Nexia Solutions

RADCONTAB 1.0: A look-up tables tool for radiological assessment of contaminated land on Nuclear Licensed Sites

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SUMMARY

This report provides the user documentation for a simple electronic spreadsheet 'look-up tables' spreadsheet tool (RADCONTAB version 1.0), developed by BNFL to facilitate radiological assessment of land affected by existing 'historic' radioactive contamination on UK Nuclear Licensed (NL) sites (and other sites with controls similar to those pertaining to NL sites).

This report contains guidance on the contexts in which the spreadsheet tool should be used, explains how the tool should be operated and gives guidance on input parameter values where this is justified.

The purpose of the look-up tables tool RADCONTAB is to enable suitably qualified but relatively non-specialised assessors to make relatively rapid assessments of the radiological implications of data for concentrations of radionuclides in contaminated land and water on NL sites.

The tool calculates doses via individual exposure pathways, with respect to unit specific activity (1 Bq g^{-1}, 1 Bq cm^{-2} or 1 Bq L^{-1}) for surface soil, buried soil and potable water. This allows the user to specify the exposure scenarios to be assessed, in terms of input parameters such as occupancy, ingestion rates or inhalation rates. This report provides guidance on suitable values for parameter values, but the onus is on the user to choose these values and justify their choice. The tool also calculates doses for user-input values of measured specific activities (in Bq g^{-1}, Bq cm^{-2} or Bq L^{-1}) in surface soil, buried soil and potable water. These doses for individual exposure pathways can be combined to derive a total dose for a particular contaminated land scenario.

The tool is based on the International Commission on Radiological Protection ICRP-60 recommendations for calculation of effective doses (ICRP, 1991). It should be noted that the ICRP are currently in the process of preparing revised recommendations, though the timescale for publication of these revised recommendations is not clear at present.

The exposure groups to which the look-up tables tool are intended to apply are:

- on-site workers during normal operations when the contaminated ground is undisturbed;
- workers involved in excavation into contaminated ground; and
- members of the public outside the site security fence (which may be within the NL site boundary).

The exposure pathways that can be assessed using the look-up tables tool are:

- direct radiation from contaminated ground (for various potential geometries);
- dermal contact with contaminated ground (excluding open wounds);
- inhalation of contaminated dust;
- ingestion of contaminated soil and dust;
- ingestion of contaminated wild foods; and
- ingestion of contaminated water.

Dermal contact with contaminated water is considered within this report only in terms of water splash involving tritium (H-3).

The radionuclides that can be assessed using the look-up tables tool are:

H-3	C-14	Cl-36	K-40	Co-60	Sr+90
Tc-99	Ru+106	Sn+126	I-129	Cs-134	Cs+137
Pb+210	Po-210	Ra+226	Ra+228	Th+228	Th+229
Th-230	Th-232	Pa-231	U-233	U-234	U+235
U-236	U+238	Np+237	Pu-238	Pu-239	Pu-240
Pu-241	Pu-242	Am-241	Cm-242	Cm-243	Cm-244

where the '+' in the radionuclide name indicates the inclusion of short-lived progeny in secular equilibrium with the parent.

VERIFICATION STATEMENT

This document has been verified and is fit for purpose. An auditable record has been made of the verification process. The scope of the verification was to confirm that: -

- The scope is accurate and represents the customer requirements
- The constraints are valid
- The assumptions are reasonable
- The document demonstrates that the project is using the latest company approved data
- The document is internally self consistent

HISTORY SHEET

Issue Number	Date	Comments
Draft 04	31/03/04	Issued to customer (accompanies RADCONTAB 0.1)
Draft 05	05/07/04	Issued to customer (accompanies RADCONTAB 0.3)
Draft 06	12/07/04	Addressing customer comments (accompanies RADCONTAB 0.3)
Draft 07	21/12/04	Addressing SAFEGROUNDS consultees' comments (accompanies RADCONTAB 0.5)
Draft 08	04/03/05	Addressing NRPB peer review comments (accompanies pre-release of RADCONTAB 1.0)
Issue 01	30/03/05	For publication following endorsement by NRPB peer reviewer (accompanies RADCONTAB 1.0)

This copy number

CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

This report provides the user documentation for a simple electronic spreadsheet 'look-up tables' tool (RADCONTAB version 1.0), developed by BNFL to facilitate radiological assessment of land affected by existing 'historic' radioactive contamination[3] on UK Nuclear Licensed (NL) sites (and other sites with controls similar to those pertaining to NL sites).

This report contains guidance on the contexts in which the spreadsheet tool should be used, explains how the tool should be operated and gives guidance on input parameter values where this is justified.

1.1 Background

The need for a tool such as that described here has emerged during characterisation of radioactive contamination on BNFL's NL sites. No clearly applicable up-to-date framework existed for assessing the radiological significance of measured concentrations of radionuclides in the land at NL sites. This situation was leading to site-specific radiological assessments being undertaken, which was often time-consuming and typically used slightly different methodologies each time.

BNFL[4] therefore commissioned the work described in this report, to provide a tool that would make radiological assessments of contaminated land at NL sites easier to accomplish on a consistent basis. In order to encourage widespread acceptance of the tool, it was decided to take the following steps:

- to consult as widely as possible on the technical specification for the tool;
- to involve an independent peer reviewer from the outset of the project to develop the tool; and
- to make the tool publicly available free of charge.

The consultation on the technical specification was undertaken using the web-site of the SAFEGROUNDS Learning Network administered by the Construction Industry Research and Information Association (CIRIA). A draft specification was posted on the SAFEGROUNDS web-site (www.safegrounds.com) in July 2003 and the consultation was closed on 1 September 2003. Following the receipt of comments from a variety of sources (other nuclear operators, the main regulator, a non-governmental organisation and a number of consultants), a finalised specification was published on the SAFEGROUNDS web-site in December 2003 (Richards, 2003).

An independent peer review of the look-up tables was provided by S. Mobbs of the National Radiological Protection Board (NRPB), with support from W. Oatway (also of the NRPB). The peer review process began in September 2003, following the completion of the consultation on the draft specification. Following this review, a draft of this report (Draft 6)

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[3] Note that in this report, the phrase 'contaminated land' is frequently used in the sense of 'land affected by radioactive contamination', and should not be taken as synonymous with any statutory definition of 'contaminated land'.
[4] (through the Reactor Sites Nuclear Research Schedule managed by British Nuclear Group - a part of BNFL)

and spreadsheet tool (RADCONTAB version 0.3) were made available for public consultation using the SAFEGROUNDS web-site.

Following consultation on the spreadsheet tool RADCONTAB version 0.3, a revised draft report and spreadsheet tool (RADCONTAB version 0.5) was submitted to the NRPB peer reviewer. In this stage of the peer review, NRPB suggested only minor editorial changes to the spreadsheet tool RADCONTAB and accompanying report, which were implemented in pre-release versions seen by NRPB prior to issue of the present report and spreadsheet tool RADCONTAB version 1.0. The peer review summary report (Mobbs and Oatway, 2005) is published on the SAFEGROUNDS web-site alongside this report.

Apart from possible future revisions or upgrades being posted on the SAFEGROUNDS web-site, no technical support is offered outside BNFL. All users should monitor the SAFEGROUNDS web-site for revisions and upgrades.

1.2 Purpose

The purpose of the look-up tables tool is to enable suitably qualified but relatively non-specialised assessors to make relatively rapid assessments of the radiological implications of data for concentrations of radionuclides in contaminated land and water on NL sites.

For example, such assessments could be done by a combination of an environmental scientist with relatively little radiological assessment expertise and a health physicist with relatively little contaminated land expertise, without recourse to specialist radiological/environmental consultants. This lack of expertise is not perceived as a limiting factor as long as the users of the tool can make sensible assumptions concerning selection of the input parameters.

The look-up tables tool should be used as a means of addressing Principle 1 of the SAFEGROUNDS contaminated land management guidance (Hill *et al*., 2002) which requires that there be a high level of protection of people and the environment. The guidance is not prescriptive and recommends a case-by-case approach to the practical specification of a high level of protection. Smith (2002) in interpreting the guidance recommends that the simplest models be used for assessments for relevant endpoints, using currently recommended values such as environmental transport factors for radionuclides and dose per unit intake of radionuclides. The look-up tables tool RADCONTAB satisfies these criteria for endpoints of individual doses to members of the public and workers on the contaminated NL site. The tool should therefore allow an early assessment of whether there is a high level of protection to people associated with the contaminated site.

In some cases of relatively high levels of land contamination, such assessments may have to be followed up by more detailed radiological assessments than the look-up tables could provide, involving specialised consultants. The aim is not to supplant detailed assessments where they are warranted, but to enable more rapid appraisal of the radiological significance of levels of contamination found, as the data emerge from site characterisation.

The look-up tables tool RADCONTAB calculates doses via individual exposure pathways with respect to unit specific activity (1 Bq g^{-1}, 1 Bq cm^{-2} or 1 Bq L^{-1}) for surface soil, buried soil and potable water. This allows the user to specify the exposure scenarios to be assessed, in terms of input parameters such as occupancy, ingestion rates or inhalation rates. This report provides guidance on suitable values for parameter values, but the onus is on the user to choose these values and justify their choice. The tool also calculates doses for user-input values of measured specific activities (in Bq g^{-1} or Bq L^{-1}) in surface soil, buried soil and potable water. These doses for individual exposure pathways can be combined to derive a total dose for a particular contaminated land scenario.

This approach differs from Generalised Derived Limits[5] (NRPB, 1998) and the dose per unit concentration values produced for the Environment Agency (Entec/NRPB, 1999) and in Oatway and Mobbs (2003). In those studies, doses are summed from a number of different exposure pathways 'hard-wired' within a scenario (often a scenario not appropriate to a NL site).

The tool can be used to represent a realistic or conservative assessment approach for the same scenario. The latter approach may be adopted, particularly if there is a need to determine maximum or upper bound doses for the exposure groups, for example to compensate for not carrying out a probabilistic assessment. The former approach may be adopted if there is a need for a best estimate deterministic assessment.

1.3 Starting points

The doses calculated by the look-up tables tool RADCONTAB are based on the dose coefficients currently recommended by the ICRP in their 1990 recommendations (ICRP, 1991). It should be noted that the ICRP are currently in the process of preparing revised recommendations, though the timescale for publication of these revised recommendations is not clear at present.

The set of radionuclides included in the tool comprises primarily medium- to long-lived radionuclides associated with nuclear power generation and the nuclear fuel cycle, with the addition of selected naturally occurring radionuclides. Short-lived radionuclides (other than progeny nuclides) are not included, as they are not expected to be found in significant concentrations in 'historic' land contamination.

Some assumptions regarding credible types of scenarios on NL sites have been made in specifying the exposure pathways to be assessed. In particular, relatively unrestricted public access to parts of NL sites where traces of radioactive contamination might be present is considered as a possibility, whereas inappropriate land use (e.g. agricultural use of radioactively contaminated land on part of an NL site) is assumed to be prevented by management of the land by the Licensee.

1.4 Scope

The following paragraphs summarise the scope of the look-up tables tool in terms of exposure groups, exposure pathways and radionuclides. The rationale for this choice of scope is set out in more detail in Section 2.

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[5] The Generalised Derived Limits are calculated environmental concentrations that would give rise to a specified dose under particular scenarios.

The exposure groups to which the look-up tables tool are intended to apply are:

- on-site workers during normal operations when the contaminated ground is undisturbed;
- workers involved in excavation into contaminated ground; and
- members of the public outside the site security fence (which may itself be within the NL site boundary).

The exposure pathways that can be assessed using the look-up tables tool are:

- direct radiation from contaminated ground (for various potential geometries);
- dermal contact with contaminated ground (excluding open wounds);
- inhalation of contaminated dust;
- ingestion of contaminated soil and dust;
- ingestion of contaminated wild foods; and
- ingestion of contaminated water.

Dermal contact with contaminated water is considered within this report only in terms of water splash involving tritium (H-3). (see Section 2.2.7).

The radionuclides that can be assessed using the look-up tables tool are:

H-3	C-14	Cl-36	K-40	Co-60	Sr+90
Tc-99	Ru+106	Sn+126	I-129	Cs-134	Cs+137
Pb+210	Po-210	Ra+226	Ra+228	Th+228	Th+229
Th-230	Th-232	Pa-231	U-233	U-234	U+235
U-236	U+238	Np+237	Pu-238	Pu-239	Pu-240
Pu-241	Pu-242	Am-241	Cm-242	Cm-243	Cm-244

where the ‘+’ in the radionuclide name indicates the inclusion of short-lived progeny in secular equilibrium with the parent.

1.5 Limitations and exclusions

The look-up tables tool RADCONTAB is explicitly not intended for application to sites where controls applicable on NL sites are not in place. Therefore exposure pathways such as those involving agriculture, horticulture, residential property, educational/recreational facilities, non-nuclear industry, public water supply, *etc*. cannot be assessed using this tool.

The look-up tables tool RADCONTAB does not allow assessment of any non-radiological health risks or other environmental detriments that may be associated with some radio-elements (e.g. uranium).

The look-up tables tool RADCONTAB is not designed for radiological assessment of the immediate aftermath of a spillage or other type of incident in which short-lived radionuclides not included in the tool might be present in the affected contaminated land. In practice, the Licensee will have to take immediate action driven by direct measurements of radiation dose and contaminant levels, leading to imposition of additional controls required to implement the Ionising Radiation Regulations.

The look-up tables tool RADCONTAB is intended for use where the concentrations of radionuclides in the land have recently been measured. It is explicitly not intended for use in predicting radiation doses over long timescales during which the distribution of radionuclides in the land might change, for example as a result of leaching and migration in groundwater.

The guidance given in this report on input parameter values for site-specific assessments should not be taken as providing ‘default values’. The user of the look-up tables tool RADCONTAB is responsible for justifying the choice of input parameter values and should document the reasoning behind such choices if the resulting assessment is to be considered as complete.

1.6 Potential extended applications

The look-up tables tool RADCONTAB could potentially be used for assessing future radiation doses if another tool or methodology is available to predict how radionuclide concentrations in the contaminated land at exposure locations (receptors) might change with time.

The calculations made by the look-up tables tool RADCONTAB may have potential applications outside the specific context of contaminated land. For instance, some of the external radiation calculations for contaminated land might be applied to large contaminated structures or to contaminated rubble, and the calculations for contaminated water might be applied to drinking water sources. However, such applications should be undertaken with caution, in full awareness of the assumptions underpinning the calculations (e.g. the assumed bulk density of the solid medium and the assumed lack of suspended sediment in water). Also, the dose calculations are undertaken using default ICRP dose coefficients that may be inappropriate for some applications.

The look-up tables tool RADCONTAB may have potential applications on non-NL sites where there are controls similar to those applicable to NL sites, and some calculations made by the tool may have potential applications to assessment of certain scenarios and exposure pathways applicable outside the context of NL or similar sites. Again, such applications should be undertaken in full awareness of the assumptions underpinning the calculations.

1.7 Disclaimer

The look-up tables tool RADCONTAB described in this report and this report itself have been reviewed and verified according to applicable BNFL procedures. However, BNFL cannot guarantee that they are wholly free of error. BNFL accepts no liability arising from use of the look-up tables tool RADCONTAB or this report.

1.8 Structure of report

Section 2 describes in further detail the exposure groups that are considered for the look-up tables tool RADCONTAB together with exposure pathways associated with contaminated land. Mathematical formulae are provided for the exposure pathway calculations to demonstrate the underlying methodology. The final part of Section 2 deals with the radionuclides to be assessed by the look-up tables, where consideration has to be given to the time-scales of contaminated land measurements and the ingrowth of daughter products or progeny in radionuclide decay chains.

Section 3 describes the functionality and structure of the look-up tables tool RADCONTAB based on worksheets within Microsoft Excel © spreadsheet software. Also discussed are input data entry and output produced by the look-up tables, and maintenance and further development issues. To assist the user in using the look-up tables, guidance on the entry of input values is provided in Section 4. Reference material for the report as a whole is provided in Section 5.

Appendices 1 to 4 provide, for reference purposes, constant data parameters such as dose coefficients and wild food concentration factors used in the calculations. Appendix 5 gives worked examples of the look-up tables themselves to complement the report. Appendix 6 provides some proof of verification and shows that excellent agreement can be reached between the results of the look-up tables and independent values from the NRPB's dose methodology for contaminated land (Oatway and Mobbs, 2003).

2. EXPOSURE GROUPS AND EXPOSURE PATHWAYS

2.1 Exposure groups

The following exposure groups have been identified in relation to contaminated land on NL sites.

- on-site workers during normal operations when the contaminated land is undisturbed;
- workers involved in excavation into contaminated land; and
- members of the public outside the site security fence (which may or may not coincide with the NL site boundary).

The list above distinguishes between workers on-site who may come into contact with contaminated land passively by walking on it or being near it, and also actively engaging in activities which involve disturbance of the land. Members of the public may come into direct contact with contaminated land if the security fence is inside the NL site boundary or if they intrude into the site. For the latter scenario (intrusion), it is proposed that exposure pathways associated with on-site workers during normal operations apply. Otherwise, members of public are outside the site security fence even if they are still within the NL site boundary.

For assessing exposure groups, the ICRP (1996) identify several age categories (3 months, 1 year, 5 years, 10 years, 15 years and adult) and provide ingestion and inhalation committed effective dose coefficients for these exposure pathways. Rather than cover all of these categories, for the look-up tables, this scheme has been truncated to cover:

- infants (1 year);
- children (10 years); and
- adults (16 years and above).

The three groups should provide sufficient coverage of the exposed population in general for radiological assessments of contaminated land.

In addition to the groups above, foetal doses are also considered. Foetal doses may apply to pregnant women workers on-site on undisturbed contaminated ground and to pregnant women outside the site security fence. It is reasonable to assume that pregnant women will not be involved in physically demanding tasks such as excavation into contaminated land. For ease of being able to use ICRP dose coefficients (ICRP, 2002), the foetal dose will be considered in terms of the offspring dose for chronic intake at conception. Although, the word ‘offspring’ is a general term for the ‘person’ from embryo to new-born child, the ICRP dose coefficient for offspring is based on the committed dose from conception to age 70 years from intakes of radionuclides received whilst in the womb.

All inhalation and ingestion dose coefficients used by the look-up tables tool RADCONTAB are provided in Appendix 1. It should be noted that although all available offspring dose coefficients are listed from ICRP (2002), only those offspring dose coefficients that exceed the corresponding adult dose coefficients are used in the look-up tables. Offspring doses for pregnant women will only therefore be calculated for certain radionuclides (Appendix 1) where they are greater than corresponding adult doses, which is in keeping with NRPB advice.

2.2 Exposure pathways

The following exposure pathways are associated with the exposure groups described and assessed in the look-up tables:

- external irradiation from contaminated ground (for various potential geometries);
- dermal contact with contaminated ground (excluding open wounds[6]);
- inhalation of contaminated dust;
- ingestion of contaminated soil and dust;
- ingestion of contaminated wild foods; and
- ingestion of contaminated water.

Ingestion of wild or free foods has been considered in more speculative terms than the other more likely exposure pathways. Ingestion of wild foods may apply, particularly for cases when the security fence is inside the NL site boundary, where there is a possibility that members of the public may gather and consume wild foods associated with any radioactively contaminated land there. It is recognised that radionuclide-specific data for ingestion of wild foods are very sparse and so the wild foods are broadly categorised as fruit and fungi applying ideally to foodstuffs such as blackberries and mushrooms. Food consumption pathways associated with agriculture, gardens, allotments, *etc*. are not applicable to NL sites[7] and are not assessed.

Ingestion of contaminated water has been included because it may be necessary to assess the risk associated with ingesting water underlying or issuing from a contaminated site. The assessment of ingestion of contaminated water is based on having measurements of concentrations of radionuclides in samples of groundwater from boreholes, groundwater drains or springs, and does not involve calculation of such concentrations from concentrations in soil.

