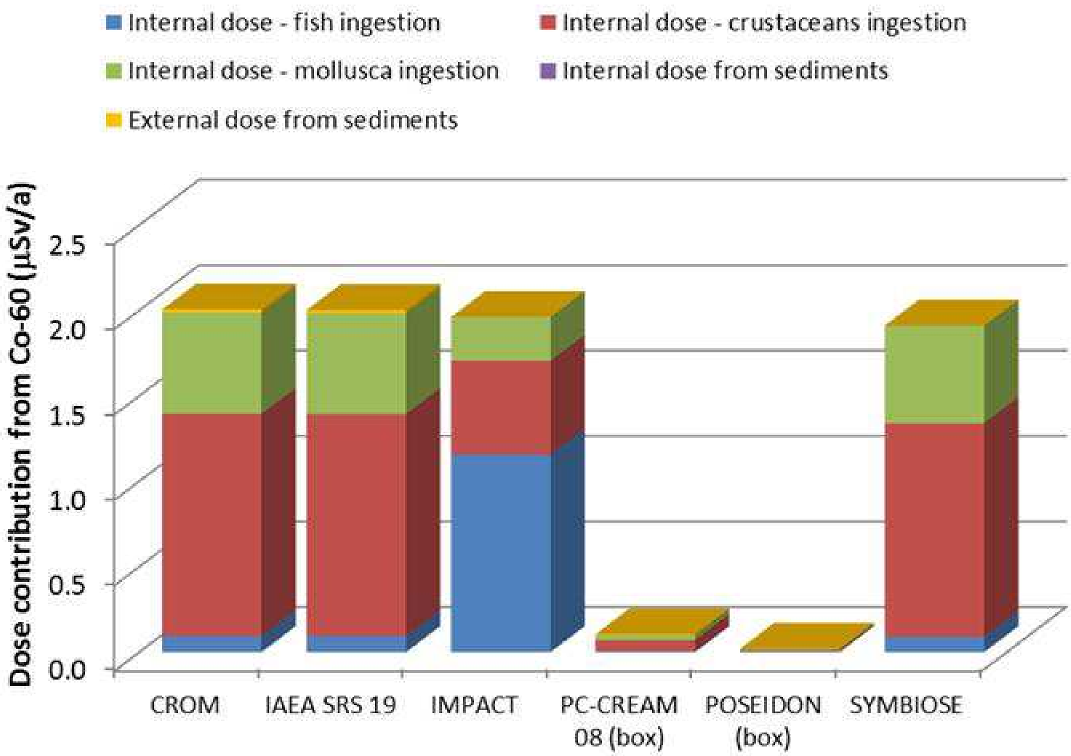

FIG. 8. Sizewell B marine – total dose (µSv/a) – ^{60}Co.

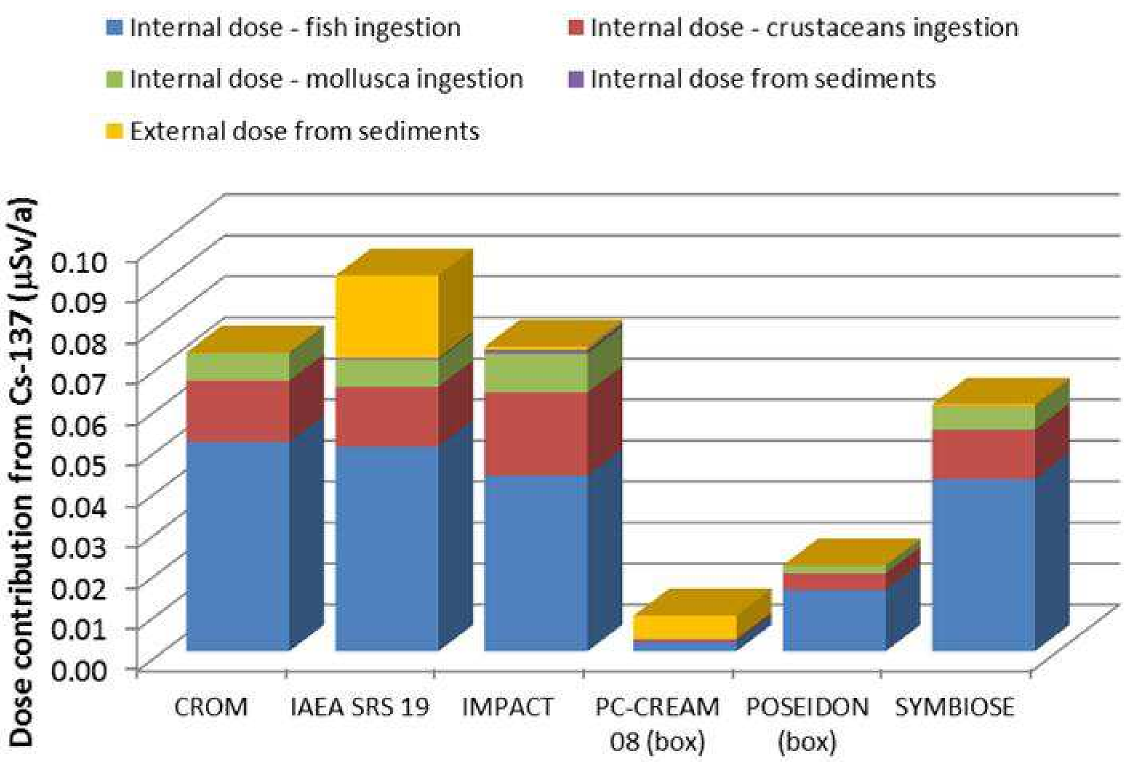

FIG. 9. Sizewell B marine – total dose (µSv/a) – ^{137}Cs.

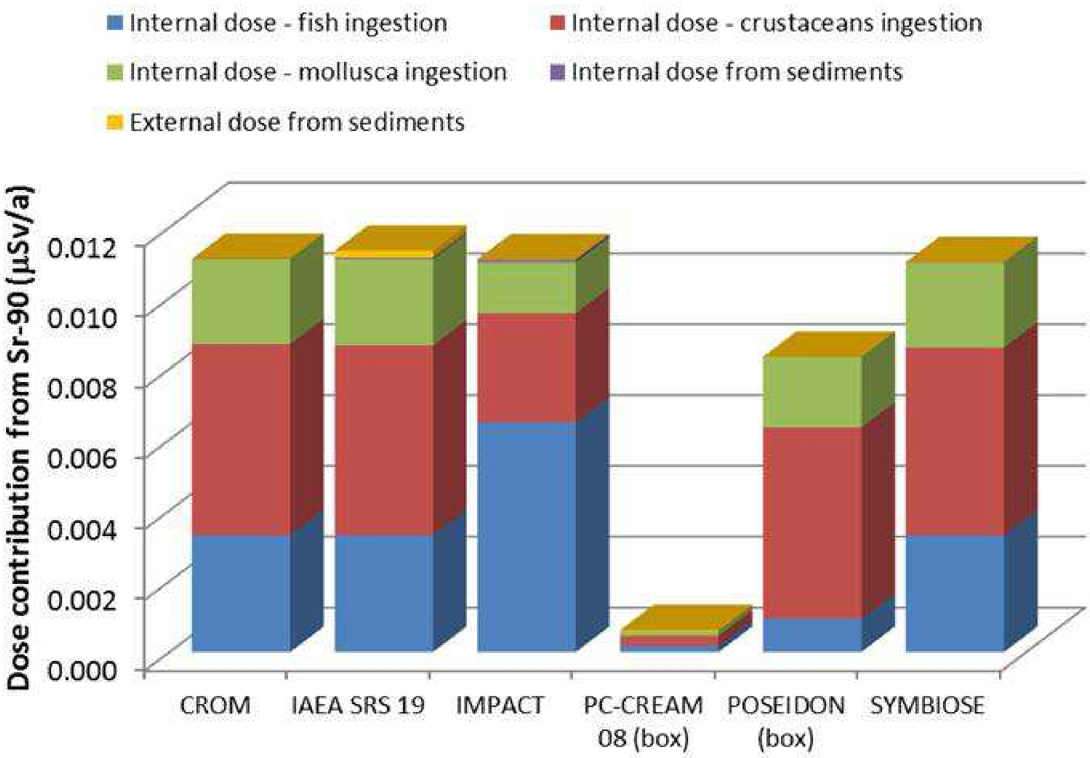

FIG. 10. Sizewell B marine – total dose (µSv/a) – ^{90}Sr.

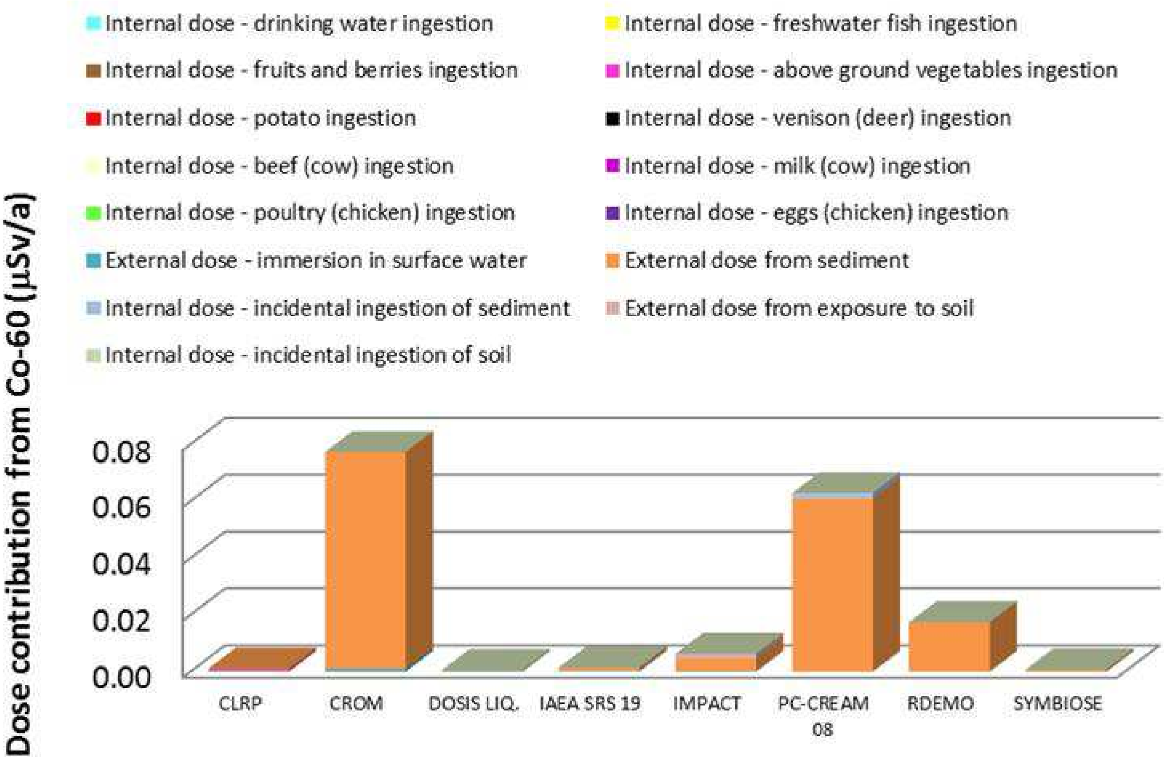

FIG. 11. Chalk River – total dose (µSv/a) – ^{60}Co.

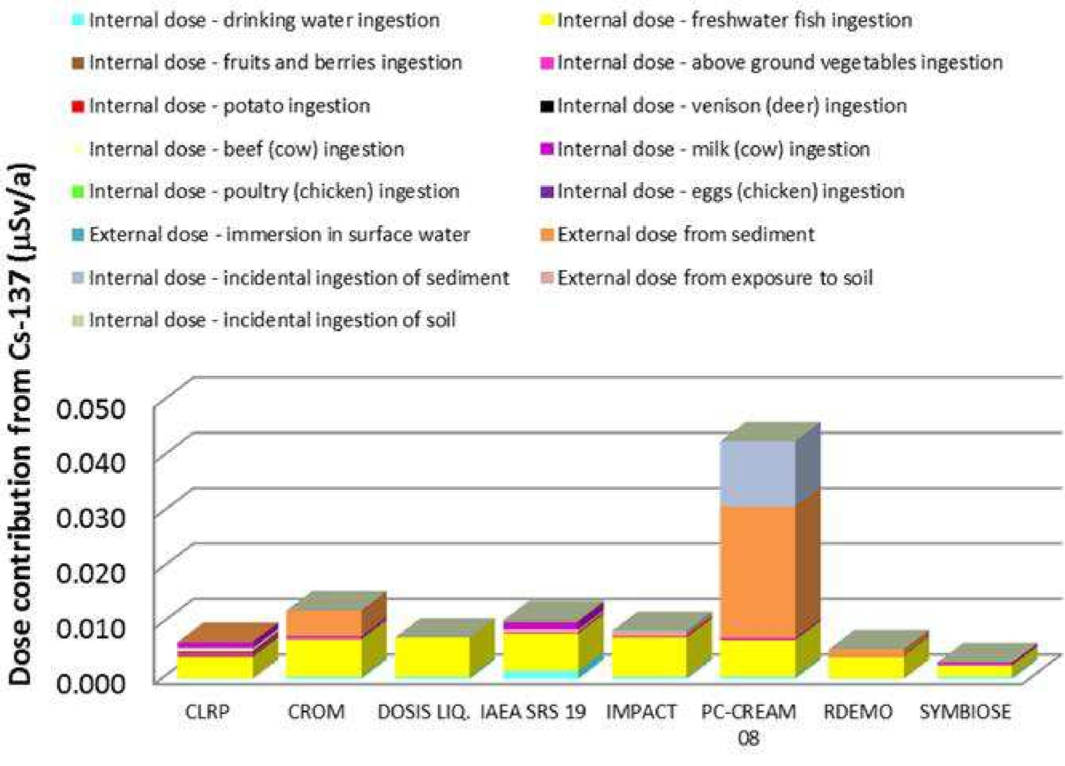

FIG. 12. Chalk River – total dose (µSv/a) – ^{137}Cs.

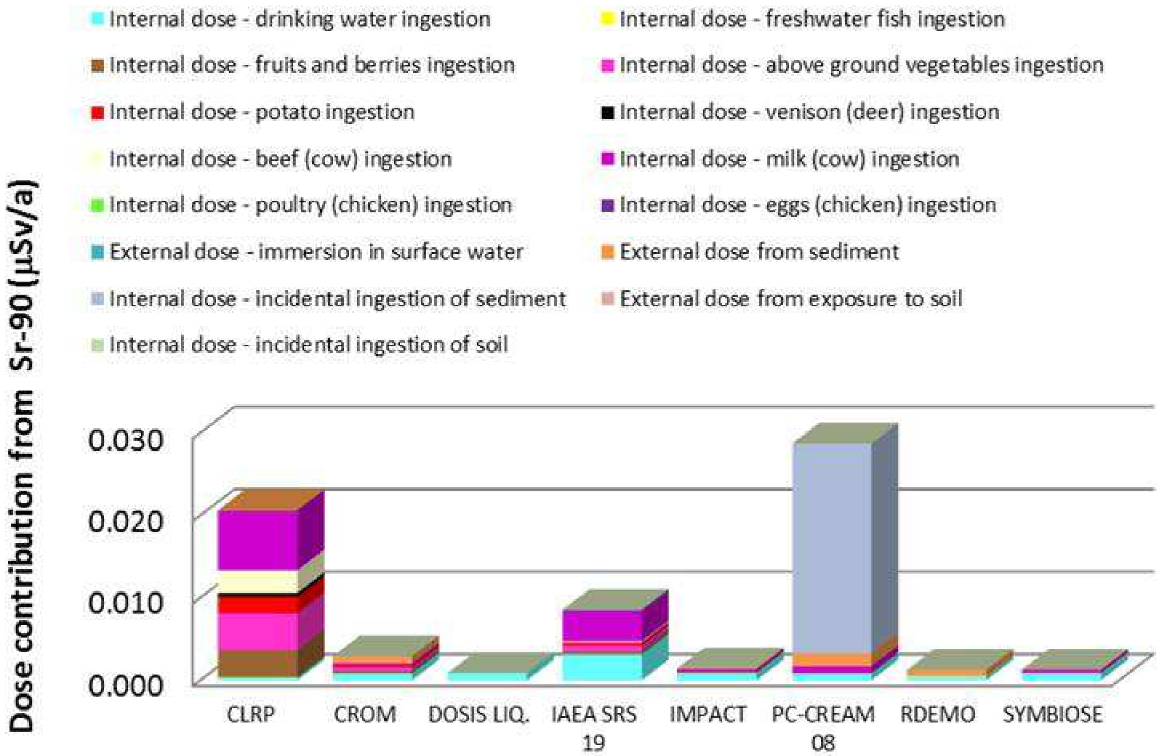

FIG. 13. Chalk River – total dose (μSv/a) – ^{90}Sr.

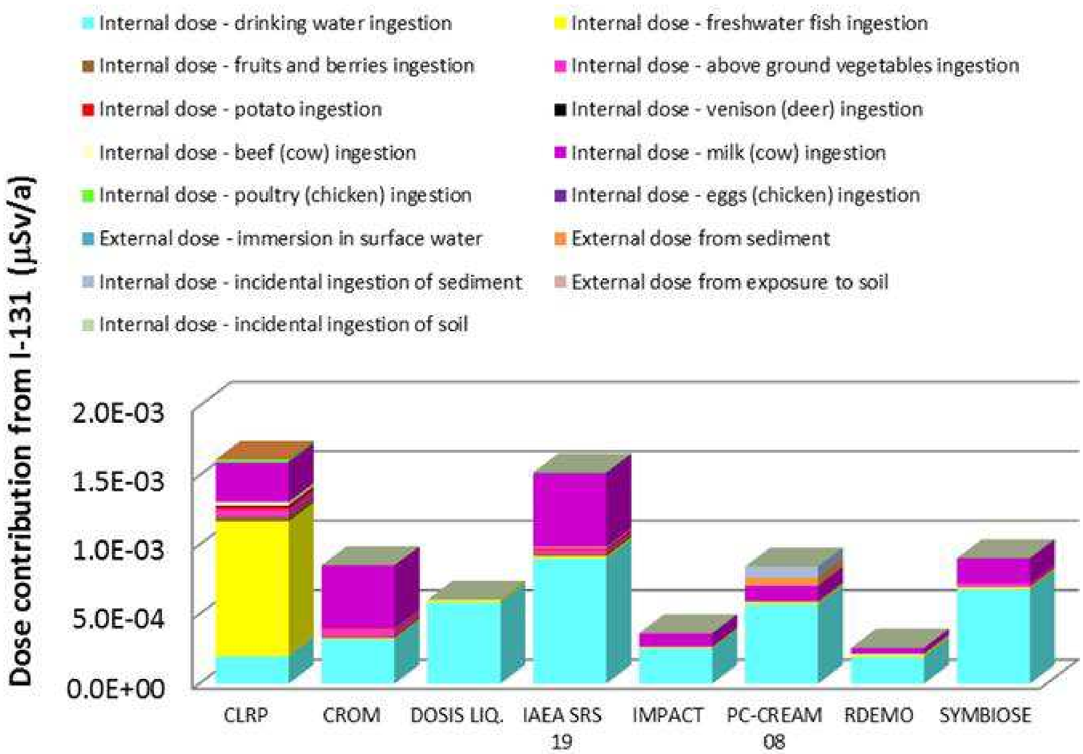

FIG. 14. Chalk River – total dose (μSv/a) – ^{131}I.

