NDAWG
National Dose Assessment Working Group

*NDAWG/2/2006*

# *Overview of Radiological Assessment Models - Key Gaps and Uncertainties*

*NDAWG Modelling Sub-group*

## SUMMARY

The Radioactive Substances Act 1993 (RSA 93) provides the framework for controlling the generation and disposal of solid, liquid and gaseous radioactive waste so as to protect the public and the environment. In particular, RSA 93 requires prior authorisation for the disposal or discharge of radioactive waste to the environment. Directions on the Environment Agency and Scottish Environment Protection Agency require these Environment Agencies to ensure that doses to reference groups of the public do not exceed specified dose constraints. The assessment of prospective public doses requires the use of models from source, through environmental pathways to the exposure of the receptor, in this case members of the public.

The National Dose Assessment Working Group (NDAWG) modelling sub-group has identified areas of significant uncertainty in models used for radiological dose assessment. Modelling techniques used for assessing doses arising from releases to air, freshwater, estuarine/coastal waters and sewer have been examined.

Modelling areas which require improvement have been ranked as either high or medium priority. The organisations which should lead on model improvement have been identified.

The areas for improvement fall into the following main groups:

- For releases to freshwater and estuarine/coastal waters, develop or improve dispersion models; models for transfer to sediment; and external dose-rate models – Environment Agency to lead R&D.
- For releases to sewer - Continue existing R&D on partitioning of radionuclides between sludge and treated effluent and research habits of workers at sewage treatment works – Environment Agency to lead R&D.
- Refine modelling of key radionuclides through important parts of the foodchain (including transfers from sludge-conditioned soil) – Food Standards Agency to lead R&D.
- Research application of sludge to land in relation to size of sewage treatment works – Food Standards Agency to lead R&D.
- Review UK generic habits data for terrestrial food consumption and improve estimates of local food consumption - Food Standards Agency to lead R&D.
- Review generic habits data for consumption of freshwater fish – NDAWG habits sub-group.
- Develop guidance on the assumptions to be used for short-term release assessments - NDAWG modelling group or a new sub-group on short-term releases.

It is recommended that the organisations identified include at least the high priority items for modelling improvement in their forthcoming work programmes. The NDAWG modelling sub-group should be re-convened in a few years to review progress and changes in model uncertainty.

## Contents

## INTRODUCTION

1 The Radioactive Substances Act 1993 (RSA 93) provides the framework for controlling the generation and disposal of solid, liquid and gaseous radioactive waste so as to protect the public and the environment. In particular, RSA 93 requires prior authorisation for the disposal or discharge of radioactive waste to the environment. Responsibility for granting an authorisation rests with the Environment Agency in England and Wales, the Scottish Environment Protection Agency (SEPA) in Scotland and the Department of Environment in Northern Ireland.

2 The Euratom Basic Safety Standards (BSS) Directive 1996 [Ref 1] requires member states, as part of the planning process for licensing practices subject to the Directive (ie, practices involving a risk from ionising radiation), to ensure that specified dose limits are not exceeded.

3 Directions on the Environment Agency (EA) and Scottish Environment Protection Agency (SEPA) [Refs 2, 3] require these Environment Agencies to ensure that doses to reference groups of the public do not exceed specified dose constraints, in discharging their functions in relation to the disposal of radioactive waste under RSA 93. There is equivalent legislation for Northern Ireland [Ref 4].

4 The Environment Agency, Scottish Environment Protection Agency and the Department of Environment in Northern Ireland in collaboration with the Food Standards Agency and National Radiological Protection Board (now the Radiation Protection Division of the Health Protection Agency – HPA-RPD) have developed and published principles and guidance for the prospective assessment of public doses [Ref 5].

5 The assessment of prospective public doses requires the use of models from source, through environmental pathways to the exposure of the receptor, in this case members of the public.

6 This paper provides an overview of significant areas of uncertainty in dose assessment models and data and provides recommendations to reduce these uncertainties.

## PURPOSE AND SCOPE

7 The purpose of the overview study was to identify significant areas of uncertainty in models used for prospective radiological assessments, such that these can be:

- Properly accounted for in uncertainty assessments.
- Future scientific work can be directed at reducing these uncertainties.

8 A modelling sub-group of the National Dose Assessment Working Group (www.ndawg.org) was established to address uncertainty in radiological assessment models. The scope of the work of the sub-group, as defined in its terms of reference, was as described below.

The aim of this sub-group is to consider issues relating to modelling the transfer of radionuclides through the environment, as part of the assessment of the radiation doses from routine releases of radionuclides. In particular it will:

- Identify the environmental media and radionuclides for which reliable models and data exist. This should be in the context of assessing doses from routine releases and the low levels of doses that are generally found.
- Identify the environmental media and radionuclides for which the models and data are not considered adequate for routine release dose assessment.

- To identify areas of further work and priorities to improve modelling based on the significance of doses from actual discharges from both nuclear and non-nuclear industry.

9 This review was concerned with individual dose and not collective dose, and focused primarily on prospective assessments. Consideration was mainly given to identifying the uncertainties in modelling transfers through the environment from source to receptor.

10 The adequacy of internal dose coefficients was not directly considered as part of this review as it has been the subject of recent debate [Ref 6]. The dose coefficients in the Basic Safety Standards Directive [Ref 1] are to be used for prospective radiological assessments undertaken for the purposes of authorising discharges of radioactive waste [Ref 5].

## METHODOLOGY

11 The review to identify significant uncertainties in models for undertaking prospective radiological assessments was undertaken as follows:

- Definition of a standard for determining acceptability of model uncertainty.
- Definition of criteria for evaluating the significance of uncertainty.
- Identification of modelling steps for assessing continuous and short-term releases to air, freshwater and coastal/estuarine water and for continuous releases to sewer. Short-term releases to sewer were not considered.
- Scoring of each modelling step to determine the uncertainty and its significance.
- Identification of measures that can be taken to reduce uncertainty.

### Standard for determining acceptability of model uncertainty

12 There are no clear international standards to determine the acceptability of models. Such acceptability is usually defined by user acceptance criteria and demonstrated by model validation. Although, in some specialised contexts, there is a movement toward the development of more physically based models, radiological impact assessment models have relied, and will continue substantially to rely, on large databases of empirical parameter values or distributions. Thus, many of the data that might be used for validation are already incorporated in the underlying databases. The issue of how new datasets could be generated for validation purposes and the identification of appropriate techniques for carrying out such validation studies are not addressed in this paper, but are potential topics for future consideration by the NDAWG.

13 In general, the adequacy of models can only be assessed in relation to how well they predict environmental measurements. The National Dose Assessment Working Group considers that models which are generally within a factor of 3 of environmental measurements may be regarded as adequate for prospective radiological assessments. Models which differ from environmental measurements by a factor of more than 10 may be considered as inadequate.

### Definition of criteria for significance of uncertainty

14 The NDAWG modelling sub-group defined the following scoring criteria for determining the significance of uncertainty:

- Uncertainty – Score of 1 if less than about factor of 3, score of 3 if greater than about a factor of 10, otherwise a score of 2.

- Dose – Score of 1 if dose from any permitted radioactive substance release is <20 μSv/y, score of 3 if dose is >100 μSv/y.

15 The dose score is intended to be a measure of the highest prospective critical group dose which may be received from discharges of a radionuclide at its limit specified in any RSA 93 authorisation in the UK.

16 These two scores were multiplied together to give a combined score and given the following priority rating (see Figure 1):

- High priority (red) – score of 6 or 9.
- Medium priority (yellow) – score of 4 or 3 (where uncertainty score = 3 and dose score = 1)
- Low priority (white) – score of 1, 2 or 3 (where uncertainty score = 1 and dose score = 3 – low uncertainty so little need to improve modelling despite high dose)

**Identify and score modelling steps**

17 The modelling steps were identified and scored by the NDAWG modelling sub-group at meetings on 13 April 2005, 21 September 2005 and 25 January 2006. These modelling steps for releases to air, freshwater, coastal/estuarine water and sewer are shown in Tables 1 – 7, along with the scores of uncertainty against each modelling step and radionuclide. The following were excluded in the consideration of releases to sewer:

- Migration of radionuclides into groundwater or run off into water courses as a result of leaching of sludge once it has been spread to land.
- Landfilling of sludge and ash following incineration of sludge.
- Special treatment of industrial wastes and tertiary treatment of sewage at sewage treatment works.

18 The dose score for each radionuclide was assigned by expert judgement of the NDAWG modelling sub-group. However, the group used the results of initial dose assessments for all RSA 93 authorisations in England and Wales to support that judgement. These initial dose assessment results were calculated using a database of RSA 93 authorisations limits in England and Wales and the dose per unit release data from the Environment Agency's initial radiological assessment methodology [Ref 7].

19 Retrospective dose assessments from the Radioactivity in Food and Environment report for 2003 [Ref 8] were also used for pathways not covered by the initial radiological assessment methodology. Expert judgement was required to assign a final score, as authorisation limits are often specified for groups of nuclides; default environmental conditions (eg, river flow rates) were assumed; the authorisation database has not yet been comprehensively checked for accuracy; dose assessment data were not available for Scotland and Northern Ireland; and it was necessary to modify scores where models are known to potentially under-predict doses.

20 The uncertainty score was also assigned by expert judgement of the NDAWG modelling group. Evidence was provided to support the judgement on uncertainty as shown in Tables 1 - 7.

## RESULTS OF ANALYSIS OF AREAS OF SIGNIFICANT UNCERTAINTY

### Releases to air

21 The modelling areas which have been assigned as high or medium priority for further development are as listed below.

**High priority:**

- Provide NRPB-R91 type charts for continuous releases using ADMS or AERMOD to encourage use of more realistic modelling data.
- Examine the effect of chemical speciation of sulphur-35 on deposition.
- Examine the effect of chemical speciation of iodine isotopes on deposition.
- Further develop modelling of transfer of sulphur-35 to plants.
- Further develop understanding of iodine-129 uptake in plants and transfers to milk.
- Review of UK generic food consumption data, in particular for home/allotment/small holding produced food.
- Define air dispersion modelling assumptions for prospective assessment of doses arising from non-accidental short-term releases.
- Refine and develop transfer rates to assess peak and integrated concentrations in foodstuffs as a result of short-term releases.
- Define habits data for consumption of foods following short term releases.

**Medium priority:**

- Develop models for transfer of organically bound tritium (OBT) from air/soil to food.
- Improve modelling of chlorine-36 from soil into plants/food.
- Improve modelling of technetium-99 from soil into plants/food.

### Releases to freshwater

22 The modelling areas which have been assigned as high or medium priority for further development are as listed below.

**High priority:**

- Improve models for dispersion in freshwater and transfer to sediments (in particular for iodine-131 which is discharged in large quantities from cancer therapy hospitals) (may need to consider chemical speciation).
- Examine the relationship between the doses arising where people are located on river banks compared with the doses over river bed sediments.
- Examine transfer of OBT and phosphorus isotopes to freshwater fish (may need to consider chemical speciation).
- Examine concentration factors (CF) for fish farms for key radionuclides (eg, phosphorus-32/33).
- Review information on freshwater fish consumption.

**Medium priority:**

- Examine freshwater dispersion and transfer to sediments for short-term releases to river.
- Examine habits of persons exposed to external radiation in relation to short-term releases (eg, duration, timing).
- Examine habits for consumption of freshwater fish in relation to short-term releases (eg, quantity, timing).

### Releases to estuary / coastal waters

23 The modelling areas which have been assigned as high or medium priority for further development are listed below.

**High priority:**

- Examine transfer of Pb-210 and Po-210 to fish (difficult to validate due to difficulty establishing background for Po-210 in shellfish in Cumbria).
- Examine modelling of particle-reactive nuclides (eg, americium-241) which are not well represented in the coastal environment.

**Medium priority:**

- Review generic habits data for increased leisure activities/other work activities (eg, diving, kite surfing, sea-washed turf cutting etc).
- Examine concentration factors for transfer to fish for OBT and Eu-154.
- Examine transfer of key radionuclides from seaweed into compost and crops (in particular Tc-99) for continuous and short-term releases.
- Review habits assumptions for consumption of crops produced on seaweed-fertilised land for continuous and short-term releases.
- Develop models for dispersion and transfer to sediments for short-term releases into the coastal environment.
- Examine habits of persons exposed to external radiation in relation to short-term releases (eg, duration, timing).
- Examine habits for consumption of fish/shellfish in relation to short-term release (eg, quantity, timing).
- Examine transfers of key radionuclides to animal products as a result of grazing on sea-washed pasture (in particular for short-term releases).
- Examine habits assumptions for consumption of animal products grazed on sea-washed land after short-term release (eg, quantity and timing).

### Releases to sewer

24 The modelling areas which have been assigned as high priority for further development are listed below.

**High priority:**

- Continue existing EA R&D on partitioning of radionuclides between sludge and treated effluent at sewage treatment works. There is a need to understand partitioning at key process steps, especially where recycling of material through chemically distinct phases of the treatment process is important. Analysis of the timeline of passage of effluent components through the works is needed. Degassing of gaseous nuclides should be considered.
- Research occupancy and proximity of sewage workers in relation to tanks/channels etc containing raw sewage and sludge, and their geometry and shielding.
- Research application of sludge to land in relation to sewage works size, including amount of land conditioned and food types produced.
- Continue and broaden research on transfer of radionuclides in sludge to soil and on into the foodchain, in particular for H-3 and C-14.
- Scope realistic doses from incineration of sludge and, if doses are potentially high, review partitioning and abatement factors.

**Categorisation of results of analysis**

25 These areas for further model development have been categorised according to what type of development work is required (eg, measurement, survey etc); the ease of the work; and which organisation should lead on the work. The results of this categorisation are shown in Tables 8 – 11.

26 It is proposed that the Food Standards Agency lead on R&D in those high and medium priority areas where there is a need to improve data on the transfer of radionuclides through the foodchain and to research the application of sludge to land in relation to the size of sewage treatment works. The Environment Agency should lead on R&D in those high and medium priority areas where there is a requirement to develop or improve dispersion models, external dose rate modelling, partitioning of radionuclides in sewage treatment works and habits of workers at sewage treatment works. It is proposed that the NDAWG habits subgroup should review generic habits data for freshwater fish consumption. Finally, either the NDAWG modelling group or a new sub-group on short-term releases should develop guidance on the assumptions to be used for short-term release assessments.

## CONCLUSIONS

27 The NDAWG modelling sub-group has identified areas of significant uncertainty in models used for radiological dose assessment. Modelling techniques used for assessing doses arising from releases to air, freshwater, estuarine/coastal waters and sewer have been examined.

28 Modelling areas which require improvement have been ranked as either high or medium priority. The organisations that should lead on model improvement have been identified.

