PAPER FOR PUBLICATION ON SAFEGROUNDS WEBSITE

Specification for 'Look-Up Tables' for Radiological Assessment of Contaminated Land and Groundwater on Nuclear Licensed Sites

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Purpose

This paper sets out a specification for the development of a set of 'look-up tables' capable of assessing dose rates from radioactively contaminated land and groundwater to a reasonable range of exposure groups and scenarios applicable to Nuclear Licensed Sites. This specification has been issued to the consultants undertaking the work and its peer review.

While the principal aim is to produce a 'tool' that will be of use to BNFL, wide acceptance of the output within the nuclear industry and its stakeholders is a key objective. Therefore, BNFL has consulted on the specification for the work and proposes to consult on the draft output, within the SAFEGROUNDS Learning Network. Publication of the final output on the SAFEGROUNDS website is envisaged, addressing to some extent the lack of quantitative guidance to come out of the SAFEGROUNDS project to date. However, the output will be a BNFL product, not a SAFEGROUNDS-endorsed publication, and this will be made clear within the published document as well as its location within the SAFEGROUNDS website.

The intention is that the look-up tables will enable suitably qualified but relatively non-specialised assessors to make a relatively quick assessment of the radiological implications of data for concentrations of radionuclides in soil and groundwater on Nuclear Licensed Sites.

Consultation Process

This 'Issue 2' paper[1] has been prepared following consultation on 'Draft D' via the SAFEGROUNDS Learning Network between mid July and the end of August 2003[2].

We (BNFL) have endeavoured to record and respond to all comments received, using the table appended to this paper.

Background

The expectations of the Nuclear Installations Inspectorate (NII) regarding management of radioactively contaminated land/ground are published in Appendix 8 of their guidance for inspectors on the management of radioactive materials and radioactive wastes on Nuclear Licensed Sites (HSE, 2001). NII expects licensees to demonstrate that they are managing radioactively contaminated land safely in compliance with all Site Licence Conditions, including the development and maintenance of a safety case (LC14).

A key aspect of safety cases for radioactively contaminated land is the calculation of radiation doses to various exposure groups.

A great deal of work has been done by various bodies to develop dose assessment scenarios for radioactively contaminated land and groundwater. These include NRPB (1998), WHO (1993), consultants to DETR/DEFRA (Hill et al. 1999) and the Environment Agency (Entec/NRPB, 1999). Very recently, NRPB have published a compilation of their experience in this type of work (NRPB, 2003)[3]. However, these studies do not add up to a reasonably comprehensive set of dose assessments for scenarios that would cover the typical issues that arise on nuclear licensed sites (e.g. worker intrusion, exposure of members of the public visiting accessible areas of the site, etc.). Furthermore, there may be significantly different (and not always documented) dose model and human habit assumptions between what appear at first sight to be similar scenarios.

Overview of Specification

This paper proposes the development of 'look-up tables' to enable suitably qualified but relatively non-specialised assessors to make a relatively quick assessment of the radiological implications of data for concentrations of radionuclides in soil and groundwater on Nuclear Licensed 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. In some cases, such assessments may have to be followed up by more detailed specialist assessments than the look-up tables could provide.

[1] The 'Issue 1' paper was an early issue to the internal consultants. Issue 2 has exactly the same technical content as Issue 1, but corrects some typographical/grammatical errors and improves some phraseology.

[2] The preceding 'Draft C' paper was tabled at the SAFEGROUNDS Project Steering Group (PSG) meeting on 22 May 2003 and initial comments from PSG members were invited (with a one month time limit) prior to preparation of Draft D.

[3] An addendum to this paper assesses the differences in approach between this recent NRPB report and the work proposed here.

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 proposed look-up tables should contain calculated doses via individual exposure pathways, with respect to unit specific activity (1 Bq/g and 1 Bq/litre) for surface soil, buried soil and potable water (including groundwater).

This differs from Generalised Derived Limits (NRPB, 1998) and the dose per unit concentration values produced for the Environment Agency (Entec/NRPB, 1999) and in NRPB (2003) all of which sum doses from a number of different exposure pathways within a scenario. Additionally, the Generalised Derived Limits are calculated environmental concentrations that would give rise to a specified dose under particular scenarios.

The approach proposed here is to minimise the 'scenario' assumptions that go into the calculations, so that the assessor is able to use the 'look-up tables' to evaluate the dose consequences of locally applicable scenarios.

In common with the previous studies mentioned above, the proposed work will use existing ICRP-60 recommendations regarding calculation of radiological doses (ICRP, 1991). It is recognised that not all SAFEGROUNDS participants may find this acceptable.

The use of existing modelling tools such as RESRAD and MicroShield may assist the development of the look-up tables, but only if they do not impose undesirable constraints.

Radionuclides to be Assessed

The starting-point for the list of radionuclides to be assessed was that used by Entec/NRPB (1999), plus some additional radionuclides of interest to BNFL, most of which are assessed in NRPB (2003). In addition, further radionuclides have been added in light of suggestions from consultees and from within BNFL.

The table below sets out the intended radionuclides to be assessed. 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 order to ensure that a useable product can be delivered within the planned timescale and budget, the radionuclides listed have been prioritised as shown in the phases indicated. The minimum deliverable will include all the radionuclides in Phases 1 and 2.

Phase	**No. of radionuclides**	**Radionuclides**
1	5	H-3 Co-60 Sr+90 Cs+137 Ra+226
2	16	C-14 Cl-36 K-40 Tc-99 Ru+106 Sn-126 I-129 Cs-134 U-234 U+235 U+238 Np+237 Pu-239 Pu-240 Pu-241 Am-241
3	15	Pb+210 Po-210 Ra+228 Th+228 Th+229 Th-230 Th-232 Pa-231 U-233 U-236 Pu-238 Pu-242 Cm-242 Cm-243 Cm-244

This list (Phases 1-3) includes the main radionuclides involved in the fuel cycle, plus radionuclides associated with naturally occurring radioactive materials (NORM), including the radionuclides which are naturally ubiquitous in rocks and soils. Most of the Phase 1 and 2 radionuclides have been selected on the basis of BNFL's priorities. The list is not intended to be final and may be regarded as a first informed iteration. It may be supplemented by additional radionuclides at a later date.

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 daughter products, have long half-lives relative to the likely period covered by contaminated land assessments and will only be included as single radionuclides.