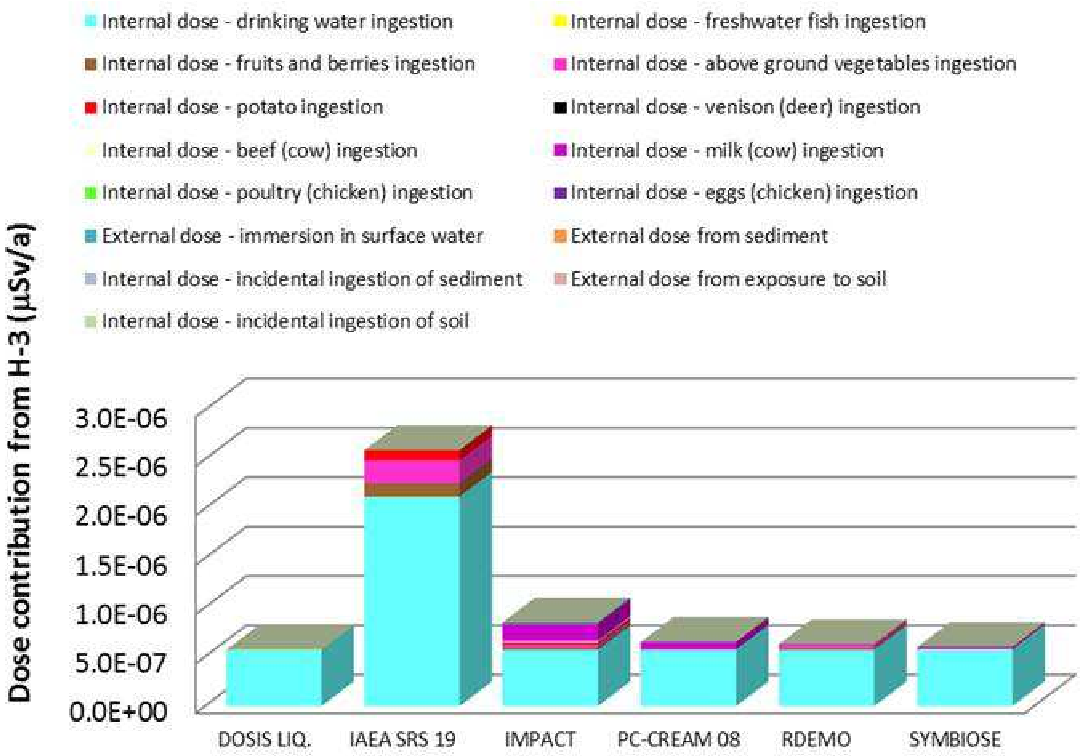

FIG. 15. Chalk River – total dose (µSv/a) – ^{3}H.

For atmospheric releases, even though all the codes include implementations of the Gaussian plume model, the subsequent models of transport of radionuclides through selected terrestrial food chain pathways play an important role when it comes to explaining the differences in results. Some models are more complex, as they consider more pathways and use more parameters than simpler models. Moreover, the values of some parameters cannot be changed in some codes.

Even though total effective doses to the representative person were similar in most Scenarios and radionuclides, doses for individual exposure pathways were different, mainly for ingestion exposure pathways.

For discharges to the marine environment results tend to fall into one of two categories with CROM, IAEA SRS 19, IMPACT and SYMBIOSE all being fairly similar and greater than the doses calculated using PC-CREAM 08 and POSEIDON. The principal reason for this is that the first four models are all based on the Gaussian plume model described in IAEA SRS 19 while PC-CREAM 08 and POSEIDON are box models. In a box model dilution within the compartment receiving the initial discharge occurs rapidly and can result in much lower water concentrations than those predicted along the center line of a plume model. Most of the models use equilibrium concentration ratios to calculate the activity concentrations in fish from water. This scenario included recommended values for these parameters as well as for ingestion rates, consequently, doses from ingestion of marine biota depend on the calculated activity concentration in the water. An additional important point is to declare whether the activity concentration in water includes any contribution from that on suspended sediment when calculating activity concentrations in seafood as this can have a significant impact for some radionuclides.

For discharges from Chalk River Laboratories the picture is more complicated because the exposure pathways involve radionuclide transfer in different environments. Following the initial discharge to the river it can be seen that doses from ^{3}H in drinking water are similar for a number of the models (given in Appendix II). In some ways this is one of the simplest exposure pathways to model because ^{3}H tends to remain dissolved in the water i.e. does not adsorb onto sediments. The models are therefore simply trying to represent downstream dilution and then estimate ingestion dose using an intake rate and appropriate ingestion dose coefficient. Thereafter, doses from more complex exposure pathways, such as those that result from the irrigation of agricultural land, tend to diverge as a consequence of the use of more models and parameters that differ from one code to the next.

Within the range of possible differences in results that could arise from the use of the codes for impact prediction, a very important one is the personal approach of the modeller, i.e. how the modeller understands the exposure scenario and the underlying assumptions they make [32]. If the scenario is not very well established, the modeller will tend to use a subjective interpretation based on his or her previous experience. In addition to these individual perceptions, differences in how the model is implemented and in parameter selection may contribute substantially to the overall spread of predictions.

6.2. SIZEWELL B ATMOSPHERIC RELEASES

The comparison among codes of the dose results for the Sizewell B atmospheric releases show that in general terms the external dose (groundshine and cloudshine) and the inhalation dose are within an acceptable range of values, considering the associated levels of uncertainty (see Figures 4–7 and calculation results in Appendix II). In general, the critical exposure pathway for ^{60}Co and ^{137}Cs was external groundshine dose.

The greatest variation in doses was found for the ingestion of terrestrial foods. The ingestion of six different food types was considered namely; cow meat and cow milk, sheep meat, root vegetables, green vegetables and fruit. Calculated doses are presented in Appendix II where it can be seen that differences are dependent on food type and radionuclide. This might be explained by the differences in complexity of the codes and how the basic data are used because values for parameters such as soil to plant concentration ratios and equilibrium transfer factors for animal products were specified in the scenario.

The analysis of the results showed that some differences could be explained by whether or not the models include some key parameters. Differences could also arise due to the fact that in some codes the values of these parameters could not be changed to the ones specified for the exercise (see Section 6.3).

The key parameters identified included:

- The use of the physical height of the release point or the effective height e.g. to include plume rise;
- Deposition velocity;
- The use of recommended external exposure dose coefficients or alternative models and data for estimating immersion and groundshine doses;
- The use of a factor to account for the non-uniformity of the ground and weathering processes on soil could lead to differences in external groundshine doses;

- Factors to account for a decreasing concentration of radionuclides in soil, such as those representing heterogeneity of the contamination, washout and erosion;
- Methods for modelling foliar uptake and the translocation of radionuclides into the vegetation are often code specific;
- The use of the soil to plant transfer parameter with different assumptions about wet and dry mass would have a significant impacton the estimate of dose from vegetable consumption and subsequent consumption of animal products;
- The time considered appropriate for hold up between plant exposure and animal consumption is an important parameter particularly for short-lived radionuclides such as ^{131}I, as can be seen in Table 3 below. It shows ingestion dose results for hold up times of 90 days (the scenario recommended value) and zero days (used by some participants). For sheep, almost no difference was found because the recommended hold up time was 1 day whereas some participants used zero days;
- The time between collection and human consumption of milk (1 day according to SRS 19 [4]) and meat (20 days according to SRS 19 [4]) is also a very important parameter;
- Inhalation of radionuclides by animals is considered in some codes.

6.3. ANALYSIS OF RESULTS OF MODEL CLRP FOR SIZEWELL B ATMOSPHERIC RELEASES

Total effective doses predicted by CLRP for Sizewell B where higher by factor of (10–50) comparing with predictions of others models, i.e.:

(1) ^{137}Cs: CLRP – 8.9 µSv/a versus 0.3 µSv/a (IMPACT, SYMBIOSE);
(2) ^{60}Co: CLRP – 12.6 µSv/a versus 0.19, 0.17 µSv/a (IMPACT, SYMBIOSE) respectively;
(3) ^{131}I: CLRP – 0.6 µSv/a versus 0.07, 0.3 µSv/a (IMPACT, SYMBIOSE) respectively;
(4) ^{85}Kr (cloud immersion): CLRP – 2.0E-07 µSv/a versus 6.3E-08, 9.5E-08 µSv/a (IMPACT, SYMBIOSE), however DCF used by CLRP was 3.76E-09 Sv/a per Bq/m^3 [14]. Recommended scenario value was somewhat lower 3.3E-09 Sv/a per Bq/m^3 [33].

As the dose conversion factors and assumption of time of exposure were almost the same for all models, and also typing errors were excluded, the reasons of discrepancies lay elsewhere.

TABLE 3. VARIATION OF THE VALUE OF INGESTION DOSE WITH THE HOLD-UP TIME BETWEEN PLANT EXPOSURE AND CONSUMPTION BY ANIMALS FOR ^{131}I

Animal	Hold up: 90 days (cow) / 1 day (sheep)		Hold up: zero days, Grazing pasture	
	Ingestion dose (milk) (mSv)	Ingestion dose (meat) (mSv)	Ingestion dose (milk) (mSv)	Ingestion dose (meat) (mSv)
Cow	3.25E-07	4.23E-08	1.00E-03	1.31E-04
Sheep		1.03E-06		1.12E-06

Generally, the CLRP model for routine releases uses the conservative approach according to the SRS 19 methodology [4], but more detailed analysis of results revealed main reasons of discrepancies:

(1) Activity concentrations at distance 300 m were higher by a factor of 1.6 because the dispersion model applied by CLRP based on SRS 19 [4] assumed, for screening purposes, category F for atmospheric stability. The significance of this assumption is greatest at short distances and in this case immersion, inhalation and groundshine doses were calculated ata distance of 300 m;
(2) Deposition rates for ^{131}I, ^{137}Cs and ^{60}Co were calculated using results of the 'screening' calculation. The total deposition (dry and wet) was based on a deposition velocity value equal to 1000 m/d (about 0.012 m/s), as indicated in SRS 19 [4].The suggested default values for this scenario used by other models are 0.01 m/s for ^{131}I and 0.001 m/s (equal to 87 m/d) for ^{137}Cs and ^{60}Co. One notes that for ^{131}I discrepancies in dose results are less apparent;
(3) The fact that deposition rates were higher by a factor of 10 for ^{60}Co and ^{137}Cs resulted in higher external doses from groundshine, i.e.:
    (a) ^{137}Cs: CLRP – 4.2 µSv/a (others: about 0.1 µSv/a) (CROM, SYMBIOSE, PC-CREAM));
    (b) ^{60}Co: CLRP – 11 µSv/a (others: about 0.3, 0.1, 0.2 µSv/a (CROM, SYMBIOSE, PC-CREAM)) respectively;
    (c) ^{131}I: CLRP – 7.30E-03 µSv/a (others: 2.7E-03, 2.2E-03, 4.1E-03 µSv/a (CROM, SYMBIOSE, PC-CREAM)) respectively;
(4) Consequently, a higher deposition rate resulted in higher radionuclide concentrations in soil and higher concentrations in agricultural products which resulted in higher ingestion doses. Additionally, some differences between consumption rates suggested for use in the scenario and those used by CLRP from [4] were noticed (see Table 4), but with the exception of beef and sheep meat, this was not the main source of differences between the model results.

Conclusions:

(1) In terms of general target of the EMRAS II Working Group 1, Reference Methodologies for Controlling Discharges of Routine Releases, that was cited "to achieve the development of standardized and harmonized models for assessing radiological impacts to people and the environment for a wide range of scenarios", using the 'screening' methodology as CLRP, is unlikely to give overpredictions of doses by a factor of more than 100 in most cases.

(2) One might suppose that uncertainty (variability) analysis performed across the participating models would give similar i.e. two order of magnitude ranges.

(3) It seems that deposition velocity (also the dispersion processes) is one of the more sensitive parameters as it contributes both to the external groundshine dose and through the food and feed chains to internal doses.

TABLE 4. CONSUMPTION RATES USED BY CLRP VS. SUGGESTED CONSUMPTION RATE VALUES FOR THE SCENARIO

Diet component	**Leafy vegetables (kg/a)**	**Root crops (kg/a)**	**Fruits (kg/a)**	**Milk (cow) (kg/a)**	**Beef (kg/a)**	**Sheep meat (kg/a)**
CLRP based on (SRS 19 [4])	84	143	54	250	100	10
Sizewell B scenario suggested values	65.6	110.9	42.4	208.4	28	2.4

6.4. SIZEWELL B MARINE RELEASES

The Sizewell B marine results can be divided into two distinct groups with fairly close agreement within each group (see Figures 8–10 and the calculation results given in Appendix II). This is due to the fact that one group of models is based on plume models and the other group on box models:

> “For example, in some of the codes the dispersing radionuclides are modelled using a Gaussian plume and it is conservatively assumed that the fish and shellfish are caught from the center line of the plume. However, in a box model instant dilution into the local box around the site is assumed and hence for this particular scenario the model is less conservative” [6].

The size of the local box is clearly also important, as it increases the activity concentration in the water and marine biota decrease leading to smaller doses. Furthermore, one of the box models (POSEIDON) used a dynamic food model rather than the direct application of equilibrium concentration ratios, resulting in less conservative but more realistic uptake behavior.

It is not true to say that one type of dispersion model is in general more conservative than another. There are cases where the box model would be more conservative than the plume model as it depends on how the model is used and the assumptions made concerning the location of seafood in relation to the dispersing plume and the habits of the individuals exposed.

The definition of this scenario includes 5 exposure pathways. For ^{60}Co and ^{90}Sr the critical exposure pathway (the one whose dose most contributed to the total dose) was in general crustacean ingestion, but for ^{137}Cs it was in general fish ingestion.

6.5. CHALK RIVER RELEASES

This was the most complex of the three dispersion scenarios considered. Not only were more model types used, five in all, but there was also a total of 15 exposure pathways which combined dispersion in the river with irrigation and uptake by plants and animals (see Figures 11–15 and calculation results in Appendix II).

For tritium and ^{131}I releases, results were very similar, and the critical exposure pathway was in general ingestion of drinking water.

For the other isotopes, the results have a lot more variability. They differ by a factor of 120 for ^{60}Co, 32 for ^{90}Sr and 14 for ^{137}Cs. Even though at first glance it might be expected that the different dispersion models would give large differences in the activity concentration in water, this is not the case for this scenario. This may be due to the fact that the location of interest is sufficiently far downstream as to enable significant dilution to occur throughout the river. Unfortunately, this could not be followed up within the time constraints of the project.

For ^{90}Sr, the critical exposure pathway of half of the codes was drinking water while for ^{137}Cs, the critical exposure pathway for almost all codes was freshwater fish ingestion with quite similar dose values. The latter result reflects the fact that cesium uptake is known to be significant and considerable amounts of data on this process are available in the literature. The models generally agree that for ^{137}Cs ingestion of drinking water and cow's milk from irrigated pasture is also important although there is less agreement as to the importance of external exposure to river washed sediments. It is noticeable that PC-CREAM 08 predicts significantly higher doses from external exposure to riverbed sediments which will be as a result of the unique method used to calculate these doses and is based on some empirical formulae published in Ref. [34].

In the case of ^{60}Co, the critical exposure pathway in almost all codes was external dose from sediment, and differences between models are reflected in the total dose results. This means that the transfer models from water to sediment and the external exposure model/dose coefficients for this exposure pathway are quite different for some codes. An attempt to normalize the sediment concentrations to the median value of the models was tried, but that did not seem to correct the results in all cases. Some success was achieved for ^{137}Cs and ^{90}Sr, but not for ^{60}Co.

6.6. SUMMARY OF RESULTS

The main findings of the results are:

(1) In general there is an acceptable agreement among the results even though the contribution to the total effective dose in the representative person from each exposure pathway can differ significantly, with greater differences being seen for the ingestion exposure pathways. External dose (groundshine and cloudshine) and inhalation dose were within an acceptable range of values, considering the associated levels of uncertainty.

(2) Total effective doses predicted by the 'screening' methodology CLRP for the Sizewell B Atmospheric Scenario were higher for all radionuclides when compared with predictions of other models.

(3) For atmospheric releases, deposition velocity is one of the most sensitive parameters as it influences both the external dose (groundshine) and, through food and feed chains, the internal doses. Other key identified parameters are:

- The physical height of the release point or the effective height;
- Recommended external exposure dose coefficients or alternative models and data for estimating immersion and groundshine doses;
- A factor to account for the non-uniformity of the ground and weathering processes on soil could lead to differences in external groundshine doses;
- Factors to account for a decreasing concentration of radionuclides in soil (representing heterogeneity of the contamination, washout and erosion);
- Methods for modelling foliar uptake and the translocation of radionuclides into the vegetation are often code specific;
- The soil to plant transfer parameter with different assumptions about wet and dry mass;

- The time considered appropriate for hold up between plant exposure and animal consumption;
- Time between collection and human consumption of milk;
- Inhalation of radionuclides by animals, considered in some codes.

(4) "For Sizewell B Marine Scenario, the differences in results are explained by the fact that different model types for dilution and transport of radionuclides were used. They can be divided into two distinct groups with fairly close agreement within each group. One group of models is based on Gaussian plume and it is conservatively assumed that the fish and shellfish are caught from the centre line of the plume. The other group is based on box models where an instant dilution into the local box around the site is assumed" [6].

The size of the local box used for modelling (length × width × depth) is clearly important, as it increases in size the estimated activity concentration in the water and edible marine biota decrease leading to smaller doses. Furthermore, one of the box models (POSEIDON) used a dynamic food model rather than the direct application of equilibrium concentration ratios, resulting in less conservative but more realistic uptake behaviour.

It is not true to say that one type of dispersion model is in general more conservative than another. There are cases where the box model would be more conservative than the plume model as it depends on how the model is used and the assumptions made concerning the location of seafood in relation to the dispersing plume and the habits of the individuals exposed.

(5) For the Chalk River Scenario there is some agreement between the five models used in regards to activity concentrations in water, and this may be due to the fact that the location of interest is sufficiently far downstream as to enable significant dilution to occur throughout the river. Model predictions tend to diverge when irrigation and uptake by crops and animals is considered.

For tritium and ^{131}I releases, results were very similar, and the critical exposure pathway was in general ingestion of drinking water. For the other isotopes, the results have a lot more variability: a factor of 120 for ^{60}Co, 32 for ^{90}Sr and 14 for ^{137}Cs. In the case of ^{60}Co, the critical exposure pathway in almost all codes was external dose from sediment, and differences between models are reflected in the total dose results. This means that the transfer models from water to sediment and the external exposure model/dose coefficients for this exposure pathway are quite different for some codes. For ^{90}Sr, the critical exposure pathway of half of the codes was drinking water while for ^{137}Cs, the critical exposure pathway for almost all codes was freshwater fish ingestion with quite similar dose values.

It is noticeable that PC-CREAM 08 predicts significantly higher doses from external exposure to riverbed sediments, which is likely a result of the unique method used to calculate these doses, which is based on some empirical formulae [7].

(6) Within the range of possible differences in results that could arise from the use of the codes for impact prediction, a very important one is the personal approach of the modeller and the parameter selection. If the scenario is not very well defined, the modeller will tend to use a subjective interpretation based on his or her previous experience.

7. CONSIDERATIONS ON SELECTION OF REPRESENTATIVE PERSON

An important part of the dose assessment procedure is the identification and definition of the group of individuals for which doses are to be assessed. Each modeler of each different country has its own approach and method to define the representative person [35, 36][4] (ex-critical group[5]) and in some countries more than one approach could be applied (these approaches are presented in more detail in Appendix III of this report). It is common practice to choose an individual (or group of people) that represents those members of the population that are likely to be the most exposed as a result of the discharges under analysis.

7.1. REPRESENTATIVE PERSON SELECTION CRITERIA APPLIED BY DIFFERENT MODELLERS

In this report, nine modellers from different countries (Argentina, Belarus, Brazil, Canada, France, Poland, Slovakia, United Kingdom and Ukraine) presented their approaches for the selection of the representative person (see reports in Appendix III).