29 The areas for improvement fall into the following main groups:

- For releases to freshwater and estuarine/coastal waters, develop or improve dispersion models; models for transfer to sediment; and external dose-rate models – Environment Agency to lead R&D.
- For releases to sewer - Continue existing R&D on partitioning of radionuclides between sludge and treated effluent and research habits of workers at sewage treatment works – Environment Agency to lead R&D.
- Refine modelling of key radionuclides through important parts of the foodchain (including transfers from sludge-conditioned soil) – Food Standards Agency to lead R&D.
- Research application of sludge to land in relation to size of sewage treatment works – Food Standards Agency to lead R&D.
- Review UK generic habits data for terrestrial food consumption and improve estimates of local food consumption - Food Standards Agency to lead R&D.
- Review generic habits data for consumption of freshwater fish – NDAWG habits sub-group.
- Develop guidance on the assumptions to be used for short-term release assessments - NDAWG modelling group or a new sub-group on short-term releases.

## RECOMMENDATIONS

30 The NDAWG modelling sub-group recommend the following:

- The Environment Agency and the Food Standards Agency should include at least the high priority areas for model improvement, where they have been identified as the lead organisation, as proposals in their forthcoming R&D programmes.
- NDAWG sub-groups should consider those areas identified to help reduce modelling uncertainty.
- The NDAWG modelling sub-group should be re-convened in a few years to review progress and changes in model uncertainty.

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## TABLES

### Table 1 Releases to air – Continuous

| Modelling Step | Nuclide | Comments | Dose Score | Uncert-ainty Score | Total Score |
|---|---|---|---|---|---|
| Dispersion | General | Currently modelled as neutrally buoyant plume (particulate, low mass gas release). Gaussian plume models (eg, NRPB-R91) are adequate in most cases to assess annual doses from continuous releases where there are no buildings, flat terrain and no coastal effects - the uncertainty is probably within a factor of 2.<br><br>Generally, where the critical group is beyond 300m then building effects can be adequately considered (eg, using effective release height, virtual source), although this is not always done, leading to uncertainty of greater than 3, but probably less than 10.<br><br>Where terrain is important (ie, not flat), account needs to be taken of this (eg, Cardiff). This is not always assessed adequately, leading to uncertainty of greater than 3, but probably less than 10.<br><br>PC Cream takes account of ingrowth (immediate progeny only) and decay during dispersion. Not all models will do this.<br><br>New generation models (eg, AERMOD and ADMS) are considered to provide better dispersion predictions. However, site specific meteorological data, topography and building information are required. These large data requirements provide a barrier to their use. Generally, Gaussuan plume models tend to be conservative compared to the new generation models.<br><br>Generally assumed that aerosol is 1 µm AMAD, which is probably adequate for HEPA filtered releases. If necessary, it is straightforward to change the particle size in ADMS. PC CREAM can also be adjusted to model different particle sizes. | | | |
| | Tritium | - | 2 | 2 | 4 |
| | OBT | - | 1 | 2 | 2 |
| | C-14 | - | 3 | 2 | 6 |
| | F-18 | This is mainly released from hospitals as a result of patient treatment and vents may be at low-level. Critical groups will be close to the release point (eg, groundsmen, office workers in an adjacent tall building) and building effects etc become more difficult to adequately model. Increased use of cyclotrons mean there will be more permit requests in future. | 1 | 3 | 3 |
| | S-35 | - | 3 | 2 | 6 |
| | Cl-36 | - | 1 | 2 | 2 |
| | Noble gases | - | 3 | 2 | 6 |
| | Co-60 | - | 1 | 2 | 2 |
| | Se-75 | - | 1 | 2 | 2 |
| | Sr-90/Y-90 | - | 1 | 2 | 2 |
| | Zr-95/Nb-95 | - | 1 | 2 | 2 |
| | Tc-99 | - | 1 | 2 | 2 |
| | Tc-99m | - | 1 | 2 | 2 |
| | Ru-106 | - | 1 | 2 | 2 |
| | Sb-125 | - | 1 | 2 | 2 |
| | I-125/I-129 | - | 3 | 2 | 6 |
| | I-131 | - | 3 | 2 | 6 |
| | Cs-134/Cs-137 | - | 1 | 2 | 2 |
| | La-140 | - | 1 | 2 | 2 |
| | Ce-144 | - | 1 | 2 | 2 |
| | Rare earths | - | 1 | 2 | 2 |
| | Tl-201 | - | 1 | 2 | 2 |
| | Pb-210 | - | 1 | 2 | 2 |
| | Po-210 | - | 1 | 2 | 2 |
| | Rn-222 | - | 2 | 2 | 4 |
| | Ra-226 | - | 1 | 2 | 2 |
| | Thorium | - | 1 | 2 | 2 |
| | Uranium | - | 1 | 2 | 2 |
| | Np-237 | - | 1 | 2 | 2 |
| | Pu-alpha | - | 1 | 2 | 2 |
| | Pu-241 | - | 1 | 2 | 2 |

**Table 1 Continued**

| Modelling Step | Nuclide | Comments | Dose Score | Uncert-ainty Score | Total Score |
|---|---|---|---|---|---|
| Dispersion (cont) | Americium | - | 1 | 2 | 2 |
| | Curium | - | 1 | 2 | 2 |
| Inhalation dose | General | Adequate breathing rate data. Required to use Basic Safety Standard dose coefficients. | | | |
| | Tritium | - | 2 | 1 | 2 |
| | OBT | - | 1 | 1 | 1 |
| | C-14 | - | 3 | 1 | 3 |
| | F-18 | - | 1 | 1 | 1 |
| | S-35 | - | 2 | 1 | 2 |
| | Cl-36 | - | 1 | 1 | 1 |
| | Noble gases | Not applicable | N/A | N/A | N/A |
| | Co-60 | - | 1 | 1 | 1 |
| | Se-75 | - | 1 | 1 | 1 |
| | Sr-90/Y-90 | - | 1 | 1 | 1 |
| | Zr-95/Nb-95 | - | 1 | 1 | 1 |
| | Tc-99 | - | 1 | 1 | 1 |
| | Tc-99m | - | 1 | 1 | 1 |
| | Ru-106 | - | 1 | 1 | 1 |
| | Sb-125 | - | 1 | 1 | 1 |
| | I-125/I-129 | - | 1 | 1 | 1 |
| | I-131 | - | 3 | 1 | 3 |
| | Cs-134/Cs-137 | - | 1 | 1 | 1 |
| | La-140 | - | 1 | 1 | 1 |
| | Ce-144 | - | 1 | 1 | 1 |
| | Rare earths | - | 1 | 1 | 1 |
| | Tl-201 | - | 1 | 1 | 1 |
| | Pb-210 | - | 1 | 1 | 1 |
| | Po-210 | - | 1 | 1 | 1 |
| | Rn-222 | - | 3 | 1 | 3 |
| | Ra-226 | - | 1 | 1 | 1 |
| | Thorium | - | 1 | 1 | 1 |
| | Uranium | - | 1 | 1 | 1 |
| | Np-237 | - | 1 | 1 | 1 |
| | Pu-alpha | - | 1 | 1 | 1 |
| | Pu-241 | - | 1 | 1 | 1 |
| | Americium | - | 1 | 1 | 1 |
| | Curium | - | 1 | 1 | 1 |
| External (plume) dose | General | Semi-infinite model data (eg, US Federal Guidance Report 13) may over-estimate doses depending on circumstances (gamma energies and cloud size) compared to a finite model. Semi-infinite models may also under-estimate the plume dose if ground-level concentrations are selected when the plume is at height and above the exposed person.<br><br>Finite model will provide results that are more realistic. However, as the dose is assessed using integrated air concentrations across the plume, it cannot be scaled by the ground-level air concentration (for example, to take account of different air concentrations at different locations and as a result of different stack heights).<br><br>PC Cream has finite and semi-infinite model. ADMS will calculate external doses. There are guidelines in ADMS documentation on the use of an appropriate model. However, ADMS cannot calculate both external doses and take account of building effects. AERMOD does not have an external dose model. | | | |
| | Tritium | Not applicable | N/A | N/A | N/A |
| | OBT | Not applicable | N/A | N/A | N/A |
| | C-14 | Not applicable | N/A | N/A | N/A |
| | F-18 | - | 1 | 1 | 1 |
| | S-35 | - | 1 | 1 | 1 |
| | Cl-36 | - | 1 | 1 | 1 |
| | Noble gases | Main exposure pathway for this group of nuclides | 3 | 1 | 3 |
| | Co-60 | - | 1 | 1 | 1 |
| | Se-75 | - | 1 | 1 | 1 |
| | Sr-90/Y-90 | - | 1 | 1 | 1 |
| | Zr-95/Nb-95 | - | 1 | 1 | 1 |

## Table 1 Continued

| Modelling Step | Nuclide | Comments | Dose Score | Uncert-ainty Score | Total Score |
|---|---|---|---|---|---|
| External (plume) dose (cont) | Tc-99 | - | 1 | 1 | 1 |
| | Tc-99m | - | 1 | 1 | 1 |
| | Ru-106 | - | 1 | 1 | 1 |
| | Sb-125 | - | 1 | 1 | 1 |
| | I-125/I-129 | - | 1 | 1 | 1 |
| | I-131 | - | 3 | 1 | 3 |
| | Cs-134/Cs-137 | - | 1 | 1 | 1 |
| | La-140 | - | 1 | 1 | 1 |
| | Ce-144 | - | 1 | 1 | 1 |
| | Rare earths | - | 1 | 1 | 1 |
| | Tl-201 | - | 1 | 1 | 1 |
| | Pb-210 | - | 1 | 1 | 1 |
| | Po-210 | - | 1 | 1 | 1 |
| | Rn-222 | - | 1 | 1 | 1 |
| | Ra-226 | - | 1 | 1 | 1 |
| | Thorium | - | 1 | 1 | 1 |
| | Uranium | - | 1 | 1 | 1 |
| | Np-237 | - | 1 | 1 | 1 |
| | Pu-alpha | - | 1 | 1 | 1 |
| | Pu-241 | - | 1 | 1 | 1 |
| | Americium | - | 1 | 1 | 1 |
| | Curium | - | 1 | 1 | 1 |
| Deposition | General | Need to include both wet and dry deposition. RP-72 model (as implemented in PC Cream and ADMS) is broadly adequate for continuous releases and for annual dose. However, CERC announced at a user group meeting last year that one of their priorities for the development of ADMS will be further consideration of deposition rate calculations, due to uncertainties, and there may be a renewed focus on this in the next couple of years.<br><br>Generally assumed that aerosol is 1 $\mu$m AMAD, which is probably adequate for HEPA filtered releases. If necessary, it is straightforward to change the particle size in ADMS and there is information in an ADMLC report on appropriate deposition rates for different particle sizes [Ref 9].<br><br>Speciation effects and partitioning between gaseous and particulate forms can cause large modelling uncertainties.<br><br>AERMOD does not have a deposition model. | | | |
| | Tritium | Deposition not considered as transfer to food based on specific activity concentration model using air concentration. | N/A | N/A | N/A |
| | OBT | Same as tritium. | N/A | N/A | N/A |
| | C-14 | Deposition not considered as transfer to food based on specific activity concentration model using air concentration. | N/A | N/A | N/A |
| | F-18 | Not applicable | N/A | N/A | N/A |
| | S-35 | Different sulphur chemical species have different deposition characteristics. | 3 | 2 | 6 |
| | Cl-36 | Different chlorine chemical species may have different deposition characteristics and there are few data for this nuclide. | 1 | 3 | 3 |
| | Noble gases | Not applicable | N/A | N/A | N/A |
| | Co-60 | - | 1 | 2 | 2 |
| | Se-75 | - | 1 | 2 | 2 |
| | Sr-90/Y-90 | - | 1 | 2 | 2 |
| | Zr-95/Nb-95 | - | 1 | 2 | 2 |
| | Tc-99 | - | 1 | 2 | 2 |
| | Tc-99m | - | 1 | 2 | 2 |
| | Ru-106 | - | 1 | 2 | 2 |
| | Sb-125 | - | 1 | 2 | 2 |
| | I-125/I-129 | Differences of up to two orders of magnitude may occur for different iodine chemical species. EMRAS work on-going [Ref 10]. | 2 | 3 | 6 |

**Table 1 Continued**

| Modelling Step | Nuclide | Comments | Dose Score | Uncert-ainty Score | Total Score |
|---|---|---|---|---|---|
| Deposition (cont) | I-131 | Differences of up to two orders of magnitude may occur for different iodine species. EMRAS work on-going. | 3 | 3 | 9 |
| | Cs-134/Cs-137 | - | 1 | 2 | 2 |
| | La-140 | - | 1 | 2 | 2 |
| | Ce-144 | - | 1 | 2 | 2 |
| | Rare earths | - | 1 | 2 | 2 |
| | Tl-201 | - | 1 | 2 | 2 |
| | Pb-210 | - | 1 | 2 | 2 |
| | Po-210 | - | 1 | 2 | 2 |
| | Rn-222 | Not applicable | N/A | N/A | N/A |
| | Ra-226 | - | 1 | 2 | 2 |
| | Thorium | - | 1 | 2 | 2 |
| | Uranium | - | 1 | 2 | 2 |
| | Np-237 | - | 1 | 2 | 2 |
| | Pu-alpha | - | 1 | 2 | 2 |
| | Pu-241 | - | 1 | 2 | 2 |
| | Americium | - | 1 | 2 | 2 |
| | Curium | - | 1 | 2 | 2 |
| External (deposited) dose | General | RP-72 model (in PC Cream) is adequate, for long-lived gamma-emitting radionuclides.<br><br>Finite and semi-infinite models can cause differences but not as great as for plume dose. Data can be for different depths which may increase uncertainty.<br><br>Occupancy/shielding factors (location factors) – occupancy outdoors is likely to be within a factor of two given the selection of realistic population groups as well supported data on time spent outdoors for manual workers or people who are office/home based. Shielding – many studies to support data used.<br><br>Models are for rural environment. Doses in urban environment will be different. Deposition may be lower/not as deep as rural, but higher/complex surfaces with deposited nuclides (not ground). | | | |
| | Tritium | - | 1 | 1 | 1 |
| | OBT | - | 1 | 1 | 1 |
| | C-14 | - | 1 | 1 | 1 |
| | F-18 | Not applicable | N/A | N/A | N/A |
| | S-35 | - | 1 | 1 | 1 |
| | Cl-36 | - | 1 | 1 | 1 |
| | Noble gases | Not applicable | N/A | N/A | N/A |
| | Co-60 | - | 1 | 1 | 1 |
| | Se-75 | | 1 | 1 | 1 |
| | Sr-90/Y-90 | - | 1 | 1 | 1 |
| | Zr-95/Nb-95 | - | 1 | 1 | 1 |
| | Tc-99 | - | 1 | 1 | 1 |
| | Tc-99m | - | 1 | 1 | 1 |
| | Ru-106 | - | 1 | 1 | 1 |
| | Sb-125 | - | 1 | 1 | 1 |
| | I-125/I-129 | - | 1 | 1 | 1 |
| | I-131 | - | 1 | 1 | 1 |
| | Cs-134/Cs-137 | - | 1 | 1 | 1 |
| | La-140 | - | 1 | 1 | 1 |
| | Ce-144 | - | 1 | 1 | 1 |
| | Rare earths | - | 1 | 1 | 1 |
| | Tl-201 | - | 1 | 1 | 1 |
| | Pb-210 | - | 1 | 1 | 1 |
| | Po-210 | - | 1 | 1 | 1 |
| | Rn-222 | Not applicable | N/A | N/A | N/A |
| | Ra-226 | - | 1 | 1 | 1 |
| | Thorium | - | 1 | 1 | 1 |
| | Uranium | - | 1 | 1 | 1 |
| | Np-237 | - | 1 | 1 | 1 |
| | Pu-alpha | - | 1 | 1 | 1 |