However, for some decay chains, progeny also require special attention especially in view of their radiological significance relative to the parent. For the time scales and circumstances involved in assessing the measurement results as discussed, the parent Pu-241 (half life 14.4 y) decays into Am-241 which is much more radiologically significant than the parent. This may also apply to the decay of Cm-242 (half life 162.8 d) to Pu-238. For these cases, activity ratios for daughters in relation to the parent will be considered (EC, 2000).

It is proposed that the look-up tables deal implicitly with Natural Uranium and Depleted Uranium (DU) by advising users of ratios for combining the isotopes of U-234, U-235 and U-238. The composition of DU can vary depending on the mass of U-235, and advice will be given for potential ratios in DU.

Exposure Groups to be Considered when Determining Which Exposure Pathways to Assess

The exposure groups for which the 'look-up tables' 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 or may not coincide with the Nuclear Licensed Site boundary).

Members of the public may come into direct contact with contaminated land if the security fence is inside the Nuclear Licensed 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 Nuclear Licensed Site boundary.

Note that these exposure groups will not have separate look-up tables – it will be for the assessor to infer the habits of the exposure groups and use the look-up tables accordingly.

ICRP (1996) identify several age categories (3 months, 1 year, 5 years, 10 years, 15 years and adult) ingestion and inhalation dose committed effective dose coefficients. For the look-up tables, it is proposed that this scheme can be 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. Unlike NRPB (2003), it is proposed to use specific ICRP ingestion and inhalation dose coefficients to members of the public (ICRP, 1996) and to workers who are occupationally exposed (ICRP, 1994).

In addition to the groups above, it has been suggested by consultees that foetal doses should be 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. In keeping with the dosimetry above, it is proposed that dose coefficients be considered for the offspring of members of the public and workers for chronic intakes (ICRP, 2002). The offspring dose considers the dose to the foetus for the time spent in the womb for an internal intake of radionuclides by the mother and the life time dose after birth. Offspring doses will only be calculated if they exceed the dose to the mother.

Exposure Pathways to be Assessed

The following exposure pathways should be assessed:

- Direct radiation from contaminated ground (for various potential geometries);
- Dermal contact with contaminated ground (excluding open wounds[4]);
- Inhalation of contaminated dust;
- Ingestion of contaminated soil and dust;
- Ingestion of wild foods;
- Ingestion of drinking water.

The likely magnitude of effects associated with dermal contact with contaminated water will be compared with dermal contact with contaminated soil and, if found to be significant, this pathway will be included as a separate table.

Food consumption pathways associated with agriculture, gardens, allotments, etc. are not applicable to Nuclear Licensed Sites[5] and should not be assessed.

It is recognised that radionuclide-specific data for ingestion of wild foods are very sparse. The organisation responsible for developing the look-up tables will have to justify use of analogues where directly applicable data are lacking.

[4] Controls in force on Nuclear Licensed Sites prevent workers with open wounds from working in contaminated areas.

[5] Some peripheral areas of some Nuclear Licensed 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.

Exposure Assumptions

Geometries of direct radiation exposure (applicable only to beta/gamma radionuclides) will be along the lines of the following:

Surface contamination (1 Bq/cm^2):
- Dose received 1 m above uniform surface contamination (extending horizontally to infinity);
- Dose received 1 m above a patch of contamination ~10m in diameter;
- Dose received by a person standing 5m 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 50m from the edge of an area of contamination extending horizontally 'to infinity' from the edge of the contamination.

Shallow contamination (1 Bq/g, 5 cm deep[6]):
- Dose received 1 m above uniform contamination;
- Dose received 1 m above a patch of contamination ~10m in diameter;
- Dose received by a person standing 5m from the edge of an area of contamination, extending horizontally 'to infinity' from the edge of the contamination;
- Dose received by a person standing 50m from the edge of an area of contamination, extending horizontally 'to infinity' from the edge of the contamination;

Contamination (1 Bq/g) extending to "infinite" depth from surface:
- Dose received 1 m above uniform contamination;
- Dose received 1 m above a patch of contamination ~10m in diameter;
- Dose received by a person standing 5m from the edge of an area of contamination, extending horizontally 'to infinity' from the edge of the contamination;
- Dose received by a person standing 50m from the edge of an area of contamination, extending horizontally 'to infinity' from the edge of the contamination;

Shallow buried contamination (1 Bq/g):
- Dose received 1 m above uniform contamination extending below a 0.1 m clean soil cover to "infinite" depth;

Deeply buried contamination (1 Bq/g):
- Dose received 1 m above uniform contamination extending below a 0.5 m clean soil cover to "infinite" depth;

Occupancy values for all exposure groups should be specified by the assessor. Since occupancies may be anything from hours to years, it is proposed that dose rates related to occupancy should be presented in microSv/hour.

Dust inhalation rates for assessment of inhalation of contaminated dust should be specified by the assessor, but the report accompanying the look-up tables will provide guidance on

[6] 5 cm is about the minimum vertical interval that a soil sample can be taken from.

appropriate values for different conditions. Note that dust inhalation rates (dust loadings in air × respiration rates) are recognised as being rather subjective, with little in the way of underpinning generic values in the radiological literature. A recommendation is being passed to the SAFEGROUNDS Learning Network that this is an area that would benefit from further research.

Ingestion rates for assessment of ingestion of contaminated dust/soil should also be specified by the assessor, and again the report accompanying the look-up tables will provide guidance on appropriate values for different conditions. The same issues of sparse underlying published values apply for dust/soil ingestion rates as for dust inhalation rates.

Ingestion rates for wild foods and drinking water should be justified by the assessor, taking account of local conditions (e.g. accessibility and abundance of wild foods and sources of potable water).

Further assumptions will also be required (e.g. dermal contact areas) and should be based on widely accepted published generic assumptions unless there is a good case for justifying other assumptions or leaving the decision to the assessor.

Presentation of Look-Up Tables

The look-up tables will be presented as a report accompanied by simple electronic spreadsheets.

The main part of the report will set out clearly the context in which it is intended that the tables should be used, emphasising in particular the following:

- The responsibility of the assessor for choosing and justifying the key inputs as regards the typical levels of contamination, the geometry for radiation calculations, the dust inhalation rates, the ingestion rates (if applicable), the occupancy values, and so on.
- The fact that the tables are not designed for dealing with unrestricted land use.
- The fact that the tables are not designed for assessment of the immediate aftermath of a spillage or other type of incident (in which case short-lived radionuclides might be present).
- The fact that the tables do not provide a basis for predicting doses over long timescales in the future, during which radionuclides might potentially migrate from their dispositions.