Most modellers use the hypothetical representative person concept (e.g. location and habit data based on conservative assumptions) whereas those from Canada and France use real representative persons (e.g. location and habit data based on realistic assumptions). Also, modellers from countries like Argentina, Slovakia, Ukraine and the UK use a combination of real or hypothetical ones. These representative persons are always assumed to be members of the general public and only the modellers from Canada considered the inclusion of nuclear facility workers in local surveys (but their workplace exposures are not included in characterizing the representative person).

The modellers from France identified a group comprising individuals whose exposure to a source is reasonably uniform and representative of that of the individuals in the population who are the more highly exposed to that source is called a ‘reference group’.

Modellers from Poland identify a ‘reference group’ or ‘representative group’ in addition to a ‘critical group’ for additional assessments.

Most of the modellers use six age groups for the assessment according to the ICRP Publication 72 [18]: <1 year, 1–2 years, 2–7 years, 7–12 years, 12–17 years, >17 years (e.g. from Belarus, Slovakia, Poland and Ukraine). Some modellers perform the assessment for 3 age groups, as proposed in the ICRP Publication 101 [36]: 1 year old infant, a 10 year old child and an adult (e.g. from Canada, France and UK). Modellers from Argentina, identify two age groups (infant and adult) for prospective assessments, while for retrospective assessments a simplified deterministic approach is used and only one age group is considered (adult). Modellers from Brazil use 4 age groups: 0–3 years, 3–11 years, 11–18 years and adult (>18 years).

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[4]The ICRP in its latest publications recommends for the purpose of protection of the public to use the concept of ‘representative person’ which is equivalent to, and replaces, the average member of the critical group recommended previously by the Commission [35]. ICRP Publication 101 states that the representative person is an individual, who will almost always be a hypothetical construct, receives a dose that is representative of the more highly exposed individuals in the population [36].

[5]For the practical purposes ‘critical group’ and ‘representative person’ concepts in this section can be considered to be one and the same.

All the countries consider gaseous (atmospheric) and liquid (marine, lake and/or river) discharges for dose assessment purposes. Some countries provided a list of radionuclides that is used for the assessment (Belarus, Brazil, Poland and Ukraine).

The location of the representative person (critical group) is more commonly assumed to be in the areas where activity concentrations in the environment (Argentina, Belarus, Brazil, UK) or doses to the public (Slovakia) are likely to be highest, taking into account population distribution (Argentina, Belarus) or closeness to the source of discharge (Canada, France, Poland, UK). Some countries isolate a territory close to a nuclear installation where residence is prohibited (Belarus, Canada, Slovakia and Ukraine). Candidates for the representative person from different countries may also be considered (UK).

Critical exposure pathways are usually selected according to the specific discharge route or based on international publications. 'Critical' pathway and 'critical radionuclides' are calculated in Slovakia.

Habit data are always taken into account when doing an assessment. As to food consumption, all the countries consider local food production. A cautious assumption that 100% of consumed food is locally grown is used in Belarus, France and Ukraine; however in France, the food growing site(s) can be different from the living area when ingestion is clearly a predominant pathway. Consumption rates are typically chosen based on national or local surveys. The UK use a 'Top Two' approach which means that only the two foods that give the highest dose are eaten at high rates while others are eaten at average rates. Means of inhalation rate(s) are normally based on the ICRP recommendations for the particular age group.

In many countries it is assumed that the representative person spends 100% of the time at their living location with the distinction being made of time spent indoors and outdoors. Shielding factors are taken into account in Belarus, France, Poland (if data are available), Ukraine (considered in guidelines), Slovakia and UK.

Though there are many common steps in identifying the representative person almost all the parameters within these steps will be different for different countries. Many parameters will depend on the installation considered and its location, i.e. radionuclides released, air and river/marine releases, etc. At the same time, a significant source of difference is data related to population location and habits, i.e. particular exposure pathways, consumption rates, time spend indoors, etc. So, obviously, the results of the dose assessment will vary greatly depending on the selection of the critical group.

7.2. GOOD PRACTICE IN SELECTION OF REPRESENTATIVE PERSON

Section 7.1 and Appendix III describe some of the approaches currently adopted in different countries and by different organizations to determine the representative person. When there is no right way to identify the representative person, certain steps can be considered to be good practice and could be used while performing a prospective dose assessment of routine releases. These steps are likely to depend on site specific conditions such as the level and composition of the discharges, the location of the local population, the availability of survey data or resources to obtain these data and the consideration of local land use both present and future. The four main steps that may need to be considered are listed below:

(1) Consider the discharge routes, i.e. atmospheric, marine and river, and the potential exposure pathways;
   (a) if possible, local conditions could be considered to ensure that all relevant exposure pathways have been taken into account.
(2) Identify radionuclides and quantities discharged for each discharge route;
(3) Define candidates for the representative person for each discharge route, i.e.:
   (a) define the location (using the information about maximum environmental concentrations, population distribution, etc.),
   (b) define age groups (ICRP 101 recommends to use 3 age groups for the purpose of prospective dose assessment [36]),
   (c) different approaches can be used to choose habit data for the representative person. In some cases, this information can be taken from surveys of real groups of people, while in others it may be obtained from national statistics or international recommendations;
(4) Calculate the dose to the different candidates to define the representative person.

Once the Scenario and the representative person are defined, the individual committed effective dose can be calculated to be compared with the appropriate dose criteria.

8. RESULTS OF THE QUESTIONNAIRE

In order to collate information about the methodologies used to control routine discharges of radionuclides to the environment, a questionnaire was distributed among the EMRAS II participants. Questions were divided into sections: Background questions, Model inputs, Model details, Other assessment issues, Results/validation, Model verification/validation, Source monitoring, Environmental monitoring, and Other.

To summarize, 13 Member States (Argentina, Belarus, Brazil, Canada, France, Hungary, Republic of Korea, Romania, Slovakia, Sweden, Tunisia, Ukraine and United Kingdom) provided information from organizations that included regulatory authorities, research institutes and operators. In all cases nuclear power reactors were either already in operation or being proposed. Moreover, in some countries assessment is made for non-nuclear facilities. In the United Kingdom a stepwise approach is taken; firstly a simple screening assessment using cautious assumptions and generic input data is carried out, and then if necessary more detailed modelling is carried out.

The modelling is mostly done by the operators/applicants (8 out of 12), but the governmental organization can be involved either in the process or as an independent control function. All respondents use a dose limit (1 mSv/a or lower to the public) as a regulatory limit, and in addition three countries (Canada, Romania and Slovakia) have discharge limits. In Canada the same model is used for both calculating doses to the public and calculating Derived Release Limits. For some respondents (4 out of 11) the concept of dose constraint is not yet distinguished from the dose limit, as described in ICRP 103 [2], even though most respondents agree that the dose constraint is a tool for input to the optimization process and ALARA. As an example, the dose constraint value used in Brazil is 0.3 mSv/a or less.

The majority of countries calculate the committed effective dose for adults and for children in different age groups, as defined by ICRP, and the critical group/representative person may differ for different exposure pathways as in France and Hungary. In a few cases (3 out of 13) organ doses are also considered. Half of the respondents calculate a collective dose to the

population but the majority of the respondents do not yet perform any dose assessment for non-human species.

Numerous exposure pathways are evaluated and these can be quite diverse. For instance, inhalation while gardening of resuspended material contaminated by aquatic discharges is included in France. Other exposure pathways related to aquatic discharges include swimming, bathing, boating, sunbathing and time spent over irrigated soil and contaminated bank sediments for a coastal/river site. Also, the assumptions made when modeling a particular exposure pathway may differ. For example, the food exposure pathway may take into account dry and wet deposition independently or as a combined total irrigation, root uptake and inadvertent ingestion of soil by grazing animals may also be considered. The data used are both site-specific, e.g. release characteristics, meteorological and hydrological data, and generic, e.g. breathing rates and dose coefficients.

For the atmospheric releases a Gaussian plume model is employed but only 2 out of 12 respondents include the effects of plume rise and building wake. Several models (6 out of 11 respondents) can comprise short-term releases in addition to continuous releases, whereas only a few models include seasonal difference or complex terrain. For the aquatic releases different models (box, dilution and non-dilution) are in use. The majority use transfer factors in part of the model, in particular between water and aquatic food. Values are taken from various publications [4, 12, 20, 37, 38].

Discharges from nuclear power plants and other nuclear facilities are essentially monitored, whereas other discharges from other industrial practices, for instance hospitals, are generally estimated. In Romania the hospital discharges are monitored. Within the environmental monitoring program, measured radionuclide activity below the detection limit is presented among the respondents as the minimum detectable activity (MDA) value itself, as 'N.D.', as zero, both MDA and zero, or, according to 2004/2/Euratom as half the MDA for statistical purpose.

In most cases, the assessment is to be validated by the environmental monitoring, but if the measured activity is below the detection limit it is practically difficult. In the United Kingdom model inter-comparisons have been done as well as comparisons with measured data, in Ukraine the 'food chain' model has been verified with Chernobyl data and in Argentina verification has been utilized with tritium environmental measurements. Another option is the use of comparative analysis for reference tasks as mentioned by the Slovakian respondent.

9. CONCLUSIONS

The objective of this work was not to define good or bad models but to try to test the performance of models developed for assessing the transfer of radionuclides in the environment and the radiological impact on man. It is important to ensure the consistency amongst the different approaches in order to provide tools for decision makers which enable similar conclusions to be reached for a similar exposure scenario, despite the possible differences in the results of the models.

For comparing models, it was important that the exposure scenario including, for example, the radioactive source term, the location of the representative person, the exposure pathways, the habit data and food consumption rates were agreed upon in advance.

This analysis could help modellers to better understand their codes, learn about other methods by comparing their results with those of other modellers and identify sensitive parameters in relation to dose. It could also help decision makers to make appropriate decisions knowing the limitations in environmental modelling by, for example, making conservative assumptions and including appropriate safety margins.

The main findings of this work have been as follows:

(1) In general there is an acceptable agreement among the results even though the contribution to the total effective dose in the representative person from each exposure pathway can differ significantly, with greater differences being seen for the ingestion exposure pathways. External dose (groundshine and cloudshine) and inhalation dose were within an acceptable range of values, considering the associated levels of uncertainty.

(2) Total effective doses predicted by the 'screening' methodology CLRP for the Sizewell Atmospheric Scenario were higher for all radionuclides, when compared with predictions of other models.

(3) For Atmospheric releases, deposition velocity (also the dispersion processes) is one of the most sensitive parameters as it contributes both to the external (ground) dose and through food and feed chains to internal doses.

(4) For Sizewell B Marine releases, the differences in results are explained by the fact that different model types for dilution and transport were used.

(5) For the Chalk River releases there is some agreement between models regarding activity concentrations in water although model predictions tend to diverge when irrigation and uptake by crops and animals is considered.

(6) Within the range of possible differences in results that could arise from the use of the codes for impact prediction, a very important one is the personal approach of the modeller and the parameter selection. If the scenario is not very well defined, the modeller will tend to use a subjective interpretation based on his or her previous experience.

(7) The criteria for selecting the Representative Person is site specific and depends on the National approach.

APPENDIX I. INPUT PARAMETERS

This Appendix presents the common parameters used as input to the models and methods described in Sections 3 and 4 respectively.

Tables 5–7 include the parameters used in each Scenario, i.e. Sizewell B Atmospheric releases (Table 5), Sizewell B Marine releases (Table 6) and Chalk River releases (Table 7). Each table presents the parameters common to all radionuclides as well as those that are radionuclide specific.

The values of some parameters were fixed in an attempt to focus on differences in the results that were due to differences in model characteristics. The values of the fixed parameters are presented in Tables 5–7. The values to be used were determined by the group. They were agreed upon during meetings and sources such as SRS 19 [4] and N288.1 [5] were used or were derived from the original information describing the release scenarios.

TABLE 5. INPUT PARAMETERS – SIZEWELL B ATMOSPHERIC RELEASES

Common input parameters	**Parameter units**	**Parameter value**
Atmospheric radioactivity release rate	Bq a^{-1}	1.00E+09
Average weather category	unitless	100% D
Distance between the source and the receptor	m	3.00E+02
Distance between the source and livestock (cows, sheep)	m	1.00E+03
Width of the sector over which the plume spreads	radians	5.20E-01
Triple joint frequency of occurrence of stability class *i* and wind speed class *k* when the wind direction blows from sector *j*	unitless	8.33E-02
Effective release height for stability class *i* and wind speed class *k*	m	1.90E+01
Mean wind speed for class *k*	m s^{-1}	5.00E+00
Inhalation rate of receptor	m^3 a^{-1}	8.40E+03
Fraction of time exposed to inhalation hazard	unitless	1.00E+00
Deposition velocity	m s^{-1}	1.00E-03
Washout coefficient	s^{-1}	1.00E-04
Soil erosion rate	kg (dry weight) m^{-2} s^{-1}	5.00E-08
Duration of facility operation from commissioning to end of facility life	a	5.00E+01
Soil dry bulk density	kg (dry weight) m^{-3}	1.30E+03
Depth of top mixed soil layer	m	1.00E-01
Time spent by the individual at the exposure location	h	7.15E+03
Time spent outdoors at the exposure location as a fraction of total time spent at the exposure location	unitless	2.00E-01
Building shielding factor for outdoor cloudshine (fraction received indoors)	unitless	2.00E-01
Dose reduction factor to account for non-uniformity of the ground surface	unitless	7.00E-01
Shielding factor for groundshine	unitless	1.00E+00
Dry/fresh weight ratio in green vegetables	kg (dry weight) plant per kg (fresh weight) plant	1.20E-01
Dry/fresh weight ratio in root vegetables	kg (dry weight) plant per kg (fresh weight) plant	2.10E-01
Dry/fresh weight ratio in domestic fruits	kg (dry weight) plant per kg (fresh weight) plant	1.60E-01
Fraction of feed from contaminated sources	unitless	1.00E+00

TABLE 5. INPUT PARAMETERS – SIZEWELL B ATMOSPHERIC RELEASES (cont.)

Common input parameters	Parameter units	Parameter value
Feed consumption by cows	kg (dry weight) d^{-1}	1.60E+01
Feed consumption by sheep	kg (dry weight) d^{-1}	1.60E+00
Soil load on feed as consumed	kg (dry weight) soil per kg (dry weight) feed	1.00E-01
Fraction of cow's daily intake by ingestion that appears in each kg of produce (milk)	d kg^{-1} (fresh weight)	1.00E-02
Fraction of cow's daily intake by ingestion that appears in each kg of produce (beef)	d kg^{-1} (fresh weight)	7.00E-02
Fraction of sheep's daily intake by ingestion that appears in each kg of produce	d kg^{-1} (fresh weight)	7.00E-02
Foliar interception fraction for green vegetables	unitless	5.00E-01
Foliar interception fraction for root vegetables	unitless	8.00E-01
Foliar interception fraction for domestic fruits	unitless	3.00E-01
Translocation factor from foliage to consumable green vegetable produce	Bq kg^{-1} (fresh weight) consumable product per Bq kg^{-1} (fresh weight) total above ground	1.00E-01
Translocation factor from foliage to consumable root vegetable produce	Bq kg^{-1} (fresh weight) consumable product per Bq kg^{-1} (fresh weight) total above ground	1.00E-01
Translocation factor from foliage to consumable domestic fruit produce	Bq kg^{-1} (fresh weight) consumable product per Bq kg^{-1} (fresh weight) total above ground	1.00E-01
Harvest index for green vegetables	unitless	9.00E-01
Harvest index for root vegetables	unitless	2.10E+00
Harvest index for domestic fruits	unitless	1.00E+00
Removal constant from vegetation due to processes other than radiological decay in green vegetables	s^{-1}	5.73E-07
Removal constant from vegetation due to processes other than radiological decay in root vegetables	s^{-1}	5.73E-07
Removal constant from vegetation due to processes other than radiological decay in domestic fruits	s^{-1}	5.73E-07
Effective duration of the deposition	a	5.00E+01
Yield of consumable green vegetable product	kg (fresh weight) m^{-2}	4.90E+00
Yield of consumable root vegetable product	kg (fresh weight) m^{-2}	2.10E+00
Yield of consumable domestic fruit product	kg (fresh weight) m^{-2}	2.20E+00
Adjustment factor for food processing	unitless	1.00E+00
Fraction of green vegetable produce from contaminated source	unitless	1.00E+00
Fraction of root vegetable produce from contaminated source	unitless	1.00E+00
Fraction of domestic fruit produce from contaminated source	unitless	1.00E+00
Intake of green vegetables	kg (fresh weight) a^{-1}	6.56E+01
Intake of root vegetables	kg (fresh weight) a^{-1}	1.11E+02
Intake of domestic fruits	kg (fresh weight) a^{-1}	4.24E+01
Hold-up time between plant exposure to contamination and feeding for cow feed	s	8.00E+06
Hold-up time between plant exposure to contamination and feeding for sheep feed	s	8.60E+04
Inhalation rate of the cow	m^3 d^{-1}	9.00E+01
Inhalation rate of the sheep	m^3 d^{-1}	8.64E+00
Fraction of the cows daily intake by inhalation that appears in each kg of produce (milk)	d kg^{-1} (fresh weight)	2.10E-04
Fraction of the cows daily intake by inhalation that appears in each kg of produce (beef)	d kg^{-1} (fresh weight)	1.41E-01
Fraction of the sheep daily intake by inhalation that appears in each kg of produce	d kg^{-1} (fresh weight)	2.74E-01

TABLE 5. INPUT PARAMETERS – SIZEWELL B ATMOSPHERIC RELEASES (cont.)

Common input parameters		**Parameter units**	**Parameter value**
Fraction of cow produce (milk) from contaminated source		unitless	1.00E+00
Fraction of cow produce (beef) from contaminated source		unitless	1.00E+00
Fraction of sheep produce from contaminated source		unitless	1.00E+00
Intake of cow produce (milk)		kg (fresh weight) a^{-1}	2.08E+02
Intake of cow produce (beef)		kg (fresh weight) a^{-1}	2.80E+01
Intake of sheep produce		kg (fresh weight) a^{-1}	2.40E+00
Radionuclide	**Radionuclide dependent input parameters**	**Parameter units**	**Parameter value**
Cobalt-60 (^{60}Co)	Dose coefficient for inhalation	Sv Bq^{-1}	3.10E-08
	Radioactive decay constant	s^{-1}	4.17E-09
	Effective dose coefficient for a semi-infinite cloud	Sv a^{-1} Bq^{-1} m^3	4.00E-06
	Effective dose coefficient for an infinite plane ground deposit	Sv a^{-1} Bq^{-1} m^2	9.44E-08
	Dose coefficient for intake from ingestion	Sv Bq^{-1}	3.40E-09
Cesium-137 (^{137}Cs)	Dose coefficient for inhalation	Sv Bq^{-1}	4.60E-09
	Radioactive decay constant	s^{-1}	7.31E-10
	Effective dose coefficient for a semi-infinite cloud	Sv a^{-1} Bq^{-1} m^3	8.70E-07
	Effective dose coefficient for an infinite plane ground deposit	Sv a^{-1} Bq^{-1} m^2	9.44E-11
	Dose coefficient for intake from ingestion	Sv Bq^{-1}	1.30E-08
Iodine-131 (^{131}I)	Dose coefficient for inhalation	Sv Bq^{-1}	7.40E-09
	Radioactive decay constant	s^{-1}	1.00E-06
	Effective dose coefficient for a semi-infinite cloud	Sv a^{-1} Bq^{-1} m^3	5.80E-07
	Effective dose coefficient for an infinite plane ground deposit	Sv a^{-1} Bq^{-1} m^2	1.15E-08
	Dose coefficient for intake from ingestion	Sv Bq^{-1}	2.20E-08
Krypton-85 (^{85}Kr)	Dose coefficient for inhalation	Sv Bq^{-1}	0.00E+00
	Radioactive decay constant	s^{-1}	2.05E-09
	Effective dose coefficient for a semi-infinite cloud	Sv a^{-1} Bq^{-1} m^3	3.30E-09
	Effective dose coefficient for an infinite plane ground deposit	Sv a^{-1} Bq^{-1} m^2	0.00E+00
	Dose coefficient for intake from ingestion	Sv Bq^{-1}	0.00E+00

TABLE 6. INPUT PARAMETERS – SIZEWELL B MARINE RELEASES

Common input parameters	**Parameter units**	**Parameter value**
Marine radioactivity release rate from source	Bq a^{-1}	1.00E+09
Average water depth in the reach occupied by the plume	m	1.00E+01
Volume of basin	m^3	3.00E+08
Diffusion rate	m^2 a^{-1}	3.15E-02
Initial dilution at the point of discharge	unitless	1.00E+00
Distance between the source and the point of interest	m	6.00E+02
The annual fraction of time that the current is towards the point of interest		1.00E+02
The annual volumetric discharge rate of liquid effluents	m^3 a^{-1}	1.50E+09
The annual average current speed in the direction towards the point of interest	m s^{-1}	1.00E+00
Suspended sediment load	t m^{-3}	8.00E-05
Sediment density	kg m^{-3}	1.60E+03
Sedimentation rate	t m^{-3} a^{-1}	1.00E-05

TABLE 6. INPUT PARAMETERS – SIZEWELL B MARINE RELEASES (cont.)