**Table 1 Continued**

| Modelling Step | Nuclide | Comments | Dose Score | Uncert-ainty Score | Total Score |
|---|---|---|---|---|---|
| External (deposited) dose (cont) | Pu-241 | - | 1 | 1 | 1 |
| | Americium | - | 1 | 1 | 1 |
| | Curium | - | 1 | 1 | 1 |
| Transfer to food | General | Deposition to plants – Total transfer to plant reasonably well know, but time dependence is poorly known. This is the major route into plants for many nuclides for routine atmospheric releases (not accidents / contaminated land).<br><br>Uptake from soil to plants – Generally adequate (not for chlorine and technetium, but extensive data have been accumulated in the context of solid radioactive waste management and they can be manipulated to provide useful results in this context). May be lower for reclaimed land, since the chemical availability of the chemical species is lower.<br><br>Transfer to animals – Eating soil may not be well considered, but data may be based on grass and soil intake. | | | |
| | Tritium | Based on specific activity concentration model using air concentration. Has been validated by IAEA EMRAS study. | 2 | 1 | 2 |
| | OBT | For continuous releases, this is modelled in the same manner as tritiated. However, this is probably inadequate. | 2 | 2 | 4 |
| | C-14 | Based on specific activity concentration model using air concentration, which is probably adequate. | 3 | 1 | 3 |
| | F-18 | Not applicable | N/A | N/A | N/A |
| | S-35 | Models developed for short term releases based on experimental short term releases, if run for continuous releases gives poor agreement with monitored results for continuous results. Might be different process operating (eg, saturation by sulphur). | 3 | 2 | 6 |
| | Cl-36 | Lack of modelling data. The published defaults indicate high uptake by plants from soil which may not always be the case, but has also been identified as an issue in studies related to solid radioactive waste management. | 1 | 3 | 3 |
| | Noble gases | Not applicable. | N/A | N/A | N/A |
| | Co-60 | Little specific data for cobalt but rarely important. | 1 | 2 | 2 |
| | Se-75 | Little specific data for selenium but unlikely to be important. Some studies have been conducted in a solid radioactive waste management context for application to Se-79. | 1 | 2 | 2 |
| | Sr-90/Y-90 | - | 1 | 1 | 2 |
| | Zr-95/Nb-95 | Relatively little data specific to zirconium/niobium but unlikely to be important. | 1 | 2 | 2 |
| | Tc-99 | Root uptake difficult to model. Very large differences in uptake for different chemical forms and for aged rather than fresh deposits. Studies of mobility in soils as a function of redox conditions have been undertaken in a solid radioactive waste management context. | 1 | 3 | 3 |
| | Tc-99m | Not important. | N/A | N/A | N/A |
| | Ru-106 | Relatively little data specific to ruthenium. | 1 | 2 | 2 |
| | Sb-125 | Relatively little data specific to antimony but unlikely to be important. | 1 | 2 | 2 |
| | I-125/I-129 | Discrepancy between modelled and monitored results for iodine-129 pasture to milk pathway. | 3 | 3 | 9 |
| | I-131 | - | 3 | 2 | 6 |
| | Cs-134/Cs-137 | - | 1 | 1 | 1 |
| | La-140 | Relatively little data specific to lanthanum but unlikely to be important. | 1 | 2 | 2 |

## Table 1 Continued

| Modelling Step | Nuclide | Comments | Dose Score | Uncert-ainty Score | Total Score |
|---|---|---|---|---|---|
| Transfer to food (cont) | Ce-144 | Relatively little data specific to cerium but unlikely to be important. | 1 | 2 | 2 |
| | Rare earths | Relatively little data specific to these elements but unlikely to be important. | 1 | 2 | 2 |
| | Tl-201 | Relatively little data specific to thallium but unlikely to be important. | 1 | 2 | 2 |
| | Pb-210 | Limited data and more would be useful for contaminated land assessments. | 1 | 2 | 2 |
| | Po-210 | Limited data and more would be useful for contaminated land assessments. | 1 | 2 | 2 |
| | Rn-222 | Not applicable | N/A | N/A | N/A |
| | Ra-226 | In-growth of progeny important. | 1 | 2 | 2 |
| | Thorium | In-growth of progeny important. | 1 | 2 | 2 |
| | Uranium | - | 1 | 2 | 2 |
| | Np-237 | Relatively little information specific to neptunium | 1 | 2 | 2 |
| | Pu-alpha | - | 1 | 2 | 2 |
| | Pu-241 | Vital to take account of in-growth of americium-241 | 1 | 2 | 2 |
| | Americium | - | 1 | 2 | 2 |
| | Curium | Relatively little information specific to curium. | 1 | 2 | 2 |
| Food dose | General | Reliant on habits (ie, local food consumed), delay times between picking and eating, preparation of food, storage changes. Required to use Basic Safety Standard dose coefficients. Reasonable UK generic habit data, although a review of these data is due, in particular focused on home/allotment/small holding grown food. | | | |
| | Tritium | - | 2 | 2 | 4 |
| | OBT | Recent scientific papers on OBT dose coefficients. | 2 | 2 | 4 |
| | C-14 | - | 3 | 2 | 6 |
| | F-18 | Not applicable. | N/A | N/A | N/A |
| | S-35 | - | 3 | 2 | 6 |
| | Cl-36 | - | 1 | 2 | 2 |
| | Noble gases | Not applicable. | N/A | N/A | N/A |
| | Co-60 | - | 1 | 2 | 2 |
| | Se-75 | - | 1 | 2 | 2 |
| | Sr-90/Y-90 | - | 1 | 2 | 2 |
| | Zr-95/Nb-95 | - | 1 | 2 | 2 |
| | Tc-99 | - | 1 | 2 | 2 |
| | Tc-99m | Not applicable. | N/A | N/A | N/A |
| | Ru-106 | - | 1 | 2 | 2 |
| | Sb-125 | - | 1 | 2 | 2 |
| | I-125/I-129 | - | 3 | 2 | 6 |
| | I-131 | - | 3 | 2 | 6 |
| | Cs-134/Cs-137 | - | 1 | 2 | 2 |
| | La-140 | - | 1 | 2 | 2 |
| | Ce-144 | - | 1 | 2 | 2 |
| | Rare earths | - | 1 | 2 | 2 |
| | Tl-201 | - | 1 | 2 | 2 |
| | Pb-210 | - | 1 | 2 | 2 |
| | Po-210 | - | 1 | 2 | 2 |
| | Rn-222 | Not applicable. | N/A | N/A | N/A |
| | Ra-226 | - | 1 | 2 | 2 |
| | Thorium | - | 1 | 2 | 2 |
| | Uranium | - | 1 | 2 | 2 |
| | Np-237 | - | 1 | 2 | 2 |
| | Pu-alpha | - | 1 | 2 | 2 |
| | Pu-241 | - | 1 | 2 | 2 |
| | Americium | - | 1 | 2 | 2 |
| | Curium | - | 1 | 2 | 2 |

### Table 2 Releases to air – Short Term

| Modelling Step | Nuclide | Comments | Dose Score | Uncert-ainty Score | Total Score |
|---|---|---|---|---|---|
| Dispersion | General | Main problem is defining representative release conditions. The impact of a short duration release can vary significantly. Could be dealt with probabilistically but not done currently.<br><br>Gaussian plume models in general are not adequate for short-term releases without modifying assumptions validated against new generation models. PC Cream does not model short-term releases.<br><br>New generation models in ideal circumstances (eg, no buildings, flat terrain) probably no better than factor of ten. Can be lot worse in other circumstances. ADMS short-term is being developed. | 3 | 3 | 9 |
| Inhalation dose | General | Inhalation factors satisfactory. Required to use Basic Safety Standard dose coefficients. | 2 | 1 | 2 |
| External (plume) dose | General | Finite external plume dose models are adequate. | 1 | 1 | 1 |
| Deposition | General | Dynamic modelling uncertain. | 1 | 2 | 2 |
| External (deposited) dose | General | External dose models for deposited radionuclides are adequate. | 2 | 1 | 2 |
| Transfer to food | General | Time dependence leads to more uncertainty than for continuous releases. Probably adequate for some nuclides, eg, Cs-137.<br><br>Seasonality is a major factor.<br><br>Effect of agricultural practices and season of the year important for short term releases.<br><br>TRIF model is available for tritium.<br><br>PRISM 3.0 model for a wide range of radionuclides is currently being tested by the FSA. This includes a full representation of kinetic effects. | 3 | 3 | 9 |
| Food dose | General | Time dependence of contamination/consumption cause uncertainties.<br><br>Seasonality will also affect foods. | 3 | 3 | 9 |

## Table 3 Releases to Freshwaters - Continuous

| Modelling Step | Nuclide | Comments | Dose Score | Uncert-ainty Score | Total Score |
|---|---|---|---|---|---|
| Dispersion | General | Models are not well validated. Many orders of magnitude variability. Need detailed modelling data and even then still have large uncertainties.<br><br>NRPB report on multiple sources [Ref 11] provided comparison of modelled versus monitoring data.<br><br>Some detailed site-specific models are available or simple generic models. Comparisons of the two types of model would be worthwhile. | | | |
| | Tritium | - | 1 | 2 | 2 |
| | OBT | - | 3 | 2 | 6 |
| | C-14 | - | 3 | 2 | 6 |
| | Na-22/24 | - | 3 | 2 | 6 |
| | P-32/33 | - | 3 | 2 | 6 |
| | S-35 | - | 1 | 2 | 2 |
| | Cl-36 | - | 1 | 2 | 2 |
| | Co-60 | - | 1 | 2 | 2 |
| | Se-75 | - | 1 | 2 | 2 |
| | Stronium/Y-90 | - | 3 | 2 | 6 |
| | Zr-95/Nb-95 | - | 1 | 2 | 2 |
| | Tc-99 | - | 1 | 2 | 2 |
| | Tc-99m | - | 2 | 2 | 4 |
| | Ru-106 | - | 1 | 2 | 2 |
| | Sb-125 | - | 1 | 2 | 2 |
| | I-125/I-129 | - | 3 | 2 | 6 |
| | I-131 | - | 3 | 2 | 6 |
| | Cs-134/Cs-137 | - | 3 | 2 | 6 |
| | La-140 | - | 1 | 2 | 2 |
| | Ce-144 | - | 1 | 2 | 2 |
| | Eu-154 | - | 1 | 2 | 2 |
| | Rare earths | - | 1 | 2 | 2 |
| | Tl-201 | - | 1 | 2 | 2 |
| | Pb-210 | - | 1 | 2 | 2 |
| | Po-210 | - | 1 | 2 | 2 |
| | Ra-226 | - | 1 | 2 | 2 |
| | Thorium | - | 3 | 2 | 6 |
| | Uranium | - | 1 | 2 | 2 |
| | Np-237 | - | 1 | 2 | 2 |
| | Pu-alpha | - | 1 | 2 | 2 |
| | Pu-241 | - | 1 | 2 | 2 |
| | Americium | - | 1 | 2 | 2 |
| | Curium | - | 1 | 2 | 2 |
| Drinking water dose | General | Habits data may assume worst case location for water abstraction. Better site-specific data will ensure this is more realistic. Consideration of treatment losses will improve realism. However, need to ensure there is no untreated water consumption.<br><br>Annual consumption rates generally adequate. Required to use Basic Safety Standard dose coefficients. | | | |
| | Tritium | - | 1 | 1 | 1 |
| | OBT | - | 1 | 1 | 1 |
| | C-14 | - | 1 | 1 | 1 |
| | Na-22/24 | - | 1 | 1 | 1 |
| | P-32/33 | - | 1 | 1 | 1 |
| | S-35 | - | 1 | 1 | 1 |
| | Cl-36 | - | 1 | 1 | 1 |
| | Co-60 | - | 1 | 1 | 1 |
| | Se-75 | - | 1 | 1 | 1 |
| | Stronium/Y-90 | - | 1 | 1 | 1 |
| | Zr-95/Nb-95 | - | 1 | 1 | 1 |
| | Tc-99 | - | 1 | 1 | 1 |
| | Tc-99m | - | 1 | 1 | 1 |
| | Ru-106 | - | 1 | 1 | 1 |
| | Sb-125 | - | 1 | 1 | 1 |