The report will contain guidance on how input parameters may be arrived at, giving any widely-used values that may assist the process (e.g. respiration rates, normal dust loadings in air, annual consumption of drinking water).

Appendices of the report will fully document the basis of the underlying calculations and the sources of data. Radiological data should be from the most up-to-date sources.

The main part of the report will clearly set out the additional calculations that the assessor must make in order to obtain dose rates in mSv/year.

The tables will be presented for unit values of input parameters such as dust inhalation rates. Electronic copies of the tables will be supplied as part of the overall product. The electronic tables will contain a simple input panel at the head of each table, allowing the assessor to vary the relevant input parameters. Within the report, only the tables for unit values of input parameters will be provided. Note that the electronic tables will have only this simple multiplicative functionality – they will not be spreadsheets with traceability to literature values. This is to reduce the potential scope for inadvertent corruption of the spreadsheets by users.

Three examples of how the tables may appear are given below:

Radiation dose rate (mSv/year) from surface contamination at 1 Bq/cm^2				
Enter occupancy (hr/year):	*1*			
Radionuclide	**Above uniform contamination**	**Above contaminated patch of 10m diameter**	**5 m from edge of contaminated area**	**50 m from edge of contaminated area**
Co-60				
Sr-90				
Cs-134				
Cs-137				
etc.				

Inhalation dose to adult (mSv/y) from contamination at 1 Bq/g	
Enter occupancy (hr/year):	*1*
Enter respiration rate (m^3/hour)	*1*
Enter dust loading in air (g/m^3)	*1*
Radionuclide	
H-3	
Co-60	
Sr-90	
Cs-134	
Cs-137	
etc.	

Ingestion dose to adult (mSv/y) from drinking water at 1 Bq/litre	
Enter consumption rate (litres/hour)	*1*
Radionuclide	
H-3	
Co-60	
Sr-90	
Cs-134	
Cs-137	
etc.	

Implementation

The work will be undertaken by BNFL's Environmental Risk Assessments team within BNFL Nuclear Science and Technology Services.

The funding of the work will be from BNFL under the auspices of the Magnox Electric plc Nuclear Research Schedule. The author of this paper will provide the technical customer role.

Independent peer review will be undertaken by NRPB (S Mobbs assisted by W Oatway). This Issue 1 specification has been reviewed and agreed to by the peer reviewer.

The project specification has been consulted on through the SAFEGROUNDS Project Steering Group and the Learning Network, through communications with Learning Network members and by posting the draft specification on the website, as set out at the beginning of this paper.

It is proposed to consult on the project output through a similar process to the specification.

Acceptance of the final project output will be BNFL's decision, based on peer reviewer recommendation.

Note that the above envisages the output as a 'BNFL product' shared through the SAFEGROUNDS network and allowing stakeholder input, but does not envisage reaching a full stakeholder consensus, not least because some stakeholders do not accept the radiological assessment methodologies recommended by ICRP and NRPB.

References

Entec/NRPB (1999) Technical support materials for the regulation of radioactively contaminated land. Environment Agency R&D Technical Report 307.

European Commission (2000) Practical use of the concepts of clearance and exemption – part I. EC Radiation Protection Report 122.

Hill M D, Thorne M C, Williams P, Leyshon-Jones P (1999) Derivation of unconditional clearance levels for solid radioactively contaminated materials. DETR Report No. DETR/RAS/98.004.

HSE (2001) Guidance for inspectors on the management of radioactive materials and radioactive wastes on Nuclear Licensed Sites (Issue dated March 2001). (published on http://www.hse.gov.uk/nsd/waste1.pdf).

ICRP (1991) 1990 recommendations of the International Commission on Radiological Protection. ICRP Publication 60. Annals of the ICRP, 21, Nos 1-3.

ICRP (1994) Dose coefficients for intake of radionuclides by workers, ICRP Publication 68.

ICRP (1996) Age-dependent doses to members of the public from intake of radionuclides: Part 5 compilation of ingestion and inhalation dose coefficients, ICRP Publication 72.

ICRP (2002) Doses to the embryo and foetus from intakes of radionuclides by the mother, ICRP Publication 88.

NRPB (1998) Revised Generalised Derived Limits for radioisotopes of strontium, ruthenium, iodine, caesium, plutonium, americium and curium. Documents of the NRPB, Vol 9, No 1, pp 2-34.

NRPB (2003) Methodology for estimating the doses to members of the public from the future use of land previously contaminated with radioactivity. (W B Oatway & S F Mobbs) NRPB report NRPN-W36 (published on http://www.nrpb.org/publications/w_series_reports).

WHO (1993) Guidelines for drinking water quality (2nd edition).

ADDENDUM:
REVIEW OF DOCUMENT NRPB-W36 (2003) WITH RESPECT TO THE FUNCTIONAL REQUIREMENTS PROPOSED IN THIS PAPER

The publication of NRPB-W36 was almost coincident with the initial drafting of this paper. This addendum considers to what extent NRPB-W36 does and does not fulfils the intent of the 'look-up tables' proposed in here.

NRPB-W36 represents work that underpins the Environment Agency R&D Technical Report 307 'Technical support materials for the regulation of radioactively contaminated land' developed by Entec/NRPB (1999). It is intended to be applied in contexts other than Nuclear Licensed Sites.

The overall approach in NRPB-W36 is not consistent with that proposed in this paper. The following table deals with specific functional requirements proposed in this paper. Note that in no sense is this assessment to be taken as a criticism of NRPB-W36 – the purpose of that document is different from the intent of the present proposal.

Functional requirement in this outline specification	**Dealt with in NRPB-W36?**	**Recommendation**
Calculate doses per unit activity in surface soil	Yes, for specific scenarios, adding doses from different exposure pathways based on human behaviour scenarios.	More flexible approach needed, to allow different scenarios more applicable to Nuclear Licensed Sites to be developed.
Calculate doses per unit activity in buried soil	Yes, but for specific scenarios related to alternative land use (e.g. playground, car-park) considering only external irradiation (Appendix I). Leaching from buried contamination not considered.	More flexible approach needed.
Calculate doses per unit activity in groundwater	Only by calculation from soil contamination, involving a scenario with public water supply from an assumed underlying Chalk aquifer (Appendix H).	Simple dose calculations using observed concentrations in groundwater are needed.
Minimise 'scenario' assumptions	No. Dose/concentration factors are calculated for specific scenarios.	More flexible approach needed.
Applicable to on-site workers on a Nuclear Licensed Site while contaminated ground is undisturbed	No. The 'Industrial' scenario (Appendix F) assumes no contamination controls – e.g. access to contaminated ground for *al fresco* lunch breaks.	More flexible approach needed.

