Methodology for Estimating the Doses to Members of the Public from Contaminated Land

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1 Introduction

In the UK, and across many countries in the world, a number of sites have become contaminated with radionuclides as a result of past or present industrial operations, past waste disposals or accidents. In some cases the sites are in use and it is important to identify whether the doses received by the users are acceptable or whether cleanup is required. Conversely, in some cases the owner of the site wishes to sell the land for redevelopment and therefore it is important to determine the potential doses that could be received and to determine appropriate cleanup levels. In 1998 NRPB developed radiological protection objectives for contaminated land (NRPB, 1998a), addressing dose criteria for both types of situation described above, and recommending that realistic assessments of the doses arising from contaminated land should be performed. Since then, NRPB has developed a methodology to assess the potential doses from exposure to radioactive residues present in land and has undertaken a number of site-specific assessments. NRPB has also developed guidance and technical supporting documentation in support of the development of a regulatory framework for the identification of radioactively contaminated land (Environment Agency, 1999). The report published recently by Oatway and Mobbs (2003), described by this paper, represents the culmination of NRPB's experience in developing assessment tools for exposure to radioactively contaminated land, and represents a definitive general methodology for assessing the doses and risks from radioactively contaminated land. The methodologies and parameter values used in previous assessments have been reviewed and updated and the methodology has been made more easily adaptable to address specific situations. This paper describes the assumptions behind the methodology, including the contamination profile, the exposed groups considered and the way the methodology could be used when dealing with contaminated land.

2 Situations which have led to contamination of land

Radionuclides could be present on land as a result of a number of past land uses. Perhaps the most common cause of radioactive contamination of land in the UK has been from radium luminising activities. Land became contaminated with radium due to the burial or discharge, often in a poorly controlled manner, of both waste materials from luminising and of disused luminised articles. The practice of incineration of wastes was also not uncommon, with the residue of the incineration being buried on the same site. Contamination of land could also occur during the extraction and handling of materials containing high levels of naturally occurring radionuclides (NORM). Other sources of local, small-scale radioactive contamination have been caused by the accumulation in pits of waste products from past activities of the nuclear industry.

3 General approach for assessing land

The EA recommended approach for identifying, assessing and categorising radioactively contaminated land involves two main stages: the initial screening assessment followed by a site-specific assessment (Environment Agency, 1999). The initial screening assessment would be used to determine whether a site-specific assessment was required and the priority for that assessment, or whether no further action was needed. If a site-specific assessment was carried out, the assessment would be used to obtain a realistic assessment of the doses from the contamination for all expected activities on the land, and to provide the radiological protection basis for justifying clean-up, and identifying the optimal clean-up strategy. The initial screening assessment would involve 3 main stages: desk study, initial site survey and initial categorisation (screening).

3.1 Desk study

Radioactive contamination of land currently in use may remain undetected for long periods of time. In particular, if the process that gave rise to contamination ceased tens of years previously there may be little record of the industry or waste arising. If land were thought to be contaminated, the initial step would be to carry out a desk study. The desk study should provide sufficient information to determine whether a monitoring survey is appropriate, and to provide input to the design of the studies so that the area to be surveyed can be identified. Any radionuclides thought likely to be present should be identified to assist those carrying out the survey.

3.2 Initial site survey

A walk over survey of the site would generally be conducted to determine the extent of any contamination. In addition to this, samples may also be taken for laboratory analysis to confirm the site survey or to aid the site survey if radionuclides are likely to be present that cannot be detected with field instruments. The sampling strategy would take into account any information about the likely vertical and spatial distribution of radionuclides from the desk study and the results of the site survey.

3.3 Initial categorisation (screening)

The results from the initial site survey of the dose rate and activity concentration measurements are used to complete an initial categorisation of the site by comparing them with screening levels, derived from appropriate dose criteria, and plotting an annual dose rate map (Environment Agency, 1999). At this point it will be decided if the land is contaminated or not and if extra effort is required in assessing the land for risks to the population. Although not intended for the identification of contaminated land, the Generalised Derived Limit (GDL) for soil can also provide a useful reference point. GDLs are calculated using cautious assumptions and present the most restrictive activity concentration in various environmental media for a dose limit of 1 mSv per year (NRPB, 1998b, NRPB, 2000). GDLs are intended to be used as convenient reference levels against which the results of environmental monitoring can be compared and are primarily for evaluating the effects of discharges from practices; their usefulness in the context of identification of contaminated land will vary from situation to situation.