## Table 3 Continued

| Modelling Step | Nuclide | Comments | Dose Score | Uncert-ainty Score | Total Score |
|---|---|---|---|---|---|
| Drinking water dose (cont) | I-125/I-129 | - | 1 | 1 | 1 |
| | I-131 | - | 3 | 1 | 3 |
| | Cs-134/Cs-137 | - | 1 | 1 | 1 |
| | La-140 | - | 1 | 1 | 1 |
| | Ce-144 | - | 1 | 1 | 1 |
| | Eu-154 | - | 1 | 1 | 1 |
| | Rare earths | - | 1 | 1 | 1 |
| | Tl-201 | - | 1 | 1 | 1 |
| | Pb-210 | - | 1 | 1 | 1 |
| | Po-210 | - | 1 | 1 | 1 |
| | Ra-226 | - | 1 | 1 | 1 |
| | Thorium | - | 1 | 1 | 1 |
| | Uranium | - | 1 | 1 | 1 |
| | Np-237 | - | 1 | 1 | 1 |
| | Pu-alpha | - | 1 | 1 | 1 |
| | Pu-241 | - | 1 | 1 | 1 |
| | Americium | - | 1 | 1 | 1 |
| | Curium | - | 1 | 1 | 1 |
| Transfer to sediments | General | Great variability in Kd used to model.<br><br>Difficulty in modelling transfer to suspended solids, deposition to river beds, subsequent process (eg, movement down river, and deeper in sediments).<br><br>Difficulty/uncertainty in transfer to river banks. | | | |
| | Tritium | - | 1 | 3 | 3 |
| | OBT | - | 1 | 3 | 3 |
| | C-14 | - | 1 | 3 | 3 |
| | Na-22/24 | - | 2 | 3 | 6 |
| | P-32/33 | Chemical behaviour and speciation important (released from non-nuclear sites). | 1 | 3 | 3 |
| | S-35 | - | 1 | 3 | 3 |
| | Cl-36 | - | 1 | 3 | 3 |
| | Co-60 | - | 1 | 3 | 3 |
| | Se-75 | - | 1 | 3 | 3 |
| | Stronium/Y-90 | - | 1 | 3 | 3 |
| | Zr-95/Nb-95 | - | 1 | 3 | 3 |
| | Tc-99 | - | 1 | 3 | 3 |
| | Tc-99m | - | 2 | 3 | 6 |
| | Ru-106 | - | 1 | 3 | 3 |
| | Sb-125 | - | 1 | 3 | 3 |
| | I-125/I-129 | - | 1 | 3 | 3 |
| | I-131 | Dose very high – need to model better. Chemical behaviour and speciation important. | 3 | 3 | 9 |
| | Cs-134/Cs-137 | - | 3 | 3 | 9 |
| | La-140 | - | 1 | 3 | 3 |
| | Ce-144 | - | 1 | 3 | 3 |
| | Eu-154 | - | 1 | 3 | 3 |
| | Rare earths | - | 1 | 3 | 3 |
| | Tl-201 | - | 1 | 3 | 3 |
| | Pb-210 | - | 1 | 3 | 3 |
| | Po-210 | - | 1 | 3 | 3 |
| | Ra-226 | - | 1 | 3 | 3 |
| | Thorium | - | 1 | 3 | 3 |
| | Uranium | - | 1 | 3 | 3 |
| | Np-237 | - | 1 | 3 | 3 |
| | Pu-alpha | - | 1 | 3 | 3 |
| | Pu-241 | - | 1 | 3 | 3 |
| | Americium | - | 1 | 3 | 3 |
| | Curium | - | 1 | 3 | 3 |
| External (deposited) dose | General | Location of person with respect to nuclides, river bed, river banks is uncertain.<br>Hunt model used. Well mixed assumption of sediment is reasonably valid. | | | |
| | Tritium | - | 1 | 2 | 2 |

## Table 3 Continued

| Modelling Step | Nuclide | Comments | Dose Score | Uncert-ainty Score | Total Score |
|---|---|---|---|---|---|
| External (deposited) dose (cont) | OBT | - | 1 | 2 | 2 |
| | C-14 | - | 1 | 2 | 2 |
| | Na-22/24 | - | 2 | 2 | 4 |
| | P-32/33 | - | 1 | 2 | 2 |
| | S-35 | - | 1 | 2 | 2 |
| | Cl-36 | - | 1 | 2 | 2 |
| | Co-60 | - | 1 | 2 | 2 |
| | Se-75 | - | 1 | 2 | 2 |
| | Stronium/Y-90 | - | 1 | 2 | 2 |
| | Zr-95/Nb-95 | - | 1 | 2 | 2 |
| | Tc-99 | - | 1 | 2 | 2 |
| | Tc-99m | - | 2 | 2 | 4 |
| | Ru-106 | - | 1 | 2 | 2 |
| | Sb-125 | - | 1 | 2 | 2 |
| | I-125/I-129 | - | 1 | 2 | 2 |
| | I-131 | - | 3 | 2 | 6 |
| | Cs-134/Cs-137 | - | 3 | 2 | 6 |
| | La-140 | - | 1 | 2 | 2 |
| | Ce-144 | - | 1 | 2 | 2 |
| | Eu-154 | - | 1 | 2 | 2 |
| | Rare earths | - | 1 | 2 | 2 |
| | Tl-201 | - | 1 | 2 | 2 |
| | Pb-210 | - | 1 | 2 | 2 |
| | Po-210 | - | 1 | 2 | 2 |
| | Ra-226 | - | 1 | 2 | 2 |
| | Thorium | - | 1 | 2 | 2 |
| | Uranium | - | 1 | 2 | 2 |
| | Np-237 | - | 1 | 2 | 2 |
| | Pu-alpha | - | 1 | 2 | 2 |
| | Pu-241 | - | 1 | 2 | 2 |
| | Americium | - | 1 | 2 | 2 |
| | Curium | - | 1 | 2 | 2 |
| Transfer to fish/shellfish | General | Variability in CF for freshwater. Often dominant pathway. CF should be for edible portion.<br><br>CF in fish farm may be different (possibly lower) due to food sourced elsewhere and throughput of water. | | | |
| | Tritium | - | 1 | 1 | 1 |
| | OBT | The transfer through to food appears to be dependent on the chemical form of the discharge (for example, linkage to DNA precursors) and also to the receiving environment (for example, a biologically active sewer) and generic modelling may therefore not be appropriate. | 3 | 2 | 6 |
| | C-14 | - | 2 | 1 | 2 |
| | Na-22/24 | - | 1 | 1 | 1 |
| | P-32/33 | Fetal dose is very high – CF is highly dependent on total phosphorus load in river – This is dependent upon use of fertilisers. | 3 | 2 | 6 |
| | S-35 | - | 1 | 1 | 1 |
| | Cl-36 | - | 1 | 2 | 2 |
| | Co-60 | - | 1 | 1 | 1 |
| | Se-75 | - | 1 | 2 | 2 |
| | Stronium/Y-90 | - | 3 | 1 | 3 |
| | Zr-95/Nb-95 | - | 1 | 1 | 1 |
| | Tc-99 | - | 1 | 1 | 1 |
| | Tc-99m | - | 1 | 1 | 1 |
| | Ru-106 | - | 1 | 1 | 1 |
| | Sb-125 | - | 1 | 1 | 1 |
| | I-125/I-129 | - | 3 | 2 | 6 |
| | I-131 | - | 3 | 2 | 6 |
| | Cs-134/Cs-137 | - | 1 | 1 | 1 |

**Table 3 Continued**

| Modelling Step | Nuclide | Comments | Dose Score | Uncert-ainty Score | Total Score |
|---|---|---|---|---|---|
| Transfer to fish/shellfish (cont) | La-140 | - | 1 | 1 | 1 |
| | Ce-144 | - | 1 | 1 | 1 |
| | Eu-154 | - | 1 | 2 | 2 |
| | Rare earths | - | 1 | 2 | 2 |
| | Tl-201 | - | 1 | 2 | 2 |
| | Pb-210 | - | 1 | 1 | 1 |
| | Po-210 | - | 1 | 1 | 1 |
| | Ra-226 | - | 1 | 1 | 1 |
| | Thorium | - | 3 | 1 | 3 |
| | Uranium | - | 1 | 1 | 1 |
| | Np-237 | - | 1 | 1 | 1 |
| | Pu-alpha | - | 1 | 1 | 1 |
| | Pu-241 | - | 1 | 1 | 1 |
| | Americium | - | 1 | 1 | 1 |
| | Curium | - | 1 | 1 | 1 |
| Fish /Shellfish dose | General | Freshwater fish consumption rate is not well validated. More data required. Required to use Basic Safety Standard dose coefficients. | | | |
| | Tritium | - | 1 | 2 | 2 |
| | OBT | - | 3 | 2 | 6 |
| | C-14 | - | 2 | 2 | 4 |
| | Na-22/24 | - | 1 | 2 | 2 |
| | P-32/33 | - | 3 | 2 | 6 |
| | S-35 | - | 1 | 2 | 2 |
| | Cl-36 | - | 1 | 2 | 2 |
| | Co-60 | - | 1 | 2 | 2 |
| | Se-75 | - | 1 | 2 | 2 |
| | Stronium/Y-90 | - | 3 | 2 | 6 |
| | Zr-95/Nb-95 | - | 1 | 2 | 2 |
| | Tc-99 | - | 1 | 2 | 2 |
| | Tc-99m | - | 1 | 2 | 2 |
| | Ru-106 | - | 1 | 2 | 2 |
| | Sb-125 | - | 1 | 2 | 2 |
| | I-125/I-129 | - | 3 | 2 | 6 |
| | I-131 | - | 3 | 2 | 6 |
| | Cs-134/Cs-137 | - | 1 | 2 | 2 |
| | La-140 | - | 1 | 2 | 2 |
| | Ce-144 | - | 1 | 2 | 2 |
| | Eu-154 | - | 1 | 2 | 2 |
| | Rare earths | - | 1 | 2 | 2 |
| | Tl-201 | - | 1 | 2 | 2 |
| | Pb-210 | - | 1 | 2 | 2 |
| | Po-210 | - | 1 | 2 | 2 |
| | Ra-226 | - | 1 | 2 | 2 |
| | Thorium | - | 3 | 2 | 6 |
| | Uranium | - | 1 | 2 | 2 |
| | Np-237 | - | 1 | 2 | 2 |
| | Pu-alpha | - | 1 | 2 | 2 |
| | Pu-241 | - | 1 | 2 | 2 |
| | Americium | - | 1 | 2 | 2 |
| | Curium | - | 1 | 2 | 2 |
| Irrigated food and animals drinking water | General | Assumptions of location of abstraction/drinking need to be realistic. Uncertainty/variability with: how much water used for irrigation; continuous or periodic; mist, hard spray or channel irrigation.<br><br>Transfer to crops use same model as atmospheric deposition. Consumption of food habit data is same source as for atmospheric deposition. Required to use Basic Safety Standard dose coefficients. | | | |
| | Tritium | - | 1 | 2 | 2 |
| | OBT | - | 1 | 2 | 2 |
| | C-14 | - | 1 | 2 | 2 |
| | Na-22/24 | - | 1 | 2 | 2 |
| | P-32/33 | - | 1 | 2 | 2 |

## Table 3 Continued

| Modelling Step | Nuclide | Comments | Dose Score | Uncert-ainty Score | Total Score |
|---|---|---|---|---|---|
| Irrigated food and animals drinking water (cont) | S-35 | - | 1 | 2 | 2 |
| | Cl-36 | - | 1 | 2 | 2 |
| | Co-60 | - | 1 | 2 | 2 |
| | Se-75 | - | 1 | 2 | 2 |
| | Stronium/Y-90 | - | 1 | 2 | 2 |
| | Zr-95/Nb-95 | - | 1 | 2 | 2 |
| | Tc-99 | - | 1 | 2 | 2 |
| | Tc-99m | - | 1 | 2 | 2 |
| | Ru-106 | - | 1 | 2 | 2 |
| | Sb-125 | - | 1 | 2 | 2 |
| | I-125/I-129 | - | 1 | 2 | 2 |
| | I-131 | - | 1 | 2 | 2 |
| | Cs-134/Cs-137 | - | 1 | 2 | 2 |
| | La-140 | - | 1 | 2 | 2 |
| | Ce-144 | - | 1 | 2 | 2 |
| | Eu-154 | - | 1 | 2 | 2 |
| | Rare earths | - | 1 | 2 | 2 |
| | Tl-201 | - | 1 | 2 | 2 |
| | Pb-210 | - | 1 | 2 | 2 |
| | Po-210 | - | 1 | 2 | 2 |
| | Ra-226 | - | 1 | 2 | 2 |
| | Thorium | - | 1 | 2 | 2 |
| | Uranium | - | 1 | 2 | 2 |
| | Np-237 | - | 1 | 2 | 2 |
| | Pu-alpha | - | 1 | 2 | 2 |
| | Pu-241 | - | 1 | 2 | 2 |
| | Americium | - | 1 | 2 | 2 |
| | Curium | - | 1 | 2 | 2 |

## Table 4 Releases to Freshwaters – Short Term

| Modelling Step | Nuclide | Comments | Dose Score | Uncert-ainty Score | Total Score |
|---|---|---|---|---|---|
| Dispersion | General | PC Cream model is not appropriate for short-term release modelling. Need site-specific model for precise short-term release modelling and requires considerable parameterisation and validation to ensure uncertainty is acceptable. Routine short-term releases are not likely to occur due to limited pumping rates/tank emptying rates and delay/dispersion through sewage treatment works. | 1 | 3 | 3 |
| Drinking water dose | General | Continuous drinking rate assumed after release. Would not be realistic to assume storage by individuals. | 1 | 1 | 1 |
| Transfer to sediments | General | Site-specific data requirements required for precise dynamic modelling of transfer to sediments. Not appropriate to use PC Cream for short-term release. | 1 | 3 | 3 |
| External (deposited) dose | General | Assumption of location of individuals in relation to deposited sediment and how long and timing after short term release. | 1 | 3 | 3 |
| Transfer to fish/shellfish | General | Some dynamic model information available in Agency R&D report [Ref 12]. If continuous consumption assumption applied then equilibrium model can be used. | 1 | 2 | 2 |
| Fish /shellfish dose | General | Assumption of when fish consumed after release and how much. CF approach not appropriate for short-term releases. | 1 | 3 | 3 |
| Irrigated food and animals drinking water | General | Same issues as for continuous, but also timing after short term release. | 1 | 2 | 2 |