Functional requirement in this outline specification	Dealt with in NRPB-W36?	Recommendation
Applicable to on-site workers on a Nuclear Licensed Site while contaminated ground is being excavated	No. The 'Construction' scenario (Appendix D) assumes no contamination controls (e.g. no use of Personal Protective Equipment).	More flexible approach needed.
Applicable to members of the public just outside a security fence (which may or may not be the boundary of a Nuclear Licensed Site)	Not considered separately, although Section 4.5 considers modelling of nearby/offsite doses at ~100m from the contamination, using reduction factors for external irradiation and inhalation of wind-blown contamination.	More flexibility is needed, to represent scenarios where members of the public are able to walk past fenced-off contaminated areas which may be significantly less than 100 m distant. Also, pathways involving consumption of wild foods (especially blackberries) need to be represented.
Consider a variety of geometries for direct radiation exposure	Yes in the methodology (4.2.1), but not in the presented results.	There may be some benefit (for comparative purposes) in including some or all the geometries used in NRPB-W36, but this should not exclude other geometries recommended in this paper.
Represent dust loadings and dust inhalation rates representative of different combinations of ground conditions and working conditions	Yes. Table 4 provides values consistent with previous NRPB work on GDLs.	Use Table 4 of NRPB-W36 as a starting-point, but bear in mind that excavations of known contamination on a Nuclear Licensed Site would be subject to dust control, by damping-down as a minimum.
Represent soil/dust ingestion rates representative of different combinations of ground conditions and working conditions	Not really. Section 4.2.5 presents suggested generic values for infants and adults, not applicable to Nuclear Licensed Sites.	This may be difficult to address in a more detailed manner for Nuclear Licensed Sites. The values in Section 4.2.5 of NRPB-W36 could be used as a 'sanity check' on any assumptions made.

Overall assessment and recommendation

NRPB-W36 does not fulfil the intent of the outline specification presented in this paper. The requirement remains for a more flexible methodology applicable to a wide range of scenarios

that may apply on Nuclear Licensed Sites, involving a greater degree of control of scenario assumptions by the assessor.

NRPB-W36 will form a useful reference for the proposed ‘look-up’ tables applicable to Nuclear Licensed sites. In some cases (e.g. dust loadings), it provides a useful starting-point.

It is planned that the methodology to be developed in response to this specification will be applied to some of the scenarios documented in NRPB-W36, in order to provide an inter-comparison.

ANNEXE:
RECORD OF COMMENTS OBTAINED DURING CONSULTATION

Source of comment (including affiliation)	Summary of comment	BNFL response	Explanation of BNFL response
Colin Taylor, British Energy*[7]	We are more likely ourselves to use spreadsheet-based tools rather than lookup tables. We have found that it is tenable to have a relatively simple Safety Case wrapped around what is effectively a RBCA-type risk assessment.	Noted	BNFL's intention is to produce a tool with broad general applicability, capable of dealing with scenarios and exposure pathways that the 'RBCA-type' approach may not be able to deal with.
Colin Taylor, British Energy*	The more tools there are available to cover the diversity of possible scenarios, the better; what we cannot afford is our potential flexibility of response in the face of need being constrained by some tools being identified as mandatory, where in practice they are disproportionate or otherwise inappropriate. As with the national Direct Toxicity Assessment project, as long as we regard this as just one tool in the toolbox it is good to see such a development.	Noted	There is no intention by BNFL (or the SAFEGROUNDS Project Steering Group) to suggest that the proposed look-up tables would be in any sense mandatory.
Marion Hill, Enviros*	As the proposal stands, the tables will be most useful to industry and regulators. I think the tables could be made useful to a wider range of stakeholders by including more tables with intermediate quantities, as well as the dose rate tables. In particular, for the inhalation and ingestion exposure pathways it would be very valuable to have intake rate tables (Bq/time) as well as dose rate tables (Sv/time). In this way those who do not agree with ICRP could use the tables with their own dose per unit intake or risk per unit intake values and come to their own judgements on the significance or otherwise of the contamination. Also, industry and regulators could do uncertainty studies more easily.	Rejected, but the report accompanying the tables should identify the issues raised.	The proposed methodology is based on unit concentrations of radionuclides in environmental media and the assessor specifying any intake rates of such media. Therefore intake rates are to be specified by the assessor, not set out in the look-up tables. The main purpose of the look-up tables is to perform the calculations implied by the ICRP methodology. The proposed electronic spreadsheets will allow

[7] * Denotes comments received on Draft C from SAFEGROUNDS Project Steering Group members. Other comments were based on Draft D (as posted on the SAFEGROUNDS website in July-August 2003.

Source of comment (including affiliation)	Summary of comment	BNFL response	Explanation of BNFL response
			the assessor to explore sensitivity of results to intake rates.
Marion Hill, Enviros*	Along similar lines to the previous comment, it might be worth having external dose rates in air (microGray/hour) as well as dose rates to people (microsievert/hour), but this is not so crucial as intake rates.	Will consider.	The radiation dose calculations are to be performed using software which may or may not readily output the intermediate calculations in microGray/hour.
Marion Hill, Enviros*	You don't say in the paper whether you will be looking at people of various ages when you do doses to the public. Presumably you will be looking at infants, children aged 5, 10 and 15, and adults?	Incorporated.	A slightly simplified scheme is proposed. See revised specification.
Marion Hill, Enviros*	I would also strongly suggest that for workers and the public you consider doses to the foetus. Note that in this case it is, of course, maternal intakes of nuclides that need to be put in tables.	Incorporated.	See revised specification.
Marion Hill, Enviros*	(a) On exposure assumptions in general, I think the simpler these are the better when data are sparse (e.g. inhalation and ingestion of dust and soil). (b) Where you encounter real difficulties in finding data, you should notify the SAFEGROUNDS PSG so that they can consider whether to try to initiate research.	(a) Incorporated (b) Noted.	(a) See response to similar comment from Shelly Mobbs. (b) Consultants undertaking the work (and/or peer reviewer) to advise if this is the case.
Marion Hill, Enviros*	I notice that you reference a report I did for Defra. I suspect that the more useful thing for you would be ref 9 in that report, which is to some work I did at WS Atkins for HSE on dermal exposure. This looked, experimentally and observationally, at how muddy building workers get when doing various things, as well as at soil ingestion and inhalation. You should be able to track down the reports on the work through HSE research abstracts. I believe more was done after I left W S Atkins (*contact given*).	Noted.	Consultants undertaking the work unable to obtain reports from HSE because they were never released into the public domain.
Colin Potter, HSE/NII	Our overall comments are that the concept of a set of agreed relationships between activity in the ground and (potential) doses to workers, population in general and	Noted in general. Not incorporated, in that BNFL	There is currently no regulatory requirement to assess radiological doses to fauna and flora from