The likely magnitude of effects associated with dermal contact with contaminated water is only considered in terms of water splash involving tritium as described in Section 2.2.7.

Methodology and calculations for the above exposure pathways are described below.

[6] Controls in force on NL sites prevent workers with open wounds from working in contaminated areas.
[7] Some peripheral areas of some NL sites are farmed. In the unlikely event that such an area was to be contaminated, a more specific assessment would be warranted, going beyond the intent of the look-up tables proposed here.

2.2.1 External irradiation from contaminated ground

External irradiation is considered to result only from radioactive materials adsorbed to soil media within the contaminated ground (i.e. 'cloud shine' from contaminated dust is not considered). This ground contamination may be exposed or buried as a result of processes that have occurred, or will be occurring, on the site. Any material that is buried will give rise to a lower dose rate than exposed material due to the shielding effects of the overlying medium.

For each radionuclide, the dose from external irradiation D_{ext} (mSv y^{-1}) is calculated as:

$$D_{ext} = C_{soil} * occ * DF_{ext,geomi} \qquad (1)$$

where:

C_{soil}	soil radionuclide concentration (Bq g^{-1}) assumed uniformly distributed within the ground or (Bq cm^{-2}) for surface contamination;
occ	occupancy (h y^{-1}) at contaminated land site; and
$DF_{ext,geomi}$	external dose factor (either mSv h^{-1} per Bq g^{-1} or mSv h^{-1} per Bq cm^{-2}) for geometry i.

In the look-up tables, the user must provide an estimate of occupancy for the exposure group of interest. Separate calculations will need to be undertaken if for instance there are periods within a year when the worker interacts passively with contaminated land such as walking on it or by being near it, or actively engages in activities which involve disturbance of the land such as excavation.

For direct exposure involving beta/gamma radionuclides, the following alternative geometries can be assessed using the look-up tables tool RADCONTAB:

⇒ 'Surface' contamination (Bq cm^{-2}), 'zero' thickness:
- Dose received 1 m above uniform contamination (extending horizontally to infinity).
- Dose received 1 m above a patch of contamination ~10 m in diameter.
- Dose received by a person standing 5 m from the edge of an area of contamination extending horizontally 'to infinity' from the edge of the contamination (to simulate a member of the public outside the fence, near but not on an area of contaminated ground).
- Dose received by a person standing 50 m from the edge of an area of contamination extending horizontally 'to infinity' from the edge of the contamination.

⇒ 'Shallow' contamination (Bq g^{-1}), 5 cm deep from the surface:
- Dose received 1 m above uniform contamination (extending horizontally to infinity).
- Dose received 1 m above a patch of contamination ~10 m in diameter.
- Dose received by a person standing 5 m from the edge of an area of contamination extending horizontally 'to infinity' from the edge of the contamination.

- Dose received by a person standing 50 m from the edge of an area of contamination extending horizontally 'to infinity' from the edge of the contamination.

⇒ 'Deep' contamination (Bq g^{-1}), extending to 'infinite' depth from the surface:
- Dose received 1 m above uniform contamination (extending horizontally to infinity).
- Dose received 1 m above a patch of contamination ~10 m in diameter.
- Dose received by a person standing 5 m from the edge of an area of contamination extending horizontally 'to infinity' from the edge of the contamination.
- Dose received by a person standing 50 m from the edge of an area of contamination extending horizontally 'to infinity' from the edge of the contamination.

⇒ 'Buried' contamination (Bq g^{-1}),
- Dose received 1 m above uniform contamination extending below a 0.1 m thick clean soil cover to 'infinite' depth (shallow buried contamination).
- Dose received 1 m above uniform contamination extending below a 0.5 m thick clean soil cover to 'infinite' depth (more deeply buried contamination).

External dose factors for the above geometries for gamma photons have been derived using the commercially available software product Microshield version 5.03 (© 1995-1998, Grove Engineering) applied for all age groups. Dose factors were also considered for beta particles (electrons) and added to corresponding dose factors for gamma photons (see Appendix 2). The effect of braking radiation or Bremstrahlung was not considered. For reference, external dose factors as used by the look-up tables tool are provided in Appendix 2.

External doses from contaminated soil being transported indoors by, for instance, footwear was not considered.

2.2.2 *Dermal contact with contaminated soil*

Whilst outdoors, an individual's skin can become contaminated with soil. The average concentration in material on the skin is assumed to be equal to the average exposed concentration in the soil.

For each radionuclide, the effective dose from contaminated soil on the skin, D_{skin} (mSv y^{-1}) is given by:

$$D_{skin} = W_t * F_{UV} * C_{soil} * occ * \rho_{skin} * \tau_{skin} * (DF_{\gamma,R} + DF_{\beta,R}) * 1000 \qquad (2)$$

where:

W_t	tissue weighting factor for ultraviolet (UV) exposed skin (= 0.01, ICRP, 1991);
F_{UV}	fraction of ultra-violet (UV) exposed skin contaminated with soil (= 0.5) considered independent of age and half the UV exposed area being represented by the face, neck, and the outer aspects of the hands and arms;
C_{soil}	soil radionuclide concentration (Bq g^{-1}) within the ground;
occ	occupancy (h y^{-1}) with contaminated soil on the skin;

ρ_{skin} density of the deposit on the skin (= 0.5 g cm^{-3}, for dispersible solids, Harvey *et al.*, 1993);
τ_{skin} thickness of the deposit on the skin (= 0.01 cm, Harvey *et al.*, 1993); and

$DF_{\gamma,R}$
$DF_{\beta,R}$ skin equivalent dose rate to the basal layer of the skin epidermis for gamma irradiation (7 mg cm^{-2}) and beta irradiation (4 mg cm^{-2}) from radionuclide R, Sv h^{-1} per Bq cm^{-2} (Mobbs and Harvey, 2000). These skin equivalent dose rates which are not dependent on age are given in Appendix 3.

In the look-up tables tool, the user must provide an estimate of occupancy for the exposure group of interest that accounts for the length of time per year with dirt on the skin.

Note:
It should be observed that from the W_t and F_{UV} parameter values above, the equivalent dose to the skin is 200 times larger than the effective dose calculated in the look-up tables. A comment to this effect is expressed in the appropriate worksheet of the look-up tables.

2.2.3 Inhalation of contaminated dust

Inhalation of contaminated material is assumed to occur for periods of time spent above the contamination and for times spent near to the contamination. The exposure will also depend on what the individual is doing and the level of physical activity that affects the dust loading in air and breathing rates of the individual.

For each radionuclide the inhalation dose D_{inh} (mSv y^{-1}) is calculated as:

$$D_{inh} = C_{dust} * DL * INH * occ * DC_{inh} * 1000 \qquad (3)$$

where:

C_{dust} dust radionuclide concentration (Bq g^{-1});
DL dust loading in air (g m^{-3});
INH inhalation rate (m^3 h^{-1});
occ occupancy (h y^{-1}) at contaminated land site; and
DC_{inh} dose coefficient for inhalation (Sv Bq^{-1}).

Inhalation dose coefficients are considered for infants, children and adult members of the public (ICRP, 1996), for workers who are occupationally exposed (ICRP, 1995a) and for offspring (ICRP, 2002).

In the look-up tables tool, the user must provide estimates of dust loading in air, inhalation rate, and occupancy for the exposure group of interest.

2.2.4 Ingestion of contaminated soil

Inadvertent ingestion of contaminated soil is assumed to occur when there is contaminated soil on the skin, for a fraction of the occupancy at the contaminated land site. For each radionuclide, the dose from inadvertent ingestion of contaminated soil $D_{ing,s}$ (mSv y^{-1}) is calculated as:

$D_{ing,s} = C_{soil} * ING_s * DC_{ing} * 1000$ (4)

where:

C_{soil} soil radionuclide concentration (Bq g^{-1}) within the ground;
ING_s inadvertent ingestion rate of contaminated soil (g y^{-1}); and
DC_{ing} dose coefficient for ingestion (Sv Bq^{-1}).

Ingestion dose coefficients are considered for infants, children and adult members of the public (ICRP, 1996), for workers who are occupationally exposed (ICRP, 1995a) and for offspring (ICRP, 2002).

In the look-up tables tool, the user must provide an estimate of the inadvertent ingestion rate of contaminated soil based on the appropriate length of time during which exposure occurs.

2.2.5 Ingestion of wild foods

For each radionuclide, the dose from ingestion of a particular wild food category (such as fungi) $D_{ing,wf}$ (mSv y^{-1}) is calculated as:

$D_{ing,wf} = C_{soil} * CF_{wf} * ING_{wf} * DC_{ing} * 1000$ (5)

where:

C_{soil} soil radionuclide concentration (1 Bq g^{-1}) within the ground;
CF_{wf} concentration factor for wild food (Bq kg^{-1} fresh weight) in relation to soil (Bq kg^{-1} dry weight);
ING_{wf} ingestion rate of wild food (g y^{-1}); and
DC_{ing} dose coefficient for ingestion (Sv Bq^{-1}).

Ingestion dose coefficients are considered for infants, children and adult members of the public (ICRP, 1996), for workers who are occupationally exposed (ICRP, 1995a) and for offspring (ICRP, 2002).

In the look-up tables, the user can consider the wild food categories of wild fruit and fungi by supplying estimates of corresponding ingestion rates. Wild food categories associated with fauna such as rabbits or pheasants have not been considered due to a lack of radionuclide concentration factor data and the fact that these fauna are mobile and unconstrained. This suggests that they are probably not going to come into contact with contaminated land very often and so their levels of radionuclides will be low.

2.2.6 Ingestion of contaminated water

For each radionuclide, the dose from ingestion of contaminated water $D_{ing,cw}$ (mSv y^{-1}) is calculated as:

$$D_{ing,cw} = C_{dw} * ING_{dw} * DC_{ing} * 1000 \qquad (6)$$

where:

C_{cw} radionuclide concentration of contaminated water (Bq L^{-1});
ING_{cw} ingestion rate of contaminated water (L y^{-1}); and
DC_{ing} dose coefficient for ingestion (Sv Bq^{-1}).

The calculation is based on the input radionuclide concentration being for dissolved contaminant. Guidance is given in Section 4.3.8 for dealing with contaminated suspended solids present in water, if applicable.

Ingestion dose coefficients are considered for infants, children and adult members of the public (ICRP, 1996) and for offspring (ICRP, 2002). Worker dose coefficients are also considered. In the look-up tables, the user needs to provide a water ingestion rate.

2.2.7 Dermal contact with contaminated water

In the context of the exposure pathways described, dermal contact with contaminated water may arise via exposures to radionuclides in the pore water of the soil in contact with the skin and, to a much greater extent, by water splashing on the skin from groundwater during drilling activities. Only the latter has been considered in this report.

For water splashing on skin, it is possible that tritium may be absorbed through the pores of the skin of an individual. As this effect is difficult to quantify from a dosimetric point of view, the dose from tritium absorption from water can be been accounted for by modifying the calculated dose from inhalation for tritiated water by a factor of 1.2 (Appendix 1). Water splashing on skin is not considered an issue for other radionuclides.

2.3 Radionuclides considered

The starting-point for the list of radionuclides to be considered was that used by Entec/NRPB (1999), plus some additional radionuclides which are known to occur on one or more BNFL sites, most of which are considered in Oatway and Mobbs (2003). In addition, further radionuclides have been added in light of suggestions from consultees to the specification and in light of BNFL's experience on NL sites.

Table 1 sets out the radionuclides for consideration. For decay chains, the parent radionuclide is provided in the list. The '+' in the radionuclide name indicates the inclusion of short-lived progeny in secular equilibrium with the parent.

In deriving the list, some radionuclides have been screened out mainly on the basis of having short half-lives (< 1 y). These radionuclides include Be-7, Zr-95, Nb-95, Ag-110m and Ce-144.

Some radionuclide decay chains such as those headed by Th-230, Th-232, Pa-231, U-233, U-234, U-236, Pu-238, Pu-239, Pu-240, Pu-242 and Am-241, along with key progeny, have long half-lives relative to the likely period covered by contaminated land assessments and are only included as single radionuclides.

Guidance for dealing with natural uranium and depleted uranium based on mass compositions of U-234, U-235 and U-238 is provided in Section 4.

Table 1: Radionuclides considered in the look-up tables

	Parent	Progeny assumed in secular equilibrium
1	H-3	
2	C-14	
3	Cl-36	
4	K-40	
5	Co-60	
6	Sr+90	Y-90
7	Tc-99	
8	Ru+106	Rh-106
9	Sn-126	Sb-126m Sb-126
10	I-129	
11	Cs-134	
12	Cs+137	Ba-137m
13	Pb+210	Bi-210
14	Po-210	
15	Ra+226	Rn-222 Po-218 Pb-214 Bi-214 Po-214
16	Ra+228	Ac-228
17	Th+228	Ra-224 Rn-220 Po-216 Pb-212 Bi-212 Po-212 Tl-208
18	Th+229	Ra-225 Ac-225 Fr-221 At-217 Bi-213 Po-213 Pb-209
19	Th-230	
20	Th-232	
21	Pa-231	
22	U-233	
23	U-234	
24	U+235	Th-231
25	U-236	
26	U+238	Th-234 Pa-234m Pa-234
27	Np+237	Pa-233
28	Pu-238	
29	Pu-239	
30	Pu-240	
31	Pu-241	
32	Pu-242	
33	Am-241	
34	Cm-242	
35	Cm-243	
36	Cm-244	

3 LOOK-UP TABLES TOOL

3.1 Structure of the tool

The look-up tables tool RADCONTAB have been produced using a Microsoft Excel© spreadsheet and comprise worksheets as detailed in Table 2. The Microsoft Excel software is commercially available and can satisfactorily house the look-up tables functionality. It also facilitates user friendly interaction with the look-up tables via ease of data entry and instantaneous production of results.

Table 2: Worksheet functionality of look-up tables spreadsheet tool RADCONTAB

Worksheet name	**Function**
Title	Title, author, date and version of look-up tables
DHistory	Development history sheet
Overview	Overview (summary) information on the functionality of the look-up tables
Instruction	Salient instruction on how to use the look-up tables (in the absence of this report)
Scenario Information	Information on the contaminated land scenario to be assessed by the look-up tables
Inh dust	Calculates dose resulting from inhalation of dust exposure pathway (Section 2.2.3) Also, offers guidance on dealing with water splash via the inhalation pathway (Section 2.2.7)
Ing soil	Calculates dose resulting from ingestion of soil exposure pathway (Section 2.2.4)
Ing wild food (fruit)	Calculates dose resulting from ingestion of wild food (fruit) exposure pathway (Section 2.2.5)
Ing wild food (fungi)	Calculates dose resulting from ingestion of wild food (fungi) exposure pathway (Section 2.2.5)
Ing water	Calculates dose resulting from ingestion of water exposure pathway (Section 2.2.6)
Skin dose	Calculates skin dose from contact with soil (Section 2.2.2)
Ext dose surface	Calculates external irradiation from surface contamination for four geometries (Section 2.2.1)
Ext dose shallow	Calculates external irradiation from shallow volume contamination for four geometries (Section 2.2.1)
Ext dose deep	Calculates external irradiation from deep volume contamination for four geometries (Section 2.2.1)
Ext dose burial	Calculates external irradiation from buried contamination for two geometries (Section 2.2.1)
Overview – Total Dose	Calculates total dose from combinations of individual exposure pathway calculations with associated overview (input parameter) data

Worksheet name	Function
Constants [ref only]	Single value constants for exposure pathway calculations (Section 2.2.2)
Wild foods [ref only]	Radionuclide concentration factors for categories of wild foods with respect to soil (Appendix 4)
Ext dose factor [ref only]	External irradiation dose factor (from Microshield calculations) for radionuclides and all geometries (Appendix 2)
Dose co intskin [ref only]	Inhalation and ingestion committed effective dose coefficients for intakes of radionuclides; also skin dose factors (Appendices 1 and 3)
References	References of data sources within the spreadsheet tool

Table 2 shows that there are a number of worksheets, essentially the look-up tables, associated with the exposure pathway calculations described in Sections 2.2.1 to 2.2.7. These worksheets advise and allow the user of the look-up tables to provide input to adapt their assessments to their particular site. They then calculate whole body effective dose per unit activity concentrations for every radionuclide listed drawing upon data provided in other reference worksheets and described in Appendices 1 to 4. For each exposure pathway calculation, the user may also specify activity concentrations for a number of radionuclides if for instance a number of appropriate measurements are available. This will enable whole body effective doses summed over all relevant radionuclides for particular exposure pathways to be assessed.

3.2 Input data entry and output

At the top of each look-up table worksheet in RADCONTAB, there is an input panel where, following user entry of data, the look-up table values are automatically tabulated below for each radionuclide.

To assist the user in entering input data, guidance as described in Section 4 is provided along side the input panel.

Table 3 shows that the look-up tables allow the user to provide a particular choice of Age Group. For each user choice, the appropriate values for the parameters as shown in Table 3 are automatically selected from the reference worksheets and used in the look-up table calculations.

Table 3: User choices for an input data category and parameters selected

Input data category	User choices	Selected parameters for user choice [reference worksheet]
Age Group	Adult public Adult worker * Child 10 y Infant 1 y Offspring public Offspring worker *	Inhalation dose coefficient Ingestion dose coefficient Offspring dose coefficient [Dose co intskin]

* not applicable to Ing wild foods worksheets

There are a number of situations where dose values cannot be calculated, including instances of missing input data and (as described in Section 2.1) where offspring doses do not exceed corresponding adult doses. Table 4 explains the responses of the look-up table worksheets when dose values cannot be calculated.

Table 4: Responses of the look-up table worksheets when dose values cannot be calculated.

Look-up table response	Explanatory comments
No Dose Data	Appears in all worksheets associated with dose calculations for internal intakes when there is a lack of radionuclide dependent dose coefficient data for Offspring and Offspring worker (see [Dose co intskin [ref only]] worksheet). This response will have precedence over the lack of fungi data described below.
No Fungi Data	Appears in the [Ing wild food (fungi)] worksheet when there is a lack of radionuclide dependent concentration factor data for fungi in [Wild foods [ref only]] worksheet.
< Adult	Appears in all worksheets associated with dose calculations for internal intakes, for the Age Group selection of 'Offspring' when the doses do not exceed the corresponding adult ones (see Section 2.1).
< Adult worker	Appears in all worksheets associated with dose calculations for internal intakes, for the Age Group selection of 'Offspring worker' when the doses do not exceed the corresponding adult worker ones (see Section 2.1).

4. GUIDANCE ON INPUTS

4.1 Introduction

This section provides users of the look-up tables tool RADCONTAB version 1.0 with guidance on choices of assumptions and parameter values which must be input by the user. This guidance is of two main types:

- qualitative guidance, designed to prompt the user to 'ask the right questions' when choosing assumptions and parameter values; and
- quantitative guidance, referring to commonly used values or ranges of values.

The quantitative guidance is set out in tabular format, which is replicated within the spreadsheet tool.

In most situations, there will be large uncertainties associated with the quantification of most if not all exposure pathways. It is strongly recommended that the spreadsheet tool should be used to explore these uncertainties, rather than just performing a single set of 'best estimate' calculations. The nature of the uncertainty analysis will be for the user to determine, taking account of which exposure pathways are capable of being significant contributors to total dose, and which input parameters are subject to largest relative uncertainty.

Qualitative and quantitative guidance is provided below and is addressed in terms of supplementing in an ordered manner the functional information given in Section 2.

4.2 Selection of exposure groups

From Section 2.1, exposure groups have been identified in relation to contaminated land and NL sites. For assessments, they do not need to cover every age group and can be truncated to cover age ranges of members of the public and adult workers as such:

- adult worker;
- adult member of the public;
- child (10 years old);
- infant (1 year old);
- offspring of worker (foetal dose); and
- offspring of member of the public (foetal dose).