## Table 5 Releases to Estuary / Coastal Waters - Continuous

| Modelling Step | Nuclide | Comments | Dose Score | Uncert-ainty Score | Total Score |
|---|---|---|---|---|---|
| Dispersion | General | Compartment models (eg, DORIS, MARINA II, WAT, IDLE) used for annual doses reasonably adequate.<br><br>CSERAM – detailed model of Irish Sea. Comparison between MARINA II and CSERAM reasonably good. Far-field NAC models for Sellafield assessment not totally adequate. Comparison with box models may be useful.<br><br>NRPB project for Defra to validate models [Ref 13].<br><br>There is a need for better evaluation of existing oceanographic and sediment data for use at various sites. | | | |
| | Tritium | - | 1 | 1 | 1 |
| | OBT | OBT dispersion into Cardiff Bay is not adequately forecast (nature of discharge at Cardiff changing). | 2 | 1 | 2 |
| | C-14 | - | 2 | 1 | 2 |
| | Na-22/24 | - | 1 | 1 | 1 |
| | P-32/33 | - | 1 | 1 | 1 |
| | S-35 | - | 1 | 1 | 1 |
| | Cl-36 | - | 2 | 1 | 2 |
| | Co-60 | - | 2 | 1 | 2 |
| | Se-75 | - | 1 | 1 | 1 |
| | Sr-90/Y-90 | - | 1 | 1 | 1 |
| | Zr-95/Nb-95 | - | 1 | 1 | 1 |
| | Tc-99 | - | 1 | 1 | 1 |
| | Tc-99m | - | 1 | 1 | 1 |
| | Ru-106 | - | 2 | 1 | 2 |
| | Sb-125 | - | 2 | 1 | 2 |
| | I-125/I-129 | - | 2 | 1 | 2 |
| | I-131 | - | 2 | 1 | 2 |
| | Cs-134/Cs-137 | - | 3 | 1 | 3 |
| | La-140 | - | 1 | 1 | 1 |
| | Ce-144 | - | 1 | 1 | 1 |
| | Eu-154 | - | 2 | 1 | 2 |
| | Rare earths | - | 1 | 1 | 1 |
| | Tl-201 | - | 1 | 1 | 1 |
| | Pb-210 | Confounding effect of naturals makes validation difficult. | 3 | 1 | 3 |
| | Po-210 | Confounding effect of naturals makes validation difficult. Possible site-specific study of Po-210 concentrations in shellfish required for Irish Sea (previous modelling has required use of high Kd and CF to match observations). May include establishment of background. | 3 | 1 | 3 |
| | Ra-226 | - | 3 | 1 | 3 |
| | Thorium | - | 3 | 1 | 3 |
| | Uranium | - | 2 | 1 | 2 |
| | Np-237 | - | 2 | 1 | 2 |
| | Pu-alpha | - | 3 | 1 | 3 |
| | Pu-241 | - | 2 | 1 | 2 |
| | Americium | Models generally weakest for Am-241. | 2 | 2 | 4 |
| | Curium | - | 2 | 1 | 2 |
| Transfer to sediments | General | Similar process to freshwater, using Kd, but better validation.<br><br>Validation for MARINA II [Ref 14] and Defra [Ref 13] shows that it is modelled adequately now, in particular for the Irish Sea, but this may not be the case as remobilisation becomes more important as discharges reduce. | | | |
| | Tritium | - | 1 | 1 | 1 |
| | OBT | - | 1 | 1 | 1 |
| | C-14 | - | 1 | 1 | 1 |
| | Na-22/24 | - | 1 | 1 | 1 |
| | P-32/33 | - | 1 | 1 | 1 |
| | S-35 | - | 1 | 1 | 1 |

## Table 5 Continued

| Modelling Step | Nuclide | Comments | Dose Score | Uncert-ainty Score | Total Score |
|---|---|---|---|---|---|
| Transfer to sediments (cont) | Cl-36 | - | 1 | 1 | 1 |
| | Co-60 | - | 2 | 1 | 2 |
| | Se-75 | - | 1 | 1 | 1 |
| | Sr-90/Y-90 | - | 1 | 1 | 1 |
| | Zr-95/Nb-95 | - | 1 | 1 | 1 |
| | Tc-99 | - | 1 | 1 | 1 |
| | Tc-99m | - | 1 | 1 | 1 |
| | Ru-106 | - | 2 | 1 | 2 |
| | Sb-125 | - | 2 | 1 | 2 |
| | I-125/I-129 | - | 2 | 1 | 2 |
| | I-131 | - | 2 | 1 | 2 |
| | Cs-134/Cs-137 | - | 3 | 1 | 3 |
| | La-140 | - | 1 | 1 | 1 |
| | Ce-144 | - | 1 | 1 | 1 |
| | Eu-154 | - | 2 | 1 | 2 |
| | Rare earths | - | 1 | 1 | 1 |
| | Tl-201 | - | 1 | 1 | 1 |
| | Pb-210 | - | 1 | 1 | 1 |
| | Po-210 | - | 1 | 1 | 1 |
| | Ra-226 | - | 1 | 1 | 1 |
| | Thorium | - | 3 | 1 | 3 |
| | Uranium | - | 1 | 1 | 1 |
| | Np-237 | - | 1 | 1 | 1 |
| | Pu-alpha | - | 1 | 1 | 1 |
| | Pu-241 | - | 1 | 1 | 1 |
| | Americium | - | 2 | 3 | 6 |
| | Curium | - | 1 | 1 | 1 |
| External (deposited) dose | General | Hunt model used. Well mixed assumption reasonably valid. Assumption that marine/coastal bed sediment same as beach, marsh, etc where people are located.<br><br>Houseboat dwellers etc – empirical models often used.<br><br>Background assumptions for external dose need reviewing.<br><br>Some pathways not adequately modelled (swimming, diving). These should be investigated. Better habit data for diving, windsurfing, kite surfing. Cutting sea-washed turf also needs to be considered, although recently assessed for NW England [Ref 15]. | | | |
| | Tritium | - | 1 | 1 | 1 |
| | OBT | - | 1 | 1 | 1 |
| | C-14 | - | 1 | 1 | 1 |
| | Na-22/24 | - | 1 | 1 | 1 |
| | P-32/33 | - | 1 | 1 | 1 |
| | S-35 | - | 1 | 1 | 1 |
| | Cl-36 | - | 1 | 1 | 1 |
| | Co-60 | - | 2 | 2 | 4 |
| | Se-75 | - | 1 | 1 | 1 |
| | Sr-90/Y-90 | - | 1 | 1 | 1 |
| | Zr-95/Nb-95 | - | 1 | 1 | 1 |
| | Tc-99 | - | 1 | 1 | 1 |
| | Tc-99m | - | 1 | 1 | 1 |
| | Ru-106 | - | 2 | 1 | 2 |
| | Sb-125 | - | 2 | 1 | 2 |
| | I-125/I-129 | - | 2 | 1 | 2 |
| | I-131 | - | 2 | 1 | 2 |
| | Cs-134/Cs-137 | Important for houseboat dwellers | 2 | 2 | 4 |
| | La-140 | - | 1 | 1 | 1 |
| | Ce-144 | - | 1 | 1 | 1 |
| | Eu-154 | - | 2 | 1 | 2 |

## Table 5 Continued

| Modelling Step | Nuclide | Comments | Dose Score | Uncert-ainty Score | Total Score |
|---|---|---|---|---|---|
| External (deposited) dose (cont) | Rare earths | - | 1 | 1 | 1 |
| | Tl-201 | - | 1 | 1 | 1 |
| | Pb-210 | - | 1 | 1 | 1 |
| | Po-210 | - | 1 | 1 | 1 |
| | Ra-226 | - | 1 | 1 | 1 |
| | Thorium | Important for houseboat dwellers | 3 | 1 | 3 |
| | Uranium | - | 1 | 1 | 1 |
| | Np-237 | - | 1 | 1 | 1 |
| | Pu-alpha | - | 1 | 1 | 1 |
| | Pu-241 | - | 1 | 1 | 1 |
| | Americium | - | 2 | 1 | 2 |
| | Curium | - | 1 | 1 | 1 |
| Transfer to fish/shellfish | General | Often dominant pathway. Large variability in CF, but default values selected for UK in PC Cream are adequate. CF should be for edible portion. | | | |
| | Tritium | - | 1 | 2 | 2 |
| | OBT | The transfer through to food appears to be dependent on the chemical form of the discharge (for example, linkage to DNA precursors) and also to the receiving environment and generic modelling may therefore not be appropriate. | 2 | 2 | 4 |
| | C-14 | - | 2 | 1 | 2 |
| | Na-22/24 | - | 1 | 2 | 2 |
| | P-32/33 | Stable phosphorus concentration in seawater means there is little uncertainty over the CF compared with freshwater. | 1 | 1 | 1 |
| | S-35 | - | 1 | 1 | 1 |
| | Cl-36 | - | 1 | 2 | 2 |
| | Co-60 | - | 2 | 1 | 2 |
| | Se-75 | - | 1 | 2 | 2 |
| | Sr-90/Y-90 | - | 1 | 1 | 1 |
| | Zr-95/Nb-95 | - | 1 | 1 | 1 |
| | Tc-99 | - | 2 | 1 | 2 |
| | Tc-99m | - | 1 | 1 | 1 |
| | Ru-106 | - | 2 | 1 | 2 |
| | Sb-125 | - | 2 | 1 | 2 |
| | I-125/I-129 | - | 2 | 1 | 2 |
| | I-131 | - | 2 | 1 | 2 |
| | Cs-134/Cs-137 | - | 3 | 1 | 3 |
| | La-140 | - | 1 | 1 | 1 |
| | Ce-144 | - | 1 | 1 | 1 |
| | Eu-154 | - | 2 | 2 | 4 |
| | Rare earths | - | 1 | 2 | 2 |
| | Tl-201 | - | 1 | 2 | 2 |
| | Pb-210 | Dose score of 3 because of retrospective dose around Whitehaven | 3 | 2 | 6 |
| | Po-210 | Dose score of 3 because of retrospective dose around Whitehaven | 3 | 2 | 6 |
| | Ra-226 | - | 3 | 1 | 3 |
| | Thorium | - | 3 | 1 | 3 |
| | Uranium | - | 2 | 1 | 2 |
| | Np-237 | - | 2 | 1 | 2 |
| | Pu-alpha | - | 3 | 1 | 3 |
| | Pu-241 | - | 2 | 1 | 2 |
| | Americium | - | 2 | 1 | 2 |
| | Curium | - | 2 | 1 | 2 |
| Fish /shellfish dose | General | Large number of habit surveys and hence habit data for UK nuclear sites. Required to use Basic Safety Standard dose coefficients. | | | |
| | Tritium | - | 1 | 1 | 1 |
| | OBT | - | 2 | 1 | 2 |

## Table 5 Continued

| Modelling Step | Nuclide | Comments | Dose Score | Uncert-ainty Score | Total Score |
|---|---|---|---|---|---|
| Fish /shellfish dose (cont) | C-14 | - | 2 | 1 | 2 |
| | Na-22/24 | - | 1 | 1 | 1 |
| | P-32/33 | - | 1 | 1 | 1 |
| | S-35 | - | 1 | 1 | 1 |
| | Cl-36 | - | 2 | 1 | 2 |
| | Co-60 | - | 2 | 1 | 2 |
| | Se-75 | - | 1 | 1 | 1 |
| | Sr-90/Y-90 | - | 1 | 1 | 1 |
| | Zr-95/Nb-95 | - | 1 | 1 | 1 |
| | Tc-99 | - | 1 | 1 | 1 |
| | Tc-99m | - | 1 | 1 | 1 |
| | Ru-106 | - | 2 | 1 | 2 |
| | Sb-125 | - | 2 | 1 | 2 |
| | I-125/I-129 | - | 2 | 1 | 2 |
| | I-131 | - | 2 | 1 | 2 |
| | Cs-134/Cs-137 | - | 3 | 1 | 3 |
| | La-140 | - | 1 | 1 | 1 |
| | Ce-144 | - | 1 | 1 | 1 |
| | Eu-154 | - | 2 | 1 | 2 |
| | Rare earths | - | 1 | 1 | 1 |
| | Tl-201 | - | 1 | 1 | 1 |
| | Pb-210 | - | 3 | 1 | 3 |
| | Po-210 | - | 3 | 1 | 3 |
| | Ra-226 | - | 3 | 1 | 3 |
| | Thorium | - | 3 | 1 | 3 |
| | Uranium | - | 2 | 1 | 2 |
| | Np-237 | - | 2 | 1 | 2 |
| | Pu-alpha | - | 3 | 1 | 3 |
| | Pu-241 | - | 2 | 1 | 2 |
| | Americium | - | 2 | 1 | 2 |
| | Curium | - | 2 | 1 | 2 |
| Transfer to seaweed and into crops (compost) | General | Lot of seaweed environmental monitoring data, but limited data on transfer to crops from use of seaweed as compost/fertiliser. | | | |
| | Tritium | - | 1 | 2 | 2 |
| | OBT | - | 1 | 2 | 2 |
| | C-14 | - | 1 | 2 | 2 |
| | Na-22/24 | - | 1 | 2 | 2 |
| | P-32/33 | - | 1 | 2 | 2 |
| | S-35 | - | 1 | 2 | 2 |
| | Cl-36 | - | 1 | 2 | 2 |
| | Co-60 | - | 1 | 2 | 2 |
| | Se-75 | - | 1 | 2 | 2 |
| | Sr-90/Y-90 | - | 1 | 2 | 2 |
| | Zr-95/Nb-95 | - | 1 | 2 | 2 |
| | Tc-99 | Key nuclide in seaweed around coasts of NW England, N Wales and SW Scotland. | 2 | 2 | 4 |
| | Tc-99m | - | 1 | 2 | 2 |
| | Ru-106 | - | 1 | 2 | 2 |
| | Sb-125 | - | 1 | 2 | 2 |
| | I-125/I-129 | - | 1 | 2 | 2 |
| | I-131 | - | 1 | 2 | 2 |
| | Cs-134/Cs-137 | - | 1 | 2 | 2 |
| | La-140 | - | 1 | 2 | 2 |
| | Ce-144 | - | 1 | 2 | 2 |
| | Eu-154 | - | 1 | 2 | 2 |
| | Rare earths | - | 1 | 2 | 2 |
| | Tl-201 | - | 1 | 2 | 2 |
| | Pb-210 | - | 1 | 2 | 2 |
| | Po-210 | - | 1 | 2 | 2 |
| | Ra-226 | - | 1 | 2 | 2 |