Common input parameters		Parameter units	Parameter value
Removal constant for sedimentation		s^{-1}	0.00E+00
Bioturbation rate		$m^2\ a^{-1}$	3.60E-05
Number of days per year that sediment intake can occur		d	4.50E+01
Incidental intake of sediment		kg (dry weight) d^{-1}	3.30E-04
Shoreline occupancy factor		h a^{-1}	7.31E+02
Shore width factor		unitless	5.00E-01
Dilution factor for shoreline deposits		unitless	1.00E+00
Modifying factor for food processing		unitless	1.00E+00
Fraction of fish produce from contaminated source		unitless	1.00E+00
Fraction of crustacean produce from contaminated source		unitless	1.00E+00
Fraction of mollusc produce from contaminated source		unitless	1.00E+00
Intake of fish		kg (fresh weight) a^{-1}	2.30E+01
Intake of crustaceans		kg (fresh weight) a^{-1}	1.12E+01
Intake of mollusc		kg (fresh weight) a^{-1}	5.10E+00
Radionuclide	**Radionuclide dependent input parameters**	**Parameter units**	**Parameter value**
Cobalt-60 (^{60}Co)	Radioactive decay constant	s^{-1}	4.17E-09
	Dose coefficient for intake by ingestion	Sv Bq^{-1}	3.40E-09
	Dose coefficient for a uniformly contaminated shoreline	Sv a^{-1} Bq^{-1} kg (dry weight)	7.50E-08
Cesium-137 (^{137}Cs)	Radioactive decay constant	s^{-1}	7.31E-10
	Dose coefficient for intake by ingestion	Sv Bq^{-1}	1.30E-08
	Dose coefficient for a uniformly contaminated shoreline	Sv a^{-1} Bq^{-1} kg (dry weight)	1.80E-08
Strontium-90 (^{90}Sr)	Radioactive decay constant	s^{-1}	7.61E-10
	Dose coefficient for intake by ingestion	Sv Bq^{-1}	2.80E-08
	Dose coefficient for a uniformly contaminated shoreline	Sv a^{-1} Bq^{-1} kg (dry weight)	3.50E-09

TABLE 7. INPUT PARAMETERS – CHALK RIVER RELEASES

Common input parameters	Parameter units	Parameter value
Flow rate for liquid effluent	$m^3\ s^{-1}$	6.50E+02
Discharge location distance offshore	m	1.00E+02
River width	m	1.50E+03
River depth	m	1.12E+01
Distance downstream to Westmeath Farm	m	5.30E+04
Distance downstream to Harrington Bay	m	8.64E+03
Water temperature	°C	7.86E+00
Mean river flow rate	$m^3\ s^{-1}$	8.40E+02
Net river velocity (current velocity)	m s^{-1}	5.00E-02
Longitudinal dispersion coefficient	$m^2\ s^{-1}$	1.50E+02
Lateral dispersion coefficient	$m^2\ s^{-1}$	4.00E-01
Sediment flow rate	$m^3\ s^{-1}$	2.00E-03
Removal constant for sedimentation	s^{-1}	0.00E+00
Suspended sediment concentration	kg m^{-3}	5.00E-02
Sedimentation rate	mm a^{-1}	1.88E+01
Burial rate	%	6.40E+00
Resuspension rate	%	9.46E+01
Sediment bulk density	g cm^{-3}	2.70E-01
Suspended sediment particle diameter	m	5.00E-05
Depth of bed sediments	m	5.00E-02
Total suspended solids	mg L^{-1}	1.70E+00
Total dissolved solids	mg L^{-1}	3.00E+01

TABLE 7. INPUT PARAMETERS – CHALK RIVER RELEASES (cont.)

Common input parameters	**Parameter units**	**Parameter value**
Friction coefficient (Manning-Strickler)	$m^{1/3}$ s^{-1}	3.00E+01
Effective accumulation time for radionuclides on bottom sediment	s	3.15E+07
Effective accumulation time for radionuclides on shore sediment	s	3.15E+07
Shore width factor for shoreline geometry	unitless	2.00E-01
Fraction of time per year the receptor is exposed to contaminated shoreline	unitless	2.00E-02
Number of days per year in which sediment ingestion can occur	d a^{-1}	4.50E+01
Incidental intake of sediment	kg (dw) d^{-1}	3.30E-04
Dilution factor for shoreline deposits	unitless	1.00E+00
Removal factor to account for any water treatment	unitless	1.00E+00
Fraction of drinking water intake that is contaminated	unitless	1.00E+00
Fraction of year spent swimming in surface water body	unitless	1.40E-02
Correction factor to account for the finite size of the bathtub	unitless	7.00E-01
Fraction of the year spent taking baths	unitless	1.40E-02
Skin surface area	m^2	2.19E+00
Diffusion rate for water-wetted skin	L a^{-1} m^{-2} skin surface area	1.05E+02
Annual average irrigation rate	L m^{-2} s^{-1}	1.10E-05
Soil dry bulk density	kg dw m^{-3}	1.30E+03
Depth of the top mixed soil layer	m	2.00E-01
Duration of facility operation	a	3.00E+01
Fraction of time per year the receptor is at the exposure location	unitless	1.00E+00
Fraction of time per year the receptor is outdoors at the exposure location	unitless	2.00E-01
Dose reduction factor to account for non-conformity of the ground surface	unitless	7.00E-01
Fraction of the outdoor groundshine dose received indoors due to shielding by buildings	unitless	2.00E-01
Incidental intake of soil	kg dw d^{-1}	3.30E-01
Number of days per year in which incidental soil ingestion could occur	d a^{-1}	1.35E+02
Long term average precipitation	m s^{-1}	3.60E-01
Leaf area index for fruits and berries	m^2 m^{-2}	3.00E+00
Leaf area index for above ground vegetables	m^2 m^{-2}	3.00E+00
Leaf area index for potatoes	m^2 m^{-2}	3.00E+00
Leaf area index for forage (deer)	m^2 m^{-2}	3.00E+00
Leaf area index for feed crops (cow and chicken)	m^2 m^{-2}	3.00E+00
Volume of water retained per unit leaf area	L m^{-2}	1.00E-01
Removal rate from leaf surfaces for reasons other than radioactive decay	s^{-1}	5.79E-07
Frequency of irrigation events using contaminated water	s^{-1}	3.34E-06
Harvest index for fruits and berries	unitless	5.00E-01
Harvest index for above ground fruits	unitless	8.00E-01
Harvest index for potatoes	unitless	8.00E-01
Harvest index for forage (deer)	unitless	1.00E+00
Harvest index for feed crops (cow and chicken)	unitless	1.00E+00
Effective duration of the deposition	s	5.20E+06
Dry/fresh weight ratio for fruits and berries	kg dw plant kg^{-1}fw plant	1.60E-01
Dry/fresh weight ratio for above ground vegetables	kg dw plant kg^{-1}fw plant	1.00E-01
Dry/fresh weight ratio for potatoes	kg dw plant kg^{-1}fw plant	2.10E-01
Dry/fresh weight ratio for forage (deer)	kg dw plant kg^{-1}fw plant	1.90E-01
Dry/fresh weight ratio for feed crops (cow and chicken)	kg dw plant kg^{-1}fw plant	8.60E-01
Isotopic discrimination factor for plant metabolism	unitless	8.00E-01
Water equivalent of plant dry matter	L water kg^{-1}dw plant	5.60E-01
Fraction of feed from contaminated sources	unitless	1.00E+00

TABLE 7. INPUT PARAMETERS – CHALK RIVER RELEASES (cont.)

Common input parameters	Parameter units	Parameter value
Hold-up time between plant exposure to contamination and feeding for venison (deer)	s	0.00E+00
Hold-up time between plant exposure to contamination and feeding for beef (cow)	s	0.00E+00
Hold-up time between plant exposure to contamination and feeding for milk (cow)	s	0.00E+00
Hold-up time between plant exposure to contamination and feeding for poultry (chicken)	s	0.00E+00
Hold-up time between plant exposure to contamination and feeding for eggs (chicken)	s	0.00E+00
Feed consumption for venison (deer)	kg dw d^{-1}	1.74E+00
Feed consumption for beef (cow)	kg dw d^{-1}	7.20E+00
Feed consumption for milk (cow)	kg dw d^{-1}	1.60E+01
Feed consumption for poultry (chicken)	kg dw d^{-1}	1.00E-01
Feed consumption for eggs (chicken)	kg dw d^{-1}	1.00E-01
Drinking water intake for venison (deer)	L d^{-1}	5.10E+00
Drinking water intake for beef (cow)	L d^{-1}	3.10E+01
Drinking water intake for milk (cow)	L d^{-1}	1.51E+02
Drinking water intake for poultry (chicken)	L d^{-1}	1.00E-01
Drinking water intake for eggs (chicken)	L d^{1}	1.00E-01
Modifying factor for food processing	unitless	1.00E+00
Fraction of venison (deer) from contaminated source	unitless	1.00E-01
Fraction of beef (cow) from contaminated source	unitless	4.40E-01
Fraction of milk (cow) from contaminated source	unitless	1.00E+00
Fraction of poultry (chicken) from contaminated source	unitless	4.40E-01
Fraction of eggs (chicken) from contaminated source	unitless	4.40E-01
Fraction of freshwater fish from contaminated source	unitless	1.00E+00
Fraction of fruits and berries from contaminated source	unitless	2.00E-01
Fraction of above ground vegetables from contaminated source	unitless	2.50E-01
Fraction of potatoes from contaminated source	unitless	2.50E-01
Fish water content	unitless	8.75E-01
Inhalation rate	m^3 s^{-1}	8.10E+03
Total water intake	L a^{-1}	8.40E+02
Soil intake	kg a^{-1}	3.70E-02
Consumption rate of venison (deer)	kg a^{-1}	8.60E+00
Consumption rate of beef (cow)	kg a^{-1}	7.30E+01
Consumption rate of milk (cow)	L a^{-1}	2.85E+02
Consumption rate of poultry (chicken)	kg a^{-1}	2.10E+01
Consumption rate of eggs (chicken)	kg a^{-1}	3.20E+01
Consumption rate of freshwater fish	kg a^{-1}	4.10E+00
Consumption rate of fruits and berries	kg a^{-1}	1.87E+02
Consumption rate of above ground vegetables	kg a^{-1}	2.53E+02
Consumption rate of potatoes	kg a^{-1}	1.12E+02

Radionuclide	Radionuclide dependent input parameters	Parameter units	Parameter value
Cobalt-60 (^{60}Co)	Radioactivity release rate	Bq a^{-1}	1.00E+09
	Radionuclide decay constant (λ)	s^{-1}	4.17E-09
	Sediment distribution coefficient (Kd)	L kg^{-1}	5.00E+03
	Concentration ratio	Bq kg^{-1}dw plant / Bq kg^{-1}dw soil	4.70E-02
	Translocation factor from foliage to consumable produce	unitless	1.00E-01
	Fraction of daily intake by ingestion that appears in each kg of produce for venison (deer)	d kg^{-1}fw	1.20E-02

TABLE 7. INPUT PARAMETERS – CHALK RIVER RELEASES (cont.)

Radionuclide	Radionuclide dependent input parameters	Parameter units	Parameter value
	Fraction of daily intake by ingestion that appears in each kg of produce for beef (cow)	d kg^{-1}fw	2.30E-03
	Fraction of daily intake by ingestion that appears in each kg of produce for milk (cow)	d kg^{-1}fw	9.50E-04
	Fraction of daily intake by ingestion that appears in each kg of produce for poultry (chicken)	d kg^{-1}fw	1.20E+00
	Fraction of daily intake by ingestion that appears in each kg of produce for eggs (chicken)	d kg^{-1}fw	2.60E-01
	Bioaccumulation factor for freshwater fish	L kg^{-1}fw	5.40E+01
	Dose coefficient for uniformly contaminated sediment	Sv a^{-1} Bq^{-1} m^2	7.50E-08
	Dose coefficient for immersion in a water body	Sv a^{-1} per Bq L^{-1}	8.11E-06
	Dose coefficient for ingestion	Sv Bq^{-1}	3.40E-09
Cesium-137 (^{137}Cs)	Radioactivity release rate	Bq a^{-1}	1.00E+09
	Radionuclide decay constant (λ)	s^{-1}	7.33E-10
	Sediment distribution coefficient (Kd)	L kg^{-1}	1.00E+03
	Concentration ratio	Bq kg^{-1}dw plant / Bq kg^{-1}dw soil	5.30E-02
	Translocation factor from foliage to consumable produce	unitless	1.00E+00
	Fraction of daily intake by ingestion that appears in each kg of produce for venison (deer)	d kg^{-1}fw	1.50E-01
	Fraction of daily intake by ingestion that appears in each kg of produce for beef (cow)	d kg^{-1}fw	3.70E-02
	Fraction of daily intake by ingestion that appears in each kg of produce for milk (cow)	d kg^{-1}fw	7.30E-03
	Fraction of daily intake by ingestion that appears in each kg of produce for poultry (chicken)	d kg^{-1}fw	4.40E+00
	Fraction of daily intake by ingestion that appears in each kg of produce for eggs (chicken)	d kg^{-1}fw	8.10E-01
	Bioaccumulation factor for freshwater fish	L kg^{-1}fw	3.50E+03
	Dose coefficient for uniformly contaminated sediment	Sv a^{-1} Bq^{-1} m^2	1.80E-08
	Dose coefficient for immersion in a water body	Sv a^{-1} per Bq L^{-1}	1.75E-06
	Dose coefficient for ingestion	Sv Bq^{-1}	1.30E-08
Strontium-90 (^{90}Sr)	Radioactivity release rate	Bq a^{-1}	1.00E+09
	Radionuclide decay constant (λ)	s^{-1}	7.55E-10
	Sediment distribution coefficient (Kd)	L kg^{-1}	1.00E+03
	Concentration ratio	Bq kg^{-1}dw plant / Bq kg^{-1}dw soil	8.70E-01
	Translocation factor from foliage to consumable produce	unitless	1.00E+00
	Fraction of daily intake by ingestion that appears in each kg of produce for venison (deer)	d kg^{-1}fw	4.00E-02
	Fraction of daily intake by ingestion that appears in each kg of produce for beef (cow)	d kg^{-1}fw	2.10E-03
	Fraction of daily intake by ingestion that appears in each kg of produce for milk (cow)	d kg^{-1}fw	2.00E-03
	Fraction of daily intake by ingestion that appears in each kg of produce for poultry (chicken)	d kg^{-1}fw	7.60E-02
	Fraction of daily intake by ingestion that appears in each kg of produce for eggs (chicken)	d kg^{-1}fw	2.70E-01
	Bioaccumulation factor for freshwater fish	L kg^{-1}fw	2.00E+00
	Dose coefficient for uniformly contaminated sediment	Sv a^{-1} Bq^{-1} m^2	3.50E-09
	Dose coefficient for immersion in a water body	Sv a^{-1} per Bq L^{-1}	3.44E-09
	Dose coefficient for ingestion	Sv Bq^{-1}	2.80E-08

TABLE 7. INPUT PARAMETERS – CHALK RIVER RELEASES (cont.)

Radionuclide	**Radionuclide dependent input parameters**	**Parameter units**	**Parameter value**
Iodine-131 (^{131}I)	Radioactivity release rate	Bq a^{-1}	1.00E+09
	Radionuclide decay constant (λ)	s^{-1}	9.97E-07
	Sediment distribution coefficient (Kd)	L kg^{-1}	1.00E+01
	Concentration ratio	Bq kg^{-1}dw plant / Bq kg^{-1}dw soil	5.00E-02
	Translocation factor from foliage to consumable produce	unitless	1.00E-01
	Fraction of daily intake by ingestion that appears in each kg of produce for venison (deer)	d kg^{-1}fw	3.20E-02
	Fraction of daily intake by ingestion that appears in each kg of produce for beef (cow)	d kg^{-1}fw	1.20E-02
	Fraction of daily intake by ingestion that appears in each kg of produce for milk (cow)	d kg^{-1}fw	7.60E-03
	Fraction of daily intake by ingestion that appears in each kg of produce for poultry (chicken)	d kg^{-1}fw	8.70E-01
	Fraction of daily intake by ingestion that appears in each kg of produce for eggs (chicken)	d kg^{-1}fw	2.90E+00
	Bioaccumulation factor for freshwater fish	L kg^{-1}fw	6.00E+00
	Dose coefficient for uniformly contaminated sediment	Sv a^{-1} Bq^{-1} m^2	1.20E-08
	Dose coefficient for immersion in a water body	Sv a^{-1} per Bq L^{-1}	1.16E-06
	Dose coefficient for ingestion	Sv Bq^{-1}	2.20E-08
Tritium (^3H)	Radioactivity release rate	Bq a^{-1}	1.00E+09
	Radionuclide decay constant (λ)	s^{-1}	1.79E-09
	Sediment distribution coefficient (Kd)	L kg^{-1}	0.00E+00
	Concentration ratio	Bq kg^{-1}dw plant / Bq kg^{-1}dw soil	0.00E+00
	Translocation factor from foliage to consumable produce	unitless	1.00E+00
	Fraction of daily intake by ingestion that appears in each kg of produce for venison (deer)	d kg^{-1}fw	0.00E+00
	Fraction of daily intake by ingestion that appears in each kg of produce for beef (cow)	d kg^{-1}fw	0.00E+00
	Fraction of daily intake by ingestion that appears in each kg of produce for milk (cow)	d kg^{-1}fw	0.00E+00
	Fraction of daily intake by ingestion that appears in each kg of produce for poultry (chicken)	d kg^{-1}fw	0.00E+00
	Fraction of daily intake by ingestion that appears in each kg of produce for eggs (chicken)	d kg^{-1}fw	0.00E+00
	Bioaccumulation factor for freshwater fish (HTO)	L kg^{-1}fw	7.51E-01
	Dose coefficient for uniformly contaminated sediment	Sv a^{-1} Bq^{-1} m^2	0.00E+00
	Dose coefficient for immersion in a water body	Sv a^{-1} per Bq L^{-1}	1.71E-10
	Dose coefficient for ingestion (HTO)	Sv Bq^{-1}	1.80E-11

APPENDIX II. CALCULATION RESULTS

TABLE 8. SIZEWELL B ATMOSPHERIC RELEASES ^{60}Co ESTIMATED DOSES (µSv/a)