Having identified the types of exposure groups, careful attention should be given to the selection of their habits and subsequent exposure pathways associated with them. As the term 'group' is used, exposure to radiation should be relatively homogeneous throughout the group. The exposed group receiving the highest dose is known as the critical group. RADCONTAB can be used to investigate the doses to a number of exposed groups, so that the critical group can be identified.

For doses to the public, the ‘critical group’ concept and its application are discussed in detail in ICRP Publications 42 and 43 (ICRP, 1985a and ICRP, 1985b). They are also developed in ICRP publication 81 (ICRP, 2000). The critical group is intended to be representative of those individuals in the population expected to receive the highest dose (ICRP, 1977).

Users of the spreadsheet tool RADCONTAB are particularly recommended to refer to the UK environmental regulators’ Principles for Assessment of Prospective Public Doses document dealing with discharges to the atmosphere and aquatic environment (Environment Agency *et al*., 2002), and the Guidance on Requirements for Authorisation document for dealing with disposals of radioactive waste to land (Environment Agency *et al*., 1997). It should be noted that neither of these UK guidance documents is designed with the assessment of contaminated land on Nuclear Licensed Sites in mind. Users should in particular bear in mind the intended period of relevance of their assessments, and therefore the extent to which exposure group habits should solely reflect current conditions or anticipate potential future conditions and behaviours. Users should also consider whether their assessments are intended to be ‘cautious’ or ‘realistic’ (see Environment Agency *et al*., 2002).

Exposure groups should be chosen not only to cover all reasonable patterns of behaviour at the contaminated site, but uncertainties associated with them. Local habit data (backed up by habit surveys where appropriate) should be used to quantify the habits with regard to exposure of members of the public. For exposure to workers on site, it should be possible to determine habits from work schedules and practice. In the absence of dietary survey data, BIOMASS (IAEA-BIOMASS-6, 2003) have concluded that using consumption rate figures in the range of the 95^{th} and the 97.5^{th} percentiles (of national data) to define a critical group is cautious but reasonable.

The choice of exposure groups is for the user to justify. Factors to bear in mind include the following:

- It may be appropriate to treat visitors to the site and workers on the site who are not engaged in work directly related to the contaminated ground as members of the public, since the differences in ICRP dose factors between workers and members of the public reflect assumptions about what these exposure groups are typically doing. For further discussion of the distinction between workers and members of the public, see Environment Agency *et al*. (2002).
- Foetal doses as described in Section 2.1 should be considered (if only to dismiss them) if an assessment is to be considered complete by modern standards. Such doses to pregnant women will only be calculated for certain radionuclides where they are greater than corresponding adult doses which is in keeping with NRPB advice.

It is worth noting that there are uncertainties associated with the derivation of the tabulated age-dependent ICRP inhalation and ingestion dose coefficients in Appendix 1 based on metabolic modelling of radionuclide intakes. These uncertainties are outside the scope of the look-up tables tool RADCONTAB. It should also be noted that the ICRP are currently in the process of preparing revised recommendations, which will include revised dose coefficients, though the timescale for publication of these revised recommendations is not clear at present.

4.3 Contaminated environmental media and exposure pathways

4.3.1 Concentrations of radionuclides in soil or water

Careful attention should be paid to the input concentrations of radionuclides in soil or water. These should not necessarily be the average (or maximum) concentrations, and there may be reasons for specifying different concentrations for different spreadsheet tool exposure pathways. Also, for radionuclides that are difficult to measure, it may be unwise to adopt a ‘fingerprint’ approach relating to scaling factors and certain measurable radionuclides because of different environmental mobilities applying to different radioelements.

The guiding principle is that the input concentrations should be appropriate to the particular medium relevant to the exposure pathway. For example:

- If the external radiation dose is being calculated using the geometry of a 10 m diameter patch of contamination (and occupancy relates to that 10 m diameter area), it would be highly pessimistic to apply the maximum observed concentration to the whole of that patch of contamination.
- The effective concentration of a radionuclide in gravelly soil for the purposes of external radiation dose may be substantially less than the concentration in dust for inhalation, if the radionuclide is mainly associated with the fine soil particles.
- For the purpose of assessing dermal contact with contaminated soil, the concentration in the contacting soil/sediment may not be the same as the bulk concentration in the ground.
- The concentration of a radionuclide in groundwater measured in a borehole may be substantially higher than the typical concentration in a stream fed by the groundwater, due to diluting surface water.

Clearly, these are site-specific considerations that the user must address.

4.3.2 Occupancies

Occupancies are for the user to specify. Care must be taken to ensure that occupancies are appropriate to the exposure pathway as well as the exposure group. For example, for the same exposure group, the occupancy pertinent to standing on a patch of contaminated ground may be quite different from that pertinent to dust inhalation.

It may be helpful to note that 1800 h y^{-1} (240 d y^{-1} and 7.5 h d^{-1}) is generally considered a typical working year. Worker occupancies with respect to contaminated ground are likely to be substantially less than this.

4.3.3 External irradiation from contaminated ground

The only additional choice required for this pathway (other than occupancy) is the geometry assumption. The assumptions for which calculations are provided by the spreadsheet tool (Section 2.2.1) are designed to cover a reasonable range of geometries that will approximate or bound the exposures from the actual geometry. It is recommended that a number of geometries should be explored to gain a balance between pessimistic (bounding) and realistic exposures, and/or to take into account uncertainty in the actual geometry of the contamination.

4.3.4 Dermal contact with contaminated soil

Dermal contact with contaminated soil is a difficult exposure pathway to quantify. It is considered likely to be only significant in the context of ‘worker’ scenarios involving excavations into contaminated ground or the handling of contaminated sediments.

The occupancy for this pathway is the contact time with the contaminated soil, rather than the duration of being present at the point where the contamination was encountered. Consideration needs to be given to how long the exposed person would retain the contaminated soil/sediment on their skin before having it washed off. The use of personal protective equipment also needs to be factored into the assessment, if applicable.

The comments in Section 4.3.1 with regard to radionuclide concentrations in the contacting soil/sediment being different to the bulk concentration in the ground are relevant to this pathway.

4.3.5 Inhalation of contaminated dust

This exposure pathway requires input of exposure group, occupancy, dust loading in air and inhalation rate. Inhalation dose coefficients are also inherent in the exposure calculations and are dependent on the size and shape of different aerosol particles. As described in Appendix 1, these dose coefficients are derived from theoretical studies based on a 1 μm activity median aerodynamic diameter (AMAD) particle size for members of the public and a larger 5 μm AMAD particle size for workers.

In terms of input for this exposure pathway, exposure group and occupancy are for the user to justify.

Parameter values for dust loading in air and inhalation rate should take account of published values, as follows.

<u>Dust loading in air</u>

The dust loading in air is a highly variable parameter, depending upon the nature of the ground/soil (including the extent of vegetation or other ground cover) and the activity (if any) taking place on the contaminated area. It is also dependent on the weather at the time of exposure and any mitigation measures such as damping-down or use of respiratory protection equipment. For further reading, dust loading in air is described in detail in NCRP (1999).

For scenarios that are analogous to the exposure groups and exposure pathways considered in Sections 2.1 and 2.2, Oatway and Mobbs (2003) use the following values for dust loading in air:

- 5E-03 g m^{-3} for workers on construction sites engaged in dust-generating activities (‘construction active’);
- 5E-04 g m^{-3} for workers on construction sites not engaged in dust-generating activities (‘construction passive’);
- 1E-04 g m^{-3} for workers on industrial sites not engaged in dust-generating activities (‘industrial passive’);
- 1E-03 g m^{-3} for members of the public engaged in dust-generating recreational activities such as outdoor sports (‘recreation active’); and
- 1E-04 g m^{-3} for members of the public not engaged directly in dust-generating recreational activities such as outdoor sports (‘recreation passive’).

The comments in Section 4.3.1 with regard to radionuclide concentrations in dust being potentially different from concentrations in soil are relevant to this pathway.

Inhalation rate

Inhalation rates are quite well established in the literature, and the values used by Oatway and Mobbs (2003) are generally applicable:

- 1.18 m^3 h^{-1} for ‘passive’ adults;
- 1.69 m^3 h^{-1} for ‘active’ adults;
- 0.87 m^3 h^{-1} for children (no ‘active’/‘passive’ distinction); and
- 0.31 m^3 h^{-1} for infants (no ‘active’/‘passive’ distinction).

Note that the ‘active’/‘passive’ distinction needs to be consistent with the specified dust loading in air.

The following table summarises the guidance given above on dust loadings in air and inhalation rates and appears within the spreadsheet tool.

Dust loading in air (g m^{-3}) - Oatway & Mobbs (2003) Construction passive 5E-04; Construction active 5E-03; Industrial passive 1E-04 Recreation passive 1E-04; Recreation active 1E-03.
Inhalation rate (m^3 h^{-1}) - Oatway & Mobbs (2003) Adult: Construction/Industrial/Recreation passive 1.18; Construction active 1.69 Child: Recreation (passive/active) 0.87; Infant: Recreation (passive/active) 0.31

4.3.6 Ingestion of contaminated soil

Ingestion of contaminated soil is a difficult exposure pathway to quantify. If this pathway is to be assessed, careful thought needs to be given to the mechanism(s) of soil ingestion that are applicable to the scenarios being considered. Some potential scenarios that might be included are:

- inadvertent ingestion of contaminated sediment associated with drinking from a contaminated spring or stream;
- inadvertent ingestion of contaminated soil or stream sediment by children; and
- ingestion of soil from incompletely washed wild food (e.g. contaminated soil adhering to fungi or contaminated dust adhering to wild fruit).

Some of the above examples imply an association with a different exposure pathway (e.g. drinking water or wild food consumption). Clearly, the intake rate assumptions for such associated pathways should be self-consistent.

The following examples give a broad indication of the types of numbers that have been used by others in assessments of this type of exposure pathway:

For soil ingestion rates, the following average values for inadvertent soil consumption over the course of a year from Smith and Jones (2003) have been advocated for assessments:

- 3.7 g y^{-1} for adults;
- 11 g y^{-1} for children; and
- 37 g y^{-1} for infants.

However, the above figures are based on assumptions unlikely to be applicable to a NL site, including a range of human behaviours that may be associated with inadvertent soil consumption over the course of a year, regardless of whether the soil is known to be contaminated or not. For the spreadsheet tool calculations, ingestion rates solely of contaminated soil are required. Therefore the values above (if used at all) should be considered alongside the fractional annual occupancy of the contaminated land site and the time during which ingestion of contaminated soil can occur.

It is worth noting that the pathological condition ‘pica’, in which infants consume unusually high quantities of soil, can result in soil ingestion rates of the order of 10 g d^{-1} whilst outside playing on the ground (USEPA, 1989). However, there would have to be exceptional reasons for including assessment of this scenario in relation to contaminated ground on a NL site. For further reading, soil ingestion rates are described in detail in NCRP (1999).

The following table summarises the guidance given above on contaminated soil ingestion rates and appears within the spreadsheet tool.

Annual soil and sediment ingestion rates (g y^{-1}) - Smith and Jones (2003) **Average:** Adult: 3.7; Child: 11; Infant: 37 **Critical** (based on a scaled up hourly rate)**:** Adult: 43.8; Child: 87.6; Infant: 438
Contaminated soil ingestion rates should ideally be less than these values as fractional annual occupancy of the contaminated land should be considered in conjunction with the proportion of this time a person has soil on their skin.
As a guide to determining an appropriate contaminated soil ingestion rate (g y^{-1}) consider - the average ingestion rate for relatively long periods of time (e.g. months) on the contaminated land for passive activities not involving significant ground disturbance. -the critical ingestion rate for relatively short periods of time (hours/days) on the contaminated land for largely physical activities (such as digging) involving significant ground disturbance.

Critical rates are also provided from Smith and Jones (2003) for dealing with contaminated soil ingestion rates for highly physical activities (such as digging) over shorter time periods (hours/days).

4.3.7 Ingestion of contaminated wild foods

Assessment of the consumption of wild foods using the spreadsheet tool requires a choice of foods (wild fruit and/or fungi). There may be site-specific information which allows one or both of these types of foods to be dismissed. Inherent in the calculation are uncertainties in the uptake kinetics of radionuclides from soil to the wild foods which are dealt with via simple equilibrium concentration factors described in sections 2.2.5 and Appendix 4.

The remaining input parameter is then the ingestion rate for each type of wild food. This parameter should be based on common-sense consideration of the likely habits of people gathering wild foods.

Table 5 provides mean and 97.5th percentile ingestion rates from Green *et al*. (1999) for blackberries and field mushrooms collected by people living in the vicinity of a number of nuclear sites, considering those individuals who engage in such activities. These particular foodstuffs have been considered as the most appropriate examples of fruit and fungi on the basis of being the most likely wild foodstuffs to be gathered by the public[8].

[8] Chanterelle mushrooms have also been obtained and consumed from near the Cardiff site. However, they have not been considered in the look-up tables because only one consumer appears to have been studied from the data in Green *et al*. (1999).

Table 5: Ingestion rates (kg y^{-1}) of blackberries and field mushrooms around nuclear sites

		Aldermaston	Cardiff	Hinkley	Sizewell
Blackberries	Mean	2.48	4.71	3.50	2.40
	97.5^{th} percentile	11.2	16.8	16.8	11.2
Field mushrooms	Mean	3.34			
	97.5^{th} percentile	16.8			

Note that these consumption rates are for the total annual 'crop', of which only a small fraction is likely to be gathered from the contaminated area. The amount of wild food assumed to be gathered from a contaminated area on a NL site must take account factors such as the size of the contaminated area, the potential for wild food growth and accessibility.

If sources of wild food consumption data other than those summarised above are to be used, care must be taken not to inadvertently use literature values for consumption rates of cultivated fruit or fungi, applicable to agricultural/horticultural use of the land.

As mentioned in Section 4.3.6, the user may wish to assess the additional dose (from soil ingestion) from consumption of incompletely washed wild food.

The following table summarises the guidance given above on ingestion of wild foods and appears within the spreadsheet tool.

For wild fruit, guidance is provided for blackberries, the most likely foodstuff to be gathered.
Annual ingestion rate (g y^{-1}) ranges of blackberries - Green *et al.* (1999) Blackberries mean consumption 2400 - 4700; 97.5^{th} percentile (11,000 - 17,000)
For contaminated wild fruit, these ranges of annual ingestion rates reflect total annual cropping amounts previously measured at various locations. They should be used as an upper bound in exceptional scenarios as it is more likely that only a small fraction of the annual crop will be contaminated.

For fungi, guidance is provided for mushrooms, the most likely foodstuff to be gathered.
Annual ingestion rate (g y^{-1}) ranges of field mushrooms - Green *et al.* (1999) Field mushrooms mean consumption 3300; 97.5^{th} percentile (17,000)
For contaminated wild fungi, these annual ingestion rates should be used as an upper bound in exceptional scenarios as it is more likely that only a small fraction will be contaminated.

4.3.8 Ingestion of contaminated water

On NL sites where there is radioactive contamination of the ground, site characterisation will usually yield data for radionuclide concentrations in groundwater. Typically, such groundwater will not be in use as drinking water, whether as a water supply or in the context of outdoor recreational activity. Nevertheless, it may be useful to be able to set the observed concentrations in context by asking the 'what if?' question with respect to consumption of contaminated groundwater (or surface water). In that context, it is helpful to specify the consumption rate as a fraction of the total annual intake. Typical values for total annual intakes of drinking water in the UK are as follows (Smith and Jones, 2003):

- adult 600 L y^{-1};
- child 350 L y^{-1}; and
- infant 260 L y^{-1}.

Clearly, only for illustrative purposes or exceptional scenarios would it be appropriate to specify a total annual drinking water intake value.

If an explicit scenario is to be represented, such as drinking water from a contaminated spring or stream during recreational activity, care must be taken not to make the consumption rate excessively large. The consumption rate should be based on the amount of occasional spring/stream water consumed multiplied by the number of visits per year water is consumed. For spring water consumption, it is likely that handfuls or scoops of water are consumed which may suggest that about 1 L y^{-1} of water is reasonable for a number of visits. With more voluminous and accessible stream water, this rate is likely to be higher perhaps amounting to at most a few litres per year.

As mentioned in Section 4.3.6, the user may wish to assess the additional dose from consumption of contaminated suspended solids present in the water. This is most easily done using a soil ingestion calculation, but care must be taken to ensure that the suspended solids ingestion rate and the radionuclide concentrations are appropriate to the suspended solids exposure pathway (the concentrations in suspended solids are very unlikely to be the same as in bulk soil).

The following table summarises the guidance given above on contaminated soil ingestion rates and appears within the spreadsheet tool.

Annual ingestion rates (L y^{-1}) of drinking water - Smith and Jones (2003) Adult: 600; Child: 350; Infant: 260.
For contaminated drinking water, these values are provided as guidance and should be used as an upper bound in exceptional scenarios. Values of the order of a few litres per year may be more appropriate.

4.3.9 Absorption of tritium from water

Absorption of tritium from water could be associated with recreational scenarios, but is most likely to be significant in the context of 'worker' activities such as drilling or excavation below the water table. For water splashing on the skin, it is possible that tritium may be absorbed through the pores of the skin of an individual. As this effect is difficult to quantify from a dosimetric point of view, the dose from tritium absorption from water can be accounted for by modifying the calculated dose from inhalation for tritiated water by a factor of 1.2 (Appendix 1). Water splashing on skin is not considered an issue for other radionuclides.

The following table summarises the guidance given for the absorption of tritium from water through the pores of the skin. The multiplication factor is applicable to sedentary adults taking very little physical exercise and so the guidance relates to selection of only the adult (public) age group.

As the guidance is linked to a modification of inhalation dose, it appears within the 'Inh dust' worksheet of the spreadsheet tool. The reference in the guidance is referred to as ICRP (1995b) within this report.

Water splashing on skin may be considered in terms of tritiated water H-3 (H2O) and the adult group only by application of a multiplication factor of 1.2 to the calculated inhalation dose (ICRP, 1995).

4.4 Radionuclides

The user must be mindful of the nature and extent of the radionuclide activity concentration data, particularly with regard to the progeny included in secular equilibrium in Table 1 and also the time when the measurements were taken. If for instance there is a contaminated land sample with a Pb-210 measurement, but with no Po-210 measurement then it may be prudent to perform a look-up table calculation for Po-210 at the same activity concentration as the measured Pb-210.

Regarding the timing of measurements, Am-241 ingrowth may be an issue for historic measurements of Pu-241. Although the activity ratio of Am-241 to the parent radionuclide of Pu-241 is about 0.03, albeit within the first 100 y (ECDGE, 2000), its ingestion and inhalation dose coefficients are factors of 20-70 higher than for Pu-241 (Appendix 1). For past measurements of Pu-241, it therefore may be prudent to also undertake a look-up table calculation for Am-241 based on 3% activity of the Pu-241.

The look-up tables do not specifically deal with natural uranium and depleted uranium. However, users can deal with these using an assumed isotopic composition and combining the data from U-234, U-235, U-236 and U-238 that are individually dealt with in the look-up tables. Guidance on the isotopic composition of natural and depleted uranium is provided in

Table 6 on the basis of activity. It should be noted that the composition of depleted uranium can vary depending on the mass of U-235; the data provided in Table 6 assume 0.2% mass U-235 which is typical for depleted uranium used in weapons and armour (Royal Society, 2001).

Table 6: **Activity fractional (%) composition of natural and depleted uranium**

Natural uranium		**Depleted uranium**	
U-234	49	U-234	15.53
U-235	2	U-235	1.07
U-236	not applicable	U-236	0.05
U-238	49	U-238	83.35

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6. ACKNOWLEDGEMENTS

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APPENDIX 1: INHALATION AND INGESTION DOSE COEFFICIENTS

The inhalation and ingestion dose coefficients used in this tool are taken from the current ICRP recommendations. It should be noted that ICRP are currently in the process of preparing revised recommendations though the timescale for publication of these revised recommendations is not clear at present.