Source of comment (including affiliation)	Summary of comment	BNFL response	Explanation of BNFL response
	possibly (although not addressed in the paper) fauna and flora is a reasonable one.	does not propose to assess doses to flora and fauna.	contaminated ground.
Colin Potter, HSE/NII	The reason for a set of tables designed for "users with limited knowledge" is not given and it does not state the purpose of the tables which raises a number of concerns, for example: *(points (a) to (g) follow, as itemised below)*	The broad issue is incorporated in the revised specification, and the introductory sections of the report will address this also.	The report cannot and will not prescribe how it will be used, but can offer guidance on its use, to minimise the risk of mis-use.
Colin Potter, HSE/NII	a) Is it a means by which inexperienced and not suitably qualified persons can make judgements on action to be taken?	Such use is not intended. This is addressed in the revised specification.	BNFL does not suggest that assessments should undertaken by persons who are not suitably qualified.
Colin Potter, HSE/NII	b) Is the introduction of look-up tables intended as an alternative to appropriate sampling of the ground? and thus could it be a means of cutting corners?	The answer to both questions is 'No'. This is addressed in the revised specification.	A major envisaged use of the look-up tables is to provide rapid appraisal of the radiological significance of levels of contamination found, as data emerge from site characterisation.
Colin Potter, HSE/NII	c) Some of the exposure pathways seem unrealistic: a number are based on direct radiation or inhalation for surface contamination which would be required to be removed under IRR99 if the contamination existed to any significant extent.	Not incorporated: Surface contamination, especially at levels below designation of Controlled Areas under IRR99 may need to be assessed in some circumstances, and so these pathways should be assessed.	Examples where surface contamination may need to be assessed: • Very low level contamination that may be exposed in an excavation; • Contamination within a Controlled Area which may cause very low shine doses outside the Controlled Area.
Colin Potter, HSE/NII	d) Look up tables could potentially reduce the transparency of assessment and thus require caution.	The look-up tables themselves will be designed to be as transparent as possible.	Assessors using the look-up tables will have to document their scenario assumptions to provide transparent assessments.
Colin Potter, HSE/NII	e) In most cases contamination of the types considered would, on licensed sites,	Not incorporated: Addressed in	For example, using the look-up tables, such

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	require interpretation by a specialist health physicist and understanding at a professional level which would seem to negate the potential benefits from the simplified tabulation proposed.	revised specification.	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 consultants.
Colin Potter, HSE/NII	f)1 If the proposal is followed up it will require development to include consideration of the particle size in e.g. dust inhalation routes and in the case of excavation on site the depth of penetration of active material could be a critical.	f)1 Incorporated in part.	The report accompanying the tables should provide guidance to assessors on appropriate values for different conditions, but it will be for the assessors to justify the assumptions they make.
	f)2 Similarly the dose will depend on the physical activity and respiration rates. These aspects are not addressed in the proposal document.	f)2 Incorporated.	As above
	f)3 Other factors that could affect dose are the type and nature of the ground and the force of contact.	f)3 Incorporated in part.	This should be mentioned in the guidance to assessors.
	f)4 Alpha species are not addressed.	f)4 Incorrect	Alpha species will be addressed
	f)5 Doses via water are not thoroughly treated.	f)5 Not incorporated.	f)5 There is no intention to cover water-related pathways that would not normally arise on a Nuclear Licensed Site (e.g. irrigation water) – see also comments of Dale Haigh and Paul Robinson.
Colin Potter, HSE/NII	g) The document gives no indication of the likely magnitude of the uncertainties of the values being developed in the project or whether they are likely to be conservative.	Incorporated in part. Addressed in revised specification.	The uncertainties in input parameters (e.g. occupancies and intake rates) and model assumptions (e.g.

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			geometries for radiation shine) are the major uncertainties and can be explored by the assessor using the electronic spreadsheets. The choice of dose factors will be conservative where alternative values are available.
Colin Potter, HSE/NII	None of the above points is seen to be insurmountable but it may be that the potential case specific differences on each site may make the simplified tabulation proposed either (a) impractical to develop in a universal form or (b) an illusion if taken at face value when the site situation is in practice more complex.	Noted.	There is no intention to make the tables universally applicable – this would indeed be impractical to develop. Proper use of the tables should avoid inappropriate application to situations that are more complex than those represented in the tables. This is true of any 'modelling' tool.
Colin Potter, HSE/NII	The work of managing and remediation of contaminated matter including land will require knowledgeable people as is made clear in Appendix 8 of HSE (NII)'s guidance to its inspectors on radioactive waste management (on the HSE website). We would be concerned if this approach was seen to be means of avoiding this.	Noted.	The guidance document referred to was taken into account in the preparation of the draft specification. The point made above regarding use by suitably qualified persons should address the potential concern.
Paul Robinson, UKAEA Dounreay	With regard to the identified exposure pathways to be assessed, is it valid not to assess other groundwater exposure pathways such as agricultural and industrial use of groundwater and the use of groundwater for dust suppression? From my background in non-radioactive groundwater and waste issues, I found that the majority of groundwater usage (on non-nuclear sites) was for industrial cooling, dust suppression and agricultural use.	Not incorporated.	These potential uses of groundwater on a Nuclear Licensed Site are considered so rare (if they occur at all) as not to warrant inclusion in the scope of the look-up tables. See also comments from Colin Potter and Dale Haigh.