## Table 5 Continued

| Modelling Step | Nuclide | Comments | Dose Score | Uncert-ainty Score | Total Score |
|---|---|---|---|---|---|
| Transfer to seaweed and into crops (compost) (cont) | Thorium | - | 1 | 2 | 2 |
| | Uranium | - | 1 | 2 | 2 |
| | Np-237 | - | 1 | 2 | 2 |
| | Pu-alpha | - | 1 | 2 | 2 |
| | Pu-241 | - | 1 | 2 | 2 |
| | Americium | - | 1 | 2 | 2 |
| | Curium | - | 1 | 2 | 2 |
| Transfer to animals grazing on seawashed pasture | General | Sea-land transfer not well known/modelled (eg, sheep eating seaweed). Root uptake usually less. | | | |
| | Tritium | - | 1 | 2 | 2 |
| | OBT | - | 1 | 2 | 2 |
| | C-14 | - | 1 | 2 | 2 |
| | Na-22/24 | - | 1 | 2 | 2 |
| | P-32/33 | - | 1 | 2 | 2 |
| | S-35 | - | 1 | 2 | 2 |
| | Cl-36 | - | 1 | 2 | 2 |
| | Co-60 | - | 1 | 2 | 2 |
| | Se-75 | - | 1 | 2 | 2 |
| | Sr-90/Y-90 | - | 1 | 2 | 2 |
| | Zr-95/Nb-95 | - | 1 | 2 | 2 |
| | Tc-99 | - | 1 | 2 | 2 |
| | Tc-99m | - | 1 | 2 | 2 |
| | Ru-106 | - | 1 | 2 | 2 |
| | Sb-125 | - | 1 | 2 | 2 |
| | I-125/I-129 | - | 1 | 2 | 2 |
| | I-131 | - | 1 | 2 | 2 |
| | Cs-134/Cs-137 | - | 1 | 2 | 2 |
| | La-140 | - | 1 | 2 | 2 |
| | Ce-144 | - | 1 | 2 | 2 |
| | Eu-154 | - | 1 | 2 | 2 |
| | Rare earths | - | 1 | 2 | 2 |
| | Tl-201 | - | 1 | 2 | 2 |
| | Pb-210 | - | 1 | 2 | 2 |
| | Po-210 | - | 1 | 2 | 2 |
| | Ra-226 | - | 1 | 2 | 2 |
| | Thorium | - | 1 | 2 | 2 |
| | Uranium | - | 1 | 2 | 2 |
| | Np-237 | - | 1 | 2 | 2 |
| | Pu-alpha | - | 1 | 2 | 2 |
| | Pu-241 | - | 1 | 2 | 2 |
| | Americium | - | 1 | 2 | 2 |
| | Curium | - | 1 | 2 | 2 |
| Food dose from seaweed/food grown with seaweed compost | General | Some site-specific habit data available. FSA have R&D planned to examine habits. | | | |
| | Tritium | - | 1 | 2 | 2 |
| | OBT | - | 1 | 2 | 2 |
| | C-14 | - | 1 | 2 | 2 |
| | Na-22/24 | - | 1 | 2 | 2 |
| | P-32/33 | - | 1 | 2 | 2 |
| | S-35 | - | 1 | 2 | 2 |
| | Cl-36 | - | 1 | 2 | 2 |
| | Co-60 | - | 1 | 2 | 2 |
| | Se-75 | - | 1 | 2 | 2 |
| | Sr-90/Y-90 | - | 1 | 2 | 2 |
| | Zr-95/Nb-95 | - | 1 | 2 | 2 |
| | Tc-99 | Doses from RIFE [Ref 8] are just above 20 μSv/y and indicate a score of 2. | 2 | 2 | 4 |
| | Tc-99m | - | 1 | 2 | 2 |
| | Ru-106 | - | 1 | 2 | 2 |
| | Sb-125 | - | 1 | 2 | 2 |
| | I-125/I-129 | - | 1 | 2 | 2 |

**Table 5 Continued**

| Modelling Step | Nuclide | Comments | Dose Score | Uncert-ainty Score | Total Score |
|---|---|---|---|---|---|
| Food dose from seaweed/food grown with seaweed compost (cont) | I-131 | - | 1 | 2 | 2 |
| | Cs-134/Cs-137 | - | 1 | 2 | 2 |
| | La-140 | - | 1 | 2 | 2 |
| | Ce-144 | - | 1 | 2 | 2 |
| | Eu-154 | - | 1 | 2 | 2 |
| | Rare earths | - | 1 | 2 | 2 |
| | Tl-201 | - | 1 | 2 | 2 |
| | Pb-210 | - | 1 | 2 | 2 |
| | Po-210 | - | 1 | 2 | 2 |
| | Ra-226 | - | 1 | 2 | 2 |
| | Thorium | - | 1 | 2 | 2 |
| | Uranium | - | 1 | 2 | 2 |
| | Np-237 | - | 1 | 2 | 2 |
| | Pu-alpha | - | 1 | 2 | 2 |
| | Pu-241 | - | 1 | 2 | 2 |
| | Americium | - | 1 | 2 | 2 |
| | Curium | - | 1 | 2 | 2 |
| Food dose from consumption of animal products which have grazed on seawashed pasture | General | Limited habit data on consumption. Doses from RIFE [Ref 8] are <20μSv/y and indicate a dose score of 1. | | | |
| | Tritium | - | 1 | 2 | 2 |
| | OBT | - | 1 | 2 | 2 |
| | C-14 | - | 1 | 2 | 2 |
| | Na-22/24 | - | 1 | 2 | 2 |
| | P-32/33 | - | 1 | 2 | 2 |
| | S-35 | - | 1 | 2 | 2 |
| | Cl-36 | - | 1 | 2 | 2 |
| | Co-60 | - | 1 | 2 | 2 |
| | Se-75 | - | 1 | 2 | 2 |
| | Sr-90/Y-90 | - | 1 | 2 | 2 |
| | Zr-95/Nb-95 | - | 1 | 2 | 2 |
| | Tc-99 | - | 1 | 2 | 2 |
| | Tc-99m | - | 1 | 2 | 2 |
| | Ru-106 | - | 1 | 2 | 2 |
| | Sb-125 | - | 1 | 2 | 2 |
| | I-125/I-129 | - | 1 | 2 | 2 |
| | I-131 | - | 1 | 2 | 2 |
| | Cs-134/Cs-137 | - | 1 | 2 | 2 |
| | La-140 | - | 1 | 2 | 2 |
| | Ce-144 | - | 1 | 2 | 2 |
| | Eu-154 | - | 1 | 2 | 2 |
| | Rare earths | - | 1 | 2 | 2 |
| | Tl-201 | - | 1 | 2 | 2 |
| | Pb-210 | - | 1 | 2 | 2 |
| | Po-210 | - | 1 | 2 | 2 |
| | Ra-226 | - | 1 | 2 | 2 |
| | Thorium | - | 1 | 2 | 2 |
| | Uranium | - | 1 | 2 | 2 |
| | Np-237 | - | 1 | 2 | 2 |
| | Pu-alpha | - | 1 | 2 | 2 |
| | Pu-241 | - | 1 | 2 | 2 |
| | Americium | - | 1 | 2 | 2 |
| | Curium | - | 1 | 2 | 2 |

## Table 6 Releases to Estuary / Coastal Waters – Short Term

| Modelling Step | Nuclide | Comments | Dose Score | Uncert-ainty Score | Total Score |
|---|---|---|---|---|---|
| Dispersion | General | Little scope in reality for routine short-term releases due to pumping capacity from tanks. Large data requirements for site-specific dynamic models. The dynamic model, CSERAM, is available for Irish Sea. | 1 | 3 | 3 |
| Transfer to sediments | General | Limited data on time dependent transfer to sediments. | 1 | 3 | 3 |
| External (deposited) dose | General | Timing and duration of occupancy on beaches etc after a release. | 1 | 2 | 2 |
| Transfer to fish/shellfish | General | Limited data on time-dependent transfer to fish. CF approach not really appropriate for short-term releases. | 1 | 2 | 2 |
| Fish /Shellfish dose | General | Timing and quantity of fish consumed after release. | 1 | 3 | 3 |
| Seaweed transfer | General | Limited data on time-dependent transfer to seaweed and then into foodstuffs. | 1 | 3 | 3 |
| Seaweed dose | General | Timing and quantity of foodstuffs consumed after release. Must be some delay in compost production. | 1 | 2 | 2 |
| Animals on seawashed pasture transfer | General | Limited data on time-dependent transfer to animals. | 1 | 3 | 3 |
| Animals on seawashed pasture dose | General | Timing and quantity of animal products consumed after release. | 1 | 3 | 3 |

## Table 7 Releases to Sewer – Continuous

| Modelling Step | Nuclide | Comments | Dose Score | Uncert-ainty Score | Total Score |
|---|---|---|---|---|---|
| Dispersion / behaviour in sewer | General | Simple dilution models used (eg, Ref 16). Assume quick transport of solids and liquids. Delay between discharge and arrival at STW for short half-life radionuclides will lead to reduction by decay. Could be direct binding to pipes and structures. Adsorption of radionuclides to solids. No significant changes in speciation. Studies have been published [Refs 17, 18]. Doses due to accessing sewage pipes leading to the STW can be addressed directly or can be included implicitly in STW doses by assuming rapid transfer and limited dilution. | | | |
| | Tritium | - | 1 | 1 | 1 |
| | OBT | - | 1 | 1 | 1 |
| | C-14 | - | 1 | 1 | 1 |
| | F-18 | - | 3 | 1 | 3 |
| | Na-22/24 | - | 3 | 1 | 3 |
| | P-32/33 | - | 1 | 1 | 1 |
| | S-35 | - | 1 | 1 | 1 |
| | Cl-36 | - | 1 | 1 | 1 |
| | Ca-45 | | 1 | 1 | 1 |
| | Co-57/58/60 | - | 3 | 1 | 3 |
| | Ga-67 | - | 3 | 1 | 3 |
| | Se-75 | - | 3 | 1 | 3 |
| | Stronium/Y-90 | - | 1 | 1 | 1 |
| | Zr-95/Nb-95 | - | 1 | 1 | 1 |
| | Tc-99 | - | 1 | 1 | 1 |
| | Tc-99m | - | 3 | 1 | 3 |
| | Ru-106 | - | 1 | 1 | 1 |
| | In-111/113m | - | 3 | 1 | 3 |
| | Sb-125 | - | 1 | 1 | 1 |
| | I-125/I-129 | - | 1 | 1 | 1 |
| | I-131 | - | 3 | 1 | 3 |
| | Cs-134/Cs-137 | - | 3 | 1 | 3 |
| | La-140 | - | 1 | 1 | 1 |
| | Ce-144 | - | 1 | 1 | 1 |
| | Eu-154 | - | 1 | 1 | 1 |
| | Rare earths | - | 1 | 1 | 1 |
| | Tl-201 | - | 3 | 1 | 3 |
| | Pb-210 | - | 1 | 1 | 1 |
| | Po-210 | - | 1 | 1 | 1 |
| | Ra-226 | - | 1 | 1 | 1 |
| | Thorium | - | 1 | 1 | 1 |
| | Uranium | - | 1 | 1 | 1 |
| | Np-237 | - | 1 | 1 | 1 |
| | Pu-alpha | - | 1 | 1 | 1 |
| | Pu-241 | - | 1 | 1 | 1 |
| | Americium | - | 1 | 1 | 1 |
| | Curium | - | 1 | 1 | 1 |
| Dispersion / behaviour at STW (liquid, gas, sludge) | General | Simple dilution models used (eg, Ref 16). Element partitioning data used. Partitioning review by HPA for FSA [Ref 19] and R&D by Environment Agency to define more partitioning data (Science project P3-109). Residence times of liquids and solids and water content of solids taken into account. Re-circulation of solids around STW may be important, particularly because of different chemical conditions (oxidising/reducing) in various stages of the treatment process. Degassing will cause release of radionuclides in volatile compounds.<br><br>Variation of treatment processes between STWs increases uncertainty in assessments using generic models. Sewage sludge can be bulked from several works, leading to complicated modelling processes. | | | |
| | Tritium | Degassing | 3 | 2 | 6 |
| | OBT | - | 3 | 2 | 6 |
| | C-14 | Degassing | 3 | 2 | 6 |
| | F-18 | - | 3 | 2 | 6 |
| | Na-22/24 | - | 3 | 3 | 9 |
| | P-32/33 | - | 3 | 2 | 6 |

**Table 7 Continued**

| Modelling Step | Nuclide | Comments | Dose Score | Uncert-ainty Score | Total Score |
|---|---|---|---|---|---|
| Dispersion / behaviour at STW (liquid, gas, sludge) (cont) | S-35 | Degassing | 3 | 2 | 6 |
| | Cl-36 | Degassing | 2 | 2 | 4 |
| | Ca-45 | - | 2 | 2 | 4 |
| | Co-57/58/60 | - | 3 | 2 | 6 |
| | Ga-67 | - | 3 | 3 | 9 |
| | Se-75 | Degassing | 3 | 2 | 6 |
| | Stronium/Y-90 | - | 3 | 2 | 6 |
| | Zr-95/Nb-95 | - | 1 | 2 | 2 |
| | Tc-99 | - | 1 | 2 | 2 |
| | Tc-99m | - | 3 | 2 | 6 |
| | Ru-106 | - | 1 | 2 | 2 |
| | In-111/113m | - | 3 | 2 | 6 |
| | Sb-125 | - | 1 | 2 | 2 |
| | I-125/I-129 | Degassing | 3 | 2 | 6 |
| | I-131 | Degassing | 3 | 2 | 6 |
| | Cs-134/Cs-137 | - | 3 | 2 | 6 |
| | La-140 | - | 1 | 2 | 2 |
| | Ce-144 | - | 1 | 2 | 2 |
| | Eu-154 | - | 1 | 2 | 2 |
| | Rare earths | - | 1 | 2 | 2 |
| | Tl-201 | - | 3 | 2 | 6 |
| | Pb-210 | - | 1 | 2 | 2 |
| | Po-210 | - | 1 | 2 | 2 |
| | Ra-226 | - | 1 | 2 | 2 |
| | Thorium | - | 1 | 2 | 2 |
| | Uranium | - | 2 | 2 | 4 |
| | Np-237 | - | 1 | 2 | 2 |
| | Pu-alpha | - | 1 | 2 | 2 |
| | Pu-241 | - | 1 | 2 | 2 |
| | Americium | - | 1 | 2 | 2 |
| | Curium | - | 1 | 2 | 2 |
| External dose in sewer, STW and sludge transport | General | External dose factors – geometries (including semi-infinite plane, line source, semi-infinite slab), self absorption and shielding (from PPE, tank structures etc) need to be taken into account. For realistic beta dose calculations it is necessary to take account of shielding. Occupancy and proximity are important. | | | |
| | Tritium | - | 1 | 2 | 2 |
| | OBT | - | 1 | 1 | 1 |
| | C-14 | - | 1 | 1 | 1 |
| | F-18 | - | 3 | 2 | 6 |
| | Na-22/24 | - | 3 | 2 | 6 |
| | P-32/33 | - | 1 | 1 | 1 |
| | S-35 | - | 1 | 1 | 1 |
| | Cl-36 | - | 1 | 1 | 1 |
| | Ca-45 | - | 1 | 2 | 2 |
| | Co-57/58/60 | - | 3 | 2 | 6 |
| | Ga-67 | - | 3 | 2 | 6 |
| | Se-75 | - | 3 | 2 | 6 |
| | Stronium/Y-90 | - | 1 | 1 | 1 |
| | Zr-95/Nb-95 | - | 1 | 2 | 2 |
| | Tc-99 | - | 1 | 1 | 1 |
| | Tc-99m | - | 3 | 2 | 6 |
| | Ru-106 | - | 1 | 2 | 2 |
| | In-111/113m | - | 3 | 2 | 6 |
| | Sb-125 | - | 1 | 2 | 2 |
| | I-125/I-129 | - | 1 | 2 | 2 |
| | I-131 | - | 3 | 2 | 6 |
| | Cs-134/Cs-137 | - | 3 | 2 | 6 |
| | La-140 | - | 1 | 2 | 2 |
| | Ce-144 | - | 1 | 2 | 2 |
| | Eu-154 | - | 1 | 2 | 2 |
| | Rare earths | - | 1 | 2 | 2 |
| | Tl-201 | - | 3 | 2 | 6 |