Inhalation dose coefficients given in Table A1 are considered for infants (1 y), children (10 y) and adult members of the public (ICRP, 1996) and for workers who are occupationally exposed (ICRP, 1995a). Also considered are dose coefficients to the offspring (as defined in Section 2.1) of members of the public and workers (ICRP, 2002). The dose coefficients are expressed in bold typeface for each radionuclide and for decay chains are calculated in terms of the parent by adding the activity ratio weighted dose coefficients (where they are known) of each short-lived progeny in secular equilibrium. With the exception of Sn-126, the activity ratio for daughter radionuclides considered in secular equilibrium in relation to the parent have been used from an ECDGE (2000) report. The activity ratio values are given for the maximum activity within the first 100 years. For Sn+126, daughter yields for Sb-126 and Sb-126m are provided from ICRP (1983).

It should be noted that although all available offspring dose coefficients are listed from ICRP (2002), only those offspring dose coefficients that exceed the corresponding adult dose coefficients are used in the look-up tables. This is because offspring doses for pregnant women are calculated only for certain radionuclides where they are greater than corresponding adult doses. For the inhalation exposure pathway, the only radionuclides considered are organically bound tritium (H-3 (OBT)) (both offspring cases), and tritiated water (H-3 (H_2O)) and Tc-99 for the offspring of workers.

For the public, 1 μm activity AMAD particles are considered and 5 μm AMAD particles are considered for the worker. The inhalation dose coefficients for members of the public are based on ICRP (1996) recommended default absorption types in body fluids. They are categorised as being fast (Type F – in green), moderate (Type M – in yellow) or slow (Type S – in blue). This categorisation also applies to the worker using recommendations for unspecified compounds in Annex F of ICRP (1995a). In the absence of recommended default absorption types, the most restrictive ICRP dose coefficients are used which apply to radionuclides designated by an asterisk (*) and listed in terms of the colour coded absorption type in Table A1. This colour coding scheme for absorption type is purely for the benefit of deriving the appropriate dose coefficients for inhalation and in some cases ingestion and is not used in the look-up tables tool itself.

For water splashing on skin, it is possible that tritium may be absorbed through the pores of the skin of an individual. As this effect is difficult to quantify from a dosimetric point of view, the dose from tritium absorption from water can be accounted for by multiplying the calculated look-up table dose from inhalation for H-3 (H_2O) by a scaling factor of 1.2. This does not apply to H-3 (OBT) considered in Table A1. The factor of 1.2 arises from ICRP (1995b) that states that for a male sedentary individual, the intake from tritiated water through the skin is one-third of the total intake or one-half of the intake from inhalation. For a more active person, these assumptions equate to a scaling factor of 1+ (0.5*sedentary breathing rate/other breathing rate). Using an adult sedentary breathing rate of 0.54 $m^3 h^{-1}$ to reflect inactivity and other adult breathing (inhalation) rates ($m^3 h^{-1}$) as given in Section 4.3.5 for the various activities defined results in the scaling factor (to one decimal place) of 1.2. The contribution from tritium absorption is less for more physically demanding activities as the inhalation rate is greater.

Radon (Rn-222) gas within the Ra-226 decay chain is not considered because only inhaled particulate are considered in deriving the dose coefficients hence these coefficients are not provided for radon in the ICRP references already cited. Radon gas of short half-life (3.8 days) is more of an issue for dwellings where the gas may not readily disperse. For the contaminated land exposure pathways, which are based on outdoor activities, the radon gas will readily disperse and not pose any health problems to the exposure groups concerned.

For C-14, adult worker inhalation coefficients are not expressed in particulate form, instead being expressed in gaseous form in Annex C of ICRP (1995a). Therefore for the adult worker, the inhalation dose coefficient as cited for an adult member of the public is used. This also applies to the offspring of workers termed ‘offspring worker’ which uses the same value as the offspring of members of the public termed ‘offspring’.

The worker dose coefficients in ICRP (1995a) are specified for uranium in terms of U compounds. Therefore for uranium, type M is used which is consistent with the dose coefficients for the members of the public. Type M applies to the less soluble uranium compounds e.g. UO_3, UF_4, UCl_4 and most other hexavalent compounds. Type M uranium dose coefficients tend to be of intermediate value in relation to the other types of coefficients.

Ingestion dose coefficients are considered in Table A2 for infants, children and adult members of the public (ICRP, 1996), for workers who are occupationally exposed (ICRP, 1995a) and for offspring and the offspring of workers (ICRP, 2002). For the adult worker group only, the colour coded absorption type in body fluids as previously described also applies to a number of radionuclides in Table A2.

The yield factor (or activity ratio) in Table A2 for daughter radionuclides considered in secular equilibrium in relation to their parent have been used from the ECDGE (2000) report. The layout of Table A2 is as described for Table A1 in terms of having to add the activity weighted dose coefficients of progeny in secular equilibrium with parent radionuclides in a number of decay chains.

For the ingestion exposure pathway, the offspring doses to pregnant women are calculated only for the following radionuclides where they are greater than corresponding adult doses.

	Offspring	**Offspring (of) Workers**
H-3 (OBT)	*	*
H-3 (H_2O)	*	*
C-14	*	*
Sr+90	*	*
Ra+226	*	*
Th+228	*	*

	Offspring	Offspring (of) Workers
U-233		*
U-234		*
U+235		*
U-236		*
U+238		*

Table A1: Inhalation dose coefficients (Sv Bq^{-1}) to members of the public and workers

	Radionuclides	1 y	10 y	Adult	Adult W	Offspring	Offspring W	activity ratio
1	H-3 (OBT)	2.7E-10	8.2E-11	4.5E-11	4.1E-11	6.3E-11	6.3E-11	
	H-3 (H2O)	2.7E-10	8.2E-11	4.5E-11	1.8E-11	3.1E-11	3.1E-11	
2	C-14	6.6E-09	2.8E-09	2.0E-09	2.0E-09	6.6E-11	6.6E-11	
3	Cl-36*	2.6E-08	1.0E-08	7.3E-09	5.1E-09	No data	No data	
4	K-40	1.7E-08	4.5E-09	2.1E-09	3.0E-09	No data	No data	
5	Co-60	3.4E-08	1.5E-08	1.0E-08	7.1E-09	1.2E-09	1.3E-09	
6	Sr-90	1.1E-07	5.1E-08	3.6E-08	3.0E-08	8.8E-09	3.1E-08	
	Y-90*	8.8E-09	2.7E-09	1.5E-09	1.6E-09	No data	No data	0.998
	Sr+90	1.2E-07	5.4E-08	3.7E-08	3.2E-08	8.8E-09	3.1E-08	
7	Tc-99	1.3E-08	5.7E-09	4.0E-09	4.0E-10	8.3E-11	4.1E-10	
8	Ru-106	1.1E-07	4.1E-08	2.8E-08	9.8E-09	4.1E-10	1.7E-09	
	Rh-106	No data	No data	No data	No data	No data	No data	1
	Ru+106	1.1E-07	4.1E-08	2.8E-08	9.8E-09	4.1E-10	1.7E-09	
9	Sn-126*	1.0E-07	4.1E-08	2.8E-08	1.4E-08	No data	No data	
	Sb-126m	1.2E-10	3.5E-11	1.9E-11	2.3E-11	No data	No data	1
	Sb-126	1.3E-08	5.1E-09	2.8E-09	1.7E-09	4.0E-10	9.0E-10	0.14
	Sn+126	1.0E-07	4.2E-08	2.8E-08	1.4E-08	No data	No data	
10	I-129	8.6E-08	6.7E-08	3.6E-08	5.1E-08	1.5E-08	2.1E-08	
11	Cs-134	7.3E-09	5.3E-09	6.6E-09	9.6E-09	3.0E-09	4.2E-09	
12	Cs-137	5.4E-09	3.7E-09	4.6E-09	6.7E-09	2.0E-09	2.7E-09	
	Ba-137m	No data	No data	No data	No data	No data	No data	0.946
	Cs+137	5.4E-09	3.7E-09	4.6E-09	6.7E-09	2.0E-09	2.7E-09	
13	Pb-210	3.7E-06	1.5E-06	1.1E-06	1.1E-06	6.1E-08	2.3E-07	
	Bi-210*	3.0E-07	1.3E-07	9.3E-08	6.0E-08	No data	No data	0.995
	Pb+210	4.0E-06	1.6E-06	1.2E-06	1.2E-06	6.1E-08	2.3E-07	
14	Po-210	1.1E-05	4.6E-06	3.3E-06	7.1E-07	1.9E-08	7.8E-08	
15	Ra-226	1.1E-05	4.9E-06	3.5E-06	1.2E-05	9.9E-08	1.8E-07	
	Rn-222	No data	No data	No data	No data	No data	No data	
	Po-218	No data	No data	No data	No data	No data	No data	
	Pb-214	4.6E-08	1.9E-08	1.4E-08	4.8E-09	No data	No data	1
	Bi-214*	6.1E-08	2.2E-08	1.4E-08	2.1E-08	No data	No data	
	Po-214	No data	No data	No data	No data	No data	No data	
	Ra+226	1.1E-05	4.9E-06	3.5E-06	1.2E-05	9.9E-08	1.8E-07	
16	Ra-228	1.0E-05	4.6E-06	2.6E-06	1.7E-06	1.1E-07	1.7E-07	
	Ac-228*	1.6E-07	5.7E-08	2.5E-08	2.9E-08	No data	No data	1
	Ra+228	1.0E-05	4.7E-06	2.6E-06	1.7E-06	1.1E-07	1.7E-07	
17	Th-228	1.3E-04	5.5E-05	4.0E-05	2.3E-05	2.9E-08	9.0E-07	
	Ra-224	8.2E-06	3.9E-06	3.0E-06	2.4E-06	4.0E-08	1.1E-07	0.973
	Rn-220	No data	No data	No data	No data	No data	No data	0.973
	Po-216	No data	No data	No data	No data	No data	No data	0.973

	Radionuclides	1 y	10 y	Adult	Adult W	Offspring	Offspring W	activity ratio
	Pb-212	4.6E-07	2.2E-07	1.7E-07	3.3E-08	No data	No data	0.973
	Bi-212*	1.1E-07	4.4E-08	3.1E-08	3.9E-08	No data	No data	0.973
	Po-212	No data	No data	No data	No data	No data	No data	0.6237
	Tl-208	No data	No data	No data	No data	No data	No data	0.3493
	Th+228	**1.4E-04**	**5.9E-05**	**4.3E-05**	**2.6E-05**	**6.8E-08**	**1.0E-06**	
18	Th-229	1.9E-04	8.7E-05	7.1E-05	6.9E-05	No data	No data	
	Ra-225	1.8E-05	8.4E-06	6.3E-06	4.8E-06	No data	No data	1
	Ac-225*	2.3E-05	1.1E-05	8.5E-06	1.0E-06	No data	No data	1
	Fr-221	No data	No data	No data	No data	No data	No data	1
	At-217	No data	No data	No data	No data	No data	No data	1
	Bi-213*	1.2E-07	4.4E-08	3.0E-08	4.1E-08	No data	No data	1
	Po-213	No data	No data	No data	No data	No data	No data	0.9784
	Pb-209	2.7E-10	9.2E-11	5.6E-11	3.2E-11	No data	No data	1
	Th+229	**2.3E-04**	**1.1E-04**	**8.6E-05**	**7.5E-05**	No data	No data	
19	Th-230	**3.5E-05**	**1.6E-05**	**1.4E-05**	**2.8E-05**	**2.6E-08**	**7.7E-07**	
20	Th-232	**5.0E-05**	**2.6E-05**	**2.5E-05**	**2.9E-05**	**2.8E-08**	**8.3E-07**	
21	Pa-231*	**2.3E-04**	**1.5E-04**	**1.4E-04**	**8.9E-05**	No data	No data	
22	U-233	**1.1E-05**	**4.9E-06**	**3.6E-06**	**2.2E-06**	**5.0E-08**	**4.0E-08**	
23	U-234	**1.1E-05**	**4.8E-06**	**3.5E-06**	**2.1E-06**	**4.9E-08**	**4.0E-08**	
24	U-235	1.0E-05	4.3E-06	3.1E-06	1.8E-06	4.5E-08	3.7E-08	
	Th-231	1.7E-09	5.2E-10	3.3E-10	3.7E-10	No data	No data	1
	U+235	**1.0E-05**	**4.3E-06**	**3.1E-06**	**1.8E-06**	**4.5E-08**	**3.7E-08**	
25	U-236	**1.0E-05**	**4.5E-06**	**3.2E-06**	**1.9E-06**	**4.6E-08**	**3.7E-08**	
26	U-238	9.4E-06	4.0E-06	2.9E-06	1.6E-06	4.4E-08	3.6E-08	
	Th-234	3.1E-08	1.1E-08	7.7E-09	5.3E-09	6.7E-12	1.4E-10	1
	Pa-234m	No data	No data	No data	No data	No data	No data	0.998
	Pa-234*	2.1E-09	7.1E-10	4.0E-10	5.5E-10	No data	No data	0.002
	U+238	**9.4E-06**	**4.0E-06**	**2.9E-06**	**1.6E-06**	**4.4E-08**	**3.6E-08**	
27	Np-237	4.0E-05	2.2E-05	2.3E-05	1.5E-05	4.3E-07	3.2E-07	
	Pa-233*	1.3E-08	5.5E-09	3.9E-09	2.8E-09	No data	No data	1
	Np+237	**4.0E-05**	**2.2E-05**	**2.3E-05**	**1.5E-05**	**4.3E-07**	**3.2E-07**	
28	Pu-238	**7.4E-05**	**4.4E-05**	**4.6E-05**	**3.0E-05**	**1.1E-06**	**8.2E-07**	
29	Pu-239	**7.7E-05**	**4.8E-05**	**5.0E-05**	**3.2E-05**	**1.2E-06**	**8.4E-07**	
30	Pu-240	**7.7E-05**	**4.8E-05**	**5.0E-05**	**3.2E-05**	**1.2E-06**	**8.4E-07**	
31	Pu-241	**9.7E-07**	**8.3E-07**	**9.0E-07**	**5.8E-07**	**1.4E-08**	**1.0E-08**	
32	Pu-242	**7.3E-05**	**4.5E-05**	**4.8E-05**	**3.1E-05**	No data	No data	
33	Am-241	**6.9E-05**	**4.0E-05**	**4.2E-05**	**2.7E-05**	**3.2E-07**	**2.4E-07**	
34	Cm-242	**1.8E-05**	**7.3E-06**	**5.2E-06**	**3.7E-06**	**5.1E-08**	**4.0E-08**	
35	Cm-243	**6.1E-05**	**3.1E-05**	**3.1E-05**	**2.0E-05**	No data	No data	
36	Cm-244	**5.7E-05**	**2.7E-05**	**2.7E-05**	**1.7E-05**	**2.6E-07**	**2.0E-07**	

Table A2: Ingestion dose coefficients (Sv Bq^{-1}) to members of the public and workers

	Radionuclides	1 y	10 y	Adult	Adult W	Offspring	Offspring W	activity ratio
1	H-3 (OBT)	**1.2E-10**	**5.7E-11**	**4.2E-11**	**4.2E-11**	**6.3E-11**	**6.3E-11**	
	H-3 (H2O)	**4.8E-11**	**2.3E-11**	**1.8E-11**	**1.8E-11**	**3.1E-11**	**3.1E-11**	
2	C-14	**1.6E-09**	**8.0E-10**	**5.8E-10**	**5.8E-10**	**8.0E-10**	**8.0E-10**	
3	Cl-36	**6.3E-09**	**1.9E-09**	**9.3E-10**	**9.3E-10**	**No data**	**No data**	
4	K-40	**4.2E-08**	**1.3E-08**	**6.2E-09**	**6.2E-09**	**No data**	**No data**	
5	Co-60	**2.7E-08**	**1.1E-08**	**3.4E-09**	**3.4E-09**	**1.9E-09**	**1.9E-09**	
6	Sr-90	7.3E-08	6.0E-08	2.8E-08	2.8E-08	4.3E-08	4.3E-08	
	Y-90	2.0E-08	5.9E-09	2.7E-09	2.7E-09	No data	No data	0.998
	Sr+90	**9.3E-08**	**6.6E-08**	**3.1E-08**	**3.1E-08**	**4.3E-08**	**4.3E-08**	
7	Tc-99	**4.8E-09**	**1.3E-09**	**6.4E-10**	**7.8E-10**	**4.6E-10**	**7.3E-10**	
8	Ru-106	4.9E-08	1.5E-08	7.0E-09	7.0E-09	3.8E-10	3.8E-10	
	Rh-106	No data	No data	No data	No data	No data	No data	1
	Ru+106	**4.9E-08**	**1.5E-08**	**7.0E-09**	**7.0E-09**	**3.8E-10**	**3.8E-10**	
9	Sn-126	3.0E-08	9.8E-09	4.7E-09	4.7E-09	No data	No data	
	Sb-126m	2.2E-10	6.6E-11	3.6E-11	3.6E-11	No data	No data	1
	Sb-126	1.4E-08	4.9E-09	2.4E-09	2.4E-09	1.4E-09	1.4E-09	0.14
	Sn+126	**3.2E-08**	**1.1E-08**	**5.1E-09**	**5.1E-09**	**No data**	**No data**	
10	I-129	**2.2E-07**	**1.9E-07**	**1.1E-07**	**1.1E-07**	**4.4E-08**	**4.4E-08**	
11	Cs-134	**1.6E-08**	**1.4E-08**	**1.9E-08**	**1.9E-08**	**8.7E-09**	**8.7E-09**	
12	Cs-137	1.2E-08	1.0E-08	1.3E-08	1.3E-08	5.7E-09	5.7E-09	
	Ba-137m	No data	No data	No data	No data	No data	No data	0.946
	Cs+137	**1.2E-08**	**1.0E-08**	**1.3E-08**	**1.3E-08**	**5.7E-09**	**5.7E-09**	
13	Pb-210	3.6E-06	1.9E-06	6.9E-07	6.8E-07	1.4E-07	1.4E-07	
	Bi-210	9.7E-09	2.9E-09	1.3E-09	1.3E-09	No data	No data	0.995
	Pb+210	**3.6E-06**	**1.9E-06**	**6.9E-07**	**6.8E-07**	**1.4E-07**	**1.4E-07**	
14	Po-210	**8.8E-06**	**2.6E-06**	**1.2E-06**	**2.4E-07**	**1.3E-07**	**2.6E-08**	
15	Ra-226	9.6E-07	8.0E-07	2.8E-07	2.8E-07	3.2E-07	3.2E-07	
	Rn-222	No data	No data	No data	No data	No data	No data	1
	Po-218	No data	No data	No data	No data	No data	No data	1
	Pb-214	1.0E-09	3.1E-10	1.4E-10	1.4E-10	No data	No data	1
	Bi-214	7.4E-10	2.1E-10	1.1E-10	1.1E-10	No data	No data	1
	Po-214	No data	No data	No data	No data	No data	No data	1
	Ra+226	**9.6E-07**	**8.0E-07**	**2.8E-07**	**2.8E-07**	**3.2E-07**	**3.2E-07**	
16	Ra-228	5.7E-06	3.9E-06	6.9E-07	6.7E-07	3.0E-07	3.0E-07	
	Ac-228	2.8E-09	8.7E-10	4.3E-10	4.3E-10	No data	No data	1
	Ra+228	**5.7E-06**	**3.9E-06**	**6.9E-07**	**6.7E-07**	**3.0E-07**	**3.0E-07**	
17	Th-228	3.7E-07	1.5E-07	7.2E-08	7.0E-08	1.1E-08	1.1E-08	
	Ra-224	6.6E-07	2.6E-07	6.5E-08	6.5E-08	2.2E-07	2.2E-07	0.973
	Rn-220	No data	No data	No data	No data	No data	No data	0.973