Exposure pathways	CLRP	CROM	DOSAMED	IAEA SRS 19 methodology	IMPACT	PC-CREAM 98	PC-CREAM 08 Modeller 1	PC-CREAM 08 Modeller 2	RDEMO	SYMBIOSE
Internal dose–cow produce (milk) ingestion	3.50E-01	1.60E-02	–	1.56E-02	5.83E-02	9.00E-04	5.45E-03	4.36E-03	9.56E-04	2.40E-02
Internal dose – cow produce (beef) ingestion	7.30E-01	1.50E-02	–	1.09E-02	7.96E-03	5.00E-05	4.22E-03	3.37E-03	2.11E-03	1.40E-02
Internal dose – sheep produce ingestion	4.38E-01	1.30E-04	–	9.37E-05	2.84E-04	6.40E-06	2.84E-05	3.19E-05	–	4.40E-05
Internal dose –root vegetable ingestión	7.18E-02	4.50E-03	–	4.21E-04	1.10E-03	1.10E-04	3.28E-05	2.78E-05	4.25E-03	5.50E-04
Internal dose - green vegetable ingestion	4.25E-02	2.70E-03	–	6.68E-05	6.49E-04	1.50E-03	1.31E-04	5.56E-04	1.40E-03	1.50E-04
Internal dose – domestic fruit ingestion	2.75E-02	1.70E-03	–	5.77E-05	4.11E-04	3.70E-04	2.60E-05	2.50E-05	2.48E-04	7.20E-05
Internal dose – inhalation	1.81E-02	2.08E-02	–	1.68E-02	1.38E-02	1.50E-02	4.96E-03	4.96E-03	2.46E-02	1.70E-02
External dose – groundshine	1.09E+01	2.86E-01	–	2.82E-01	1.03E-01	1.60E-01	1.62E-01	1.35E-01	3.08E-01	1.10E-01
External dose – air immersion (cloudshine)	2.48E-04	9.20E-05	–	9.28E-05	7.63E-05	3.41E-05	3.56E-05	3.56E-05	3.19E-05	1.15E-04
Total dose	**1.26E+01**	**3.47E-01**	**2.87E+00**	**3.27E-01**	**1.85E-01**	**1.78E-01**	**1.77E-01**	**1.48E-01**	**3.42E-01**	**1.66E-01**

TABLE 9. SIZEWELL B ATMOSPHERIC RELEASES ^{137}Cs ESTIMATED DOSES (μSv/a)

Exposure pathways	CLRP	CROM	DOSAMED	IAEA SRS 19 methodology	IMPACT	PC-CREAM 98	PC-CREAM 08 Modeller 1	PC-CREAM 08 Modeller 2	RDEMO	SYMBIOSE
Internal dose – cow produce (milk) ingestion	1.23E+00	5.80E-02	–	5.64E-02	1.98E-01	8.70E-03	1.62E-02	8.86E-03	7.14E-03	1.10E-01
Internal dose – cow produce (beef) ingestion	1.84E+00	3.90E-02	–	2.84E-02	2.70E-02	6.00E-03	1.11E-02	6.09E-03	1.20E-03	6.00E-02
Internal dose – sheep produce ingestion	1.10E+00	2.00E-03	–	1.46E-03	4.66E-03	1.10E-03	9.27E-04	7.42E-04	–	1.10E-03
Internal dose – root vegetable ingestión	2.70E-01	1.70E-02	–	1.63E-02	4.15E-02	1.10E-02	6.80E-03	7.08E-03	2.92E-02	1.80E-02
Internal dose – green vegetable ingestion	1.60E-01	9.90E-03	–	2.58E-03	2.44E-02	7.10E-03	7.57E-04	2.31E-03	1.01E-02	6.60E-03
Internal dose – domestic fruit ingestion	1.03E-01	6.40E-03	–	2.22E-03	1.55E-02	2.40E-03	2.71E-03	9.06E-04	4.11E-02	2.90E-03
Internal dose – inhalation	2.69E-03	3.10E-03	–	2.49E-03	2.05E-03	2.20E-03	2.28E-03	2.28E-03	3.66E-03	2.60E-03
External dose – groundshine	4.21E+00	1.18E-01	–	1.18E-01	2.01E-02	9.51E-02	1.30E-01	1.07E-01	1.06E-01	1.20E-01
External dose – air immersion (cloudshine)	5.39E-05	5.70E-05	–	2.02E-05	1.66E-05	8.20E-06	1.90E-06	1.80E-06	6.62E-06	2.50E-05
Total dose	**8.91E+00**	**2.53E-01**	**8.16E-01**	**2.28E-01**	**3.33E-01**	**1.34E-01**	**1.71E-01**	**1.35E-01**	**1.98E-01**	**3.21E-01**

TABLE 10. SIZEWELL B ATMOSPHERIC RELEASES ^{131}I ESTIMATED DOSES (μSv/a)

Exposure pathways	CLRP	CROM	DOSAMED	IAEA SRS 19 methodology	IMPACT	PC-CREAM 98	PC-CREAM 08 Modeller 1	PC-CREAM 08 Modeller 2	RDEMO	SYMBIOSE
Internal dose – cow produce (milk) ingestion	3.60E-01	2.30E-02	–	1.54E-01	8.83E-04	4.70E-02	3.95E-02	4.10E-02	5.31E-03	2.70E-01
Internal dose – cow produce (beef) ingestion	1.05E-01	3.10E-03	–	1.50E-02	1.20E-04	2.20E-03	1.74E-03	1.81E-03	1.23E-04	4.20E-03
Internal dose – sheep produce ingestion	6.30E-02	2.60E-04	–	1.29E-04	5.59E-03	2.90E-04	9.74E-05	1.29E-04	–	1.00E-05
Internal dose – root vegetable ingestión	4.73E-02	5.60E-02	–	3.07E-03	2.70E-02	1.20E-02	7.57E-03	7.93E-03	6.17E-03	9.40E-03
Internal dose – green vegetable ingestion	2.80E-02	3.30E-02	–	4.86E-04	1.59E-02	3.40E-02	2.69E-03	1.25E-02	1.83E-03	1.50E-03
Internal dose – domestic fruit ingestion	1.81E-02	2.10E-02	–	4.20E-04	1.01E-02	1.70E-02	1.34E-03	1.28E-03	1.11E-06	1.30E-03
Internal dose – inhalation	4.33E-03	5.00E-03	–	3.99E-03	3.29E-03	3.60E-03	3.65E-03	3.65E-03	5.46E-03	4.10E-03
External dose – groundshine	7.30E-03	2.68E-03	–	1.83E-03	4.25E-03	2.22E-03	4.10E-03	3.95E-03	2.14E-03	2.20E-03
External dose – air immersion (cloudshine)	3.59E-05	1.30E-05	–	1.34E-05	1.11E-05	5.66E-06	5.60E-06	5.50E-06	2.20E-05	1.70E-05
Total dose	**6.33E-01**	**1.44E-01**	**1.69E-01**	**1.79E-01**	**6.71E-02**	**1.18E-01**	**6.07E-02**	**7.23E-02**	**2.11E-02**	**2.93E-01**

TABLE 11. SIZEWELL B ATMOSPHERIC RELEASES ^{85}Kr ESTIMATED DOSES (µSv/a)

Exposure pathways	**CLRP**	**CROM**	**DOSAMED**	**IAEA SRS 19 methodology**	**IMPACT**	**PC-CREAM 98**	**PC-CREAM 08 Modeller 1**	**PC-CREAM 08 Modeller 2**	**RDEMO**	**SYMBIOSE**
Internal dose – cow produce (milk) ingestion	–	–	–	–	–	–	–	–	–	–
Internal dose – cow produce (beef) ingestion	–	–	–	–	–	–	–	–	–	–
Internal dose – sheep produce ingestion	–	–	–	–	–	–	–	–	–	–
Internal dose – root vegetable ingestión	–	–	–	–	–	–	–	–	–	–
Internal dose – green vegetable ingestion	–	–	–	–	–	–	–	–	–	–
Internal dose – domestic fruit ingestion	–	–	–	–	–	–	–	–	–	–
Internal dose – inhalation	–	–	–	–	–	–	–	–	–	–
External dose – groundshine	–	–	–	–	–	–	–	–	–	–
External dose – air immersion (cloudshine)	2.05E-07	4.80E-07	1.88E-07	7.66E-08	6.30E-08	2.12E-07	2.82E-07	2.82E-07	1.23E-07	9.51E-08
Total dose	**2.05E-07**	**4.80E-07**	**1.88E-07**	**7.66E-08**	**6.30E-08**	**2.12E-07**	**2.82E-07**	**2.82E-07**	**1.23E-07**	**9.51E-08**

TABLE 12. SIZEWELL B MARINE RELEASES ^{60}Co ESTIMATED DOSES (µSv/a)

Exposure pathways	**CROM**	**IAEA SRS 19 methodology**	**IMPACT**	**PC-CREAM 08**	**POSEIDON**	**SYMBIOSE**
Internal dose – fish ingestion	9.38E-02	9.32E-02	1.16E+00	4.77E-03	2.00E-03	9.00E-02
Internal dose – crustaceans ingestion	1.30E+00	1.30E+00	5.49E-01	6.63E-02	1.00E-02	1.25E+00
Internal dose – mollusc ingestion	5.93E-01	5.90E-01	2.55E-01	3.02E-02	8.00E-03	5.70E-01
Internal dose from sediments	4.60E-06	2.58E-05	5.15E-05	–	–	4.65E-06
External dose from sediments	1.70E-02	1.80E-02	7.65E-04	2.83E-03	–	5.80E-04
Total dose	**2.00E+00**	**2.00E+00**	**1.96E+00**	**1.04E-01**	**2.00E-02**	**1.91E+00**

TABLE 13. SIZEWELL B MARINE RELEASES ^{137}Cs ESTIMATED DOSES (μSv/a)

Exposure pathways	CROM	IAEA SRS 19 methodology	IMPACT	PC-CREAM 08	POSEIDON	SYMBIOSE
Internal dose – fish ingestion	5.11E-02	4.99E-02	4.28E-02	2.25E-03	1.50E-02	4.20E-02
Internal dose – crustaceans ingestion	1.49E-02	1.46E-02	2.03E-02	6.57E-04	4.00E-03	1.20E-02
Internal dose – mollusc ingestion	6.80E-03	6.63E-03	9.44E-03	2.99E-04	2.00E-03	5.60E-03
Internal dose from sediments	7.26E-05	4.35E-04	8.86E-04	–	–	7.30E-05
External dose from sediments	4.71E-06	2.01E-02	8.26E-04	5.56E-03	–	5.70E-04
Total dose	**7.29E-02**	**9.15E-02**	**7.43E-02**	**8.76E-03**	**2.10E-02**	**6.02E-02**

TABLE 14. SIZEWELL B MARINE RELEASES ^{90}Sr ESTIMATED DOSES (μSv/a)

Exposure pathways	CROM	IAEA SRS 19 methodology	IMPACT	PC-CREAM 08	POSEIDON	SYMBIOSE
Internal dose – fish ingestion	3.30E-03	3.30E-03	6.49E-03	1.76E-04	9.40E-04	3.30E-03
Internal dose – crustaceans ingestion	5.40E-03	5.36E-03	3.08E-03	2.85E-04	5.40E-03	5.30E-03
Internal dose – mollusc ingestion	2.40E-03	2.44E-03	1.43E-03	1.30E-04	2.00E-03	2.40E-03
Internal dose from sediments	9.10E-06	4.62E-05	9.19E-05	–	–	9.10E-06
External dose from sediments	5.35E-08	1.92E-04	7.74E-06	2.35E-05	–	6.40E-06
Total dose	**1.11E-02**	**1.13E-02**	**1.11E-02**	**6.14E-04**	**8.34E-03**	**1.10E-02**

TABLE 15. CHALK RIVER RELEASES ^{60}Co ESTIMATED DOSES (µSv/a)

Exposure pathways	CLRP	CROM[(1)]	DOSIS LIQUIDAS	IAEA SRS 19 methodology	IMPACT	PC-CREAM 08[(2)]	RDEMO	SYMBIOSE
Internal dose – drinking water ingestion	3.41E-05	8.62E-05	1.08E-04	3.20E-04	1.07E-04	8.45E-05	5.37E-05	8.90E-05
Internal dose – freshwater fish ingestion	4.99E-05	2.30E-05	2.84E-05	2.27E-05	2.83E-05	2.23E-05	2.62E-05	1.20E-05
Internal dose – fruits and berries ingestion	8.70E-05	2.10E-05	–	2.95E-05	7.34E-07	2.50E-07	8.26E-08	–
Internal dose – above ground vegetables ingestion	1.18E-04	3.52E-05	–	4.99E-05	1.43E-06	2.27E-06	5.75E-07	1.90E-05
Internal dose – potato ingestion	5.21E-05	1.57E-05	–	2.21E-05	5.59E-07	5.05E-08	–	7.90E-06
Internal dose – venison (deer) ingestion	4.13E-05	6.31E-09	–	1.95E-07	1.21E-08	–	–	–
Internal dose – beef (cow) ingestion	2.49E-04	2.53E-06	–	5.86E-06	3.56E-07	1.54E-06	2.77E-05	6.60E-07
Internal dose – milk (cow) ingestion	3.21E-04	2.34E-05	–	5.04E-05	5.79E-06	2.53E-05	2.34E-06	1.10E-05
Internal dose – poultry (chicken) ingestion	1.91E-06	4.83E-06	–	1.18E-05	2.66E-07	–	–	8.70E-07
Internal dose – eggs (chicken) ingestion		1.60E-06	–	3.91E-06	8.77E-08	–	–	3.00E-07
External dose – immersion in surface water	1.34E-05	8.95E-04	2.05E-04	2.16E-05	1.58E-05	–	4.13E-06	7.30E-06
External dose from sediment	2.03E-04	7.63E-02	2.87E-04	9.44E-04	4.51E-03	6.09E-02	1.74E-02	7.40E-04
Internal dose – incidental ingestion of sediment		–	–	2.82E-05	9.49E-06	1.92E-03	–	4.60E-06
External dose from exposure to soil		1.17E-15	–	3.50E-05	1.69E-03	–	1.42E-06	–
Internal dose – incidental ingestion of soil		–	–	1.25E-08	1.66E-08	–	–	–
Total dose	**1.17E-03**	**7.74E-02**	**6.28E-04**	**1.54E-03**	**6.37E-03**	**6.30E-02**	**1.75E-02**	**8.93E-04**

NOTES:

(1) The end points are the doses from the various pathways to adult residents of Harrington Bay, and the food which they (Harrington residents) eat from the Westmeath farm.

(2) Harrington for: drinking water, fish and incidental sediment ingestion, external dose from sediment – Westmeath only for: fruits and berries, vegetables, potato, beef and milk ingestion.

TABLE 16. CHALK RIVER RELEASES ^{137}Cs ESTIMATED DOSES (µSv/a)

Exposure pathways	CLRP	CROM[(1)]	DOSIS LIQUIDAS	IAEA SRS 19 methodology	IMPACT	PC-CREAM 08[(2)]	RDEMO	SYMBIOSE
Internal dose – drinking water ingestion	1.30E-04	3.90E-04	4.12E-04	1.46E-03	4.12E-04	3.85E-04	8.24E-05	3.90E-04
Internal dose – freshwater fish ingestion	3.82E-03	6.70E-03	7.04E-03	6.71E-03	7.04E-03	6.57E-03	4.02E-03	2.00E-03
Internal dose – fruits and berries ingestion	3.11E-04	9.70E-05	–	1.11E-04	5.65E-06	1.35E-05	7.61E-07	–
Internal dose – above ground vegetables ingestion	4.21E-04	1.62E-04	–	1.88E-04	8.48E-06	1.08E-05	3.15E-06	7.60E-05
Internal dose – potato ingestion	1.86E-04	7.30E-05	–	8.31E-05	4.93E-06	4.75E-06	–	3.50E-05
Internal dose – venison (deer) ingestion	1.01E-04	4.66E-06	–	8.69E-06	6.85E-07	–	–	–
Internal dose – beef (cow) ingestion	6.07E-04	3.62E-05	–	3.37E-04	2.59E-05	6.04E-05	9.84E-06	5.80E-05
Internal dose – milk (cow) ingestion	1.09E-03	2.20E-04	–	1.39E-03	1.86E-04	2.83E-04	6.94E-05	3.60E-04
Internal dose – poultry (chicken) ingestion	6.68E-06	1.10E-05	–	1.54E-04	5.66E-06	–	–	1.50E-05
Internal dose – eggs (chicken) ingestion		3.10E-06	–	4.31E-05	1.59E-06	–	–	4.10E-06
External dose – immersion in surface water	7.26E-10	5.47E-05	1.30E-05	5.57E-06	7.02E-06	–	9.13E-07	1.60E-06
External dose from sediment	1.40E-05	4.60E-03	1.73E-05	5.71E-05	2.95E-04	2.38E-02	1.17E-03	4.30E-05
Internal dose – incidental ingestion of sediment		–	–	2.58E-05	7.28E-06	1.18E-02	–	4.30E-06
External dose from exposure to soil		1.17E-15	–	1.36E-05	6.39E-04	–	4.79E-07	–
Internal dose – incidental ingestion of soil		–	–	7.68E-08	1.78E-07	–	–	–
Total dose	**6.69E-03**	**1.24E-02**	**7.48E-03**	**1.06E-02**	**8.64E-03**	**4.29E-02**	**5.36E-03**	**2.99E-03**

NOTES:

(1) The end points are the doses from the various pathways to adult residents of Harrington Bay, and the food which they (Harrington residents) eat from the Westmeath farm.

(2) Harrington for: drinking water, fish and incidental sediment ingestion, external dose from sediment –Westmeath only for: fruits and berries, vegetables, potato, beef and milk ingestion.

TABLE 17. CHALK RIVER RELEASES ^{90}Sr ESTIMATED DOSES (µSv/a)

Exposure pathways	**CLRP**	**CROM**[1]	**DOSIS LIQUIDAS**	**IAEA SRS 19 methodology**	**IMPACT**	**PC-CREAM 08**[2]	**RDEMO**	**SYMBIOSE**
Internal dose – drinking water ingestion	2.81E-04	8.45E-04	8.88E-04	3.14E-03	8.87E-04	8.29E-04	4.44E-04	8.50E-04
Internal dose – freshwater fish ingestion	6.86E-05	8.25E-06	8.67E-06	8.25E-06	1.66E-05	8.09E-06	1.30E-04	8.60E-06
Internal dose – fruits and berries ingestion	3.31E-03	2.87E-04	–	4.02E-04	7.38E-05	1.85E-05	2.64E-05	–
Internal dose – above ground vegetables ingestion	4.47E-03	4.30E-04	–	6.81E-04	8.34E-05	4.01E-05	5.62E-05	1.70E-04
Internal dose – potato ingestion	1.98E-03	2.30E-04	–	3.01E-04	7.12E-05	2.04E-05	–	3.30E-05
Internal dose – venison (deer) ingestion	4.63E-04	2.80E-06	–	2.31E-05	1.00E-06	–	–	–
Internal dose – beef (cow) ingestion	2.78E-03	9.50E-06	–	1.88E-04	8.10E-06	1.00E-05	4.42E-06	7.30E-06
Internal dose – milk (cow) ingestion	7.26E-03	2.30E-04	–	3.58E-03	2.01E-04	8.03E-04	1.84E-05	2.10E-04
Internal dose – poultry (chicken) ingestion	3.45E-05	1.10E-06	–	2.69E-05	9.27E-07	–	–	5.00E-07
Internal dose – eggs (chicken) ingestion		1.10E-06	–	1.46E-04	5.02E-06	–	–	2.80E-06
External dose – immersion in surface water	1.84E-08	1.00E-05	2.35E-06	1.09E-08	6.46E-08	–	1.83E-09	3.10E-09
External dose from sediment	2.72E-06	8.90E-04	3.36E-06	1.11E-05	4.44E-05	1.54E-03	6.14E-04	8.40E-06
Internal dose – incidental ingestion of sediment		–	–	5.56E-05	1.81E-05	2.55E-02	–	9.20E-06
External dose from exposure to soil		–	–	2.41E-07	6.21E-05	–	2.51E-07	–
Internal dose – incidental ingestion of soil		–	–	1.64E-07	1.86E-07	–	–	–
Total dose	**2.06E-02**	**2.94E-03**	**9.02E-04**	**8.56E-03**	**1.47E-03**	**2.87E-02**	**1.29E-03**	**1.30E-03**

NOTES:

[1] The end points are the doses from the various pathways to adult residents of Harrington Bay, and the food which they (Harrington residents) eat from the Westmeath farm.