## Table 7 Continued

| Modelling Step | Nuclide | Comments | Dose Score | Uncert-ainty Score | Total Score |
|---|---|---|---|---|---|
| External dose in sewer, STW and sludge transport (cont) | Pb-210 | - | 1 | 1 | 1 |
| | Po-210 | - | 1 | 1 | 1 |
| | Ra-226 | - | 1 | 1 | 1 |
| | Thorium | - | 1 | 1 | 1 |
| | Uranium | - | 1 | 1 | 1 |
| | Np-237 | - | 1 | 1 | 1 |
| | Pu-alpha | - | 1 | 1 | 1 |
| | Pu-241 | - | 1 | 1 | 1 |
| | Americium | - | 1 | 1 | 1 |
| | Curium | - | 1 | 1 | 1 |
| Internal dose at STW (inhalation and inadvertent ingestion) | General | Simple dust in air approach used for sludge and sewage. Inhalation of gaseous radionuclides released from STW. Generalised habit data used for inadvertent ingestion rates. Mechanical resuspension from sludge agitation. Drying of sludge.<br>Occupancy is a factor. | | | |
| | Tritium | - | 1 | 2 | 2 |
| | OBT | - | 1 | 2 | 2 |
| | C-14 | - | 1 | 2 | 2 |
| | F-18 | - | 1 | 2 | 2 |
| | Na-22/24 | - | 1 | 2 | 2 |
| | P-32/33 | - | 1 | 2 | 2 |
| | S-35 | - | 1 | 2 | 2 |
| | Cl-36 | - | 1 | 2 | 2 |
| | Ca-45 | | 1 | 2 | 2 |
| | Co-57/58/60 | - | 1 | 2 | 2 |
| | Ga-67 | - | 1 | 2 | 2 |
| | Se-75 | - | 1 | 2 | 2 |
| | Stronium/Y-90 | - | 1 | 2 | 2 |
| | Zr-95/Nb-95 | - | 1 | 2 | 2 |
| | Tc-99 | - | 1 | 2 | 2 |
| | Tc-99m | - | 1 | 2 | 2 |
| | Ru-106 | - | 1 | 2 | 2 |
| | In-111/113m | - | 1 | 2 | 2 |
| | Sb-125 | - | 1 | 2 | 2 |
| | I-125/I-129 | - | 1 | 2 | 2 |
| | I-131 | - | 1 | 2 | 2 |
| | Cs-134/Cs-137 | - | 1 | 2 | 2 |
| | La-140 | - | 1 | 2 | 2 |
| | Ce-144 | - | 1 | 2 | 2 |
| | Eu-154 | - | 1 | 2 | 2 |
| | Rare earths | - | 1 | 2 | 2 |
| | Tl-201 | - | 1 | 2 | 2 |
| | Pb-210 | - | 1 | 2 | 2 |
| | Po-210 | - | 1 | 2 | 2 |
| | Ra-226 | - | 1 | 2 | 2 |
| | Thorium | - | 1 | 2 | 2 |
| | Uranium | - | 1 | 2 | 2 |
| | Np-237 | - | 1 | 2 | 2 |
| | Pu-alpha | - | 1 | 2 | 2 |
| | Pu-241 | - | 1 | 2 | 2 |
| | Americium | - | 1 | 2 | 2 |
| | Curium | - | 1 | 2 | 2 |
| Application to land | General | Important factors are frequency of application, treatment standards and relationship with food type, form of application where applied to land (slurry, or cake or pellet, injection or surface dressing), quantity applied, soil standards, regulations controlling application, storage before application.<br><br>For short half life nuclides, the frequency of application and delay becomes important. Need to determine fate of sludges used in agriculture, in particular food production. | | | |
| | Tritium | - | 3 | 2 | 6 |
| | OBT | - | 3 | 2 | 6 |
| | C-14 | - | 3 | 2 | 6 |

## Table 7 Continued

| Modelling Step | Nuclide | Comments | Dose Score | Uncert-ainty Score | Total Score |
|---|---|---|---|---|---|
| Application to land (cont) | F-18 | - | 1 | 2 | 2 |
| | Na-22/24 | - | 3 | 2 | 6 |
| | P-32/33 | - | 3 | 2 | 6 |
| | S-35 | - | 3 | 2 | 6 |
| | Cl-36 | - | 2 | 2 | 4 |
| | Ca-45 | This could give to significant fetal doses. | 2 | 2 | 4 |
| | Co-57/58/60 | - | 3 | 2 | 6 |
| | Ga-67 | - | 1 | 2 | 2 |
| | Se-75 | - | 3 | 2 | 6 |
| | Stronium/Y-90 | - | 3 | 2 | 6 |
| | Zr-95/Nb-95 | - | 1 | 2 | 2 |
| | Tc-99 | - | 1 | 2 | 2 |
| | Tc-99m | - | 1 | 2 | 2 |
| | Ru-106 | - | 1 | 2 | 2 |
| | In-111/113m | - | 1 | 2 | 2 |
| | Sb-125 | - | 1 | 2 | 2 |
| | I-125/I-129 | - | 3 | 2 | 6 |
| | I-131 | - | 3 | 2 | 6 |
| | Cs-134/Cs-137 | - | 3 | 2 | 6 |
| | La-140 | - | 1 | 2 | 2 |
| | Ce-144 | - | 1 | 2 | 2 |
| | Eu-154 | - | 1 | 2 | 2 |
| | Rare earths | - | 1 | 2 | 2 |
| | Tl-201 | - | 1 | 2 | 2 |
| | Pb-210 | - | 1 | 2 | 2 |
| | Po-210 | - | 1 | 2 | 2 |
| | Ra-226 | - | 1 | 2 | 2 |
| | Thorium | - | 1 | 2 | 2 |
| | Uranium | - | 2 | 2 | 4 |
| | Np-237 | - | 1 | 2 | 2 |
| | Pu-alpha | - | 1 | 2 | 2 |
| | Pu-241 | - | 1 | 2 | 2 |
| | Americium | - | 1 | 2 | 2 |
| | Curium | - | 1 | 2 | 2 |
| Transfer to soil | General | Uncertainties in release rates from applied slurry, cake, pellets etc applied to soil. Degradation of organic matter by biological processes rather than physical processes. Degassing may be a feature. Substantial amounts of organic matter are administered which deliberately change nature of soil (organic matter, pH etc). Could be co-administration with lime. Uncertainty whether standard transfer factors apply.<br><br>Ongoing research for FSA by HPA using Cardiff STW pellets will give behaviour of tritium (ie degassing, leaching into soil, retention in pellet) and uptake into plant. | | | |
| | Tritium | Biological breakdown process lead to large uncertainties in transfer process. | 3 | 3 | 9 |
| | OBT | Biological breakdown process lead to large uncertainties in transfer process. | 3 | 3 | 9 |
| | C-14 | Biological breakdown process lead to large uncertainties in transfer process. | 3 | 3 | 9 |
| | F-18 | - | 1 | 2 | 2 |
| | Na-22/24 | - | 3 | 2 | 6 |
| | P-32/33 | - | 3 | 2 | 6 |
| | S-35 | - | 3 | 2 | 6 |
| | Cl-36 | - | 2 | 2 | 4 |
| | Ca-45 | - | 2 | 2 | 4 |
| | Co-57/58/60 | - | 3 | 2 | 6 |
| | Ga-67 | - | 1 | 2 | 2 |
| | Se-75 | - | 3 | 2 | 6 |
| | Stronium/Y-90 | - | 3 | 2 | 6 |
| | Zr-95/Nb-95 | - | 1 | 2 | 2 |
| | Tc-99 | - | 1 | 2 | 2 |
| | Tc-99m | - | 1 | 2 | 2 |
| | Ru-106 | - | 1 | 2 | 2 |

## Table 7 Continued

| Modelling Step | Nuclide | Comments | Dose Score | Uncert-ainty Score | Total Score |
|---|---|---|---|---|---|
| Transfer to soil (cont) | In-111/113m | - | 1 | 2 | 2 |
| | Sb-125 | - | 1 | 2 | 2 |
| | I-125/I-129 | - | 3 | 2 | 6 |
| | I-131 | - | 3 | 2 | 6 |
| | Cs-134/Cs-137 | - | 3 | 2 | 6 |
| | La-140 | - | 1 | 2 | 2 |
| | Ce-144 | - | 1 | 2 | 2 |
| | Eu-154 | - | 1 | 2 | 2 |
| | Rare earths | - | 1 | 2 | 2 |
| | Tl-201 | - | 1 | 2 | 2 |
| | Pb-210 | - | 1 | 2 | 2 |
| | Po-210 | - | 1 | 2 | 2 |
| | Ra-226 | - | 1 | 2 | 2 |
| | Thorium | - | 1 | 2 | 2 |
| | Uranium | - | 2 | 2 | 4 |
| | Np-237 | - | 1 | 2 | 2 |
| | Pu-alpha | - | 1 | 2 | 2 |
| | Pu-241 | - | 1 | 2 | 2 |
| | Americium | - | 1 | 2 | 2 |
| | Curium | - | 1 | 2 | 2 |
| External dose - soil/fields and sludge during application | General | Important factors are geometry for external dose factors and shielding factors for soil and in sludge during storage/application. Application methods and dilution, occupancy and proximity are important. | | | |
| | Tritium | - | 1 | 1 | 1 |
| | OBT | - | 1 | 1 | 1 |
| | C-14 | - | 1 | 1 | 1 |
| | F-18 | - | 1 | 1 | 1 |
| | Na-22/24 | - | 3 | 1 | 3 |
| | P-32/33 | - | 1 | 1 | 1 |
| | S-35 | - | 1 | 1 | 1 |
| | Cl-36 | - | 1 | 1 | 1 |
| | Ca-45 | - | 1 | 1 | 1 |
| | Co-57/58/60 | - | 3 | 1 | 3 |
| | Ga-67 | - | 1 | 1 | 1 |
| | Se-75 | - | 2 | 1 | 2 |
| | Stronium/Y-90 | - | 1 | 1 | 1 |
| | Zr-95/Nb-95 | - | 1 | 1 | 1 |
| | Tc-99 | - | 1 | 1 | 1 |
| | Tc-99m | - | 1 | 1 | 1 |
| | Ru-106 | - | 1 | 1 | 1 |
| | In-111/113m | - | 1 | 1 | 1 |
| | Sb-125 | - | 1 | 1 | 1 |
| | I-125/I-129 | - | 1 | 1 | 1 |
| | I-131 | - | 1 | 1 | 1 |
| | Cs-134/Cs-137 | - | 3 | 1 | 3 |
| | La-140 | - | 1 | 1 | 1 |
| | Ce-144 | - | 1 | 1 | 1 |
| | Eu-154 | - | 1 | 1 | 1 |
| | Rare earths | - | 1 | 1 | 1 |
| | Tl-201 | - | 1 | 1 | 1 |
| | Pb-210 | - | 1 | 1 | 1 |
| | Po-210 | - | 1 | 1 | 1 |
| | Ra-226 | - | 1 | 1 | 1 |
| | Thorium | - | 1 | 1 | 1 |
| | Uranium | - | 2 | 1 | 2 |
| | Np-237 | - | 1 | 1 | 1 |
| | Pu-alpha | - | 1 | 1 | 1 |
| | Pu-241 | - | 1 | 1 | 1 |
| | Americium | - | 1 | 1 | 1 |
| | Curium | - | 1 | 1 | 1 |

## Table 7 Continued

| Modelling Step | Nuclide | Comments | Dose Score | Uncert-ainty Score | Total Score |
|---|---|---|---|---|---|
| Transfer to food from soil (or direct by animal ingestion) | General | Uncertainties in transfer factors for food from atmospheric releases have been considered under releases to air. Additional uncertainties in deriving transfer factors for sludge application are as follows:<br>• Chemical form of radionuclide after sludge breakdown (eg in soil solution).<br>• Animal uptake of sludge (pellets) – might be important for nuclides that do not readily transfer into grass. | | | |
| | Tritium | Existing models are for transfer of gaseous tritium to plant. Large uncertainties for modelling transfer via plant roots. | 3 | 3 | 9 |
| | OBT | Existing models are for transfer of gaseous tritium to plant. Large uncertainties for modelling transfer via plant roots. | 3 | 3 | 9 |
| | C-14 | Existing models are for transfer of gaseous carbon-14 to plant. Large uncertainties for modelling transfer via plant roots. | 3 | 3 | 9 |
| | F-18 | - | 1 | 1 | 1 |
| | Na-22/24 | Uncertainties as caught up in nutrient cycle. | 1 | 2 | 2 |
| | P-32/33 | Uncertainties as caught up in nutrient cycle. | 3 | 2 | 6 |
| | S-35 | Uncertainties as caught up in nutrient cycle. | 3 | 2 | 6 |
| | Cl-36 | - | 2 | 1 | 2 |
| | Ca-45 | Uncertainties as caught up in nutrient cycle. | 2 | 2 | 4 |
| | Co-57/58/60 | - | 2 | 1 | 2 |
| | Ga-67 | - | 1 | 1 | 1 |
| | Se-75 | - | 3 | 1 | 3 |
| | Stronium/Y-90 | Uncertainties as caught up in nutrient cycle. | 3 | 2 | 6 |
| | Zr-95/Nb-95 | - | 1 | 1 | 1 |
| | Tc-99 | - | 1 | 1 | 1 |
| | Tc-99m | - | 1 | 1 | 1 |
| | Ru-106 | - | 1 | 1 | 1 |
| | In-111/113m | - | 1 | 1 | 1 |
| | Sb-125 | - | 1 | 1 | 1 |
| | I-125/I-129 | - | 3 | 1 | 3 |
| | I-131 | - | 3 | 1 | 3 |
| | Cs-134/Cs-137 | - | 2 | 1 | 2 |
| | La-140 | - | 1 | 1 | 1 |
| | Ce-144 | - | 1 | 1 | 1 |
| | Eu-154 | - | 1 | 1 | 1 |
| | Rare earths | - | 1 | 1 | 1 |
| | Tl-201 | - | 1 | 1 | 1 |
| | Pb-210 | - | 1 | 1 | 1 |
| | Po-210 | - | 1 | 1 | 1 |
| | Ra-226 | - | 1 | 1 | 1 |
| | Thorium | - | 1 | 1 | 1 |
| | Uranium | - | 1 | 1 | 1 |
| | Np-237 | - | 1 | 1 | 1 |
| | Pu-alpha | - | 1 | 1 | 1 |
| | Pu-241 | - | 1 | 1 | 1 |
| | Americium | - | 1 | 1 | 1 |
| | Curium | - | 1 | 1 | 1 |
| Food dose | General | Restrictions on application of sludge may limit food types. Sludge production rates could limit quantities and types of affected foods. Uncertainties are no different to those already identified for releases to air. Required to use Basic Safety Standard dose coefficients. Reasonable UK generic habit data. | | | |
| | Tritium | - | 3 | 1 | 3 |
| | OBT | - | 3 | 1 | 3 |
| | C-14 | - | 3 | 1 | 3 |
| | F-18 | - | 1 | 1 | 1 |
| | Na-22/24 | - | 1 | 1 | 1 |
| | P-32/33 | Fetal doses could be an issue. | 3 | 1 | 3 |
| | S-35 | - | 3 | 1 | 3 |
| | Cl-36 | - | 2 | 1 | 2 |