	Radionuclides	1 y	10 y	Adult	Adult W	Offspring	Offspring W	activity ratio
	Po-216	No data	No data	No data	No data	No data	No data	0.973
	Pb-212	6.3E-08	2.0E-08	6.0E-09	5.9E-09	No data	No data	0.973
	Bi-212	1.8E-09	5.0E-10	2.6E-10	2.6E-10	No data	No data	0.973
	Po-212	No data	No data	No data	No data	No data	No data	0.6237
	Tl-208	No data	No data	No data	No data	No data	No data	0.3493
	Th+228	**1.1E-06**	**4.2E-07**	**1.4E-07**	**1.4E-07**	**2.3E-07**	**2.3E-07**	
18	Th-229	1.0E-06	6.2E-07	4.9E-07	4.8E-07	No data	No data	
	Ra-225	1.2E-06	5.0E-07	9.9E-08	9.5E-08	No data	No data	1
	Ac-225	1.8E-07	5.4E-08	2.4E-08	2.4E-08	No data	No data	1
	Fr-221	No data	No data	No data	No data	No data	No data	1
	At-217	No data	No data	No data	No data	No data	No data	1
	Bi-213	1.4E-09	3.9E-10	2.0E-10	2.0E-10	No data	No data	1
	Po-213	No data	No data	No data	No data	No data	No data	0.9784
	Pb-209	3.8E-10	1.1E-10	5.7E-11	5.7E-11	No data	No data	1
	Th+229	**2.4E-06**	**1.2E-06**	**6.1E-07**	**6.0E-07**	**No data**	**No data**	
19	Th-230	**4.1E-07**	**2.4E-07**	**2.1E-07**	**2.1E-07**	**8.6E-09**	**8.6E-09**	
20	Th-232	**4.5E-07**	**2.9E-07**	**2.3E-07**	**2.2E-07**	**9.4E-09**	**9.4E-09**	
21	Pa-231	**1.3E-06**	**9.2E-07**	**7.1E-07**	**7.1E-07**	No data	No data	
22	U-233	**1.4E-07**	**7.8E-08**	**5.1E-08**	**8.5E-09**	**1.5E-08**	**1.5E-08**	
23	U-234	**1.3E-07**	**7.4E-08**	**4.9E-08**	**8.3E-09**	**1.5E-08**	**1.5E-08**	
24	U-235	1.3E-07	7.1E-08	4.7E-08	8.3E-09	1.4E-08	1.4E-08	
	Th-231	2.5E-09	7.4E-10	3.4E-10	3.4E-10	No data	No data	1
	U+235	**1.3E-07**	**7.2E-08**	**4.7E-08**	**8.6E-09**	**1.4E-08**	**1.4E-08**	
25	U-236	**1.3E-07**	**7.0E-08**	**4.7E-08**	**7.9E-09**	**1.4E-08**	**1.4E-08**	
26	U-238	1.2E-07	6.8E-08	4.5E-08	7.6E-09	1.3E-08	1.3E-08	
	Th-234	2.5E-08	7.4E-09	3.4E-09	3.4E-09	1.5E-11	1.5E-11	1
	Pa-234m	No data	No data	No data	No data	No data	No data	0.998
	Pa-234	3.2E-09	1.0E-09	5.1E-10	5.1E-10	No data	No data	0.002
	U+238	**1.5E-07**	**7.6E-08**	**4.9E-08**	**1.2E-08**	**1.3E-08**	**1.3E-08**	
27	Np-237	2.1E-07	1.1E-07	1.1E-07	1.1E-07	3.6E-09	3.6E-09	
	Pa-233	6.2E-09	1.9E-09	8.7E-10	8.7E-10	No data	No data	1
	Np+237	**2.2E-07**	**1.1E-07**	**1.1E-07**	**1.1E-07**	**3.6E-09**	**3.6E-09**	
28	Pu-238	**4.0E-07**	**2.4E-07**	**2.3E-07**	**2.3E-07**	**9.0E-09**	**9.0E-09**	
29	Pu-239	**4.2E-07**	**2.7E-07**	**2.5E-07**	**2.5E-07**	**9.5E-09**	**9.5E-09**	
30	Pu-240	**4.2E-07**	**2.7E-07**	**2.5E-07**	**2.5E-07**	**9.5E-09**	**9.5E-09**	
31	Pu-241	**5.7E-09**	**5.1E-09**	**4.8E-09**	**4.7E-09**	**1.1E-10**	**1.1E-10**	
32	Pu-242	**4.0E-07**	**2.6E-07**	**2.4E-07**	**2.4E-07**	**No data**	**No data**	
33	Am-241	**3.7E-07**	**2.2E-07**	**2.0E-07**	**2.0E-07**	**2.7E-09**	**2.7E-09**	
34	Cm-242	**7.6E-08**	**2.4E-08**	**1.2E-08**	**1.2E-08**	**4.7E-10**	**4.7E-10**	
35	Cm-243	**3.3E-07**	**1.6E-07**	**1.5E-07**	**1.5E-07**	**No data**	**No data**	
36	Cm-244	**2.9E-07**	**1.4E-07**	**1.2E-07**	**1.2E-07**	**2.2E-09**	**2.2E-09**	

APPENDIX 2: EXTERNAL IRRADIATION DOSE FACTORS

External dose factors for the geometries mentioned in Section 2.2.1 for gamma photons have been derived using the commercially available software product Microshield version 5.03 for all age groups. Dose factors were also considered for beta particles (electrons) and these were added to the corresponding dose factors for gamma photons to produce an overall factor for each radionuclide. The effect of braking radiation or Bremstrahlung was not considered.

For beta particle contributions to the external irradiation dose, as there is a lack of commercially available software, literature values have been considered. For surface contamination, such dose factors have been obtained 1 m above an infinite plane source from Delacroix *et al*. (2002) for skin and multiplied by a skin tissue weighting factor of 0.01 (ICRP, 1991) to obtain an effective whole body dose. These dose factors although for an infinite source, were also applied to the 10 m diameter patch of contamination. For sub-surface contamination, dose factors for beta particles were obtained from Mobbs and Harvey (2000) for a semi-infinite slab source. They were applied to the shallow and deep contaminated geometries mentioned above for uniform contamination and the 10 m diameter patch of contamination.

For external irradiation doses received off the edge of the contaminated land, for surface and sub-surface contamination, the beta particle contributions could not be determined and were not included. This was also the case for the buried contamination geometries. The omission of beta particle contributions to the doses received from these geometries was considered to be acceptable because beta particle contributions to external irradiation dose are only significant for persons being located directly above the contaminated land.

The derived external dose factors are provided in Table A3 (below) for:

- ‘surface’ contamination (zero thickness);
- ‘shallow’ contamination (5 cm deep from surface); and
- ‘deep’ contamination (extending to infinite depth from surface).

In each case, a variety of surface area geometries was considered as detailed in Section 2.2.1.

For the Microshield calculations, a 2 km diameter circular area of contamination was used to represent the infinite plane source with the external irradiation dose factors being determined 1 m above the centre of the circle. They were also determined using this geometry for edge distances of 5 and 50 m beyond the circumference of the circle. The circle of contamination was reduced as appropriate for the 10 m diameter patch of contamination, with the dose in air being determined above the centre point.

For the shallow and infinitely deep contamination, an upright cylinder of 2 km diameter was used with a density of 1.5 g cm^{-3} approximating to soil media. The contaminated cylindrical depth was taken to be 5 cm for shallow contamination and 5 m for infinitely deep contamination. A wide annular shielding layer of identical density was considered around the cylinder to effectively allow for shielding from uncontaminated ground around the contaminated area. External dose factors were determined 1 m above the centre of the upright cylinder and at distances of 5 and 50 m beyond the edge of the cylinder.

In addition, ‘infinitely deep’ contamination buried by 10 cm and 50 cm of clean soil was considered (but for only a single surface area geometry). For these calculations, the upright cylinder geometry of 2 km diameter was again employed. The buried infinitely deep contamination was again considered as a 5 m deep cylinder but this time with an additional adjoining cylindrical layer to represent shielding from uncontaminated soil to depths of 10 and 50 cm.

In carrying out the Microshield calculations, consideration was also given to radial, circular and axial integration factors particularly for the three dimensional sources of contamination.

Table A3 : External dose factors for the various contaminated land geometries

Nuclides	Surface Contamination (mSv h^{-1} per Bq cm^{-2})				Shallow contamination 5 cm deep (Sv h^{-1} per Bq g^{-1})				Deep contamination infinite depth (mSv h^{-1} per Bq g^{-1})				Buried contamination (mSv h^{-1} per Bq g^{-1})	
	1 m above infinite uniform	1 m above 10 m diam patch	5 m from edge infinite uniform	50 m from edge infinite uniform	1 m above infinite uniform	1 m above 10 m diam patch	5 m from edge infinite uniform	50 m from edge infinite uniform	1 m above infinite uniform	1 m above 10 m diam patch	5 m from edge infinite uniform	50 m from edge infinite uniform	1 m above deep burial 0.1 m clean soil	1 m above deep burial 0.5 m clean soil
H-3 (OBT)	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
H-3 (H2O)	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
C-14	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Cl-36	2.7E-07	2.6E-07	2.1E-09	6.5E-10	5.3E-08	4.6E-08	1.9E-09	1.0E-10	7.1E-08	6.4E-08	2.2E-09	1.0E-10	6.9E-09	4.9E-11
K-40	9.3E-06	4.9E-06	1.8E-06	5.8E-07	2.0E-05	1.2E-05	2.1E-06	1.4E-07	4.3E-05	3.5E-05	2.5E-06	1.8E-07	1.5E-05	5.5E-07
Co-60	1.1E-04	3.2E-05	2.9E-05	9.5E-06	3.2E-04	2.0E-04	3.3E-05	2.1E-06	6.8E-04	5.5E-04	4.0E-05	2.1E-06	2.2E-04	6.7E-06
Sr+90	6.1E-06	6.1E-06	3.7E-12	7.5E-16	2.1E-06	2.1E-06	3.0E-14	3.2E-20	2.1E-06	2.1E-06	3.3E-14	7.6E-19	7.9E-35	7.6E-35
Tc-99	2.0E-12	2.0E-12	0.0E+00	0.0E+00	3.8E-11	3.8E-11	0.0E+00	0.0E+00	3.8E-11	3.8E-11	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Ru+106	1.7E-05	1.0E-05	2.7E-06	8.3E-07	3.3E-05	2.4E-05	2.5E-06	1.4E-07	5.7E-05	4.8E-05	2.9E-06	1.4E-07	1.0E-05	1.4E-07
Sn+126	9.0E-05	2.7E-05	2.5E-05	7.8E-06	2.5E-04	1.7E-04	2.2E-05	1.2E-06	4.7E-04	3.8E-04	2.6E-05	1.2E-06	8.8E-05	8.7E-07
I-129	1.9E-06	7.7E-07	4.1E-07	2.7E-08	3.0E-07	2.5E-07	1.2E-08	7.2E-11	3.0E-07	2.5E-07	1.2E-08	7.9E-11	7.2E-15	2.0E-30
Cs-134	7.3E-05	2.2E-05	2.0E-05	6.4E-06	2.1E-04	1.4E-04	2.0E-05	1.2E-06	4.1E-04	3.4E-04	2.4E-05	1.2E-06	9.4E-05	1.3E-06
Cs+137	2.7E-05	8.8E-06	7.5E-06	2.3E-06	7.7E-05	5.1E-05	7.2E-06	4.1E-07	1.5E-04	1.2E-04	8.4E-06	4.1E-07	3.2E-05	3.6E-07
Pb+210	1.8E-06	1.7E-06	4.6E-08	8.0E-09	3.1E-07	3.0E-07	2.9E-09	3.9E-11	3.1E-07	3.0E-07	2.9E-09	4.0E-11	1.0E-12	1.3E-29
Po-210	3.9E-10	1.2E-10	1.1E-10	3.4E-11	1.1E-09	7.4E-10	1.1E-10	6.5E-12	2.3E-09	1.8E-09	1.3E-10	6.5E-12	5.6E-10	8.6E-12
Ra+226	7.6E-05	2.3E-05	2.2E-05	6.9E-06	2.3E-04	1.5E-04	2.3E-05	1.4E-06	4.7E-04	3.9E-04	2.7E-05	1.4E-06	1.4E-04	5.2E-06
Ra+228	4.4E-05	1.3E-05	1.2E-05	3.9E-06	1.3E-04	8.3E-05	1.3E-05	7.4E-07	2.6E-04	2.1E-04	1.5E-05	7.4E-07	7.0E-05	1.7E-06
Th+228	6.5E-05	1.9E-05	1.8E-05	6.2E-06	1.9E-04	1.2E-04	2.1E-05	1.4E-06	4.4E-04	3.5E-04	2.6E-05	1.2E-05	1.5E-04	1.1E-05
Th+229	1.2E-05	4.9E-06	5.0E-06	1.5E-06	3.2E-05	2.6E-05	2.4E-06	1.1E-07	5.2E-05	5.0E-05	3.4E-06	1.1E-07	8.4E-06	1.5E-07
Th-230	5.0E-08	2.4E-08	9.8E-09	2.4E-09	3.4E-08	2.7E-08	1.9E-09	6.6E-11	4.2E-08	3.5E-08	2.1E-09	6.6E-11	9.3E-10	9.7E-13
Th-232	3.6E-08	2.0E-08	5.6E-09	1.1E-09	1.5E-08	1.2E-08	7.3E-10	2.4E-11	1.7E-08	1.4E-08	8.0E-10	2.4E-11	1.1E-10	1.1E-14
Pa-231	2.3E-06	8.0E-07	6.1E-07	1.7E-07	4.9E-06	3.5E-06	3.9E-07	1.9E-08	8.2E-06	6.7E-06	4.5E-07	1.9E-08	8.2E-07	2.1E-09
U-233	4.2E-08	2.1E-08	7.6E-09	1.7E-09	3.6E-08	2.7E-08	2.4E-09	1.1E-10	5.3E-08	4.4E-08	2.8E-09	1.1E-10	3.0E-09	6.7E-12
U-234	4.8E-08	3.1E-08	5.7E-09	7.1E-10	1.1E-08	9.0E-09	5.3E-10	1.8E-11	1.3E-08	1.1E-08	5.7E-10	1.8E-11	9.6E-11	1.3E-13
U+235	1.0E-05	3.0E-06	3.0E-06	4.4E-07	2.2E-05	1.6E-05	1.6E-06	6.8E-08	3.3E-05	2.7E-05	1.8E-06	6.8E-08	1.5E-06	1.2E-09
U-236	4.2E-08	2.8E-08	4.3E-09	3.5E-10	5.8E-09	4.8E-09	2.4E-10	7.2E-12	5.9E-09	5.5E-09	2.4E-10	7.2E-12	2.3E-11	1.0E-15
U+238	7.1E-06	6.0E-06	4.1E-07	1.3E-07	5.1E-06	4.2E-06	2.7E-07	1.5E-08	7.7E-06	6.5E-06	3.1E-07	1.5E-08	1.2E-06	3.0E-08
Np+237	1.3E-05	3.7E-06	3.6E-06	1.1E-06	2.8E-05	2.0E-05	2.1E-06	9.9E-08	4.4E-05	3.6E-05	2.4E-06	9.9E-08	3.9E-06	1.0E-08
Pu-238	3.8E-08	2.7E-08	3.2E-09	1.1E-10	2.9E-09	2.4E-09	1.2E-10	2.7E-12	3.2E-09	2.8E-09	1.2E-10	2.7E-12	1.1E-10	6.3E-13
Pu-239	1.8E-08	8.5E-10	2.2E-09	3.3E-10	7.6E-09	5.6E-09	5.1E-10	2.3E-11	1.1E-08	9.3E-09	5.8E-10	2.3E-11	9.5E-10	4.0E-12
Pu-240	3.7E-08	2.6E-08	3.3E-09	1.7E-10	3.1E-09	2.6E-09	1.3E-10	2.4E-12	3.3E-09	2.6E-91	1.3E-10	2.4E-12	6.5E-11	8.5E-14
Pu-241	1.2E-10	4.7E-11	3.3E-11	9.9E-12	1.7E-10	1.3E-10	9.8E-12	3.6E-13	2.2E-10	1.8E-10	1.1E-11	3.6E-13	1.8E-12	3.4E-16
Pu-242	4.1E-08	2.7E-08	4.0E-09	1.3E-10	3.2E-09	2.8E-09	1.3E-10	2.4E-12	3.5E-09	3.0E-09	1.3E-10	2.4E-12	7.4E-11	7.8E-15
Am-241	2.1E-06	4.7E-07	5.8E-07	1.3E-07	1.2E-06	1.0E-06	5.1E-08	1.2E-09	1.3E-06	1.1E-06	6.4E-08	1.2E-09	4.1E-10	3.0E-12
Cm-242	6.0E-08	3.8E-08	6.7E-09	9.3E-11	4.2E-09	3.7E-09	1.6E-10	2.8E-12	4.6E-09	4.1E-09	1.6E-10	2.8E-12	1.8E-10	1.5E-12
Cm-243	7.5E-06	2.1E-06	2.2E-06	6.8E-07	1.5E-05	1.1E-05	1.1E-06	4.8E-08	2.3E-05	1.9E-05	1.3E-06	4.8E-08	1.4E-06	2.8E-09
Cm-244	5.1E-08	3.3E-08	5.3E-09	5.2E-11	2.8E-09	2.5E-09	7.2E-11	1.7E-13	2.8E-09	2.5E-09	7.4E-11	1.8E-13	5.0E-16	5.9E-32

APPENDIX 3: SKIN EQUIVALENT DOSE RATE FACTORS

The skin equivalent dose rates to the basal layer of the skin epidermis for gamma irradiation and beta irradiation (Mobbs and Harvey, 2000) for the list of radionuclides in are given below in Table A4.

Table A4: Skin equivalent dose rates to the basal layer of the skin epidermis for beta (4 mg cm^{-2}) and gamma (7 mg cm^{-2}) irradiation (Sv h^{-1} per Bq cm^{-2}).

		Beta	Gamma	Daughters included in secular equilibrium
1	H-3 (OBT)	0.0E+00	0.0E+00	
	H-3 (H2O)	0.0E+00	0.0E+00	
2	C-14	9.0E-07	0.0E+00	
3	Cl-36	2.5E-06	1.1E-11	
4	K-40	2.4E-06	8.0E-09	
5	Co-60	1.8E-06	1.3E-07	
6	Sr+90	5.1E-06	2.4E-12	Y-90
7	Tc-99	1.6E-06	2.5E-14	
8	Ru+106	2.9E-06	1.2E-08	Rh-106
9	Sn-126	1.8E-06	3.9E-08	
10	I-129	6.5E-07	9.7E-09	
11	Cs-134	1.8E-06	8.8E-08	
12	Cs+137	2.5E-06	3.3E-08	Ba-137m
13	Pb+210	2.6E-06	8.3E-09	Bi-210
14	Po-210	0.0E+00	4.8E-13	
15	Ra+226	8.5E-06	1.2E-07	Rn-222, Po-218, Pb-214, Bi-214, Po-214
16	Ra+228	3.1E-06	5.8E-08	Ac-228
17	Th+228	6.3E-06	1.0E-07	Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Po-212, Tl-208
18	Th+229	6.3E-06	7.3E-08	Ra-225, Ac-225, Fr-221, At-217, Bi-213, Po-213, Pb-209
19	Th-230	1.0E-07	3.8E-09	
20	Th-232	9.5E-06	1.7E-07	
21	Pa-231	1.5E-07	2.9E-09	
22	U-233	5.3E-09	1.7E-09	
23	U-234	7.4E-09	2.7E-09	
24	U+235	2.5E-06	5.3E-08	Th-231
25	U-236	4.6E-09	9.4E-11	
26	U+238	3.8E-06	9.2E-09	Th-234, Pa-234m, Pa-234
27	Np+237	3.5E-06	3.2E-08	Pa-233
28	Pu-238	0.0E-00	2.7E-09	
29	Pu-239	4.3E-10	1.0E-09	
30	Pu-240	0.0E+00	2.6E-09	
31	Pu-241	0.0E+00	3.3E-12	
32	Pu-242	0.0E+00	8.6E-11	
33	Am-241	5.5E-08	1.7E-08	
34	Cm-242	0.0E+00	2.4E-09	
35	Cm-243	1.9E-06	8.0E-09	
36	Cm-244	0.0E+00	2.2E-09	

APPENDIX 4: WILD FOOD CONCENTRATION FACTORS

Table A5 provides the concentration factors for wild fungi and fruit for the look-up tables.

