Guidance on the Assessment of Exposure from Land Contaminated with Heterogeneously Distributed Radioactive Material

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Abstract

The majority of assessments of radioactively contaminated land will consider situations where the level of contamination is not uniform; this is referred to as heterogeneous contamination. There may be variability in the radionuclides present or in the activity concentration within the ground, and there may be areas where contamination is associated with discrete radioactive objects.

This paper outlines guidance being prepared by the HPA[1] on assessing the radiological implications of land contaminated with heterogeneously distributed radioactivity. Within the guidance particular emphasis will be given to the issues that need to be considered when assessing a site that is contaminated by discrete radioactive objects.

1 Introduction

Land may become contaminated with radioactive material as a result of a number of past uses (Defra, 2006), current uses, or accidents. Examples include radionuclides in the ground as a result of nuclear accidents such as Chernobyl or accidental releases such as leaking pipes on nuclear or non-nuclear sites. Due to the various mechanisms that can result in radioactivity being present in land the level of radioactivity, the radionuclides, and the area where radioactivity is present could vary considerably.

Radioactivity may also be associated with discrete objects, which contain levels of radioactivity per unit mass many orders of magnitude higher than the ambient level. Although the term 'hot particle' is commonly used to describe radioactivity associated with a discrete object, such objects can range in size from less than a millimetre to many centimetres. Typical examples include flakes of metal, scale from pipes, wires and radium dials. Such objects may therefore not resemble what may commonly be thought of as a particle. The term 'discrete radioactive object' is therefore preferred, recognising that it is important that a clear description of the form of the contamination is given in any assessment to help avoid misinterpretation by stakeholders.

The term 'heterogeneous' contamination is used to encompass land that is contaminated in a non-uniform way. This includes land where there are patches of contamination, land that is contaminated by discrete radioactive objects, or land that is contaminated with a mix of patches and objects.

A radiological assessment of contaminated land may be performed for a number of different purposes. These include assessing land as part of the delicensing process, where the aim is to demonstrate that there is 'no danger' after controls associated with a site license have been removed (HSE, 2005); as part of the investigation into whether land should be determined as contaminated land under the Part 2A regime (GB Parliament, 1990; GP Parliament, 2007a;

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GB Parliament, 2007b; GB Parliament, 2007c; Scottish Government, 2007), or as input to a remediation strategy for land contaminated by historical events (Haywood and Smith, 1990; SAFEGROUNDS, 2011a; SAFEGROUNDS, 2011b).

When assessing the radiological consequences of contamination by discrete radioactive objects it is important that both the dose and the probability of receiving that dose are taken into account, and presented separately. This aids interpretation of the results, particularly in situations where deterministic effects could result but where the probability of the dose being received is low. Where exposure is limited to the risk of stochastic effects, the risk to health can be considered to be proportional to the magnitude of the dose and the overall risk to health can be calculated by multiplying the probability of receiving the dose, the effective dose and the health risk factor.

2 HPA guidance on assessing heteroegneous contaminated land

Assessment of the radiological implications of heterogeneous contamination is not straightforward (Dale et al, 2008) and in 2009 the Health Protection Agency (HPA) committed to providing guidance in this area (HPA, 2009). This paper presents an overview of a document being prepared by HPA that fulfils that commitment. In particular, the HPA aims to provide practical guidance for assessing health risks associated with radioactively contaminated land, especially where radioactivity is associated with discrete objects. The guidance will build on previous guidance issued by the HPA (NRPB, 1998; HPA, 2006), and experience gained from recent radiological assessments involving discrete radioactive objects (Wilkins et al, 2006; DPAG, 2006; 2008; Brown and Etherington, 2011). It also takes into account recent recommendations from the International Commission on Radiological Protection (ICRP) (ICRP, 2007).

Details of the assessment calculations, such as the selection of appropriate land uses, the area to include in the assessment, the radioactivity level and the appropriate radiological criteria need to be determined for each site. The radiological assessment of land containing discrete radioactive objects poses particular difficulties and specific guidance is being developed for this situation. In all cases, care should be taken to avoid the use of overly cautious assumptions to compensate for the level of uncertainty.

The guidance will consider situations where land is being redeveloped for future use (planned exposure situations) and situations where people are already being exposed (existing exposure situations). It does not address the situation where land has become contaminated as a result of an accident and is still considered as an emergency exposure situation. The guidance will also not consider in any detail management options that are available for remediating contaminated land, or how suitable options should be selected; other sources of guidance are available on this (EA, 2004; Towler et al, 2009; SAFEGROUNDS, 2011c).