[2] Harrington for: drinking water, fish and incidental sediment ingestion, external dose from sediment – Westmeath only for: fruits and berries, vegetables, potato, beef and milk ingestion.

TABLE 18. CHALK RIVER RELEASES ^{131}I ESTIMATED DOSES (μSv/a)

Exposure pathways	CLRP	CROM(1)	DOSIS LIQUIDAS	IAEA SRS 19 methodology	IMPACT	PC-CREAM 08(2)	RDEMO	SYMBIOSE
Internal dose – drinking water ingestion	1.99E-04	3.20E-04	5.87E-04	9.02E-04	2.54E-04	5.71E-04	1.93E-04	6.80E-04
Internal dose – freshwater fish ingestion	9.70E-04	9.40E-06	1.72E-05	1.72E-05	7.43E-06	1.67E-05	1.77E-05	1.60E-05
Internal dose – fruits and berries ingestion	3.75E-05	8.90E-06	–	1.64E-05	3.64E-07	9.15E-07	8.19E-11	–
Internal dose – above ground vegetables ingestion	5.08E-05	5.00E-05	–	2.78E-05	9.79E-07	2.73E-06	5.15E-08	2.70E-05
Internal dose – potato ingestion	2.25E-05	6.70E-06	–	1.23E-05	2.09E-07	2.52E-07	–	1.60E-11
Internal dose – venison (deer) ingestion	4.16E-06	2.40E-07	–	1.04E-07	5.00E-08	–	–	–
Internal dose – beef (cow) ingestion	2.62E-05	3.80E-06	–	6.49E-06	3.56E-06	2.51E-06	6.15E-06	1.10E-07
Internal dose – milk (cow) ingestion	2.86E-04	4.50E-04	–	5.30E-04	9.56E-05	1.12E-04	4.19E-05	1.80E-04
Internal dose – poultry (chicken) ingestion	1.81E-05	5.40E-07	–	1.55E-06	1.33E-07	–	–	3.10E-08
Internal dose – eggs (chicken) ingestion		2.70E-06	–	7.86E-06	4.44E-07	–	–	8.30E-07
External dose – immersion in surface water	1.91E-06	5.30E-07	5.18E-07	1.35E-06	8.25E-07	–	2.13E-07	1.00E-06
External dose from sediment	3.24E-09	8.70E-07	3.27E-09	4.47E-09	5.27E-07	5.78E-05	8.02E-09	4.00E-08
Internal dose – incidental ingestion of sediment		–	–	1.59E-07	4.49E-08	8.06E-05	–	1.00E-08
External dose from exposure to soil		–	–	2.03E-08	4.37E-07	–	2.83E-10	–
Internal dose – incidental ingestion of soil		–	–	2.90E-10	1.75E-10	–	–	–
Total dose	**1.62E-03**	**8.54E-04**	**6.05E-04**	**1.52E-03**	**3.64E-04**	**8.44E-04**	**2.59E-04**	**9.05E-04**

NOTES:

(1) The end points are the doses from the various pathways to adult residents of Harrington Bay, and the food which they (Harrington residents) eat from the Westmeath farm.

(2) Harrington for: drinking water, fish and incidental sediment ingestion, external dose from sediment – Westmeath only for: fruits and berries, vegetables, potato, beef and milk ingestion.

TABLE 19. CHALK RIVER RELEASES ^{3}H ESTIMATED DOSES (µSv/a)

Exposure pathways	**CLRP**	**CROM**	**DOSIS LIQUIDAS**	**IAEA SRS 19 methodology**	**IMPACT**	**PC-CREAM 08[1]**	**RDEMO**	**SYMBIOSE**
Internal dose – drinking water ingestion			5.71E-07	2.12E-06	5.70E-07	5.71E-07	5.70E-07	5.70E-07
Internal dose – freshwater fish ingestion			2.09E-09	2.09E-09	2.09E-09	2.09E-09	2.50E-09	2.40E-09
Internal dose – fruits and berries ingestion			–	1.37E-07	2.13E-08	5.58E-12	1.70E-08	–
Internal dose – above ground vegetables ingestion			–	2.32E-07	3.86E-08	1.18E-11	3.39E-08	2.00E-09
Internal dose – potato ingestion			–	1.03E-07	1.50E-08	5.23E-12	–	3.20E-10
Internal dose – venison (deer) ingestion			–	–	3.95E-10	–	–	–
Internal dose – beef (cow) ingestion			–	–	1.47E-08	1.88E-09	1.11E-09	4.70E-09
Internal dose – milk (cow) ingestion			–	–	1.69E-07	7.62E-08	4.89E-09	1.70E-08
Internal dose – poultry (chicken) ingestion			–	–	4.15E-09	–	–	1.30E-09
Internal dose – eggs (chicken) ingestion			–	–	6.32E-09	–	–	1.80E-09
External dose – immersion in surface water			9.04E-11	5.71E-10	8.73E-09	–	8.95E-11	–
External dose from sediment			–	–	–	–	–	–
Internal dose – incidental ingestion of sediment			–	–	–	–	–	–
External dose from exposure to soil			–	–	–	–	–	–
Internal dose – incidental ingestion of soil			–	1.28E-10	–	–	–	–
Total dose			**5.73E-07**	**2.59E-06**	**8.50E-07**	**6.51E-07**	**6.29E-07**	**6.00E-07**

NOTES:

[1] Harrington for: drinking water, fish and incidental sediment ingestion, external dose from sediment – Westmeath only for: fruits and berries, vegetables, potato, beef and milk ingestion.

APPENDIX III. APPROACHES TO DEFINE THE REPRESENTATIVE PERSON (EX-CRITICAL GROUP) IN DIFFERENT COUNTRIES

This Appendix presents approaches applied in different countries to define a critical group or representative person for the purpose of dose assessment from routine discharges from nuclear installation.

III.1. ARGENTINA

In Argentina, the characterization of the Representative Person (RP) adopted by the Nuclear Regulatory Authority could be divided into three aspects:

(1) Geographical location;
(2) Composition;
(3) Habit data and exposure pathways.

Also, there are some differences if the assessment is prospective or retrospective (dose assessment for past routine releases).

III.1.1. Geographical location

Site specific information is used for the geographical location of the RP. This information includes the population distribution around the nuclear power plant and the dispersion conditions in the site (discharge point characteristics, meteorological data and surface water receptor body conditions) for identifying the place with maximum radioactivity concentration.

In Argentina there is no exclusion zone around the nuclear power plants. For prospective assessments, the location is selected in a hypothetically inhabited place with maximum radioactivity concentration. For retrospective assessments, the location is selected in an inhabited place, also with maximum radioactivity concentration.

III.1.2. Composition

For prospective assessments, two age groups are used: infants and adults.

For retrospective assessments, and in a simplified deterministic approach, a single age group is considered: adults. This way, the selection of a stable 'reference group' allows the evaluation of trends in population doses due to annual releases.

III.1.3. Habit data and exposure pathways

Table 20 below shows habit data and consumption rates for critical pathways considered, selected with a deterministic approach based on site specific information and international publications. Local food production is assumed to occur where the radioactivity concentration in those foods is expected to be the greatest.

TABLE 20. HABIT DATA FOR DOSE ASSESSMENT OF THE REPRESENTATIVE PERSON

Exposure pathways	**Infant**	**Adults**
Ingestion		
Green and root vegetables, and fruit (kg/a)	90	270
Cow meat (kg/a)	20	75
Cow milk (L/a)	290	140
Water and beverages (L/a)	290	730
Freshwater fish (kg/a)	5	65
Inhalation		
Breathing rate (m^3/a)	1400	8400
External exposure		
Surface contaminated owing to air deposition (h/a)	2628	2628
Working/playing over contaminated sediments (h/a)	1000	2000
Submersion in air (h/a)	8760	8760

III.2. BELARUS

The ‘representative person’ concept is used for the purpose of protection of the public in Belarus. It superseded the ‘critical group’ concept that was used previously [39]. As defined in the new Belarussian Sanitarian Rules and Standards (SRS) “Requirements to Radiation Safety” [40] ‘representative person’ is an individual who is representative of the most highly exposed individuals in the population.

For regulation of routine releases Belarussian SRS “The Hygienic Requirements to Nuclear Power Plant Design and Operation” [41] establishes quotas for public exposure from radiation factors (emissions and discharges) during normal operation of the NPP which means that radioactive substances can be discharged to the air and surface water if the dose to the representative person will not exceed 100 µSv per year (50 µSv/a from atmospheric and 50 µSv/a from liquid discharges). In this document the values of annual permissible emissions of radioactive gases and aerosols to the atmosphere for the ‘main’ radionuclides and their groups (noble gases, ^{131}I, ^{60}Co, ^{134}Cs and ^{137}Cs) are also provided.

To define the location of representative person the data about population distribution around the nuclear installation are used together with the data about highest concentrations of radionuclides in the environment. According to Belarusian legislation the Sanitary Protective Zone (SPZ) should be established around each nuclear installation. The SPZ is the territory where dwelling and any kind of recreation or economic activity is strictly prohibited. The size of the SPZ will depend on the type of installation and on estimated levels of public exposure. The representative person is assumed to live in the areas around the NPP the most affected by the discharges but beyond the SPZ.

While doing an assessment of the impact of routine releases the following pathways are usually considered for atmospheric discharges:

- External exposure from air (gamma and beta);
- External exposure from ground (gamma and beta);
- Inhalation of plume and resuspended material;
- Ingestion of food (milk, meat, green and root vegetables, fruits, etc.).

For the purpose of dose assessment 6 age groups are used, as specified by the ICRP [18] (<1 year, 1–2 years, 2–7 years, 7–12 years, 12–17 years, >17 years), but in some cases for the purpose of prospective assessment only one age group could be considered (usually adults).

The national standard "Criteria for Assessment of Radiation Exposure" [42] defines the exposure duration period for public – 8800 hours per year – as well as inhalation rates for each age group (presented in the Table 21).

Shielding factors are also used during dose assessment process in accordance with international recommendations. The conservative approach is that the most exposed persons spend 50 % of time outdoors (this value was defined based on Chernobyl studies).

Food consumption rates are taken from the real data based on regional or national surveys (see Table 22). As to the food origin, a conservative assumption is normally used, i.e. all the food is of a local origin.

Thus, in order to define a representative person in Belarus, an individual effective dose should be assessed for different age groups and exposure pathways. Then maximum individual effective dose at the defined distance from the NPP should be identified for particular age group (and/or professional group). The individual doses would have lognormal distribution and 95^{th} percentile of the individual effective doses corresponds to a hypothetical representative person.

So the representative person in Belarus can be defined as hypothetical adult person living in the vicinity of the nuclear installation (beyond the SPZ), in rural area, consuming locally produced food and spending lot of time outdoors (about 11–12 hours/day). Dose to the representative person in case of normal operation of nuclear installation should not exceed established criteria (100 μSv per year).

TABLE 21. BREATHING RATES USED FOR ASSESSMENTS IN BELARUS

Age, years	**Breathing rate, m^3/y**
<1	1000
1–2	1900
2–7	3200
7–12	5200
12–17	7300
>17	8100

TABLE 22. FOOD AND DRINKING WATER CONSUMPTION RATES USED FOR ASSESSMENTS IN BELARUS*

Product	**Intake, kg/y (l/y) [43]**
Cow milk	62.99
Cow meat	33.82
Sheep meat	0.35
Green vegetables	15.28
Root vegetables	82.03
Fruit	29.82
Drinking water	730
Freshwater fish	14.83

*The data presented for adults only.

III.3. BRAZIL

The Central Nuclear Almirante Álvaro Alberto (CNAAA) is located on the Itaorna Beach in Angra dos Reis, Rio de Janeiro, Brazil. It consists of two pressurized water reactors, Angra I, with a net output of 657 MWe, first connected to the power grid in 1985 and Angra II, with a net output of 1,350 MWe, connected in 2000. Work on a third reactor, Angra III, with a projected output of 1,245 MWe, began in 1984 but was halted in 1986. Work started again on 1 June 2010 for entry into service in 2015.

Habit surveys carried out within about 10 km of the site were unable to identify any group of people who could be identified as the critical group in terms of receiving a potential radiation exposure that would be homogeneous and representative of those most exposed in the population. Therefore, the 'worst case scenario' was considered and hypothetical 'representative persons' were considered for four age groups: (0–3 years); (3–11 years); (11–18 years) and adult (>18 years). These individuals are assumed to live and work in the area that is likely to be most affected by the discharges; their habits are summarized in Table 23. Because of the light construction of many buildings in Brazil shielding factors are not taken into account.

Gaseous discharges to atmosphere and liquid discharges to seawater are considered for this site. The radionuclides considered in the assessment are listed in Table 24 and exposure pathways considered are given in Table 25.

TABLE 23. HABIT DATA FOR HYPOTHETICAL GROUPS USED IN ANGRA NPP ASSESSMENTS

Exposure pathway	**Age groups (years)**			
	0–3	**3–11**	**11–18**	**>18**
Other vegetable (kg/y)	19.3	21.8	25.2	30.3
Leafy vegetable (kg/y)	0.82	0.83	0.93	1.30
Meat (kg/y)	2.67	2.94	3.16	3.58
Milk (L/y)	6.66	6.66	5.74	4.99
Inhalation rate (m^3/y)	1400	3700	8000	8000
Fish (kg/y)	11.4	8.91	13	20.5
Other marine products (kg/y)	1.02	1.82	1.86	3.24
Beach recreation (hours/y)	241	199	483	241

TABLE 24. RADIONUCLIDES CONSIDERED IN ANGRA ASSESSMENTS

^{41}Ar, ^{85}Kr, ^{85m}Kr, ^{87}Kr, ^{88}Kr, ^{131m}Xe, ^{133m}Xe, ^{133}Xe, ^{135}Xe, ^{135m}Xe, ^{137}Xe, ^{138}Xe; ^{3}H, ^{131}I, ^{133}I,^{134}I,^{135}I, ^{54}Mn, ^{59}Fe, ^{58}Co, ^{60}Co, ^{89}Sr, ^{51}Cr, ^{65}Zn, ^{90}Sr, ^{134}Cs, ^{137}Cs, ^{141}Ce, ^{144}Ce, ^{140}Ba, ^{124}Sb, ^{125}Sb, ^{57}Co, ^{95}Zr, ^{95}Nb, ^{140}La^{103}Ru, ^{106}Ru, ^{110m}Ag, ^{123m}Te, ^{239}Po, ^{240}Po, ^{241}Am, ^{242}Cm, ^{244}Cm

TABLE 25. EXPOSURE PATHWAYS CONSIDERED IN ANGRA ASSESSMENTS

Discharge route	**Exposure pathway**
Release to atmosphere	External exposure from airborne: gamma and beta External exposure from ground: gamma Inhalation Food ingestion
Release to sea	Beach Recreation Ingestion of marine products

III.4. CANADA

According to the Canadian Standards Association Standard N288.1 [5], when developing constraints on radiological release for the purpose of public protection, individuals who form a homogeneous group with respect to the following exposure factors can been grouped together: factors such as proximity to the release, dietary and behavioral habits, age and metabolism, and variations in the environment. An individual with characteristics that reflect those of the group that receives the highest dose from a particular source is known as the representative person for the radionuclide in question [36]. Derived Release Limits (DRLs) are developed by considering a representative person with average rather than extreme characteristics within this most exposed group.

The standard uses age classes based on ICRP Publication 101 [36]. These 3 age classes (1 year, 10 years and adult) correspond to the following age ranges 0–5 years, 6–15 years and 16–70 years.

There might be more than one representative person for a DRL calculation. The representative person should be identified by performing DRL calculations for all potential persons. The representative person may change for each radionuclide. It should also be assumed that the representative person could be of any age. Separate DRL calculations are performed for each age class and the smallest value should be taken as the DRL for that site and radionuclide.

Aboriginal communities living near the facility are considered as the basis for potential representative persons if those communities rely on traditional hunting, fishing and food gathering activities. These people can also have significantly different behaviors and diets than other local groups.

In ICRP Publication 46 [44], the ‘homogenous group’ criterion for the characterization of the representative person has been defined as the distribution of individual doses within the group which lies within a total range of a factor of 10, provided that the mean dose is less than one-tenth the dose limit. Standard N288.1 [5] uses this definition.

Homogeneity across age classes is not required. A group that is spatially dispersed such that there is more than a tenfold range in radionuclide concentration would not satisfy the homogeneity criterion. However, the group has to be sufficiently large to be reliably characterized.

A sample size of at least 20–30 households should be used. In areas of low population density, this could involve a spatial area that exceeds the tenfold range in radionuclide concentration; but sufficient sample size is more important. The conditions on size and homogeneity should not be based on single individuals or household with extreme behaviors.

The representative person can reflect distinct behaviors in different individuals of a given group if the homogeneity condition is satisfied. For example, some individuals might draw their drinking water from wells and others of the same group can get their water from a surface source. When the number of people using wells is large enough to meet the size constraints, then well water is used for the representative person. If only a small number of people use wells, then they are considered extreme individuals and surface water becomes the water source for the represented person. If the numbers in each group are about the same, an average concentration equal to the well water concentration multiplied by the fraction of well-water users can be assumed, provided that the homogeneity criterion is met.

Representative persons should be realistically characterized rather than assigned hypothetical features that are worse case or implausible. Site-specific surveys on diet and habits should be made to identify and characterize the representative persons. The degree of use of local food and water resources is included in surveys. Other factors such as overall rates of air, food, and water intake are physiologically governed and tend to be less site-specific.

Nuclear facility workers may be included in local surveys, but their workplace exposures are not included in characterizing the representative person.

DRLs are conservative estimates, but not overly so. Conservatism is introduced typically at the 95th percentile level for food, water, soil, and air intake rates and occupancy factors. Whereas all other model parameters should be selected as to be realistic, using the 95th percentile is in line with the ICRP Publication 101 [36] guidance.

III.5. FRANCE

In France[6], release authorization for nuclear facilities require the licensee to submit an impact study (décret 2007-1557 du 2 novembre 2007). The latter states that the exposure of the public to ionizing radiation due to the facility must be assessed, taking into account direct radiation of the installation and transfer of radionuclides by different vectors, including food chains.

To perform these assessments, reference groups are used, with the definition given in the European Commission Council Directive [45] laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiation:

> "Reference group of the population: a group comprising individuals whose exposure to a source is reasonably uniform and representative of that of the individuals in the population who are the more highly exposed to that source."

Preferably real population groups are chosen as possible reference groups. This can be done after field observation, or after identification of living areas on maps.

Concerning the size of the group, the dose assessment should be performed for groups with only a few individuals if they receive the highest doses.

Generally, when dealing with gaseous releases, reference groups are chosen in a 360° angle around the facility relatively close to it. If the wind rose shows predominant directions, more reference groups can be chosen. When dealing with liquid releases to sea, populations with the most intense use of marine environment are looked for.

Unless site specific information leads to identifying vulnerable age groups, three age groups would be considered, as proposed in ICRP Publication 101 [36] (0–5 infant, 6–15 child, 16-70 year old adult), with dose coefficients and corresponding habit data for a 1 year old infant, a 10 year old child and an adult.

[6] The criteria for selection of critical group presented in this report were defined by the modeller. The actual choice of reference group in France depends on the operator.

The individuals in the group are usually assumed to spend all time on their living location, with distinction of time spent inside and outside.