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Paul Robinson, UKAEA Dounreay	A footnote in the draft specification assumes that any farmed peripheral areas of nuclear sites are outside the intent of this paper. Is this a reasonable assumption to make prior to establishing/ruling out a potential groundwater/aerial pathway from the contaminated main area of the site?	Not incorporated.	The use of the look-up tables should not rule out the assessment of other pathways by appropriate methods. Farmed peripheral areas of Nuclear Licensed Sites do exist but are rare, and do not warrant inclusion in the scope of the look-up tables. If a potential groundwater/aerial pathway from contaminated land were present that might significantly affect agricultural land, then almost certainly there would be a need for a more detailed assessment than the look-up tables are intended for.
Paul Robinson, UKAEA Dounreay	One final point, which may or may not be completely irrelevant, is there any potential for gaseous transportation of radionuclide contamination? Could for example methane or carbon dioxide gaseous flows within the ground transport nuclear contamination?	Not incorporated.	Again, the use of the look-up tables should not rule out the assessment of other pathways by appropriate methods. Gaseous transportation might conceivably be relevant in some situations (e.g. buried 'legacy' wastes) but again it is not the intent for the look-up tables to cover all possible scenarios, however rare.
Shelly Mobbs, NRPB	If the doses to the different exposure groups (workers onsite, public offsite) are from the same lookup tables and some pathways are specifically excluded because they do not occur on sites then it needs to be made very clear that some situations will not be covered. For example, doses to members of the public outside the site will not include doses from agriculture etc.	Incorporated.	The limitations of the look-up tables will be clearly documented in the accompanying report.
Shelly Mobbs, NRPB	ICRP dose factors are different for workers and adult members of the public so how	Incorporated. Addressed in	Will consider dose factors

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	will this be addressed?	revised specification.	for the public and workers
Shelly Mobbs, NRPB	If the same lookup tables are used for all exposure groups then this implies that all age groups (and foetus) will need to be considered for all exposure pathways and geometries. This is unnecessary. Public will only be relevant for exposure scenarios that concern contamination that is not directly below them.	Incorporated in part.	A range of age groups (including foetus) will be assessed. Note that members of the public (including children) might be able to access trace contaminated land on the Nuclear Licensed Site but outside the security fence.
Shelly Mobbs, NRPB	It is not clear how the inhalation and ingestion results will be presented. External is in Sv/h, are they also in Sv/h? The separate look up table for dust inhalation rates is presumably g/h.	Incorporated. Addressed in revised specification.	Clarified in revised specification.
Shelly Mobbs, NRPB	Given the sparse data, how is uncertainty being addressed?	Incorporated. Addressed in revised specification.	See response to similar question on uncertainty from Colin Potter.
Shelly Mobbs, NRPB	The specification does not mention a spreadsheet. If the whole point is that these values can be scaled up by the concentration in the soil then a spreadsheet would be an obvious deliverable.	Incorporated.	Revised specification requires simple spreadsheets as part of the product.
Shelly Mobbs, NRPB	Is future migration of contamination offsite considered?	No. Migration (in groundwater) is not to be assessed (whether off-site or on-site).	Migration implies time-dependency of contaminant concentrations (over and above radioactive decay) and possibly time-dependency of what exposure pathways may be involved. This is beyond the scope of what can be achieved using look-up tables.
Shelly Mobbs, NRPB	The tables of dust inhalation rates and dust ingestion rates are very detailed and will require a lot of new data as there is not that much data already in existence. (a) Is this level of detail really necessary? (b) Is a measurement programme planned?	(a) Accepted that such detail is not necessary. (b) No measurement programme is planned within the project scope.	(a) Unnecessary detail will be avoided. (b) The proposed approach is to use available data, interpreted as far as possible by expert judgement.

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			Recommendations on research needs are being forwarded to the SAFEGROUNDS Project Steering Group.
Richard Bramhall, Low Level Radiation Campaign	The draft relies too heavily on flawed assumptions about radiation dose and its relationship with health detriment estimates. *(see attached detailed discussion notes on Health Detriment Estimates below)*	See below.	
Hugh Richards, seeking to extract the key points from Richard Bramhall's notes on Health Detriment Estimates	Richard Bramhall asserts that the methodology and modelling of internal exposure at low dose by the ICRP is judged by the European Committee on Radiation Risk (ECRR) to be wholly inadequate and that indications from the three day CERRIE workshop held in Oxford 21-23 July 2003 are that the current risk model is profoundly insecure on grounds of its theoretical modelling and the epidemiology which reveals the health effects of low level exposure. He draws attention to a radiation risk model proposed by ECRR.	Noted.	The main purpose of the look-up tables is to allow ICRP-based calculations to be done more easily. The accompanying report will consider appropriate ranges for parameters such as dust inhalation rates which could be used by assessors who wish to use alternative radiation risk models (as well as by assessors using the look-up tables).
Hugh Richards, seeking to extract the key points from Richard Bramhall's notes on Health Detriment Estimates	Richard Bramhall also states: "A major problem for any site characterisation using conventional dose assumptions is that the material being considered, even though it may present with low average activity, is likely to contain respirable dust particles of Plutonium Oxide and other predominantly alpha emitters in particulate form which do not register a gamma signal on analysis."	Noted.	Assessors using the tables need to consider which radionuclides are present within the contamination with which they are concerned.
Richard Bramhall, Low Level Radiation Campaign	The basic idea of characterising sites is obviously a good one - it is highly necessary for stakeholders to know what is present. *(extract from Conclusions section of attached detailed discussion notes ON Health Detriment Estimates below)*	Noted	
Richard Bramhall, Low Level Radiation Campaign	Predictions about the health impact of contaminants are contentious and we recommend that it should be left to the various stakeholders to decide which source of advice they want to follow on	Noted	The look-up tables are not intended to be mandatory. The report will clearly state the dependence on the ICRP model for dose