3.4 Site specific assessment

If a site-specific assessment of the area is required then two radiological assessments of the site should be carried out. Firstly, present day doses to site users and those on nearby land should be estimated using measured values of dose rates and activity concentrations in relevant environmental materials where available. The results of habit surveys should be used. Where measured values are not available, reasonable estimates should be made.

Secondly, a prospective assessment should be performed covering future periods. Estimates of doses should be made, based on exposures arising from likely habits and reasonable future land use. In the UK this may be linked to all land uses that do not require planning permission. The dose assessments made should be realistic and based on the habit survey. Addition over exposure pathways should be performed as appropriate.

The results of the assessments are then compared with the appropriate dose criteria.

4 General dose assessment methodology

The methodology developed by the NRPB allows a site specific assessment of a site to be made. In calculating the dose to site users, 7 exposure scenarios have been defined. These have been selected as representing the scenarios most likely to be experienced when conducting such an assessment. The exposure scenarios represent situations whereby members of the public become exposed to radionuclides. The exposure scenarios considered are given in Table 1, along with a description of the scenario and the age groups considered to be exposed.

The methodology calculates the effective dose to a site occupant per unit activity concentration in the soil. No account is made for decay over the year, except for short-lived daughter in-growth, as the nuclides considered are generally long lived. The methodology also allows the derivation of clean-up levels to be made.

4.1 Spatial distribution of the contamination in the soil

Usually insufficient information is available to characterise the spatial distribution of the contamination at a site in detail. This may be due to the contamination occurring a sufficiently long time ago that either no records exist or such records have been lost. For those cases where the characterisation cannot be determined, the more pessimistic assumption is that the contamination is, or has become over time, uniformly distributed. However, it is unlikely that the site will be contaminated with a uniform distribution of radionuclides. In fact it is more probable that the site will consist of separate areas of contamination of varying sizes and depths. In the methodology, 2 different horizontal and 3 different vertical spatial distributions have been considered giving rise to 6 contamination profiles for each land use scenario. These are discussed below.

4.1.1 Exposed, uniform contamination distribution

This distribution represents contamination that is evenly distributed over the site and extends to a depth of 1m. There is no overlying uncontaminated soil or other material.

4.1.2 Buried, uniform contamination distribution

This distribution considers contamination that has been, or will be, buried under an attenuating medium. For most scenarios this medium corresponds to clean soil 15 cm in depth, although for the concrete scenario this medium corresponds to a layer of tarmac or concrete. The contamination is assumed to be present under the medium at approximately the same activity concentration over the entire site.

Table 1 Summary of the different scenarios considered in the general methodology

Scenario	General description	Exposed person
Agriculture	Farm where contamination is assumed to be restricted to one field. Farmer spends time on the field, including manually working and ploughing the ground. Farmer and family eat produce from the farm	Farmer (adult) Farmer's family (adult, 10y child, infant)
Recreation area	Family members use a grassed area for recreation, e.g., dog-walking or playing	General user (adult, 10y child, infant)
	Fisherman fishing from bank of river or lake in park. Fisherman and family eat catch.	Fisherman (adult) Fisherman's family (adult, 10y child, infant)
	Swimming in the lake by all family members	Swimmers (adult, 10y child, infant)
	A park worker spends entire working year within the recreational area and performs minor maintenance tasks	Park worker (adult)
Construction	Site being developed over the course of a year for future industrial use or housing. Mechanical disturbance of soil.	Construction worker (adult)
School	School building and school playing field built on contaminated land used by adult staff and children	School child (10y) Teacher (adult) Caretaker (adult)
Industrial	Administrative or light-manufacturing offices with small outdoor garden area	Office worker (adult)
Housing	Housing estate consisting of a house and garden area, garden assumed partly grassed and partly used to grow foodstuffs	Resident (adult, 10y child, infant)
Covered area	Car park used regularly each weekday by adult	Car driver (adult)
	Playground used by children	Children (10y child, infant)

4.1.3 Disturbed buried, uniform contamination distribution

This distribution considers contaminated material that has been buried, but becomes re-exposed following certain tasks undertaken by the site occupant. Mixing of the contamination with clean soil placed over it is assumed to occur during the disturbance of the ground that re-exposes the buried contamination. The exposed material for this distribution is thus present at a reduced or diluted concentration, with the decrease in the activity concentration depending on the scenario and the mechanism that re-exposed the contamination.

4.1.4 Exposed, patchy contamination distribution

This distribution considers exposure to exposed contamination but for this distribution it is considered that the contamination is not present over the whole of the site. This results in exposure to the contamination for only some of the time whilst onsite, and for other times no direct exposure occurs. For times where occupancy is assumed to be random, a factor is used to scale the dose calculated in the uniform exposed profile to the area of the site assumed to be contaminated.