The exposure pathways considered for assessing the dose impact of the discharges depend on the type of discharges and the environmental media involved in the subsequent transfer of radionuclides. The following pathways are most usually considered:

- External irradiation due to the atmospheric plume;
- External irradiation due to radioactive material in the environment met by an individual of a reference group through his daily/occasional activities. The environment media sources are thus: agricultural soils, sediments and water in the marine environment (beach activity, fishing gear handling, using boats, bathing) sediments and water in the river environment (activities on the banks of the river, using boats, bathing), bare soil in urban/dwelling areas (for which a shielding factor is taken into account);
- Internal irradiation following ingestion of radionuclides in foods (from terrestrial, marine or river environment, including drinking water);
- Internal irradiation following accidental ingestion;
- Internal irradiation due to inhalation of radioactivity in the air (from the plume or resuspended material).

Regarding food consumption, local surveys are used for quantities when possible; if not, regional or national data is used. As for food origin, it is scarcely known; a cautious attitude is to consider 100% locally grown. However when ingestion is clearly a predominant pathway, the food growing site(s) can be different from the living area.

III.6. POLAND

Doses are calculated to the critical group which is defined as representative of those members of the population who receive the highest exposure (committed effective dose) from the considered source by virtue of age, dietary/behavioral habits and where they live.

In addition, a reference group or representative group may be considered. The former is defined as those members of the population receiving the doses from considered source that will be used as a basic criterion for assessments purposes. This might be the critical group, most numerous group living in the area of interest (highest collective doses), special habit group, whole population etc. The representative group is defined as those members of the population receiving doses that fall within a range of doses derived from the assessment procedure. The group could be a particular age group of the population according to ICRP Publication 63 [46], critical group/groups etc. It is highly recommended to consider real situations based on surveys of dietary habits, outdoor and indoor residence times, endemic factors relating to health (e.g. for radioactive iodine), etc.

The assessments should be carried out for multiple pathways. These would include:

(a) External plume (immersion);
(b) External ground;
(c) External water (immersion);
(d) Internal inhalation;
(e) Internal ingestion (all diet products including drinking water).

The radionuclides typically considered are: ^{134}Cs, ^{137}Cs, ^{131}I, ^{3}H, ^{90}Co, ^{90}Sr.

Committed effective doses are calculated to the age groups as defined in [13]. The dietary and behavioral habits are based on local survey data if available or national statistics. If data are available on the shielding characteristics of the dwellings these will be used otherwise the most conservative, i.e. no shielding, approach will be assumed. Indoor and outdoor residence times are taken into account and more unusual habits such as consumption of free foods (e.g. mushrooms, wild forest berries and game) is considered. The location of this group is considered to be within a 30 km radius of the discharge site. Inhalation rates are those published by ICRP for ICRP reference man [47].

III.7. SLOVAKIA

III.7.1. Definition of critical group

The Ordinance of the Government of the Slovak Republic No. 345/2006 Coll. on Basic Requirement for the Protection of Workers' and Citizens' Health against Ionizing Radiation says that critical group of citizens is group comprised of persons, for which irradiation is sufficiently uniform and representative for individuals from that population, who are the most irradiated by a given radiation source.

The Ordinance also provides that radioactive substances can be discharged from nuclear installations to the air and surface water if it is provided that effective doses in the relevant critical population group will not exceed 250 µSv per calendar year due to these discharges. This value is considered the limit value for designing and constructing nuclear installations. In case of several nuclear facilities constructed in one location, which will affect the same critical group, this limit value applies to overall radiation from all nuclear facilities in given location or region.

The Public Healthy Authority of the Slovak Republic defines in its Decision No. OOZPZ/6773/2011 for radioactive substance releases (liquid and gaseous) from operations at the Nuclear Power Plant (NPP) Mochovce that the basic radiological limit is 50 µSv/a to the representative person. The representative person is a person whose dose from radioactive releases is representative of a person in the highest irradiated zone surrounding the NPP. Program RDEMO is prescribed for determination of the critical group in this Decision. This document also prescribes annual guidance balance values for groups of radionuclides, radionuclides which must be monitored and others conditions for safety releases of radioactive substances and their monitoring.

III.7.2. Determination of critical group

The area around NPP Mochovce (with 60 km radius) is divided to 192 zones. Released activity, meteorological data, production and consumption of foodstuffs, local habits of population, etc. are input data for radiological impact assessment. Program RDEMO calculates individual effective doses for 6 age categories and 10 irradiation exposure pathways for each zone. The settled zone with maximum individual effective dose for inhabitant from all zones is considered the critical zone or critical population group. The critical exposure pathway, critical radionuclides and equivalent doses for inhabitant are also calculated.

III.8. UNITED KINGDOM

III.8.1. Public Health England (PHE) methodology

These subsections describe how PHE would approach the problem of selecting the representative person for a prospective dose assessment. It draws on advice currently being developed by members of the National Dose Assessment Working Group (NDAWG) (http://www.ndawg.org/) and from the findings of the report [48] and the guidance provided in Ref. [49]. PHE considers the term ‘representative person’ to be equivalent to the ‘average member of the critical group’ described in previous ICRP recommendations.

III.8.1.1. Staged approach

A staged approach is adopted to ensure that the expenditure of time, effort and money are commensurate with the level of risk associated with the discharges. Initially it is reasonable to carry out a screening assessment to estimate the magnitude of the annual committed effective dose likely to arise from the discharge. If the dose to the representative person is <0.02 mSv then no further assessment is required. However, if this is not the case then a more detailed site-specific assessment of dose may be required.

For both approaches the following steps are taken:

(a) Consider the discharge routes, i.e. atmospheric, marine and river, and the potential exposure pathways;
(b) Define candidates for representative person for each discharge route;
(c) Assess the dose for these candidates to identify the representative person for the discharging site.

III.8.1.2. Screening assessment

A simple and cautious screening assessment may first be carried out using generic assumptions about the location and habits of the candidate representative persons. The suggested steps to be followed are those defined in (a)–(c) above.

Discharge routes and exposure pathways

The forms of discharge, i.e. liquid or gaseous, and the part of the environment into which they are released will dictate which exposure pathways should be considered. The pathways commonly considered are listed below:

- Internal irradiation following inhalation of radionuclides in the air either following releases to atmosphere or following the resuspension of radionuclides from the ground or in seaspray;
- External gamma irradiation from radionuclides in environmental media including air, soil and sediments;
- External radiation direct from the site of interest;
- Internal irradiation following the ingestion of radionuclides in terrestrial and aquatic foods and drinking water;
- Internal irradiation following inadvertent ingestion (e.g. soil, sediment or seawater);

— External beta irradiation due to exposure from radionuclides in environmental media;
— Internal irradiation from direct absorption of radionuclides through the skin (e.g. tritium).

Defining candidates for representative person

Having identified the principal exposure pathways the candidates for representative person can be considered. Generic assumptions will be made about the habits of the representative person but it is reasonable to take into account the locations where activity concentrations in the environment are likely to be highest. Assumptions should not be overly cautious and it is important to retain some realism in the calculation. For example, calculations of external exposure to and inhalation of the radioactive plume may be carried out quite close to the discharge point, e.g. 100 m, while ingestion of terrestrial food may be calculated at 500 m to account for the larger area needed to grow food or support animals. The habits themselves will tend to be cautious but should still be feasible. They could be based on generic studies of appropriate habits or national data. Typically it will be assumed that only the two foods that give the highest dose are eaten at high rates (corresponding, for example, to the 95^{th} or 97.5^{th} percentile of the national distribution of ingestion rates) while others are eaten at average rates (50^{th} percentile). This assumption is commonly referred to as the 'Top Two' approach. It will usually be assumed that individuals spend all their time at a particular location, some of which will be indoors where doses will be reduced.

Carry out assessment for these candidates

For each candidate representative person a dose assessment should be made taking into account all possible exposure pathways, i.e. from different discharge routes. For a screening study the dose assessment would normally only be carried out for three age groups: adults (20 years), children (10 years) and infants (1 year). Normally, it would be assumed that all age groups reside at the same location. The individual who receives the highest dose from the discharging site will be selected as the representative person. The representative person in this case is likely to be a hypothetical construct.

III.8.1.3. More detailed site specific assessment

The principal aim of this assessment is to obtain more detailed information about the site so that a more realistic assessment of dose can be made. The suggested steps to be followed are those defined in steps (a)–(c) in Section III.8.1.1.

Discharge routes and exposure pathways

As for the screening assessment the forms of discharge, i.e. liquid or gaseous, and the parts of the environment into which they are discharged will dictate which exposure pathways should be considered. However, in addition to those listed above (under the heading "Discharge routes and exposure pathways") it may be necessary to consider other more unusual pathways based on local knowledge.

Define candidates for representative person

"Having identified the principal exposure pathways the candidates for representative person can be considered. Candidates will need to be identified with particular combinations of habits, both critical and average, based on local knowledge and plausible assumptions. These

combinations of habits will need to be realistic and not lead to implausible situations such as a full-time working person spending an equal proportion of the day on leisure activities or a person having an excessive calorie intake" [49].

An individual may be a candidate for the representative person because of where he/she lives and works, or the activities he/she carries out. Initially, local knowledge should be used to identify candidates, for example by using maps to locate dwellings and reviewing existing habit surveys. Candidates may be extant or they may be hypothetical. The habits of existing candidates can be derived by reviewing data from recent habit surveys or commissioning new surveys. These may be augmented by the use of generic studies of appropriate habits or national data, provided it is unlikely that there will be strong differences to local data. For example, where it is expected that an individual is a high consumer of a particular food the 97.5th percentile of the distribution of national data could be used or the 50th percentile for an average consumer.

For hypothetical candidates judgment will be used to identify likely individuals and the locations where they might reside using local knowledge. The sort of information required includes the use currently made of land and dwellings and whether planning permission has been granted for potential changes to these. In addition, locations where activity concentrations in the environment are likely to be highest will influence the selection of potential candidates. Survey data specific to potential candidates will not be available and the choice of habits will depend more on the use of generic studies of such habits or national data and assumptions about feasible intake rates. The 'Top Two' approach described previously (under the heading "Defining candidates for representative person" above) may be used.

Typical candidates for the representative person may include the following:

- Consumers of shellfish and fish who spend time on contaminated sediments collecting shellfish;
- Fishermen who dig bait, and catch and eat fish;
- People who eat local terrestrial produce and walk dogs on a beach;
- People who eat local fish and shellfish and local terrestrial produce;
- Farmers who work outdoors close to the discharging site and eat local terrestrial produce.

> "Candidates for the representative person may be located in areas remote from the site as a result of discharges to sewers or the interplay of dispersion and accumulation mechanisms in the environment. Sometimes, it may be necessary to consider candidates for the representative person from different countries. A full range of exposure pathways should be considered for each of the candidates for the representative person. For example, the people who are candidates for the representative person due to their direct radiation exposure from the site are likely to be exposed to any atmospheric discharges and, depending on the circumstances, could also be exposed to liquid discharges. However, in most cases it is not realistic to assume that the same people receive the highest doses from all pathways and therefore a simple addition of doses attributed to different pathways is not necessarily appropriate. Instead, a combination of habits typical of average and most exposed people may be assumed. For example, the candidates for the representative person who eat locally produced terrestrial foods at higher than average rates, could be assumed to eat a proportion of locally produced aquatic foods at average rates" [49].

Carry out dose assessment for these candidates

For each candidate representative person a dose assessment should be made which takes into account all possible exposure pathways and uses habit data defined above. Thus the representative person for the discharging site considered can be identified:

> "The term 'representative person' is used solely to refer to an individual receiving a dose that is representative of the more highly exposed individuals in the population. The dose to the representative person will result from a combination of exposure pathways arising from all routes of discharge and include exposure due to direct irradiation from the site. It is not appropriate to define separate representative persons for discharges to different environmental media. The dose to the representative person will be compared with the source or site constraint as appropriate" [49].

III.8.2. Environment Agency (EA) methodology

The EA's Initial Radiological Assessment System (IRAS) is a method of estimating prospective doses to generic representative persons using simple cautious assumptions [50, 51].

This approach ensures that doses are very unlikely to be underestimated. If these cautious assessments predict doses to be less than the 0.02 mSv/a 'threshold of optimisation', there are no required further assessments for the purpose of discharging radioactive waste to the environment. It will be expected that this will be the case for many small users of radioactive substances, because they tend to use lower quantities of shorter half-life radionuclides. Therefore, the IRAS allows to screen out discharges of low regulatory concern, and concentrate the EA's resources on those where doses are predicted to be higher.

IRAS calculates doses by multiplying the discharge limits by dose per unit release factors (DPURs). These have been derived for four discharge scenarios, 100 radionuclides, seven exposure groups, four age groups and 41 exposure pathways (see below in: Exposure groups and pathways used in IRAS). The DPURs used are the highest for each radionuclide for all age groups. The limiting representative person is representative of the exposure group that receives the highest dose.

The representative person is intended to be "representative of those individuals in the population expected to receive the highest dose". The UK Environment Agencies have published joint guidance for assessing prospective public doses [52].

In the IRAS, the EA has defined hypothetical exposure groups (see below in: Exposure groups and pathways used in IRAS) to cover the full range of possible pathways using reasonable habit patterns. EA made assumptions about their location and habits to maximize the dose they would receive from each of the discharge scenarios (but not unrealistically so). The limiting critical group is simply the exposure group that receives the highest dose.

The first stage of the assessment uses simple generic conservative assumptions (for example, release at ground level, low river flow rates etc.). If the resulting effective dose rate to the representative person is greater than 20 μSv/a then a second, more realistic, assessment is completed. This is done by scaling to take account of site-specific dispersion conditions (for example, actual stack release heights, river flow rates etc.). If the dose rate to the representative person is still greater than 20 μSv/a, the exposure pathways are reviewed to see if they are realistic (such as is there a drinking water abstraction nearby, is the brook culverted

so children cannot actually access it), and the methodology refined (for example, calculating dose rates to all age groups separately, looking at food consumption rates).

The geographical location is only taken into consideration where it affects the environmental concentrations as a consequence of the dispersion process.

III.8.2.1. Exposure groups and pathways used in the IRAS

Release to atmosphere

Local resident family:

- Inhalation of radionuclides in the effluent plume;
- External irradiation from radionuclides in the effluent plume and deposited to the ground;
- Consumption of terrestrial food incorporating radionuclides deposited to the ground.

Release to coast

Fisherman family:

- External irradiation from radionuclides deposited in shore sediments;
- Consumption of seafood incorporating radionuclides.

Release to river

Angler family:

- External irradiation from radionuclides deposited in bank sediments;
- Consumption of freshwater fish incorporating radionuclides;
- Consumption of drinking water containing radionuclides.

Irrigated food consumer family:

- Consumption of terrestrial food irrigated with river water and incorporating radionuclides.

Release to sewer

Sewage treatment workers (adults only):

- External irradiation from radionuclides in raw sewage and sludge;
- Inadvertent inhalation and ingestion of raw sewage and sludge containing radionuclides.

Farming family living on land conditioned with sewage sludge:

- Consumption of food produced on land conditioned with sludge and incorporating radionuclides;
- External irradiation from radionuclides in sludge conditioned soil;
- Inadvertent inhalation and ingestion of sludge conditioned soil.

Children playing in brook which receives treated effluent from sewage works (children only):

- External irradiation from radionuclides deposited in bank sediments;
- Inadvertent consumption of water and sediment containing radionuclides.

Angler family (river receives treated effluent from sewage works):

- External irradiation from radionuclides deposited in bank sediments;
- Consumption of freshwater fish incorporating radionuclides;
- Consumption of water containing radionuclides.

Irrigated food consumer family (river receives treated effluent from sewage works):

- Consumption of terrestrial food irrigated with river water and incorporating radionuclides.

Fisherman family (estuary/coastal water receives treated effluent from sewage works, typically via a river):

- External irradiation from radionuclides deposited in sediments;
- Consumption of fish incorporating radionuclides.

III.9. UKRAINE

III.9.1. Ministry of Health methodology

For regulation of routine discharges doses are calculated to the critical group. According to the Ukrainian legislation, the critical group is a group of members of the public, which, by their gender, age, social and professional conditions, habitation places and other features, receives or can receive the highest levels of exposure from the source.

The Ukrainian legislation establishes sanitary-protective zones (SPZ) around the most radiologically hazardous sites (NPPs, RAW processing and disposal facilities, uranium mines, hydrometallurgy plants for milling of uranium ores, etc.). Radius of a SPZ depends on a type of facility, and it is from several hundred meters to several kilometers (2.5–3 km for NPPs). Habitation in the SPZ is prohibited.

Ukrainian guidelines define that members of the public could potentially have permanent residence at any locality beyond the SPZ, because in the future new settlements may appear at any location beyond the SPZ. It is assumed that members of the critical group reside at the same place (in the real or hypothetical settlement) during the whole year and consume only local foodstuffs. Therefore, critical group in the Ukrainian legislation is a hypothetical critical group.

Where two discharge routes exist (liquid and atmospheric) they are considered separately. A quota of the dose limit for the members of the public is established for each route. Table 26 gives lists of radionuclides considered for NPPs, and Table 27 identifies the exposure pathways considered.

TABLE 26. RADIONUCLIDES CONTROLLED IN DISCHARGES FROM UKRAINIAN NPPS

Discharge route	Radionculides
Atmospheric (for daily control)	^{131}I, noble gases (as a predefined composition), long-lived radionuclides (as an average for NPP composition of ^{51}Cr, ^{54}Mn, ^{59}Fe, ^{58}Co, ^{60}Co, ^{89}Sr, ^{90}Sr, ^{95}Zr, ^{95}Nb, ^{110m}Ag, ^{134}Cs, ^{137}Cs)
Atmospheric (for monthly control)	^{3}H, ^{51}Cr, ^{54}Mn, ^{59}Fe, ^{58}Co, ^{60}Co, ^{89}Sr, ^{90}Sr, ^{95}Zr, ^{95}Nb, ^{110m}Ag, ^{134}Cs, ^{137}Cs
Liquid	^{3}H, ^{51}Cr, ^{54}Mn, ^{59}Fe, ^{58}Co, ^{60}Co, ^{65}Zn, ^{89}Sr, ^{90}Sr, ^{95}Zr, ^{95}Nb, ^{106}Ru, ^{110m}Ag, ^{131}I, ^{134}Cs, ^{137}Cs, ^{144}Ce

TABLE 27. EXPOSURE PATHWAYS CONSIDERED FOR THE ESTABLISHMENT OF DISCHARGE LIMITS

Discharge route	Exposure pathways
Atmospheric discharge	External exposure from the cloud; External exposure from the soil after fallout; Inhalation (including resuspension); Ingestion of contaminated foodstuff (milk and dairy foods, meat, vegetables, cereals, etc.).
Liquid discharge	Drinking water consumption; Ingestion of fish; Ingestion due to water consumption by domestic animals (milk and dairy foods, meat); Ingestion due to irrigation (vegetables, cereals, milk and dairy foods, meat etc.); External exposure from soil due to irrigation; External exposure from water (swimming) and sand (sunbathing) at the riverside.

The geographical location of the critical group is taken into consideration in so far as it has an influence on the dispersion of the radioactive material in the environment. For example, site specific meteorological and hydrological data are used.

Doses to the critical group are calculated for the 6 age groups as specified by the ICRP [18]. The maximum dose is used for the establishment of discharge limits. The dietary habits of each age group (e.g. special foodstuffs, consumption rates) are considered. A typical diet (including fish consumption) and water consumption rates are specified by Ukrainian guidelines. As well as fishing, swimming and sunbathing are considered with predefined data, i.e. exposure times. Inhalation rates are specified for each reference age according to the ICRP's Publication 72 [18].

Ukrainian guidelines do consider the use of a shielding factor for dose calculations; however, in practice shielding factors are generally not used. This means that the population is effectively assumed to be outdoors during the whole year.

REFERENCES

[1] EUROPEAN COMMISSION, FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANIZATION, NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, UNITED NATIONS ENVIRONMENT PROGRAMME, WORLD HEALTH ORGANIZATION, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, IAEA Safety Standards Series No. GSR Part 3, IAEA, Vienna (2014).

[2] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, The 2007 Recommendations of the International Commission on Radiological Protection, ICRP Publication 103 (2007).