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	this aspect and to make decisions accordingly. *(extract from Conclusions section of attached detailed discussion notes ON Health Detriment Estimates below)*		calculation. Calculation of human health risks from radiation doses will not be within the scope of the tables.
Richard Bramhall, Low Level Radiation Campaign	Important nuclides need to be added to the list of "Radionuclides to be Assessed". *(see below)*	See below.	
Richard Bramhall, Low Level Radiation Campaign	It is hard to escape the conclusion that K40 has been included in the nuclides to be assessed because it would make the artificial isotopes look insignificant. We don't see the point of K40 but if BNFL wants to keep it in we shall not object.	Noted.	K40 is more or less ubiquitous in rock and soils. K40 is proposed to be included for completeness, to assist the evaluation of background dose rates.
Richard Bramhall, Low Level Radiation Campaign	Other radionuclides have been omitted e.g. Kr85 and Kr85m and other noble gases which will be adsorbed in various materials. We would also like to see analysis of I-129, Ag-110m, S-35, Zn-65, Eu-155,Eu-154, Ru-106, Ce-144, Mn-54, Zr-95, Nb-95, Be-7, C-14.	Incorporated in part.	The intention is to include those radionuclides which may reasonably be expected to be present in 'legacy' contaminated ground on nuclear sites as a result of leaks and spills that have typically taken place several years or even decades ago. Therefore we would not include radionuclides that are never found in the environment except in association with much higher concentrations of other radionuclides or radionuclides with very short half-lives.
Dale Haigh, Golder Associates (Nottingham)	This proposal to produce a "tool" which will be of benefit to a wide range of stakeholders within the nuclear industry is timely and will undoubtedly provide a number of benefits. We note the comments of Colin Taylor (British Energy) that this should be regarded as one of the tools within a toolbox for stakeholders and support this idea. We do feel that the proposals represent an	Noted.	

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	important step in linking risk assessment of non-radioactive contaminated land and radioactive contaminated land in terms of assessing exposure. It will also be a useful tool to aid consideration of different remedial options in that the impact to on site-workers and remedial contractors can be quantified. We therefore wish the proposal every success. We do not have any specific questions in the areas identified with italics in the consultation draft. However, we would comment that we consider the consultation process to be an effective and useful one. We have identified a few questions below which may be of some use within the consultation process.		
Dale Haigh, Golder Associates (Nottingham)	Is uncertainty associated with the dose rates to be included in some manner within the look up tables, or is another strategy such as using a conservative approach to be adopted?	See response.	See response to similar questions from Colin Potter.
Dale Haigh, Golder Associates (Nottingham)	Will the specific exposure pathways be considered further by the appropriate contractor as additional pathways may be appropriate (e.g. contact with contaminated water (surface, ground or process) as well as soil)?	Incorporated in part.	Dermal contact with contaminated water can be assessed at a simple level as if the water were soil. The slight errors resulting from the different densities of water and soil will be minor in comparison with other sources of error. It will be for the assessor to work out the applicable concentrations of radionuclides in water, taking account of potential contaminated suspended solids as well as dissolved contaminants.
Dale Haigh, Golder Associates (Nottingham)	Within the exposure assumptions, there is a suggestion that assessment of doses at 5m and 50m should be undertaken. Would it be more appropriate to consider doses at	Rejected.	The attenuation of shine dose with distance from the source is not linear, and therefore cannot be

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	X (m) distant from the source and therefore provide a distance factor?		represented by a distance factor.
Dale Haigh, Golder Associates (Nottingham)	The proposed inhalation rates include different soil types presumably in an "open" setting. Should these rates also consider excavation inside buildings / box structures which may produce a different inhalation scenario compared to an open site? This may be especially important for the scenario where persons are dealing with contaminated land (within some form of containment structure).	Noted.	It will be for the assessor to specify the dust inhalation rates. For the scenario where remediation of contaminated land is being undertaken within a containment structure, very specific dose assessments will be required and/or respiratory protection is likely to be specified. Such situations are outside the scope and intent of the proposed tables.
Mike Harris, independent consultant	Any information provided on this basis will be valuable in conducting assessments on a wide range of contaminated sites and would be applicable to both industrial and nuclear sites. The exact basis for the derivation of the data should be clear to allow a potential user to apply it or to modify it to meet specific conditions. It may be worth commenting that outside nuclear licensed sites there is often a need to work backwards in order to derive decontamination targets for say development of sites for housing. Hence starting with a risk based dose and working back to an acceptable residual activity concentration after decontamination. I think that the format you are suggesting should be OK for this but it may be worth considering as the work proceeds.	Noted	
Mike Harris, independent consultant	Contamination is very rarely uniform in nature and is quite often patchy or a series of point sources. How is it intended to address this in the development of the tables?	Not incorporated.	The assessor will have to justify the choice of geometry for radiation shine calculations and/or explore uncertainty in the geometry using different

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			models. If the models supplied are not sufficiently close to reality (or bounding calculations are too pessimistic), the look-up tables should not be used.
Mike Harris, independent consultant	It is noted that U238 series is considered as a potential source. Is it possible that DU (both UK and US derived) could also be provided as a separate source as this would be useful for a number of defence sites.	Incorporated.	
Mike Harris, independent consultant	It is noted that ingestion rates are linked to excavations. Presumably this excludes public exposure groups. Could some thought be given to the potential public ingestion from the casual use of potentially contaminated areas and in particular the ingestion of soil by infants (Pica).	Noted / Not incorporated.	The assessor will have to specify the ingestion rates, taking account of the guidance given in the report. The intended use of the tables does not cover land with uncontrolled use, and therefore pathological levels of ingestion by infants (Pica) should not be modelled using this approach.
Mike Harris, independent consultant	Some comment in the final report on the sources and potential magnitude of errors would be useful.	Incorporated.	See response to comment on uncertainties from Colin Potter.
Mike Harris, independent consultant	I am sure that everyone will have a slightly different wish list for work of this type and I recognise that the objective will be to aim it at BNFL/Magnox problems, however I consider that the potential flexibility embodied in the suggested approach will make it a useful document for a range of circumstances.	Noted.	
Guy Hitchins, Entec UK Ltd. (Dounreay)	The specification it seems to be very thorough in the variety of source-pathway-receptor relationships which will be available - when we worked on Environment Agency R&D Report P307 (referenced in the specification), we decided to use the Use Classes Order as a basis for dose to land occupiers/users, as we were dealing with potential 'practice' and 'intervention' scenarios. Making the	General comments noted. Specific suggestion of a 'process map' incorporated.	We have asked the internal consultants to put a 'process map' in the report.