3 Outline of the HPA guidance

The guidance will be divided into a number of sections that cover the main aspects of a radiological assessment. Within each section a description of the aspects that need to be taken into account will be discussed, together with approaches that can be used to address these. Examples of aspects of a radiological assessment where HPA will offer guidance include the following.

- Performing a tiered assessment, including guidance on performing a scoping assessment using generic data and how this can be refined where necessary in order to improve the level of confidence in the results.
- Defining suitable assessment areas, including guidance on how an area can be divided up into separate areas for assessment based on contamination location, radioactivity levels, radionuclide composition and land uses.
- Identifying a suitable source. For land contaminated by patches of radioactivity, guidance will be given on how to determine a representative activity concentration. For discrete radioactive objects, where the radioactivity content of the objects may cover many orders of magnitude, guidance will be given on how to select appropriate source terms.
- Selection of appropriate exposure scenarios and pathways with respect to land use, exposed population groups and contaminated object size.
- Assessing the probability of encountering discrete radioactively contaminated objects, including guidance on estimating object populations and accounting for dynamic environmental processes.
- Interpreting estimated doses and health risks including defining when the health risk could be considered to be 'acceptable' or 'negligible'.
- The use of sensitivity and uncertainty analysis within an assessment

In addition to providing guidance on each of the areas listed above, summary tables will also be included that list questions which take an assessor through the important aspects of an assessment. Table 1 presents examples of the types of questions that need to be addressed when undertaking an assessment, covering aspects such as determining the type of contamination present, the exposure scenarios and pathways, and the source of parameter values for use in the assessment. Table 2 presents examples of questions relating to the estimation of the probability of encountering discrete radioactive objects within an area of contaminated land. Table 3 presents examples of questions that will aid the assessment of the implications and the optimisation process for existing exposure situations.

4 Example of an application of the guidance

Since 2006 an intensive programme of monitoring for radioactive objects has been carried out on beaches in the vicinity of the Sellafield site in West Cumbria and a large number of radioactive objects have been identified and removed. These objects comprise particles with sizes smaller than or similar to grains of sand (less than 2 mm) and contaminated pebbles and stones. HPA carried out an assessment of the health risks to people using the beaches along the Cumbrian coast from contaminated objects on the beaches on behalf of the Environment Agency. This work is described in Brown and Etherington (2011) and is also presented at this conference as a poster presentation. The assessment is used here to illustrate how the proposed guidance can be applied to an assessment of a real situation.

Table 1: Examples of initial questions to consider when performing an assessment

Question	Relevance
Why is the assessment being performed?	Different models and parameter values may be required for assessments of, for example, to determine if contaminated land requires designation or delicensing.
Which type of exposure situation is relevant?	Different dose and risk criterion are used when assessing existing or planned exposure situations.
What type of contamination is present?	Is radioactivity associated with discrete objects, uniform contamination or patches of contamination? Does the probability of exposure occurring need to be assessed?
Which radionuclides are present?	The radiological impact will depend on radionuclide specific characteristics such as radioactive decay rates, environmental transfer factors, emitted radiation, behaviour in the body etc.
What level(s) of radioactivity is (are) present?	This will directly affect the estimates of the radiological impact. Selection of an appropriate activity concentration to use within an assessment will also depend on the type of assessment being performed.
What is the physical extent of the contamination?	Knowledge of where the contamination is, in relation to the site area or other physical boundaries, could be used to define the area being assessed. This will also allow certain parameter values, such as occupancy, to be defined. The extent of each type of contamination needs to be defined. If applicable, the effects of migration of radioactivity from the site should also be included.
What is the land being used for?	This will allow the exposure scenarios, pathways and exposed age groups to be defined.
What exposure pathways are applicable?	Determines the exposure pathways to be considered in the assessment.
Will the assessment be using mostly generic parameter values or are site specific values available?	Use of generic values will mean that the assessment is unlikely to represent the site to any great degree and suitable caution should be used when interpreting the results. However, such an initial assessment is valuable in scoping the potential level of dose. If suitable site specific data are available then greater confidence can be attached to the results.
Is there the potential for deterministic effects?	Previous experience may show early in the assessment whether deterministic effects are likely if exposure occurs. In such situations assessing exposure to individual tissues or organs is required.