**Table 7 Continued**

| Modelling Step | Nuclide | Comments | Dose Score | Uncert-ainty Score | Total Score |
|---|---|---|---|---|---|
| Food dose (cont) | Ca-45 | Fetal doses could be an issue. | 2 | 1 | 2 |
| | Co-57/58/60 | - | 2 | 1 | 2 |
| | Ga-67 | - | 1 | 1 | 1 |
| | Se-75 | - | 3 | 1 | 3 |
| | Stronium/Y-90 | - | 3 | 1 | 3 |
| | Zr-95/Nb-95 | - | 1 | 1 | 1 |
| | Tc-99 | - | 1 | 1 | 1 |
| | Tc-99m | - | 1 | 1 | 1 |
| | Ru-106 | - | 1 | 1 | 1 |
| | In-111/113m | - | 1 | 1 | 1 |
| | Sb-125 | - | 1 | 1 | 1 |
| | I-125/I-129 | - | 3 | 1 | 3 |
| | I-131 | - | 3 | 1 | 3 |
| | Cs-134/Cs-137 | - | 2 | 1 | 2 |
| | La-140 | - | 1 | 1 | 1 |
| | Ce-144 | - | 1 | 1 | 1 |
| | Eu-154 | - | 1 | 1 | 1 |
| | Rare earths | - | 1 | 1 | 1 |
| | Tl-201 | - | 1 | 1 | 1 |
| | Pb-210 | - | 1 | 1 | 1 |
| | Po-210 | - | 1 | 1 | 1 |
| | Ra-226 | - | 1 | 1 | 1 |
| | Thorium | - | 1 | 1 | 1 |
| | Uranium | - | 1 | 1 | 1 |
| | Np-237 | - | 1 | 1 | 1 |
| | Pu-alpha | - | 1 | 1 | 1 |
| | Pu-241 | - | 1 | 1 | 1 |
| | Americium | - | 1 | 1 | 1 |
| | Curium | - | 1 | 1 | 1 |
| Internal non-food dose (inhalation and inadvertent ingestion) | General | Simple dust in air approach used for sludge and soil conditioned with sludge. Possible inhalation of gaseous radionuclides during sludge breakdown. Generalised habit data used for inadvertent ingestion rates. Mechanical resuspension (eg, ploughing). Occupancy is a factor. | | | |
| | Tritium | - | 1 | 2 | 2 |
| | OBT | - | 1 | 2 | 2 |
| | C-14 | - | 1 | 2 | 2 |
| | F-18 | - | 1 | 2 | 2 |
| | Na-22/24 | - | 1 | 2 | 2 |
| | P-32/33 | - | 1 | 2 | 2 |
| | S-35 | - | 1 | 2 | 2 |
| | Cl-36 | - | 1 | 2 | 2 |
| | Ca-45 | - | 1 | 2 | 2 |
| | Co-57/58/60 | - | 1 | 2 | 2 |
| | Ga-67 | - | 1 | 2 | 2 |
| | Se-75 | - | 1 | 2 | 2 |
| | Stronium/Y-90 | - | 1 | 2 | 2 |
| | Zr-95/Nb-95 | - | 1 | 2 | 2 |
| | Tc-99 | - | 1 | 2 | 2 |
| | Tc-99m | - | 1 | 2 | 2 |
| | Ru-106 | - | 1 | 2 | 2 |
| | In-111/113m | - | 1 | 2 | 2 |
| | Sb-125 | - | 1 | 2 | 2 |
| | I-125/I-129 | - | 1 | 2 | 2 |
| | I-131 | - | 1 | 2 | 2 |
| | Cs-134/Cs-137 | - | 1 | 2 | 2 |
| | La-140 | - | 1 | 2 | 2 |
| | Ce-144 | - | 1 | 2 | 2 |
| | Eu-154 | - | 1 | 2 | 2 |
| | Rare earths | - | 1 | 2 | 2 |
| | Tl-201 | - | 1 | 2 | 2 |
| | Pb-210 | - | 1 | 2 | 2 |
| | Po-210 | - | 1 | 2 | 2 |

**Table 7 Continued**

| Modelling Step | Nuclide | Comments | Dose Score | Uncert-ainty Score | Total Score |
|---|---|---|---|---|---|
| Internal non-food dose (inhalation and inadvertent ingestion) (cont) | Ra-226 | - | 1 | 2 | 2 |
| | Thorium | - | 1 | 2 | 2 |
| | Uranium | - | 1 | 2 | 2 |
| | Np-237 | - | 1 | 2 | 2 |
| | Pu-alpha | - | 1 | 2 | 2 |
| | Pu-241 | - | 1 | 2 | 2 |
| | Americium | - | 1 | 2 | 2 |
| | Curium | - | 1 | 2 | 2 |
| Incineration partitioning and abatement | General | Important factors are partitioning between ash and off-gases which depends on temperature and ash production, scrubbing and filtration. Decay may be less than for disposal to land as sludge may be incinerated reasonably quickly after production. Needs to be >30% solids to combust well. | | | |
| | Tritium | - | 1 | 2 | 2 |
| | OBT | - | 1 | 2 | 2 |
| | C-14 | - | 1 | 2 | 2 |
| | F-18 | - | 1 | 2 | 2 |
| | Na-22/24 | - | 1 | 2 | 2 |
| | P-32/33 | - | 2 | 2 | 4 |
| | S-35 | - | 1 | 2 | 2 |
| | Cl-36 | - | 1 | 2 | 2 |
| | Ca-45 | - | 1 | 2 | 2 |
| | Co-57/58/60 | - | 1 | 2 | 2 |
| | Ga-67 | - | 1 | 2 | 2 |
| | Se-75 | - | 1 | 2 | 2 |
| | Stronium/Y-90 | - | 1 | 2 | 2 |
| | Zr-95/Nb-95 | - | 1 | 2 | 2 |
| | Tc-99 | - | 1 | 2 | 2 |
| | Tc-99m | - | 1 | 2 | 2 |
| | Ru-106 | - | 1 | 2 | 2 |
| | In-111/113m | - | 1 | 2 | 2 |
| | Sb-125 | - | 1 | 2 | 2 |
| | I-125/I-129 | - | 2 | 2 | 4 |
| | I-131 | - | 3 | 2 | 6 |
| | Cs-134/Cs-137 | - | 1 | 2 | 2 |
| | La-140 | - | 1 | 2 | 2 |
| | Ce-144 | - | 1 | 2 | 2 |
| | Eu-154 | - | 1 | 2 | 2 |
| | Rare earths | - | 1 | 2 | 2 |
| | Tl-201 | - | 1 | 2 | 2 |
| | Pb-210 | - | 1 | 2 | 2 |
| | Po-210 | - | 1 | 2 | 2 |
| | Ra-226 | - | 1 | 2 | 2 |
| | Thorium | - | 2 | 2 | 4 |
| | Uranium | - | 1 | 2 | 2 |
| | Np-237 | - | 1 | 2 | 2 |
| | Pu-alpha | - | 1 | 2 | 2 |
| | Pu-241 | - | 1 | 2 | 2 |
| | Americium | - | 1 | 2 | 2 |
| | Curium | - | 1 | 2 | 2 |

**Table 8 Categorisation of High and Medium Priority Areas for Model Development – Releases to air**

| Priority for improvement | Modelling area for improvement | Improvement type | Ease | Lead organisation |
|---|---|---|---|---|
| High | Provide NRPB-R91 type charts for continuous releases using ADMS or AERMOD to encourage use of more realistic modelling data | Model runs | Medium | EA R&D |
| | Examine the effect of chemical speciation of sulphur-35 on deposition | Measurements – field and experimental | Difficult | FSA R&D |
| | Examine the effect of chemical speciation of iodine isotopes on deposition | Measurements – field and experimental | Difficult | FSA R&D |
| | Further development of modelling of transfer of sulphur-35 to plants | Measurements – field and experimental | Difficult | FSA R&D |
| | Further development of understanding of iodine-129 uptake in plants and milk | Measurements – field and experimental | Difficult | FSA R&D |
| | Review of UK generic food consumption data, in particular for home/allotment/small holding produced food. | National survey | Medium | FSA R&D |
| | Define air dispersion modelling assumptions for prospective assessment of doses arising from non-accidental short-term releases | Review of research | Medium | NDAWG modelling /new short term release group |
| | Refine and develop information on the degree and kinetics of transfers to assess peak and integrated concentrations in foodstuffs as a result of short-term releases | Measurements – field and experimental | Difficult | FSA R&D |
| | Define habits data for consumption of foods following short-term releases | Review of research | Medium | NDAWG modelling /new short-term release group |
| Medium | Develop models for transfer of organically bound tritium (OBT) from air/soil to food | Measurements – field and experimental | Difficult | FSA R&D |
| | Improve modelling of chlorine-36 from soil into plants/food. Could interpret data from studies related to solid radioactive waste management. | Measurements – field and experimental | Difficult | FSA R&D |
| | Improve modelling of technetium-99 from soil into plants/food. Could interpret data from studies related to solid radioactive waste management. | Measurements – field and experimental | Difficult | FSA R&D |

**Table 9 Categorisation of High and Medium Priority Areas for Model Development – Releases to freshwater**

| Priority for improvement | Modelling area for improvement | Improvement type | Ease | Lead organisation |
|---|---|---|---|---|
| High | Improve models for dispersion in freshwater and transfer to sediments (in particular for iodine-131 which is discharged in large quantities from cancer therapy hospitals) (may need to consider chemical speciation) | Measurements – field and experimental | Medium | EA R&D |
| | Examine relationship between dose arising where people are located on river banks compared to the dose over river bed sediments | Measurements required - field | Medium | EA R&D |
| | Examine transfer of OBT and phosphorus isotopes to freshwater fish (may need to consider chemical speciation) | Measurements – field and experimental | Medium | FSA R&D |
| | Examine concentration factors (CF) for fish farms for key radionuclides (eg, phosphorus-32/33) | Measurements – field and experimental | Medium | FSA R&D |
| | Review freshwater fish consumption habits | Review research | Medium | NDAWG habits group |
| Medium | Examine freshwater dispersion and transfer to sediments for short-term releases to rivers | Measurements – field and experimental | Difficult | EA R&D |
| | Examine habits of persons exposed to external radiation in relation to short-term releases (eg duration, timing) | Review of research | Medium | NDAWG modelling /new short-term release group |
| | Examine habits for consumption of freshwater fish in relation to short-term releases (eg quantity, timing) | Review of research | Medium | NDAWG modelling /new short-term release group |

**Table 10 Categorisation of High and Medium Priority Areas for Model Development – Releases to estuary / coastal waters**

| Priority for improvement | Modelling area for improvement | Improvement type | Ease | Lead organisation |
|---|---|---|---|---|
| High | Examine transfer of Pb-210 and Po-210 to fish (difficult to validate due to difficulty establishing background for Po-210 in shellfish in Cumbria) | Measurements – field and experimental | Difficult | FSA R&D |
| | Examine modelling of particle-reactive nuclides (eg americium-241) which are not well represented in marine/coastal environment | Measurements – field and experimental | Difficult | EA R&D |
| Medium | Review generic habit data for increased leisure activities/other work activities (eg diving, kite surfing, sea-washed turf cutting etc) | Review of research / surveys | Medium | NDAWG habits / modelling sub-group |
| | Examine concentration factors for transfer to fish for OBT and Eu-154 | Measurements – field and experimental | Difficult | FSA R&D |
| | Examine transfer of key radionuclides from seaweed into compost and crops (in particular Tc-99) for continuous and short-term releases | Measurements – field and experimental | Difficult | FSA R&D |
| | Review habits assumptions for consumption of crops produced on seaweed fertilised land for continuous and short-term releases | Review of research / surveys | Medium | NDAWG habits / modelling / new short term release group |
| | Develop models for dispersion and transfer to sediments for short-term releases into the coastal environment | Measurements – field and experimental | Difficult | EA R&D |
| | Examine habits of persons exposed to external radiation in relation to short-term releases (eg duration, timing) | Review of research / surveys | Medium | NDAWG modelling /new short term release sub-group |
| | Examine habits for consumption of fish/shellfish in relation to short-term releases (eg quantity, timing) | Review of research / surveys | Medium | NDAWG modelling /new short-term release sub-group |
| | Examine transfer of key radionuclides to animal products as a result of grazing on sea-washed pasture (in particular for short-term releases) | Measurements – field and experimental | Difficult | FSA R&D |
| | Examine habits assumptions for consumption of animal products grazed on sea-washed land after short-term releases (eg quantity and timing) | Review of research / surveys | Medium | NDAWG modelling /new short-term release sub-group |

**Table 11 Categorisation of High and Medium Priority Areas for Model Development – Releases to sewer**

| Priority for improvement | Modelling area for improvement | Improvement type | Ease | Lead organisation |
|---|---|---|---|---|
| High | Continue existing EA R&D on partitioning of radionuclides between sludge and treated effluent at sewage treatment works. Need to understand partitioning at key process steps, especially where recycling important. Analysis of timeline needed. Degassing of gaseous nuclides to be considered. | Measurements – field and experimental | Difficult | EA R&D |
| | Research occupancy and proximity of sewage workers in relation to tanks/channels etc containing raw sewage and sludge, and their geometry and shielding. | Survey | Medium | EA R&D |
| | Research application of sludge to land in relation sewage works size, including amount of land conditioned and food types produced | Survey | Medium | FSA R&D |
| | Continue and broaden research on transfer of radionuclides in sludge to soil and on into foodchains, in particular for H-3 and C-14. | Measurements – field and experimental | Difficult | FSA R&D |
| | Scope realistic doses from incineration of sludge and, if doses are potentially high, review partitioning and abatement factors. | Study/survey | Medium | EA R&D |

| | | | Dose score | | |
|---|---|---|---|---|---|
| | | | <20 μSv/y | 20-100 μSv/y | >100 μSv/y |
| | | | 1 | 2 | 3 |
| Uncertainty score | > Factor of 10 | 3 | 3 | 6 | 9 |
| | Factor of 3 – 10 | 2 | 2 | 4 | 6 |
| | < Factor of 3 | 1 | 1 | 2 | 3 |

**Figure 1 Scoring definitions and assignment of total scores**