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	work more specific to Nuclear Licensed Sites in terms of exposure scenario would be useful. My main comment would be to ensure that the deliverable for this work has an easy to follow 'process map' for the various exposure scenarios, so that it is simple to follow a particular example through to the required look up tables. This would make it easy to reference appropriate scenarios.		
David Hodgkinson, Quintessa Ltd. (Henley)	This comment concerns the topic of 'Presentation of Look-Up Tables'. As a complement to the report containing the look-up tables, it is proposed that an online model should be hosted on the BNFL and/or SAFEGROUNDS web site. This would enable the specified calculations to be carried out for any appropriate set of parameters by anyone with an internet connection, thereby facilitating openness and transparency.	Noted for future consideration.	The planned product includes simple electronic spreadsheets. BNFL will consider the need for a web-based application once the main product has been produced.

NOTES BY RICHARD BRAMHALL (LOW LEVEL RADIATION CAMPAIGN) ON HEALTH DETRIMENT ESTIMATES

The ICRP estimation of health detriment following low dose exposures currently involves calculations which apply risk factors for fatal cancer and heritable genetic illnesses to collective doses to populations. These collective doses are themselves calculated through complex modelling based on estimating environmental dispersion, human exposure and biokinetic behaviour of the isotopic substances and their physical forms. Following the calculation of organ doses the ICRP risk model applies risk factors which are almost entirely deduced from linear extrapolations of external acute radiation exposures at high or moderate dose. This procedure has been the subject of considerable scientific criticism and more recently has been considered in some depth by the European Committee on Radiation Risk [ECRR2003]. The committee concluded that the methodology and modelling of internal exposure at low dose by the ICRP was wholly inadequate. In ECRR2003, the committee presented a new risk model which allowed for various enhancements of risk due mainly to the anisotropy of ionisation which may result from internal exposure to certain man made nuclides and also to sub-micron diameter hot particles. In the committee's opinion, based on epidemiological and theoretical considerations, such exposures may result in high local cell doses even in situations where average doses are very low, leading to enhancements of mutagenic efficiency. For further information on the model and its predictions for various isotopic exposures refer to ECRR2003.

In the last 15 years there has been increasing debate among the radiation risk community of scientists and medical researchers about the health effects of very low dose radiation exposure, particularly from internal fission-product isotopes e.g. [Nussbaum and Koehnlein 1994].

This has followed a number of discoveries which have not been considered or incorporated into ICRP60. They include:

- Epidemiological evidence of cancer and other ill health in populations exposed to internal contamination by the Chernobyl accident.
- Epidemiological evidence of increases in leukaemia in children living near nuclear sites.
- Epidemiological evidence of cancer excess in adults living near radioactive contamination sources.
- Subtle genetic effects in minisatellite loci in children and animals exposed to internal contamination from Chernobyl and in experiments.
- The discovery of "genomic instability" whereby a single radiation track through a cell causes an increased level of general mutation in offspring of the cell.
- The discovery of the "bystander effect" whereby cells local to a cell which has been traversed by a radiation track also exhibit genomic instability; on a macroscopic scale, such effects show themselves as chromosome instability and aberration, a phenomenon associated with cancer.
- Theoretical arguments about multiple hits to cells (Second Event theory) the location of certain DNA seeking isotopes (Sr-90, Ba-140), transmutation, hot particle doses and Auger emitters all of which are believed to carry enhancement of hazard over the same averaged dose delivered externally.
- Experimental (cell biology and epidemiology) and theoretical falsification of the linear no threshold theory of dose response which underpins the ICRP risk model.

As a consequence of the atmosphere of uncertainty about low dose exposure generated by this and other evidence the UK government has set up a new committee to examine the radiation risk model. This Committee Examining Radiation Risk from Internal Emitters (CERRIE) was purposely set up in an oppositional structure with scientists from the conventional establishment opposed by scientists critical of the current risk model. Its remit is to report on the safety of the present risk model for estimating the health consequences of internal exposures. The final report is expected in early 2004 but indications from the three day CERRIE workshop held in Oxford 21-23 July 2003 are that the current risk model is profoundly insecure on grounds of its theoretical modelling and the epidemiology which reveals the health effects of low level exposure.

Anisotropy: molecular, atomic and particulate sources

A major problem for any site characterisation using conventional dose assumptions is that the material being considered, even though it may present with low average activity, is likely to contain respirable dust particles of Plutonium Oxide and other predominantly alpha emitters in particulate form which do not register a gamma signal on analysis.

The dose from Plutonium Oxide particles to local tissues varies significantly with the diameter of the particle. Particles ranging from 0.5 microns to 2 microns deliver their dose to tissue cells within a 30 micron radius. These highly localised doses range between 7.3 and more than 400,000Sv per year. (This assumes a density of 11.6, Alpha decay energy of 5.2 MeV, alpha particle range 30 microns and Relative Biological Effectiveness factor of 20). Therefore very considerable doses to local tissue may result from inhalation of sub-micron Plutonium particles. These dose regimes also involve increasing probability of multiple sequential tracks to individual cells within their repair replication cycle, which increases the probability of double strand DNA breaks and second event sequences. These lead in turn to fixed mutation and an increased probability of cancer. The ECRR has pointed out that risks from particulate doses result from a definite window of local dose range which lies between very high multiple track cell killing doses and very low doses that give rise to single tracks to cells within the repair cycle time of about ten hours. The higher the specific activity of the particle constituent, the smaller the size of particle that will deliver this intermediate dose. In passing it should be noted that the recent CERRIE workshop revealed new evidence of the importance of these second event sequences. It will probably be necessary to wait for CERRIE's final report for the detail. In addition Busby pointed out to the workshop that particles in tissue absorb incident gamma and x rays incident from natural background; they amplify and re-broadcast the radiation in the form of photons with a short range in body tissue. The effect is proportional to the cube of the atomic number of the element of which the particle is composed, so Uranium and Plutonium have an enormous capacity to concentrate the energy of incident gamma and x-rays into the small volume of tissue immediately surrounding them. This effect is not dependent on any radioactive characteristic of the element, but has a clear implication for particles like Uranium and Plutonium which are common in the environment.

Conclusion

The basic idea of characterising sites is obviously a good one - it is highly necessary for stakeholders to know what is present. However, predictions about the health impact of contaminants are contentious and we recommend that it should be left to the various stakeholders to decide which source of advice they want to follow on this aspect and to make decisions accordingly. Stakeholders around the world know that ICRP is not infallible; for example the Tjarutja, original occupants of the Maralinga test site in Australia, are not sure

they want to take the site back. *New Scientist* has reported that they are concerned that as radiological standards change the recently completed remediation may come to be considered inadequate.