[3] EUROPEAN ATOMIC ENERGY COMMUNITY, FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANIZATION, INTERNATIONAL MARITIME ORGANIZATION, NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, UNITED NATIONS ENVIRONMENT PROGRAMME, WORLD HEALTH ORGANIZATION, Fundamental Safety Principles, IAEA Safety Standards Series No. SF-1, IAEA, Vienna (2006).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Generic Models for Use in Assessing the Impact of Discharges of Radioactive Substances to the Environment, Safety Reports Series No. 19, IAEA, Vienna (2001).

[5] CANADIAN STANDARDS ASSOCIATION, Guidelines for Calculating Derived Release Limits for Radioactive Material in Airborne and Liquid Effluents for Normal Operations of Nuclear Facilities, N288.1-08, Mississauga, ON (2008).

[6] STOCKI, T., TELLERIA, D., BERGMAN, L., PROEHL, G., AMADO, V., BONCHUK, I., BOYER, P., CHYLY, P., CURTI, A., HELING, R. , KLIAUS, V., KRAJEWSKI, P., LATOUCHE, G., LAURIA, D., MOURLON, C., NEWSOME, L. , SÁGI, L., SMITH, J., Reference Methodologies for Radioactive Controlled Discharges an Activity within the IAEA's Programme Environmental Modelling for Radiation Safety II (EMRAS II), Radioprotection **46** 6 (2011) S687–S693.

[7] CLYNE, F.J., TIPPLE, J.R., MCTAGGART, K.A., Radiological Habits Survey: Sizewell (2005) Cefas report reference RL02/06. Available at: http://www.cefas.co.uk/publications/environment/Sizewell2005.pdf

[8] WILSON, R.M., et al., Critical Review of Soil Ingestion Rates for Use in Contaminated Site Risk Assessments in Canada, Health Canada Science Forum Proceedings, Ottawa, ON(2006).

[9] ENVIRONMENT AGENCY, FOOD STANDARDS AGENCY, NORTHERN IRELAND ENVIRONMENT AGENCY AND SCOTTISH ENVIRONMENT PROTECTION AGENCY, Radioactivity in Food and the Environment, 2007, RIFE-13, Bristol, Belfast, London and Stirling (2008).

[10] PUNT, A., KRUSE, P., TITLEY, J.G., Radiological Assessment – British Energy Sizewell B, Authorisation review 2005/6, post-consultation amended version. Environment Agency report reference NMA/TR/2006/05a (2006). Available at: http://publications.environment-agency.gov.uk/pdf/GeHO0307BMHQ-e-e.pdf

[11] ATOMIC ENERGY OF CANADA LIMITED, Report: Derived Release Limits (DRLs) for AECL's Chalk River Laboratories, CRL-509200-RRD-001 Revision 0, AECL, Mississauga (2007).

[12] EUROPEAN COMMISSION, Radiation Protection 72, Methodology for Assessing the Radiological Consequences of Routine Releases of Radionuclides to the Environment, Report EUR 15760 (1995).
[13] INTERNATIONAL ATOMIC ENERGY AGENCY, International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources, Safety Series No. 115, IAEA, Vienna (1996).
[14] ECKERMAN, K.F., RYMAN, J.C., External Exposure to Radionuclides in Air, Water, and Soil, Federal Guidance Report No. 12, US Environmental Protection Agency, Washington, DC, Report EPA-402-R-93-081 (1993).
[15] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Age-dependent Doses to Members of the Public from Intake of Radionuclides, Part 2, Ingestion Dose Coefficients, ICRP Publication 67, Pergamon, Oxford, New York (1993).
[16] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Age-dependent Doses to Members of the Public from Intake of Radionuclides, Part 3, Ingestion Dose Coefficients, ICRP Publication 69, Pergamon, Oxford (1995).
[17] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Age-dependent Doses to Members of the Public from Intake of Radionuclides, Part 4, Inhalation Dose Coefficients, ICRP Publication 71, Pergamon, Oxford (1995).
[18] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Age-dependent Doses to Members of the Public from Intake of Radionuclides, Part 5, Compilation of Ingestion and Inhalation Dose Coefficients, ICRP Publication 72, Pergamon, Oxford (1996).
[19] GORMAN, D.J., The Basis for the Derived Limits for the Emissions of Radionuclides in Airborne and Liquid Effluents from Ontario Hydro's Nuclear Facilities, Ontario Hydro Report SSD-86-3 (1986).
[20] NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS, Screening Models for Releases of Radionuclides to Atmosphere, Surface Water and Ground, NCRP Report No. 123, Volume I and Volume II (1996).
[21] SMITH, J.G., SIMMONDS, J.R. (Eds.), The Methodology for Assessing the Radiological Consequences of Routine Releases of Radionuclides to the Environment used in PC-CREAM 08 (2009).
[22] CLARKE, R.H., The First Report of a Working Group on Atmospheric Dispersion: A Model for Short and Medium Range Dispersion of Radionuclides Released to the Atmosphere, Chilton, NRPB-R91 (1979).
[23] EUROPEAN COMMISSION, MARINA II, Update of the MARINA Project on the Radiological Exposure of the European Community from Radioactivity in North European Marine Waters, Radiation Protection 132, EC, Luxembourg (2003).
[24] LEPICARD, S., HELING, R., MADERICH, V., POSEIDON-R/RODOS Models for Radiological Assessment of Marine Environment after Accidental Releases: Application to Coastal Areas of the Baltic, Black and North Seas, J. Environ. Radioactivity **72** (2004) 153–161.
[25] MADERICH, V., BEZHENAR, R., HELING, R., DE WITH, G., JUNG, K.T., MYOUNG, J.G., CHO, Y.-K., QIAO, F., ROBERTSON, L., Regional Long-term Model of Radioactivity Dispersion and Fate in the Northwestern Pacific and Adjacent Seas: Application to the Fukushima Daiichi Accident, J. Environ. Radioactivity **131** (2014) 4–18.

[26] HELING, R., KOZIY, L., BULGAKOV, V., On the Dynamical Uptake Model Developed for the Uptake of Radionuclides in Marine Organisms for the POSEIDON-R Model System, Radioprotection **37** (2002) C1, 833–838.
[27] LEPICARD, S., RAFFESTIN, D, RANCILLAC, F., POSEIDON: A Dispersion Computer Code for Assessing Radiological Impacts in European Seawater Environment, Radiation Protection Dosimetry **75** (1998) 79–83.
[28] GONZE, M.A., et al., SYMBIOSE: A Modeling and Simulation Platform for Environmental Chemical Risk Assessment Proceedings of the Third International Symposium on the Protection of the Environment from Ionising Radiation (SPEIR 3) held in Darwin, Australia, 22–26 July 2002, IAEA, Vienna (2003) 266–274.
[29] GONZE, M-A., MOURLON, C., GARCIA-SANCHEZ, L., LE DIZES-MAUREL, S, NICOULAUD, V., GERBER, P.-P., VERMOREL, F., SYMBIOSE: A Simulation Platform for Conducting Radiological Risk Assessments, Communication Displayed at the ICRER 2011 Conference, June 2011, McMaster University, Canada (2011).
[30] MOURLON, C., GONZE, M-A., MÉTIVIER, J.M., OLIVE, G., PARACHE, V., VERMOREL, F, CADET, M., A Landscape-level Dose Assessment of a French NPP Using the SYMBIOSE Platform, oral and displayed communication at the ICRER 2011 Conference, June 2011, McMaster University, Canada (2011).
[31] BEAUGELIN-SEILLER, K., BOYER, P., GARNIER-LAPLACE, J., ADAM, C., CASTEAUR: A Simple Tool to Assess the Transfer of Radionuclides in Waterways, Health Physics **84** (3) (2002) 539–542.
[32] KIRCHNER, G., STEINER, M., Uncertainties in Radioecological Assessment Models – Their Nature and Approaches to Reduce Them, Applied Radiation and Isotopes **66**, Elsevier (2008) 1750–1753.
[33] STOCKI, T.J., LO, M.-C., BOCK, K., BEATON, L.A., TISI, S.D.R., TRAN, A., SULLIVAN, T., UNGAR, R.K., Monte Carlo Simulations of Semi-infinite Clouds of Radioactive Gases, Radioprotection **44** 5 (2009) 735–739.
[34] HUNT, G.J., Simple Models for Prediction of External Radiation Exposure from Aquatic Pathways, Rad. Prot. Dos. **8** 4 (1984) 215–224.
[35] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, 1990 Recommendations of the International Commission on Radiological Protection, ICRP Publication 60, Pergamon, Oxford (1991).
[36] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Assessing Dose of the Representative Person for the Purpose of the Radiation Protection of the Public, ICRP Publication 101, Elsevier (2006).
[37] INTERNATIONAL ATOMIC ENERGY AGENCY, Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environments, Technical Reports Series No. 472, IAEA, Vienna (2010).
[38] US NUCLEAR REGULATORY COMMISSION, Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I, US NRC Regulatory Guide 1.109 (1977).
[39] MINISTRY OF HEALTH OF REPUBLIC OF BELARUS, Standards of Radiation Safety, Hygienic normative, Minsk, Belarus (2000).
[40] REPUBLICAN CENTER OF HYGIENE, EPIDEMIOLOGY AND PUBLIC HEALTH, Requirements to Radiation Safety, Radiation Hygiene: Miscellany of normative documentation, Sanitarian Rules and Standards, Minsk, Belarus (2013) 6–34.

[41] REPUBLICAN CENTER OF HYGIENE, EPIDEMIOLOGY AND PUBLIC HEALTH, The Hygienic Requirements to Nuclear Power Plant Design and Operation, Sanitarian Rules and Standards, Minsk, Belarus (2010).

[42] REPUBLICAN CENTER OF HYGIENE, EPIDEMIOLOGY AND PUBLIC HEALTH, Criteria for Assessment of Radiation Exposure, Radiation Hygiene: Miscellany of normative documentation, Hygienic normative, Minsk, Belarus (2013) 35–167.

[43] NATIONAL STATISTICAL COMMITTEE OF REPUBLIC OF BELARUS, Statistical Digest, Minsk, Belarus (2009) p. 599.

[44] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Principles for the Disposal of Solid Radioactive Waste, ICRP Publication 46, Pergamon, Oxford (1985).

[45] EUROPEAN COMMISION, Council Directive 96/29/EURATOM of 13 May 1996 – Ionizing Radiation (1996).

[46] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Principles for Intervention for Protection of the Public in a Radiological Emergency, ICRP Publication 63, Pergamon, Oxford (1992).

[47] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Basic Anatomical and Physiological Data for Use in Radiological Protection Reference Values, ICRP Publication 89, Ann. ICRP 32 (3–4), Pergamon, Oxford (2002).

[48] JONES K.A., WALSH, C., BEXON, A., SIMMONDS, J.R., JONES, A.L., HARVEY, M., ARTMANN, A., MARTENS, R., Guidance on the Assessment of Radiation Doses to Members of the Public due to the Operation of Nuclear Installations under Normal Conditions, HPA RPD 019 (2006). Available at: http://webarchive.nationalarchives.gov.uk/20140714084352/http://www.hpa.org.uk/publications/radiation/hparpdseriesreports/hparpd019/

[49] ENVIRONMENT AGENCY, SCOTTISH ENVIRONMENT PROTECTION AGENCY, NORTHERN IRELAND ENVIRONMENT AGENCY, HEALTH PROTECTION AGENCY, FOOD STANDARDS AGENCY, Principles for the Assessment of Prospective Public Doses Arising from Authorised Discharges of Radioactive Waste to the Environment, Radioactive Substances Regulation under the Radioactive Substances Act (RSA-93) or under the Environmental Permitting Regulations (EPR-10), Environment Agency, Nuclear Regulatory Group, Cumbria, UK (2012).

[50] ALLOTT, R.W., LAMBERS, B.,TITLEY, J.G., Initial Radiological Assessment Methodology – Part 1, User Report, Environment Agency report reference SC030162/SR1 (2006). Available at: http://publications.environment-agency.gov.uk/pdf/SCHO0106BKDT-e-e.pdf

[51] LAMBERS, B., THORNE, M.C., Initial Radiological Assessment Methodology – Part 2, Methods and Input Data, Environment Agency report reference SC030162/SR2 (2006). Available at: http://publications.environment-agency.gov.uk/pdf/SCHO0106BKDV-e-e.pdf

[52] ENVIRONMENT AGENCY, SCOTTISH ENVIRONMENT PROTECTION AGENCY, DEPARTMENT OF ENVIRONMENT NORTHERN IRELAND, NATIONAL RADIOLOGICAL PROTECTION BOARD, FOOD STANDARDS AGENCY, Authorisation of Discharges of Radioactive Waste to the Environment – Principles for the Assessment of Prospective Public Dose, interim guidance, Environment Agencies (2002). Available at: http://publications.environment-agency.gov.uk/pdf/PMHO1202BKLH-e-e.pdf

ANNEX: QUESTIONNAIRE

Questionnaire completed by (full name):	
Organization/Institute contact details (in full):	

BACKGROUND QUESTIONS

1. (a) Which facilities require modeling in order to control discharges into the environment?

1. (b) What type of facilities are these?		
☐ Nuclear power reactor	☐ Fuel enrichment facilities	☐ Isotope production facilities
☐ Research reactors	☐ Research laboratories	☐ Irradiators
☐ Fuel fabrication facilities	☐ Radiopharmaceutical companies	☐ Hospitals and clinics
Other:		

1. (c) How do you determine if modeling is necessary? (e.g. It could be related to the inventory, the significance of the discharges or the safety characteristics of the installation, etc. The Netherlands use a formal method to determine if modelling is necessary)

2.Who performs the modeling? If different modelling is performed in more than one organization please specify. (e.g. Regulators, operators, applicants, independent government organization, consultants)

3.(a) What are the regulatory limit values? Are they doses, concentrations, or are they expressed in other units? (e.g. dose limit of 1 mSv/a)

3.(b) What are the constraints values?

3.(c) How are the discharge limits expressed? (e.g. annual activity, activity rate, short term activity, annual doses)

MODEL INPUTS

4.What type of discharges to the environment do you model? (e.g. atmospheric, freshwater, marine, sewer)

5. (a) What data do you put into the model? (e.g. the source term)

5. (b) Are the radionuclides grouped together? How are they grouped and why?

5. (c) Do you use analogues?(i.e. Ca to model Sr-90 or K to model Cs-137).

6. (a) In your model do you use site specific, generic data, or both?

6. (b) What is the source of the generic data? (e.g. local, provincial, national, international)

6. (c) If it is a combination, which data is site specific and which data is generic?

7. (a) To whom is the dose used in the assessment (e.g. organ doses, effective doses, committed effective doses) calculated?

7. (b) Do you use the terms critical/reference/representative group or person? How do you define it?

7. (c) Is it a real or hypothetical situation?

7. (d) Is the habit data generic or specific?

7.(e) Provide a general description of the assumption used. (e.g. A person or group of persons living at the fence, eating local food, drinking milk from a distant farm, etc.)

7. (f) Where is the receptor located? (e.g. At the site boundary, beyond a sanitary exclusion zone)

7. (g) Do you define age groups, and if so what are they? What criteria do you use to select the age groups? (e.g. Reference)

MODEL DETAILS

8. Which exposure pathways do you consider for the aquatic release mode?

9. Which exposure pathways do you consider for the atmospheric release mode?

10. How do you consider direct radiation? (e.g. Dose rate in the outside walls of a Hospital)

11. Does the aquatic model assume equilibrium or is it dynamic?

12. What are the features of your aquatic model? (e.g. Does the model use any of the following: Box model, non-dilution model, dilution model, 3-dimensional model, other)

13. Does the atmospheric model assume equilibrium or is it dynamic?

14. What are the features of your atmospheric model? (e.g. Does the model use any of the following: Gaussian plume model, semi-infinite cloud model, box model, non-dilution model, dilution model, 3-dimensional model, other)

15. (a) Does the aquatic model include transfer factors? (e.g. Concentration ratios, transfer rates, transfer coefficients)

15. (b) If so which ones? (e.g. soil:water, water:biota, food:man)

15. (c) What reference are they obtained from?

16. (a) Does the atmospheric model include transfer factors? (e.g. Concentration ratios, transfer rates, transfer coefficients)

16. (b) If so which ones?

16. (c) What reference are they obtained from?

17. What is the source of the dose coefficients used in the aquatic model? (Please provide references)

18. What is the source of the dose coefficients used in the atmospheric model? (Please provide references)

19. Which physical processes are considered in the aquatic model? (e.g. Sedimentation, resuspension)

20. Which physical processes are considered in the atmospheric model? (e.g. Dry and wet deposition)

21. Does the model take into account progeny? Give a brief description.

OTHER ASSESSMENT ISSUES

22. (a) Do you use collective dose?

22. (b) How do you use the collective dose?

22. (c) What is the integration time?

22. (d) Up to what distance?

22. (e) Which population distribution(s) do you use?

22. (f) How do you define the population distribution? (Please provide reference)

23. (a) Does your model allow assessment of short term releases in addition to the continuous releases?

23. (b) What are the integration period of the short term discharge limits? (e.g. Monthly, weekly, daily)

24. Does the model have seasonal and climate dependent parameters? If yes, which climatic conditions and seasonal variation can you consider? (e.g. Tropical, temperate, arctic)

25. Do you consider topology? Do you consider complex topography? (e.g. Mountains, valleys)

26. (a) Does your model allow assessment of multiple sources from the same site?

26. (b) How does it do this? (e.g. do you use a virtual source or source by source in sequence)

26. (c) Are the discharge limits for multiple sources different?

27. (a) Do you consider the protection of wildlife (biota) in the assessment? How do you achieve this?

27. (b) Does your country have radiological criteria included in the national regulations that specifically protect biota?

27. (c) Are there known cases where the inclusion of biota in the method affects the authorized discharge limit?

RESULTS/VALIDATION

28. (a) How do you use the results of the models to determine the value of the authorized source term (discharge limits)?

28. (b) Are the limits for groups of radionuclides? If so how are they determined?

29. How often do you review the authorisations?

MODEL VERIFICATION/VALIDATION

30. After the prospective assessment is performed, are you obliged to use source and/or environmental monitoring to validate your model and verify your assumptions?

SOURCE MONITORING

31. (a) Are the authorized discharges to the environment monitored or estimated? Clarify for which installation. (e.g. Estimations for Hospitals, measurements for NPPs)

31. (b) If they are monitored is it continuous monitoring or periodic?

31. (c) Which radionuclides are considered?

31. (d) For the monitoring of the releases, what is the method detection limit with respect to the discharges?

ENVIRONMENTAL MONITORING

32. (a) Are the concentrations in the relevant environmental compartments routinely monitored, monitored once or estimated? Clarify for which installations. (e.g. Hospitals, NPPs)

32. (b) If they are monitored routinely, which are the frequencies?

32. (c) Which radionuclides are considered?

32. (d) For the monitoring of the environment, what is the method detection limit with respect to the expected concentrations?

33. Which environmental compartments/media are considered?

SOURCE AND ENVIRONMENTAL MONITORING

34.What approach do you take if the measurement results are less than the detection limit, and why do you take this approach? (e.g. Is the measurement assigned a zero or the value of the detection limit)

OTHER

35. (a) What is the quality assurance method of the calculations?

35. (b) Are the calculations validated? How? (e.g. By monitoring, experimental data, other)

35. (c) How is the model shown to be reliable?

36. Is the method compatible with the IAEA standards? Please describe in which ways it is compatible. (e.g. BSS, SRS 19, SG W2.3, RS G 1.8, other)

37. (a) What strategy is applied to ensure that the regulatory value is not exceeded?

37. (b) To what degree do the authorized discharge levels allow flexibility by the operators? (e.g. Are trade-offs allowed, reducing one radionuclide but increasing another)

37. (c) How do you ensure the principle of ALARA is followed? (e.g. Optimization, dose constraints, BAT, other)

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