4.1.5 Buried, patchy contamination distribution

This distribution considers exposure to contamination that has been buried. However, the contamination does not cover the whole site so that the exposure time is decreased by a factor representing the fraction of time spent over or near to radionuclides in the soil.

4.1.6 Disturbed buried, patchy contamination distribution

This distribution considers the exposure to contamination that was buried but has been re-exposed due to human activities. However, for this distribution, the contamination is not present over the entire site so that the dose is calculated assuming occupancy of contaminated areas that are buried or re-exposed, and of areas that are uncontaminated.

Table 2 Contamination types and pathways considered in the general methodology

Scenario	Contamination distribution	Exposed person	Pathways
Agricultural	Exposed uniform Disturbed buried uniform Exposed patch Disturbed buried patch	Farmer	External, Skin contamination, Inhalation of suspended contamination, Inadvertent ingestion of contamination, Ingestion of food
	Exposed uniform Disturbed buried uniform Exposed patch Disturbed buried patch	Farmer's family	Ingestion of food
Recreation	Exposed uniform Exposed patch	General user, park worker	External, Skin contamination, Inhalation of suspended contamination, Inadvertent ingestion of contamination
	Buried uniform Buried patch	General user, park worker	External
	Exposed uniform Exposed patch	Fisherman	External, Skin contamination, Inhalation of suspended contamination, Inadvertent ingestion of contamination, Ingestion of fish
	Exposed uniform Exposed patch	Fisherman's family	Ingestion of fish
	Exposed uniform Exposed patch	Swimmer	External, Inadvertent ingestion of lake water
	Disturbed buried uniform Disturbed buried patch	Park worker	External, Skin contamination, Inhalation of suspended contamination, Inadvertent ingestion of contamination
Construction	Exposed uniform Disturbed buried uniform Exposed patch Disturbed buried patch	Construction worker	External, Skin contamination, Inhalation of suspended contamination, Inadvertent ingestion of contamination
	Buried uniform Buried patch	Construction worker	External
School	Exposed uniform Exposed patch	Teacher, School child, caretaker	External, Skin contamination, Inhalation of suspended contamination, Inadvertent ingestion of contamination
	Buried uniform Buried patch	Teacher, School child, caretaker	External
Industrial	Exposed uniform	Office worker	External, Skin contamination, Inhalation of suspended contamination, Inadvertent ingestion of contamination
	Exposed patch Buried uniform	Office worker	External
Housing	Exposed uniform Disturbed buried uniform Exposure patch Disturbed buried patch	Resident	External, Skin contamination, Inhalation of suspended contamination, Inadvertent ingestion of contamination, Ingestion of food
	Buried uniform Buried patch	Resident	External
Covered area	Buried uniform	Car driver, Child	External

4.2 Exposure pathways

The methodology considers that exposure to site occupants can occur via 8 pathways. These are:

- external irradiation for contaminated soil in the ground,
- external irradiation from contaminated soil present on the skin,
- inhalation of suspended contaminated soil,
- inadvertent ingestion of contaminated soil,
- ingestion of food grown in contaminated soil,

- ingestion of contaminated drinking water,
- inadvertent ingestion of contaminated lake water whilst swimming,
- ingestion of fish caught in a contaminated lake

Not all the exposure pathways considered in the methodology are applicable to all of the exposure scenarios presented in Table 1. The annual effective dose is, therefore, the sum of the doses from the relevant exposure pathways for each scenario. The exposure pathways considered for each scenario are given in Table 2. Note that the pathway of ingesting drinking water is not included in any of the scenarios as a separate pathway, but the doses from this pathway are calculated in the methodology and the results can be summed with that in the defined scenarios if this pathway is required.

Table 3 Radionuclides considered in the methodology and notation*

Radionuclide parent	Radionuclide daughters assumed to be in secular equilibrium with parent
H-3	-
Fe-55	-
Co-60	-
Ni-63	-
Sr+90	Y-90
Tc-99	-
Ru+106	Rh-106
Cs-134	-
Cs+137	Ba-137m
Ce+144	Pr-144, Pr-144m
Pm-147	-
Sm-147	-
Sm-151	-
Eu-154	-
Pb+210	Bi-210
Po-210	-
Ra+226	Rn-222, Po-218, Pb-214, Bi-214, Po-214
Ac+227	Th-227, Ra-223, Rn-219, Po-215, Pb-211, Bi-211, Tl-207
Ra+228	Ac-228
Th+228	Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Po-212, Tl-208
Th+229	Ra-225, Ac-225, Fr-221, At-217, Bi-213, Po-213, Pb-209
Th-230	-
Pa-231	-
Th-232	-
U-233	-
U-234	-
U+235	Th-231
U-236	-
U+238	Th-234, Pa-234m, Pa-234
Np+237	Pa-223
Pu-238	-
Pu-239	-
Pu-240	-
Pu-241	-
Am-241	-
Cm-244	-

* '+' in the radionuclide name indicates the inclusion of short-lived radioactive daughters in secular equilibrium.