Data for fungi are sparse and are only readily available for caesium and strontium i.e. Copplestone *et al.* (2001). Concentration factor values cited for fungi in IAEA-BIOMASS-6 (2003) for Tc-99, I-129 and Np-237 do not explicitly apply to fungi and are the highest plant uptake values from IAEA (1994) divided by ten to convert to approximate fresh weight concentration factors. This practice has not been extended to the other radionuclides.

The most recent assessment of fruit concentration factors is given by EPRI (1996). This assessment considered concentration factor data for herbaceous fruit from Ashton and Summerling (1988) before a decision was made for their best estimates. Generally, the concentration factor data for wild fruit given in Table A5 have been selected on the basis of being the most conservative value. For Ru only average tomato data from Mayall (1995) was available. Mayall (1995) concentration factor data for Pb in blueberries was used in preference to lower values from Ashton and Summerling (1988). This was also the case for Np and Cm (strawberries from Mayall (1995)).

Table A5: Wild food concentration factors (Bq/kg fwt per Bq/kg dwt soil) selected for the look-up tables

Radioelement	Fungi	Source	Fruit	Source
H	NV		1.00E+00	Ashton & Summerling (1988)
C	NV		1.25E-01	Ashton & Summerling (1988)
Cl	NV		5.00E+00	Ashton & Summerling (1988)
K	NV		5.00E-02	Analogue for Cs
Co	NV		1.00E-02	Ashton & Summerling (1988)
Sr	4.76E-03	Copplestone *et al.* (2001)	5.00E-01	Ashton & Summerling (1988)
Tc	7.80E+02	IAEA-BIOMASS-6	2.00E+01	EPRI (1996)
Ru	NV		2.14E-04	Mayall (1995) [1]
Sn	NV		1.00E-01	Ashton & Summerling (1988)
I	3.40E-03	IAEA-BIOMASS-6	5.00E-02	EPRI (1996)
Cs	1.13E+00	Copplestone *et al.* (2001)	5.00E-02	EPRI (1996), Ashton & Summerling (1988)
Pb	NV		1.69E-01	Mayall (1995)
Po	NV		2.00E-04	EPRI (1996)
Ra	NV		4.00E-02	EPRI (1996)
Th	NV		5.00E-04	EPRI (1996)
Pa	NV		4.00E-02	EPRI (1996)
U	NV		1.00E-04	EPRI (1996), Ashton & Summerling (1988)
Np	5.70E-02	IAEA-BIOMASS-6 (2003)	3.00E-03	Mayall (1995) [2]
Pu	NV		1.00E-04	EPRI (1996)
Am	NV		1.00E-03	EPRI (1996)
Cm	NV		1.30E-04	Mayall (1995) [2]

NV - No Value
1 Average value from tomatoes
2 Strawberry value

APPENDIX 5: RADCONTAB LOOK-UP TABLES OUTPUT FOR WORKED EXAMPLE

For a worked example, whose details are provided in Figure A1, additional figures (A2 to A13) are provided of illustrative RADCONTAB look-up tables output dealing with the exposure pathways mentioned, overview and total dose. Figure A1 also contains hand-calculated dose values and the most dominant radionuclide associated with each exposure pathway. The worked example applies to exposure pathways associated with a recreational adult visitor on a NL site but outside the security fence. It should be noted that ingestion of contaminated soil/dust can only be specified once using the tool, and so inclusion of dust radionuclide concentrations on blackberries (Figure A3 in the example) precludes soil radionuclide concentrations (such as via inadvertent soil consumption) from being considered in such a scenario. The radionuclides chosen include Cs+137 and Sr+90 which are examples of beta/gamma emitters found at radioactively contaminated sites. Also included are an alpha emitter (Pu-240) and tritium (H-3). Only one external radiation pathway is used in the worked example ('deep' contamination; Figure A10). Figures A9 and A11 use the same input concentrations and occupancies to allow comparison. Figure A8 is not used in the worked example. Here the input concentrations are in Bq cm^{-2}, not Bq g^{-1}, so different illustrative values are used.

The look-up table output consists of a title, input data panels (for data and commentary) and the calculated doses (mSv y^{-1}). The comment on equivalent dose to the skin (Section 2.2.2) and the quantitative guidance as discussed in Section 4 are not included in the examples, although they are present in the tool itself. The layout of each table was designed with a view to be able to set the print area to conveniently cover the title, input data panel and the calculated doses for producing hard copies.

For clarity, the input data panel cells are provided in a yellow background colour and those cells containing the radionuclide names are in a light blue background colour. Cells containing the calculated dose values are provided in a light green background colour, whereas cells where dose values cannot be calculated are in a white colour. The most dominant radionuclide contributions to the calculated dose are highlighted by purple cells in the spreadsheet[9], as is the most dominant exposure pathway in the calculation of total dose (Figure A13).

Most figures up to Figure A11, with the exception of Figures A8 to A10, demonstrate the use of specifying activity concentrations which results in whole body effective doses and percentage contribution for each radionuclide considered and the combined total dose. Part of this capability is also shown for the external irradiation doses represented by Figures A8 to A10, though the percentage contribution is not illustrated because the number of columns required (due to the large number of geometries) is too large to print readily. Figure A11 illustrates this capability applied to external irradiation doses from buried soil contamination.

[9] In hard copies of the look-up table output, the purple cells may appear in print as a mauve mid-blue colour.

The figures show look-up table output for the 'Adult' age group in keeping with the worked example. Other age groups can be selected by drop-down menus (not evident in the Figures). The calculated doses and dominant radionuclide for each exposure pathway are in exact agreement with the hand-calculated values in Figure A1.

Figure A12 provides an illustration of the Scenario Information worksheet which provides an overview of the overall calculation and contains the basis of input data and measured radionuclide concentrations entered into the worksheets for each individual exposure pathway. The user can also enter a scenario title, scenario background information and a reference number at the top of this worksheet to provide a complete description of the nature of the calculations. This reference number provides a link to the Overview-Total Dose worksheet as illustrated in Figure A13 which provides an overview of the input parameters selected and allows the user the freedom to combine certain exposure pathways to obtain total dose. Only one external irradiation geometry (e.g. deep soil contamination) can be selected when combining exposure pathways. The user must also select in the appropriate column, whether the external irradiation doses are for contamination in an infinite plane, or circular patch or at the specified distances from the edge of the contamination. The total dose value in Figure A13 and the most dominant exposure pathway are in agreement with the hand-calculated data in Figure A1.

The Scenario Information and Overview-Total Dose worksheets are designed to capture the nature/input and outcomes of the calculations. Rather than have executables of the look-up tables for every contaminated land study, it is advised that printouts of these worksheets be filed for every study. Alternatively, these worksheets could be saved within other Microsoft Excel applications that have been created by the user.

Figure A1: Worked example for recreational visitor on NL site but outside security fence

Contamination details

Surface contaminated soil area 10 m in diameter - assumed to extend to depth
Soils contaminated with Cs+137, Sr+90 and Pu-240
Pore water and groundwater contaminated with H-3, Sr+90 and Cs+137
Contamination levels in dust 10 times higher than in soils
Contaminated spring water accessible to site visitor
Contamination levels in soil, dust and water as given below
Tritium (1000 Bq L^{-1}) in soils assumed to be porewater at 40% porosity (saturated)
Porewater assumed to be same as groundwater. In this example: 1 Bq L^{-1} in porewater = 0.0002 Bq g^{-1} in soil.
Dust assumed to be free of tritium (due to evaporation)

Habits

Visitor on site 1 hour per week (50 h y^{-1})
Spends only 20% of that time on the contaminated area (10 h y^{-1})
Has the occasional drink from the contaminated spring (1 L y^{-1})
Eats 100 g blackberries per year from the contaminated area (no fungi)
Nominal 10 hours contact time with ground per year for skin dose calculation
Ingestion of dust on blackberries at 0.1 g y^{-1} (0.1% of wet weight of fruit)

	Concentrations in soils (Bq g^{-1})				Concentrations in water (Bq L^{-1})				Dose (mSv y^{-1})	Main radionuclide(s)
	Cs+137	Sr+90	Pu-240	H-3	Cs+137	Sr+90	Pu-240	H-3		
Dust inhalation	10	1	0.1	N/A	N/A	N/A	N/A	N/A	**3.00E-05**	Pu-240
Soil (dust) ingestion	10	1	0.1	N/A	N/A	N/A	N/A	N/A	**1.86E-05**	Cs+137
Wild food ingestion	1	0.1	0.01	0.2	N/A	N/A	N/A	N/A	**2.20E-04**	Sr+90
Water ingestion	N/A	N/A	N/A	N/A	1	10	0	1000	**3.41E-04**	Sr+90
Skin dose	1	0.1	0.01	0.2	N/A	N/A	N/A	N/A	**7.61E-07**	Cs+137
External dose	1	0.1	0.01	0.2	N/A	N/A	N/A	N/A	**1.20E-03**	Cs+137
Total									**1.81E-03**	

Figure A2: Look-up table - Inhalation of contaminated dust

Whole body effective dose from the inhalation of dust contaminated with unit activity concentration ($mSv\ y^{-1}$ per $Bq\ g^{-1}$)

Whole body effective dose ($mSv\ y^{-1}$) from the inhalation of dust contaminated with a specified activity concentration

	Values entered
Age Group	Adult
Dust loading in air ($g\ m^{-3}$)	1.00E-04
Inhalation rate ($m^3\ h^{-1}$)	1.18
occupancy ($h\ y^{-1}$)	50

Basis of Input:

Contamination levels in dust 10 times higher than in soils.
Dust assumed to be free of tritium (due to evaporation).
Visitor on site 1 hour per week (50 $h\ y^{-1}$).

	$mSv\ y^{-1}$ per $Bq\ g^{-1}$	Specified activity concentration $Bq\ g^{-1}$	Whole body effective dose $mSv\ y^{-1}$	Radionuclide contribution %
H-3 (OBT)	2.66E-10			
H-3 (H2O)	2.66E-10			
C-14	1.18E-08			
Cl-36	4.31E-08			
K-40	1.24E-08			
Co-60	5.90E-08			
Sr+90	2.18E-07	1.00E+00	2.18E-07	1%
Tc-99	2.36E-08			
Ru+106	1.65E-07			
Sn+126	1.65E-07			
I-129	2.12E-07			
Cs-134	3.89E-08			
Cs+137	2.71E-08	1.00E+01	2.71E-07	1%
Pb+210	7.08E-06			
Po-210	1.95E-05			
Ra+226	2.07E-05			
Ra+228	1.53E-05			
Th+228	2.54E-04			
Th+229	5.07E-04			
Th-230	8.26E-05			
Th-232	1.48E-04			
Pa-231	8.26E-04			
U-233	2.12E-05			
U-234	2.07E-05			
U+235	1.83E-05			
U-236	1.89E-05			
U+238	1.71E-05			
Np+237	1.36E-04			
Pu-238	2.71E-04			
Pu-239	2.95E-04			
Pu-240	2.95E-04	1.00E-01	2.95E-05	98%
Pu-241	5.31E-06			
Pu-242	2.83E-04			
Am-241	2.48E-04			
Cm-242	3.07E-05			
Cm-243	1.83E-04			
Cm-244	1.59E-04			
TOTAL			3.00E-05	

Figure A3: Look-up table - Ingestion of contaminated soil/dust

Whole body effective dose from the inadvertent ingestion of soil contaminated with unit activity concentration (mSv y^{-1} per Bq g^{-1})

Whole body effective dose (mSv y^{-1}) from the inadvertent ingestion of soil contaminated with a specified activity concentration

	Values entered
Age Group	Adult
Soil ingestion rate (g y^{-1})	0.1

Basis of Input:

Ingestion of dust on blackberries at 0.1 g y^{-1} (0.1% of wet weight of fruit)

	mSv y^{-1} per Bq g^{-1}	Specified activity concentration Bq g^{-1}	Whole body effective dose mSv y^{-1}	Radionuclide contribution %
H-3 (OBT)	4.20E-09			
H-3 (H2O)	1.80E-09			
C-14	5.80E-08			
Cl-36	9.30E-08			
K-40	6.20E-07			
Co-60	3.40E-07			
Sr+90	3.10E-06	1.00E+00	3.10E-06	17%
Tc-99	6.40E-08			
Ru+106	7.00E-07			
Sn+126	5.10E-07			
I-129	1.10E-05			
Cs-134	1.90E-06			
Cs+137	1.30E-06	1.00E+01	1.30E-05	70%
Pb+210	6.90E-05			
Po-210	1.20E-04			
Ra+226	2.80E-05			
Ra+228	6.90E-05			
Th+228	1.40E-05			
Th+229	6.10E-05			
Th-230	2.10E-05			
Th-232	2.30E-05			
Pa-231	7.10E-05			
U-233	5.10E-06			
U-234	4.90E-06			
U+235	4.70E-06			
U-236	4.70E-06			
U+238	4.90E-06			
Np+237	1.10E-05			
Pu-238	2.30E-05			
Pu-239	2.50E-05			
Pu-240	2.50E-05	1.00E-01	2.50E-06	13%
Pu-241	4.80E-07			
Pu-242	2.40E-05			
Am-241	2.00E-05			
Cm-242	1.20E-06			
Cm-243	1.50E-05			
Cm-244	1.20E-05			
TOTAL			1.86E-05	

Figure A4: Look-up table - Ingestion of contaminated wild fruit

Whole body effective dose from the ingestion of wild foods grown in soil contaminated with unit activity concentration (mSv y^{-1} per Bq g^{-1})

Whole body effective dose (mSv y^{-1}) from the ingestion of wild foods grown in soil contaminated with a specified activity concentration

	Values entered
Age Group	Adult
Wild Food Type	Fruit
Ingestion rate (g y^{-1})	1.00E+02

Basis of Input:

Eats 100 g blackberries per year from the contaminated area.

	mSv y^{-1} per Bq g^{-1}	Specified activity concentration Bq g^{-1}	Whole body effective dose mSv y^{-1}	Radionuclide contribution %
H-3 (OBT)	4.20E-06			
H-3 (H2O)	1.80E-06	2.00E-01	3.60E-07	0%
C-14	7.25E-06			
Cl-36	4.65E-04			
K-40	3.10E-05			
Co-60	3.40E-06			
Sr+90	1.55E-03	1.00E-01	1.55E-04	70%
Tc-99	1.28E-03			
Ru+106	1.50E-07			
Sn+126	5.10E-05			
I-129	5.50E-04			
Cs-134	9.50E-05			
Cs+137	6.50E-05	1.00E+00	6.50E-05	29%
Pb+210	1.17E-02			
Po-210	2.40E-05			
Ra+226	1.12E-03			
Ra+228	2.76E-03			
Th+228	7.00E-06			
Th+229	3.05E-05			
Th-230	1.05E-05			
Th-232	1.15E-05			
Pa-231	2.84E-03			
U-233	5.10E-07			
U-234	4.90E-07			
U+235	4.70E-07			
U-236	4.70E-07			
U+238	4.90E-07			
Np+237	3.30E-05			
Pu-238	2.30E-06			
Pu-239	2.50E-06			
Pu-240	2.50E-06	1.00E-02	2.50E-08	0%
Pu-241	4.80E-08			
Pu-242	2.40E-06			
Am-241	2.00E-05			
Cm-242	1.56E-07			
Cm-243	1.95E-06			
Cm-244	1.56E-06			
TOTAL			2.20E-04	

Figure A5: Look-up table - Ingestion of contaminated wild fungi

Whole body effective dose from the ingestion of wild foods grown in soil contaminated with unit activity concentration (mSv y^{-1} per Bq g^{-1})

Whole body effective dose (mSv y^{-1}) from the ingestion of wild foods grown in soil contaminated with a specified activity concentration

	Values entered
Age Group	Adult
Wild Food Type	Fungi
Ingestion rate (g y^{-1})	0.00E+00

Basis of Input:
No fungi is assumed to have been consumed.

	mSv y^{-1} per Bq g^{-1}	Specified activity concentration Bq g^{-1}	Whole body effective dose mSv y^{-1}	Radionuclide contribution %
H-3 (OBT)	No Fungi Data			
H-3 (H2O)	No Fungi Data	2.00E-01	No Fungi Data	
C-14	No Fungi Data			
Cl-36	No Fungi Data			
K-40	No Fungi Data			
Co-60	No Fungi Data			
Sr+90	0.00E+00	1.00E-01		
Tc-99	0.00E+00			
Ru+106	No Fungi Data			
Sn+126	No Fungi Data			
I-129	0.00E+00			
Cs-134	No Fungi Data			
Cs+137	0.00E+00	1.00E+00		
Pb+210	No Fungi Data			
Po-210	No Fungi Data			
Ra+226	No Fungi Data			
Ra+228	No Fungi Data			
Th+228	No Fungi Data			
Th+229	No Fungi Data			
Th-230	No Fungi Data			
Th-232	No Fungi Data			
Pa-231	No Fungi Data			
U-233	No Fungi Data			
U-234	No Fungi Data			
U+235	No Fungi Data			
U-236	No Fungi Data			
U+238	No Fungi Data			
Np+237	0.00E+00			
Pu-238	No Fungi Data			
Pu-239	No Fungi Data			
Pu-240	No Fungi Data	1.00E-02	No Fungi Data	
Pu-241	No Fungi Data			
Pu-242	No Fungi Data			
Am-241	No Fungi Data			
Cm-242	No Fungi Data			
Cm-243	No Fungi Data			
Cm-244	No Fungi Data			
TOTAL				

Figure A6: Look-up table - Ingestion of contaminated water

Whole body effective dose from the ingestion of water contaminated with unit activity concentration (mSv y^{-1} per Bq L^{-1})

Whole body effective dose (mSv y^{-1}) from the ingestion of water contaminated with a specified activity concentration

	Values entered
Age Group	Adult
Water ingestion rate (L y^{-1})	1.00E+00

Basis of Input:

Has the occasional drink from the contaminated spring (1 L y^{-1})

	mSv y^{-1} per Bq L^{-1}	Specified activity concentration Bq L^{-1}	Whole body effective dose mSv y^{-1}	Radionuclide contribution %
H-3 (OBT)	4.20E-08			
H-3 (H2O)	1.80E-08	1.00E+03	1.80E-05	5%
C-14	5.80E-07			
Cl-36	9.30E-07			
K-40	6.20E-06			
Co-60	3.40E-06			
Sr+90	3.10E-05	1.00E+01	3.10E-04	91%
Tc-99	6.40E-07			
Ru+106	7.00E-06			
Sn+126	5.10E-06			
I-129	1.10E-04			
Cs-134	1.90E-05			
Cs+137	1.30E-05	1.00E+00	1.30E-05	4%
Pb+210	6.90E-04			
Po-210	1.20E-03			
Ra+226	2.80E-04			
Ra+228	6.90E-04			
Th+228	1.40E-04			
Th+229	6.10E-04			
Th-230	2.10E-04			
Th-232	2.30E-04			
Pa-231	7.10E-04			
U-233	5.10E-05			
U-234	4.90E-05			
U+235	4.70E-05			
U-236	4.70E-05			
U+238	4.90E-05			
Np+237	1.10E-04			
Pu-238	2.30E-04			
Pu-239	2.50E-04			
Pu-240	2.50E-04	0.00E+00	0.00E+00	
Pu-241	4.80E-06			
Pu-242	2.40E-04			
Am-241	2.00E-04			
Cm-242	1.20E-05			
Cm-243	1.50E-04			
Cm-244	1.20E-04			
TOTAL			3.41E-04	