Table 2: Examples of questions relating to the probability of encountering a discrete radioactive object

Question	Relevance
What do people do in the areas where discrete radioactive objects are located?	This will determine the relevant exposure scenarios, exposure pathways and parameter values for the assessment.
What is the population of discrete radioactive objects?	Probability of encountering an object depends upon the population of objects present on the land. This depends on the number of objects found, the area monitored and the detection probability.
Is the population of objects constant or time variant?	The instantaneous probability of encountering an object is related to the instantaneous number of objects present. If the number of objects varies with time the so does the probability of encounter.

Table 3: Examples of key considerations in assessing the radiological implications of contaminated land in existing exposure situations

Question	Relevance
How confident am I in the estimate of dose and in the probability of receiving that dose?	This is particularly important if the estimated dose is approaching or exceeds a dose criterion. Improved estimates may be needed and this may require a review of the model used or obtaining more site specific data by monitoring, surveying or experiment.
Where contamination is by discrete radioactive objects, could exposure give rise to serious deterministic effects?	Some deterministic effects are transient in nature and are therefore not considered to be serious deterministic effects. If serious deterministic effects could be received then the probability of receiving that dose should be reduced to be negligible. Where the probability of receiving a serious deterministic effect is negligible then the remediation strategy need only consider simple actions. More extensive or disruptive actions should be considered if the probability is higher than this.
Where contamination is by discrete radioactive objects, are experimental studies needed to characterise the objects?	Using standard models may not give a reasonable representation of the situation and so experimental work, for example in vivo or in vitro work to define uptake factors, should be considered. This is important if the estimated doses are approaching a dose criterion.
Would additional monitoring be useful?	Additional information on the distribution of the contamination and its characteristics would improve confidence in the dose and probability estimates. Monitoring over extended periods would improve understanding of the level of contamination in dynamic environments, such as beaches. Trigger levels could be specified to indicate when additional work is required. More sensitive equipment may become available and its use would improve knowledge on the contamination and its distribution. Reassurance monitoring may be requested by stakeholders.
What is the source of the	Knowledge of the source of the contamination and how the level of

contamination? Will recontamination occur? What is the site history?	contamination could change over time is very important. Such knowledge will assist in understanding the extent of the contamination and whether additional monitoring is required. This is particularly important if new contamination could be added to the site or if the site is part a dynamic environment. If a suitable site history is not available then need to rely more on monitoring.
What are local stakeholder views?	Pressures from stakeholders, including regulators and local residents, may impact on any remediation strategy developed.
What is the appropriate regulatory regime?	Identifying the relevant regulatory regime allows estimates of dose or risk to be placed within a suitable context and may provide direction on future action. For example, determining land as contaminated or removal of a site license.
Is remediation justified and optimised?	Appropriate options will vary from site to site, depending on site specific characteristics. Justification and optimisation of the remediation strategy should be based on the best available technique for that site, taking into account potential exposure to human and non-human species, societal and economic factors. The 'no remediation' option should be considered as part of the protection strategy if residual doses are below the reference level set.

Previously, HPA has recommended that, where an exposure is not guaranteed to occur, the level of potential exposure needs to be assessed, including an assessment of the probability of encountering radioactivity (HPA, 2006). The guidance currently being developed will build on this recommendation. Brown and Etherington assessed the level of potential exposure using a two stage process. Firstly, estimates were made of the likelihood that people using the beaches for various activities could come into contact with a radioactive object. Secondly, for the unlikely event that an individual does come into contact with such an object, the resulting radiation dose and associated health risks were assessed.

Within the guidance, a staged approach for undertaking an assessment will be discussed, firstly scoping the radiological consequences and then, if necessary, performing a detailed assessment. Where a detailed assessment is performed as much realistic data should be used as possible, with time and effort expended to collect such data being justified and optimised. Due to the unique nature of the area around Sellafield, and also due to public perception, Brown and Etherington decided that a detailed assessment was required from the outset. As a consequence, specific surveys were carried out to determine the habits of users of the beaches in that area. In addition, laboratory investigations were carried out to determine the physical and chemical characteristics of the objects, including derivation of realistic gut uptake fractions. However, the assessment did make use of some generic parameter values, for example inadvertent ingestion rates, as no site specific information was available.

In order to assess the potential risk to health where exposure is to radioactive objects, dividing the population of objects into groups that share similar characteristics will be discussed in the guidance. Within Brown and Etherington this approach was used, with the object population being divided into groups according to:

- Object size. Objects were labelled as stones or particles depending on their size. Different pathways and parameter values were defined for these groups of sizes.