4.3 Radionuclides considered in a contaminated land assessment

In the methodology doses have been calculated for 36 radionuclides. Some of these radionuclides decay into daughters that are themselves radioactive. For a number of these radionuclides, the parent and daughter radionuclides are likely to be in *secular equilibrium* due to the short half-life of the daughter relative to the parent. Doses per unit contamination have therefore been determined for the parent taking into account contributions from short-lived daughters. The notation “+” is used to indicate the inclusion of short-lived daughters. A list of the radionuclides considered, and the assumptions regarding which daughters are assumed to be in equilibrium with their parents, is presented in Table 3. These radionuclides represent those most likely to be encountered on a contaminated land site under investigation in the UK.

4.4 Use of the results given in the general assessment methodology

The doses presented in the methodology are based on realistic but conservative assumptions as all future uses of the land and individual occupancy and work patterns cannot be predicted. They can be used for general studies on doses from contaminated land. The methodology is designed to be flexible so that more site specific parameter values can be entered if required. The methodology has tables presenting doses for each scenario and spatial distribution as given above. It also has tables showing the dominant exposure pathway for each radionuclide for all scenarios, essentially presenting the worst case dose assessment for all future uses of the land given a contamination profile. An example of this for Ra-226 plus short lived daughters (denoted Ra+226) is presented in Table 4. This shows the effects on the dose calculated for different contamination profiles and exposure scenarios.

Table 4 Dominant dose and exposure scenario for exposure to soil contaminated with Ra+226

Contamination profile	Dose Sv y^{-1} per Bq g^{-1}	Dominant scenario	Dominant age group
Exposed, uniform	$7.58\ 10^{-4}$	Construction	Adult
Buried, uniform	$1.60\ 10^{-4}$	Housing	Child
Disturbed buried, uniform	$2.24\ 10^{-4}$	Housing	Child
Exposed, patchy	$1.18\ 10^{-4}$	Housing	Child
Buried, patchy	$8.02\ 10^{-5}$	Housing	Adult/Infant
Disturbed buried, patchy	$8.37\ 10^{-5}$	Housing	Adult

In the UK, significant change of use of land normally requires planning permission. The categorisation of land use is given by the Use Classes Order 1987. This identifies the main uses of land and what changes can be made (permitted changes) without the requirement for planning permission. Therefore, if planning permission is being sought, the land can be considered to be undergoing change of use and this could be considered a practice situation. If planning permission is not being sought and radioactivity is present, the same or similar businesses and individuals would be exposed in similar ways and this could be considered an intervention situation. This approach gives a practical definition of intervention and practice situations. The methodology was originally developed to assess the doses that could arise from the future use of an area of land that is being subjected to a change of use (a practice situation). However, the methodology can also be used for situations where no change of land use is considered and an assessment of existing doses is needed for current occupants of the land (an intervention situation). The information in the methodology allows a simple estimate of the doses to be received by the occupants of the land, through scaling the results in the tables to the actual inventory of the site under assessment.

5 Summary and conclusions

This paper describes a report by Oatway and Mobbs that details a methodology to assess the doses to members of the public from the use of land contaminated with radionuclides. Doses are presented per unit activity concentration for a number of radionuclides, representing those radionuclides that experience has shown are likely to be present on land as a result of a variety of industrial practices in the past. A range of spatial distributions of the contamination is also considered, ranging from exposed material to material that has been buried under a layer of clean topsoil. The exposure scenarios considered represent those most likely to arise for these sites, including the construction of a variety of building types and the use of the land for farming and recreational purposes. Exposure pathways include external, inhalation and the ingestion of both contaminated soil and of food products that may be grown on the site. Three age groups are considered, representing the likely mix of people who may occupy the sites in the scenarios considered. Doses from the most restrictive use of the land are also presented. The methodology can also be used to derive activity concentrations in soil that correspond to given dose criteria.

The parameter values selected in this methodology, and used to calculate the doses per unit activity concentration presented in this paper, are chosen to be cautious but realistic. If a more site-specific assessment is required, then the model employs a large degree of flexibility in both the use of parameters and the combination of scenarios so it can be used for a variety of cases.

6 References

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