Figure A7: Look-up table – Dermal contact with contaminated soil

Whole body effective dose from the presence of soil on the skin contaminated with unit activity concentration (mSv y^{-1} per Bq g^{-1})		Whole body effective dose (mSv y^{-1}) from the presence of soil on the skin contaminated with a specified activity concentration		
	Value entered	Basis of Input:		
occupancy (h y^{-1})	10	Visitor on site 1 hour per week (50 h y^{-1}) Spends 20% of that time on the contaminated area (10 h y^{-1}).		
	mSv y^{-1} per Bq g^{-1}	Specified activity concentration Bq g^{-1}	Whole body effective dose mSv y^{-1}	Radionuclide contribution %
H-3 (OBT)	0.00E+00			
H-3 (H2O)	0.00E+00	2.00E-01	0.00E+00	0%
C-14	2.25E-07			
Cl-36	6.25E-07			
K-40	6.02E-07			
Co-60	4.83E-07			
Sr+90	1.28E-06	1.00E-01	1.28E-07	17%
Tc-99	4.00E-07			
Ru+106	7.28E-07			
Sn+126	4.60E-07			
I-129	1.65E-07			
Cs-134	4.72E-07			
Cs+137	6.33E-07	1.00E+00	6.33E-07	83%
Pb+210	6.52E-07			
Po-210	1.20E-13			
Ra+226	2.16E-06			
Ra+228	7.90E-07			
Th+228	1.60E-06			
Th+229	1.59E-06			
Th-230	2.60E-08			
Th-232	2.42E-06			
Pa-231	3.82E-08			
U-233	1.75E-09			
U-234	2.53E-09			
U+235	6.38E-07			
U-236	1.17E-09			
U+238	9.52E-07			
Np+237	8.83E-07			
Pu-238	6.75E-10			
Pu-239	3.58E-10			
Pu-240	6.50E-10	1.00E-02	6.50E-12	0%
Pu-241	8.25E-13			
Pu-242	2.15E-11			
Am-241	1.80E-08			
Cm-242	6.00E-10			
Cm-243	4.77E-07			
Cm-244	5.50E-10			
TOTAL			7.61E-07	

Figure A8: Look-up table - External irradiation from surface ground contamination

Whole body effective dose due to external irradiation from soil contaminated with unit activity concentration (mSv y^{-1} per Bq cm^{-2}) for surface

Whole body effective dose (mSv y^{-1}) due to external irradiation from soil contaminated with a specified activity concentration for surface contamination

Basis of Input: This scenario is not considered for this assessment

	Value entered
occupancy (h y^{-1})	10

	1 m above infinite uniform	1 m above 10 m diam patch	5 m from edge infinite uniform	50 m from edge infinite uniform	Specified activity concentration	1 m above infinite uniform	1 m above 10 m diam patch	5 m from edge infinite uniform	50 m from edge infinite uniform
	mSv y^{-1} per Bq cm^{-2}	mSv y^{-1} per Bq cm^{-2}	mSv y^{-1} per Bq cm^{-2}	mSv y^{-1} per Bq cm^{-2}	Bq cm^{-2}	mSv y^{-1}	mSv y^{-1}	mSv y^{-1}	mSv y^{-1}
H-3 (OBT)	0.00E+00	0.00E+00	0.00E+00	0.00E+00					
H-3 (H2O)	0.00E+00	0.00E+00	0.00E+00	0.00E+00					
C-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00					
Cl-36	2.70E-06	2.60E-06	2.10E-08	6.50E-09					
K-40	9.30E-05	4.90E-05	1.80E-05	5.80E-06					
Co-60	1.10E-03	3.20E-04	2.90E-04	9.50E-05					
Sr+90	6.10E-05	6.10E-05	3.70E-11	7.50E-15	2.00E+00	1.22E-04	1.22E-04	7.40E-11	1.50E-14
Tc-99	2.00E-11	2.00E-11	0.00E+00	0.00E+00					
Ru+106	1.70E-04	1.00E-04	2.70E-05	8.30E-06					
Sn+126	9.00E-04	2.70E-04	2.50E-04	7.80E-05					
I-129	1.90E-05	7.70E-06	4.10E-06	2.70E-07					
Cs-134	7.30E-04	2.20E-04	2.00E-04	6.40E-05					
Cs+137	2.70E-04	8.80E-05	7.50E-05	2.30E-05	2.00E+01	5.40E-03	1.76E-03	1.50E-03	4.60E-04
Pb+210	1.80E-05	1.70E-05	4.60E-07	8.00E-08					
Po-210	3.90E-09	1.20E-09	1.10E-09	3.40E-10					
Ra+226	7.60E-04	2.30E-04	2.20E-04	6.90E-05					
Ra+228	4.40E-04	1.30E-04	1.20E-04	3.90E-05					
Th+228	6.50E-04	1.90E-04	1.80E-04	6.20E-05					
Th+229	1.20E-04	4.90E-05	5.00E-05	1.50E-05					
Th-230	5.00E-07	2.40E-07	9.80E-08	2.40E-08					
Th-232	3.60E-07	2.00E-07	5.60E-08	1.10E-08					
Pa-231	2.30E-05	8.00E-06	6.10E-06	1.70E-06					
U-233	4.20E-07	2.10E-07	7.60E-08	1.70E-08					
U-234	4.80E-07	3.10E-07	5.70E-08	7.10E-09					
U+235	1.00E-04	3.00E-05	3.00E-05	4.40E-06					
U-236	4.20E-07	2.80E-07	4.30E-08	3.50E-09					
U+238	7.10E-05	6.00E-05	4.10E-06	1.30E-06					
Np+237	1.30E-04	3.70E-05	3.60E-05	1.10E-05					
Pu-238	3.80E-07	2.70E-07	3.20E-08	1.10E-09					
Pu-239	1.80E-07	8.50E-09	2.20E-08	3.30E-09					
Pu-240	3.70E-07	2.60E-07	3.30E-08	1.70E-09	2.00E-02	7.40E-09	5.20E-09	6.60E-10	3.40E-11
Pu-241	1.20E-09	4.70E-10	3.30E-10	9.90E-11					
Pu-242	4.10E-07	2.70E-07	4.00E-08	1.30E-09					
Am-241	2.10E-05	4.70E-06	5.80E-06	1.30E-06					
Cm-242	6.00E-07	3.80E-07	6.70E-08	9.30E-10					
Cm-243	7.50E-05	2.10E-05	2.20E-05	6.80E-06					
Cm-244	5.10E-07	3.30E-07	5.30E-08	5.20E-10					
TOTAL						5.52E-03	1.88E-03	1.50E-03	4.60E-04

Figure A9: Look-up table - External irradiation from shallow ground contamination

Whole body effective dose due to external irradiation from soil contaminated with unit activity concentration (mSv y^{-1} per Bq g^{-1}) for shallow contamination

Whole body effective dose (mSv y^{-1}) due to external irradiation from soil contaminated with a specified activity concentration for shallow contamination 5 cm

Basis of Input: This scenario is not considered for this assessment

	Value entered
occupancy (h y^{-1})	10

Nuclide	1 m above infinite uniform (mSv y^{-1} per Bq g^{-1})	1 m above 10 m diam patch (mSv y^{-1} per Bq g^{-1})	5 m from edge infinite uniform (mSv y^{-1} per Bq g^{-1})	50 m from edge infinite uniform (mSv y^{-1} per Bq g^{-1})	Specified activity concentration (Bq g^{-1})	1 m above infinite uniform (mSv y^{-1})	1 m above 10 m diam patch (mSv y^{-1})	5 m from edge infinite uniform (mSv y^{-1})	50 m from edge infinite uniform (mSv y^{-1})
H-3 (OBT)	0.00E+00	0.00E+00	0.00E+00	0.00E+00					
H-3 (H2O)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00					
Cl-36	5.30E-07	4.60E-07	1.90E-08	1.00E-09					
K-40	2.00E-04	1.20E-04	2.10E-05	1.40E-06					
Co-60	3.20E-03	2.00E-03	3.30E-04	2.10E-05					
Sr+90	2.10E-05	2.10E-05	3.00E-13	3.20E-19	1.00E-01	2.10E-06	2.10E-06	3.00E-14	3.20E-20
Tc-99	3.80E-10	3.80E-10	0.00E+00	0.00E+00					
Ru+106	3.30E-04	2.40E-04	2.50E-05	1.40E-06					
Sn+126	2.50E-03	1.70E-03	2.20E-04	1.20E-05					
I-129	3.00E-06	2.50E-06	1.20E-07	7.20E-10					
Cs-134	2.10E-03	1.40E-03	2.00E-04	1.20E-05					
Cs+137	7.70E-04	5.10E-04	7.20E-05	4.10E-06	1.00E+00	7.70E-04	5.10E-04	7.20E-05	4.10E-06
Pb+210	3.10E-06	3.00E-06	2.90E-08	3.90E-10					
Po-210	1.10E-08	7.40E-09	1.10E-09	6.50E-11					
Ra+226	2.30E-03	1.50E-03	2.30E-04	1.40E-05					
Ra+228	1.30E-03	8.30E-04	1.30E-04	7.40E-06					
Th+228	1.90E-03	1.20E-03	2.10E-04	1.40E-05					
Th+229	3.20E-04	2.60E-04	2.40E-05	1.10E-06					
Th-230	3.40E-07	2.70E-07	1.90E-08	6.60E-10					
Th-232	1.50E-07	1.20E-07	7.30E-09	2.40E-10					
Pa-231	4.90E-05	3.50E-05	3.90E-06	1.90E-07					
U-233	3.60E-07	2.70E-07	2.40E-08	1.10E-09					
U-234	1.10E-07	9.00E-08	5.30E-09	1.80E-10					
U+235	2.20E-04	1.60E-04	1.60E-05	6.80E-07					
U-236	5.80E-08	4.80E-08	2.40E-09	7.20E-11					
U+238	5.10E-05	4.20E-05	2.70E-06	1.50E-07					
Np+237	2.80E-04	2.00E-04	2.10E-05	9.90E-07					
Pu-238	2.90E-08	2.40E-08	1.20E-09	2.70E-11					
Pu-239	7.60E-08	5.60E-08	5.10E-09	2.30E-10					
Pu-240	3.10E-08	2.60E-08	1.30E-09	2.40E-11	1.00E-02	3.10E-10	2.60E-10	1.30E-11	2.40E-13
Pu-241	1.70E-09	1.30E-09	9.80E-11	3.60E-12					
Pu-242	3.20E-08	2.80E-08	1.30E-09	2.40E-11					
Am-241	1.20E-05	1.00E-05	5.10E-07	1.20E-08					
Cm-242	4.20E-08	3.70E-08	1.60E-09	2.80E-11					
Cm-243	1.50E-04	1.10E-04	1.10E-05	4.80E-07					
Cm-244	2.80E-08	2.50E-08	7.20E-10	1.70E-12					
TOTAL						7.72E-04	5.12E-04	7.20E-05	4.10E-06

Figure A10: Look-up table - External irradiation from infinitely deep ground contamination

Whole body effective dose due to external irradiation from soil contaminated with unit activity concentration ($mSv\ y^{-1}$ per $Bq\ g^{-1}$) for infinitely deep contamination

Whole body effective dose ($mSv\ y^{-1}$) due to external irradiation from soil contaminated with a specified activity concentration for infinitely deep contamination

Basis of Input: surface contaminated soil area 10 m in diameter - assumed to extend to depth
vistor on site 1 h each week. Spends 20% of that time in the contaminated area (10 h y^{-1}).

	Value entered
occupancy (h y^{-1})	10

	1 m above infinite uniform	1 m above 10 m diam patch	5 m from edge infinite uniform	50 m from edge infinite uniform	Specified activity concentration	1 m above infinite uniform	1 m above 10 m diam patch	5 m from edge infinite uniform	50 m from edge infinite uniform
	$mSv\ y^{-1}$ per $Bq\ g^{-1}$	$mSv\ y^{-1}$ per $Bq\ g^{-1}$	$mSv\ y^{-1}$ per $Bq\ g^{-1}$	$mSv\ y^{-1}$ per $Bq\ g^{-1}$	$Bq\ g^{-1}$	$mSv\ y^{-1}$	$mSv\ y^{-1}$	$mSv\ y^{-1}$	$mSv\ y^{-1}$
H-3 (OBT)	0.00E+00	0.00E+00	0.00E+00	0.00E+00					
H-3 (H2O)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00					
Cl-36	7.10E-07	6.40E-07	2.20E-08	1.00E-09					
K-40	4.30E-04	3.50E-04	2.50E-05	1.80E-06					
Co-60	6.80E-03	5.50E-03	4.00E-04	2.10E-05					
Sr+90	2.10E-05	2.10E-05	3.30E-13	7.60E-18	1.00E-01	2.10E-06	2.10E-06	3.30E-14	7.60E-19
Tc-99	3.80E-10	3.80E-10	0.00E+00	0.00E+00					
Ru+106	5.70E-04	4.80E-04	2.90E-05	1.40E-06					
Sn+126	4.70E-03	3.80E-03	2.60E-04	1.20E-05					
I-129	3.00E-06	2.50E-06	1.20E-07	7.90E-10					
Cs-134	4.10E-03	3.40E-03	2.40E-04	1.20E-05					
Cs+137	1.50E-03	1.20E-03	8.40E-05	4.10E-06	1.00E+00	1.50E-03	1.20E-03	8.40E-05	4.10E-06
Pb+210	3.10E-06	3.00E-06	2.90E-08	4.00E-10					
Po-210	2.30E-08	1.80E-08	1.30E-09	6.50E-11					
Ra+226	4.70E-03	3.90E-03	2.70E-04	1.40E-05					
Ra+228	2.60E-03	2.10E-03	1.50E-04	7.40E-06					
Th+228	4.40E-03	3.50E-03	2.60E-04	1.20E-04					
Th+229	5.20E-04	5.00E-04	3.40E-05	1.10E-06					
Th-230	4.20E-07	3.50E-07	2.10E-08	6.60E-10					
Th-232	1.70E-07	1.40E-07	8.00E-09	2.40E-10					
Pa-231	8.20E-05	6.70E-05	4.50E-06	1.90E-07					
U-233	5.30E-07	4.40E-07	2.80E-08	1.10E-09					
U-234	1.30E-07	1.10E-07	5.70E-09	1.80E-10					
U+235	3.30E-04	2.70E-04	1.80E-05	6.80E-07					
U-236	5.90E-08	5.50E-08	2.40E-09	7.20E-11					
U+238	7.70E-05	6.50E-05	3.10E-06	1.50E-07					
Np+237	4.40E-04	3.60E-04	2.40E-05	9.90E-07					
Pu-238	3.20E-08	2.80E-08	1.20E-09	2.70E-11					
Pu-239	1.10E-07	9.30E-08	5.80E-09	2.30E-10					
Pu-240	3.30E-08	2.60E-08	1.30E-09	2.40E-11	1.00E-02	3.30E-10	2.60E-10	1.30E-11	2.40E-13
Pu-241	2.20E-09	1.80E-09	1.10E-10	3.60E-12					
Pu-242	3.50E-08	3.00E-08	1.30E-09	2.40E-11					
Am-241	1.30E-05	1.10E-05	6.40E-07	1.20E-08					
Cm-242	4.60E-08	4.10E-08	1.60E-09	2.80E-11					
Cm-243	2.30E-04	1.90E-04	1.30E-05	4.80E-07					
Cm-244	2.80E-08	2.50E-08	7.40E-10	1.80E-12					
TOTAL						1.50E-03	1.20E-03	8.40E-05	4.10E-06

Figure A11: Look-up table - External irradiation from buried soil contamination

Whole body effective dose due to external irradiation from soil contaminated with unit activity concentration (mSv y^{-1} per Bq g^{-1}) for buried contamination

Whole body effective dose (mSv y^{-1}) due to external irradiation from soil contaminated with a specified activity concentration for buried contamination

Basis of Input: This scenario is not considered for this assessment

	Value entered
occupancy (h y^{-1})	10

	1 m above shallow burial 0.1 m clean soil mSv y^{-1} per Bq g^{-1}	1 m above deep burial 0.5 m clean soil mSv y^{-1} per Bq g^{-1}	Specified activity concentration Bq g^{-1}	1 m above shallow burial 0.1 m clean soil mSv y^{-1}	1 m above deep burial 0.5 m clean soil mSv y^{-1}	Radionuclide contribution %	Radionuclide contribution %
H-3 (OBT)	0.00E+00	0.00E+00					
H-3 (H2O)	0.00E+00	0.00E+00	2.00E-01	0.00E+00	0.00E+00	0%	0%
C-14	0.00E+00	0.00E+00					
Cl-36	6.90E-08	4.90E-10					
K-40	1.50E-04	5.50E-06					
Co-60	2.20E-03	6.70E-05					
Sr+90	7.90E-34	7.60E-34	1.00E-01	7.90E-35	7.60E-35	0%	0%
Tc-99	0.00E+00	0.00E+00					
Ru+106	1.00E-04	1.40E-06					
Sn+126	8.80E-04	8.70E-06					
I-129	7.20E-14	2.00E-29					
Cs-134	9.40E-04	1.30E-05					
Cs+137	3.20E-04	3.60E-06	1.00E+00	3.20E-04	3.60E-06	100%	100%
Pb+210	1.00E-11	1.30E-28					
Po-210	5.60E-09	8.60E-11					
Ra+226	1.40E-03	5.20E-05					
Ra+228	7.00E-04	1.70E-05					
Th+228	1.50E-03	1.10E-04					
Th+229	8.40E-05	1.50E-06					
Th-230	9.30E-09	9.70E-12					
Th-232	1.10E-09	1.10E-13					
Pa-231	8.20E-06	2.10E-08					
U-233	3.00E-08	6.70E-11					
U-234	9.60E-10	1.30E-12					
U+235	1.50E-05	1.20E-08					
U-236	2.30E-10	1.00E-14					
U+238	1.20E-05	3.00E-07					
Np+237	3.90E-05	1.00E-07					
Pu-238	1.10E-09	6.30E-12					
Pu-239	9.50E-09	4.00E-11					
Pu-240	6.50E-10	8.50E-13	1.00E-02	6.50E-12	8.50E-15	0%	0%
Pu-241	1.80E-11	3.40E-15					
Pu-242	7.40E-10	7.80E-14					
Am-241	4.10E-09	3.00E-11					
Cm-242	1.80E-09	1.50E-11					
Cm-243	1.40E-05	2.80E-08					
Cm-244	5.00E-15	5.90E-31					
TOTAL				3.20E-04	3.60E-06		

Figure A12: Scenario Information worksheet for worked example

Scenario Summary — Reference: e.g. Contam/ENV/1/1.001

General Contamination details specific to more than one scenario

Recreational Visitor on NL site but outside security fence

Surface contaminated soil area 10 m in diameter - assumed to extend to depth.
Soils contaminated with Sr+90, Cs+137 and Pu-240.
Pore water and groundwater contaminated with H-3, Sr+90 and Cs+137.
Contaminated Springwater accessible to visitor.
Tritium in (1000 Bq L^{-1}) in soils assumed to be porewater at 40% porosity (saturated).
Porewater assumed to be same as groundwater. In this example: 1Bq L^{-1} in porewater = 0.0002 Bq g^{-1} in soil.