- Emitted radiation. Objects were labelled as either 'alpha-rich', 'beta-rich' or 'cobalt-rich' objects. This grouping allowed the health effects to be determined for objects that led to similar doses and health risks.

- Radioactivity level. Objects were placed within order of magnitude bands based on measured radioactivity content. This allowed more realistic estimates of the health risks from coming into contact with objects containing different levels of radioactivity, as the object population distribution was skewed towards objects with relatively low activity.

Similarly, dividing the area being assessed into suitable areas based on characteristics of the land, for example what the land is being used for, will also be discussed in the guidance. In deciding whether it was necessary to divide the beaches into smaller areas for an assessment, Brown and Etherington took into account the available monitoring and habit information. In particular, it was noted that monitoring has not occurred across the whole beach due to limitations in using the vehicle-based monitoring system on non-sand areas and also that monitoring has been targeted to beaches with high occupancy and where the highest numbers of objects have been found. Habit surveys of beach use were undertaken along the affected coastline with most effort targeted to those beaches with suspected high occupancy. Based on the information gathered, Brown and Etherington divided the beach area into five separate beaches. These areas were selected to be those where sufficient objects had been found to allow an estimate of the instantaneous object population to be made, and also where sufficient habit data existed to define with confidence the characteristics of a set of representative persons. Although objects had been found in other areas it was decided that no quantitative assessment could be made due to the lack of suitable information and the resulting very large uncertainties. In those areas, only a subjective evaluation of the health risk was made.

Within a radiological assessment, exposure scenarios and pathways need to be defined. The selection of suitable exposure scenarios and pathways for use within an assessment including, for example, the relationship between object size and appropriate exposure pathway, will be discussed in the guidance. Within Brown and Etherington, the exposure scenarios were defined using information gathered by the habit surveys. In order not to require excessive amounts of calculation, beach use was grouped into broad categories of walking, bait digging and leisure. These groups covered several land uses identified within the habit survey. For example, the walking group were intended to include those beach users who walked dogs, combed the beach for artefacts and general walkers. Account of different object size was made when defining appropriate exposure pathways within each scenario. For example, objects available for inhalation were limited to those that were relatively small, whilst larger objects were considered available for inadvertent ingestion.

In order to estimate the probability of encountering an object the number of objects present should be used. Within Brown and Etherington, the population of objects on the beaches, within each of the groups listed above and for each pathway, where this was dependent on object size, was estimated. This calculation used the estimated detection probability of the monitoring system and information about the number of objects found, including the depth they were found at. When estimating the object population, account was made of any repeat monitoring.

Brown and Etherington concluded that the overall health risks to beach users are very low and significantly lower than other risks that people accept when using the beaches. The highest calculated lifetime risks of radiation-induced fatal cancer are of the order of one hundred thousand times smaller than the level of risk that the Health and Safety Executive considers to be the upper limit for an acceptable level of risk (1 in a million) for members of the public and workers (HSE, 2001). It is also very unlikely that deterministic effects, such as skin ulceration, could occur from encountering an object. As a result of the assessment undertaken, HPA recommended that that regular monitoring of Sellafield beach (where the majority of the objects have been found) and monitoring at one or two other beaches with high public occupancy will provide regulators and the public with continued reassurance that the risks associated with radioactive objects remain very low.

5 Concluding statement

It is important to recognise that every site has unique features that need to be explicitly considered when performing a radiological assessment. It is, therefore, not possible to specify an assessment methodology that could be used for all sites and contamination types. However, some over-arching guidance can be given reflecting the general approach that could be followed in most situations.

This paper provides an overview of a document currently being prepared by HPA that aims to provide practical guidance on assessing the radiological implications of land contaminated by a heterogeneous distribution of radioactivity. This builds on previous advice given by HPA and NRPB. Situations involving the redevelopment of land for future use (planned exposure situations) and situations where people are already being exposed (existing exposure situations) are considered.

HPA aims to provide guidance on the radiological protection aspects of interpreting the results of a radiological assessment. An important point is that decisions made in relation to remediation of land where there is radioactivity present are not based solely on numerical estimates; account must also be made of stakeholder views, especially with regards to perceived levels of risk.

Within this paper an example of how the proposed guidance could be used is given in relation to the assessment of the health risks from contamination of beaches with discrete radioactive objects in the vicinity of the Sellafield site in west Cumbria.

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