Dust Inhalation

Contamination levels in dust 10 times higher than in soils.
Dust assumed to be free of tritium (due to evaporation).
Visitor on site 1 hour per week (50 h y-1).

Sr+90 = 1.00E+00 Bq/g; Cs+137 = 1.00E+01 Bq/g; Pu-240 = 1.00E-01 Bq/g;

Soil Ingestion

Ingestion of dust on blackberries at 0.1 g y-1 (0.1% of wet weight of fruit)

Sr+90 = 1.00E+00 Bq/g; Cs+137 = 1.00E+01 Bq/g; Pu-240 = 1.00E-01 Bq/g;

Wild food ingestion (fruit)

Eats 100 g blackberries per year from the contaminated area.

H-3 (H2O) = 2.00E-01 Bq/g; Sr+90 = 1.00E-01 Bq/g; Cs+137 = 1.00E+00 Bq/g; Pu-240 = 1.00E-02 Bq/g;

Wild food ingestion (fungi)

No fungi is assumed to have been consumed.

H-3 (H2O) = 2.00E-01 Bq/g; Sr+90 = 1.00E-01 Bq/g; Cs+137 = 1.00E+00 Bq/g; Pu-240 = 1.00E-02 Bq/g;

Water Ingestion

Has the occasional drink from the contaminated spring (1 L y-1)

H-3 (H2O) = 1.00E+03 Bq/g; Sr+90 = 1.00E+01 Bq/g; Cs+137 = 1.00E+00 Bq/g; Pu-240 = 0.00E+00 Bq/g;

Skin Dose

Visitor on site 1 hour per week (50 h y-1)
Spends 20% of that time on the contaminated area (10 h y-1).

H-3 (H2O) = 2.00E-01 Bq/g; Sr+90 = 1.00E-01 Bq/g; Cs+137 = 1.00E+00 Bq/g; Pu-240 = 1.00E-02 Bq/g;

External dose - surface

This scenario is not considered for this assessment.
However, the concentration has been entered for illustrative purposes.

Sr+90 = 2.00E+00 Bq/cm2; Cs+137 = 2.00E+01 Bq/cm2; Pu-240 = 2.00E-02 Bq/cm2;

Figure A13: Overview -Total Dose worksheet for worked example

Overview — Reference : e.g. Contam/ENV/1/1.001

Pathway	Inh Dust	Ing Soil	Ing Wild Foods - Fruit	Ing Wild Foods - Fungi	Ing Water	Skin Dose	Ext dose surface	Ext dose shallow	Ext dose deep	Ext dose buried	Total Radionuclide Dose	Radionuclide Contribution %
Age Group	Adult	Adult	Adult	N/A	Adult							
Dust loading in air (g m^{-3})	1.00E-04											
Inhalation rate (m^{3}h^{-1})	1.18											
Ingestion rate (g y^{-1})		1.00E-01	1.00E+02	N/A	1.00E+00							
occupancy (h y^{-1})	50					10	N/A	N/A	10	N/A		
Total Dose (mSv y^{-1})												
Include? (Y/N)	Y	Y	Y	N	Y	Y	Y - Ext Dose Deep					
Mechanism							1 m above - infinite uniform	1 m above - 10 m diam patch	1 m above - 10 m diam patch	deep burial		
H-3 (OBT)				N/A			N/A	N/A		N/A		
H-3 (H2O)			3.6E-07	N/A	1.8E-05	0.0E+00	N/A	N/A	0.0E+00	N/A	1.84E-05	1%
C-14				N/A			N/A	N/A		N/A		
Cl-36				N/A			N/A	N/A		N/A		
K-40				N/A			N/A	N/A		N/A		
Co-60				N/A			N/A	N/A		N/A		
Sr+90	2.2E-07	3.1E-06	1.6E-04	N/A	3.1E-04	1.3E-07	N/A	N/A	2.1E-06	N/A	4.71E-04	26%
Tc-99				N/A			N/A	N/A		N/A		
Ru+106				N/A			N/A	N/A		N/A		
Sn+126				N/A			N/A	N/A		N/A		
I-129				N/A			N/A	N/A		N/A		
Cs-134				N/A			N/A	N/A		N/A		
Cs+137	2.7E-07	1.3E-05	6.5E-05	N/A	1.3E-05	6.3E-07	N/A	N/A	1.2E-03	N/A	**1.29E-03**	**71%**
Pb+210				N/A			N/A	N/A		N/A		
Po-210				N/A			N/A	N/A		N/A		
Ra+226				N/A			N/A	N/A		N/A		
Ra+228				N/A			N/A	N/A		N/A		
Th+228				N/A			N/A	N/A		N/A		
Th+229				N/A			N/A	N/A		N/A		
Th-230				N/A			N/A	N/A		N/A		
Th-232				N/A			N/A	N/A		N/A		
Pa-231				N/A			N/A	N/A		N/A		
U-233				N/A			N/A	N/A		N/A		
U-234				N/A			N/A	N/A		N/A		
U+235				N/A			N/A	N/A		N/A		
U-236				N/A			N/A	N/A		N/A		
U+238				N/A			N/A	N/A		N/A		
Np+237				N/A			N/A	N/A		N/A		
Pu-238				N/A			N/A	N/A		N/A		
Pu-239				N/A			N/A	N/A		N/A		
Pu-240	3.0E-05	2.5E-06	2.5E-08	N/A		6.5E-12	N/A	N/A	2.6E-10	N/A	3.20E-05	2%
Pu-241				N/A			N/A	N/A		N/A		
Pu-242				N/A			N/A	N/A		N/A		
Am-241				N/A			N/A	N/A		N/A		
Cm-242				N/A			N/A	N/A		N/A		
Cm-243				N/A			N/A	N/A		N/A		
Cm-244				N/A			N/A	N/A		N/A		
Total Pathway Dose	3.00E-05	1.86E-05	2.20E-04	N/A	3.41E-04	7.61E-07	N/A	N/A	1.20E-03	N/A	1.81E-03	
	2%	1%	12%		19%	0%			66%			

APPENDIX 6: VERIFICATION OF LOOK-UP TABLE TOOL

Output from the look-up tables spreadsheet tool was compared with tabulated data from the NRPB's dose methodology for contaminated land (Oatway and Mobbs, 2003) which considered dose coefficients for members of the public rather than workers for all of their scenarios. Doses from the construction scenario for adults in Table 25 from Oatway and Mobbs (2003) for exposed uniform contamination were found to be suitable for comparison purposes using the adult group as opposed to adult worker group in the look-up tables spreadsheet tool.

Construction Scenario

Inadvertent soil ingestion

From Table 25 of Oatway and Mobbs (2003), it is possible to perform comparisons for H-3 and Pb+210 because inadvertent soil ingestion is a dominant exposure pathway and these radionuclides are also contained within the spreadsheet tool. In comparing doses, a soil ingestion rate (RATE) of 5.04 g y^{-1} was used in the spreadsheet tool to conform to the rate used in Oatway and Mobbs (2003) which was calculated as:

$$RATE = T_{os} * F_{od} * F_{dh} * ING_{s,hour}$$

where for the construction scenario:
T_{os} = time spent on site = 0.23 *8760 = 2014.8 h y^{-1}
F_{od} = fraction of time outdoors on site = 1
F_{dh} = fraction of outdoor time a person has dirt on their hands = 0.5
$ING_{s,hour}$ = hourly critical group ingestion rate of soil = 5E-03 g h^{-1}
(Smith and Jones, 2003)

Using the soil ingestion rate above results in excellent agreement for the inadvertent soil ingestion dose between Oatway and Mobbs (2003) and the spreadsheet tool as shown in Table A6. It should be noted that for H-3, tritiated water is considered in the spreadsheet tool. As Oatway and Mobbs (2003) consider doses on the basis of 1 Bq L^{-1} as opposed to 1 Bq g^{-1}, an amount of water in bulk soil of 1.3E-4 L g^{-1} (cited in Oatway and Mobbs, 2003) was applied to their data.

Table A6: Inadvertent soil ingestion (Construction scenario) – comparison of doses

	Oatway and Mobbs (2003)			TOOL
Radionuclide	**Total dose (Sv y^{-1})**	**Dominant pathway contribution**	**Exposure pathway dose (mSv y^{-1})**	**Exposure pathway dose (mSv y^{-1})**
H-3	1.18E-14	1.00	9.08E-08	9.07E-08
Pb+210	6.46E-06	0.54	3.49E-03	3.48E-03

Skin contamination

From Table 25 of Oatway and Mobbs (2003), it is possible to perform comparisons for Tc-99 because skin contamination is a dominant exposure pathway and this radionuclide is contained within the spreadsheet tool. In comparing doses, an occupancy value of 1000 h y^{-1} was used in the spreadsheet tool to conform to the time spent with dirt on the skin considered by Oatway and Mobbs (2003).

Using the occupancy value above results in excellent agreement for the skin contamination pathway dose between Oatway and Mobbs (2003) and the spreadsheet tool as shown in Table A7.

Table A7: Skin contamination (Construction scenario) – comparison of doses

	Oatway and Mobbs (2003)			TOOL
Radionuclide	**Total dose (Sv y^{-1})**	**Dominant pathway contribution**	**Exposure pathway dose (mSv y^{-1})**	**Exposure pathway dose (mSv y^{-1})**
Tc-99	6.06E-08	0.66	4.00E-05	4.00E-05

Inhalation of dust

From Table 25 of Oatway and Mobbs (2003), it is possible to perform comparisons for Po-210 and many of the actinides because inhalation of dust is a dominant exposure pathway and these radionuclides are also contained within the spreadsheet tool. In comparing doses, an occupancy value of 2014.8 h y^{-1} was used in the spreadsheet tool to correspond to the time spent outside previously discussed. From the specification of the Construction Scenario as given in section D2 of Appendix D of Oatway and Mobbs (2003) an average dust inhalation rate (RATE) of 1.1465E-03 g h^{-1} was calculated from the parameters listed. This dust inhalation rate was achieved in the spreadsheet tool by entering a dust loading of 1E-03 g m^{-3} and a breathing rate of 1.1465 m^3 h^{-1}.

Using the spreadsheet input values above results in excellent agreement for the inhalation of dust pathway dose between Oatway and Mobbs (2003) and the spreadsheet tool as shown in Table A8.

Table A8: Inhalation of dust (Construction scenario) – comparison of doses

	Oatway and Mobbs (2003)			TOOL
Radionuclide	**Total dose ($Sv\ y^{-1}$)**	**Dominant pathway contribution**	**Exposure pathway dose ($mSv\ y^{-1}$)**	**Exposure pathway dose ($mSv\ y^{-1}$)**
Po-210	1.37E-05	0.56	7.67E-03	7.62E-03
Th+229	2.84E-04	0.70	1.99E-01	1.99E-01
Th-230	3.35E-05	0.97	3.25E-02	3.23E-02
Pa-231	3.39E-04	0.95	3.22E-01	3.23E-01
Th-232	5.89E-05	0.98	5.77E-02	5.77E-02
U-233	8.65E-06	0.96	8.30E-03	8.32E-03
U-234	8.36E-06	0.97	8.11E-03	8.08E-03
U-236	7.64E-06	0.97	7.41E-03	7.39E-03
Pu-238	1.07E-04	0.99	1.06E-01	1.06E-01
Pu-239	1.17E-04	0.99	1.16E-01	1.15E-01
Pu-240	1.17E-04	0.99	1.16E-01	1.15E-01
Pu-241	2.10E-06	0.99	2.08E-03	2.08E-03
Am-241	1.01E-04	0.96	9.70E-02	9.70E-02
Cm-244	6.30E-05	0.99	6.24E-02	6.24E-02

<u>External irradiation exposure pathway</u>

From Table 25 of Oatway and Mobbs (2003), it is possible to perform comparisons of effective doses (1 m above the source of contamination) associated with the external irradiation pathway for a number of radionuclides that are contained within the spreadsheet tool. In comparing doses, an occupancy value of 2014.8 h y^{-1} was used in the spreadsheet tool to correspond to the time spent outside as previously discussed.

In comparing dose values, the spreadsheet tool values have been cited for shallow (5 cm deep) contamination and infinitely deep (actually 5 m deep) contamination for 1 Bq g^{-1} contamination spread uniformly through an infinite expanse of soil of density 1.5 g cm^{-3}. This is because Oatway and Mobbs (2003) have considered 1 m deep contamination in deriving external dose factors from their GRANIS model.

Results of the dose comparisons are shown below in Table A9 where it can be observed that with the exception of Sr+90, the dose values from Oatway and Mobbs (2003) lie in between the doses obtained from the spreadsheet tool for shallow and deep contamination. Sr+90 is exceptional because it is a higher energy beta particle emitter and in the derivation of external irradiation dose factors for the spreadsheet tool, no distinction was made with depth for the beta particle contributions as it was for the gamma photon contributions. The latter contributions were readily obtained from Microshield calculations whereas the beta particle contributions were much more difficult to ascertain and were literature values from Mobbs and Harvey (2003).

Table A9: External irradiation (Construction scenario) – comparison of doses

	Oatway and Mobbs (2003)			TOOL		Ratio TOOL/O&M	
Radionuclide	**Total dose ($Sv\ y^{-1}$)**	**Dominant pathway contribution**	**Exposure pathway dose ($mSv\ y^{-1}$)**	**Dose shallow ($mSv\ y^{-1}$)**	**Dose deep ($mSv\ y^{-1}$)**	**Shallow**	**Deep**
Co-60	1.11E-03	1.00	1.11E+00	6.45E-01	1.37E+00	0.58	1.23
Sr+90	3.06E-06	0.88	2.69E-03	4.23E-03	4.23E-03	1.57	1.57
Ru+106	8.18E-05	1.00	8.18E-02	6.65E-02	1.15E-01	0.81	1.41
Cs-134	6.34E-04	1.00	6.34E-01	4.23E-01	8.26E-01	0.67	1.30
Cs+137	2.41E-04	1.00	2.41E-01	1.55E-01	3.02E-01	0.64	1.25
Ra+226	7.58E-04	0.99	7.50E-01	4.63E-01	9.47E-01	0.62	1.26
Ra+228	4.11E-04	0.98	4.02E-01	2.62E-01	5.24E-01	0.65	1.30
Th+228	7.78E-04	0.87	6.77E-01	3.83E-01	8.87E-01	0.57	1.31
U+235	5.28E-05	0.86	4.54E-02	4.43E-02	6.65E-02	0.98	1.46
U+238	1.79E-05	0.61	1.09E-02	1.03E-02	1.55E-02	0.94	1.42
Np+237	1.23E-04	0.56	6.89E-02	5.64E-02	8.87E-02	0.82	1.29

Generally from Table A9, doses for external irradiation from the spreadsheet tool are higher than such doses from Oatway and Mobbs (2003) allowing for differences in depth in the derivation of their external dose factors. This is not a serious issue because the use of the spreadsheet tool values should make for a more conservative contaminated land assessment. Other than proving that the external irradiation doses from the spreadsheet tool lie within a sensible range, these doses cannot be precisely verified as they can for the inhalation and ingestion exposure pathways.

School Scenario

Although the school scenario as specified in Oatway and Mobbs (2003) is not in the remit of the functionality of the spreadsheet tool, it is useful in checking the functionality of the tool in terms of exposures to children (10 years). This is particularly useful in ensuring that age dependent ingestion and inhalation dose coefficients are correctly applied. Doses from the school scenario in Table 31 from Oatway and Mobbs (2003) for exposed uniform contamination were found to be suitable for comparison purposes.

Inadvertent soil ingestion

From Table 31 of Oatway and Mobbs (2003), it is possible to perform comparisons for H-3, Pb+210 and Po-210 because inadvertent soil ingestion is a dominant exposure pathway and these radionuclides are also contained within the spreadsheet tool. In comparing doses, a soil ingestion rate (RATE) of 0.7 g y^{-1} was used in the spreadsheet tool to conform to the rate for children used in Oatway and Mobbs (2003) which was calculated as:

$RATE = T_{os} * F_{od} * F_{dh} * ING_{s,hour}$

where for the school scenario:
T_{os} = time spent on site = 0.16 *8760 = 1401.6 h y^{-1}
F_{od} = fraction of time outdoors on site = 0.2
F_{dh} = fraction of outdoor time a person has dirt on their hands = 0.25
$ING_{s,hour}$ = hourly critical group ingestion rate of soil = 1E-02 g h^{-1} (Smith and Jones, 2003)

Using the soil ingestion rate above results in excellent agreement for the inadvertent soil ingestion pathway dose between Oatway and Mobbs (2003) and the spreadsheet tool as shown in Table A10. It should be noted that for H-3, tritiated water is considered in the spreadsheet tool. As Oatway and Mobbs (2003) consider doses on the basis of 1 Bq L^{-1} as opposed to 1 Bq g^{-1}, an amount of water in bulk soil of 1.3E-4 g L^{-1} (cited in Oatway and Mobbs, 2003) was applied to their data.

Table A10: Inadvertent soil ingestion (School scenario) – comparison of doses

	Oatway and Mobbs (2003)			**TOOL**
Radionuclide	**Total dose (Sv y^{-1})**	**Dominant pathway contribution**	**Exposure pathway dose (mSv y^{-1})**	**Exposure pathway dose (mSv y^{-1})**
H-3	2.10E-15	1.00	1.62E-08	1.61E-08
Pb+210	1.55E-06	0.86	1.33E-03	1.33E-03
Po-210	2.36E-06	0.77	1.82E-03	1.82E-03

<u>Inhalation of dust</u>

From Table 31 of Oatway and Mobbs (2003), it is possible to perform comparisons for many of the actinides because inhalation of dust is a dominant exposure pathway and these radionuclides are also contained within the spreadsheet tool. In comparing doses, an occupancy value of 1401.6 h y^{-1} was used in the spreadsheet tool to correspond to the time spent outside previously discussed. From the specification of the School Scenario as given in section E2 of Appendix E of Oatway and Mobbs (2003) an average dust inhalation rate (RATE) of 8.265E-05 g h^{-1} was calculated from the parameters listed. This dust inhalation rate was achieved in the spreadsheet tool by entering a dust loading of 1E-04 g m^{-3} and a breathing rate of 0.8265 m^3 h^{-1}.

Using the spreadsheet input values above results in excellent agreement for the inhalation of dust pathway dose between Oatway and Mobbs (2003) and the spreadsheet tool as shown in Table A11.

Table A11: Inhalation of dust (School scenario) – comparison of doses

	Oatway and Mobbs (2003)			TOOL
Radionuclide	**Total dose ($Sv\ y^{-1}$)**	**Dominant pathway contribution**	**Exposure pathway dose ($mSv\ y^{-1}$)**	**Exposure pathway dose ($mSv\ y^{-1}$)**
Th+229	2.49E-05	0.50	1.25E-02	1.27E-02
Th-230	2.03E-06	0.91	1.85E-03	1.85E-03
Pa-231	1.97E-05	0.88	1.73E-02	1.74E-02
Th-232	3.22E-06	0.94	3.03E-03	3.01E-03
U-233	6.34E-07	0.90	5.71E-04	5.68E-04
U-234	6.11E-07	0.91	5.56E-04	5.56E-04
U-236	5.72E-07	0.91	5.21E-04	5.21E-04
Pu-238	5.27E-06	0.97	5.11E-03	5.10E-03
Pu-239	5.75E-06	0.97	5.58E-03	5.56E-03
Pu-240	5.75E-06	0.97	5.58E-03	5.56E-03
Pu-241	9.98E-08	0.96	9.58E-05	9.61E-05
Am-241	5.17E-06	0.90	4.65E-03	4.63E-03
Cm-244	3.24E-06	0.97	3.14E-03	3.13E-03

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