DEWAR - Effectiveness of Decontamination Options, Wastes Arising and other Practical Aspects of Recovery Countermeasures in Inhabited Areas

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Statement of Use
The findings of this project will be particularly valuable to the Environment Agency and Food Standards Agency in planning contingencies to manage the recovery phase of an incident involving radioactive contamination of the environment. Other partners including SEPA, SE, MOD, DEFRA, NIDOE will wish to be aware of the findings for the purposes of emergency planning.

RSR Site Controllers and Duty Tactical Managers within the Agency's radiation incident management arrangements should be familiar with the CONDO software package and the broader social and practical consequences of developing a recovery strategy. Environment Agency policy and process managers in RSR and waste functions will need to consider the contingencies that will need to be set up to support the Agency's role in recovery. Managers should also identify issues to be pursued in conjunction with multi-agency partners in recovery, via the Nuclear Emergency Planning Liaison Group.

Key words
Recovery phase, Decontamination, Remediation techniques, Radiological accidents, Nuclear accidents, CONDO

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EXECUTIVE SUMMARY

Background

Following an accidental release of radioactivity that results in contamination of the environment, an appropriate protective response would be required. During the release, and until the source of the release had been brought under control, emergency countermeasures might be required to protect the public from short term, relatively high exposures to radiation. In the longer term, or recovery phase, a response strategy would need to be developed with the two aims of protecting people from continuing exposure and of enabling lifestyles and economic activity to return to normal. Since radioactivity can be measured down to levels well below those that pose a significant health hazard, it is unlikely that it would be a practical goal to remove from the environment all measurable radioactivity resulting from the accident. Therefore a balance would need to be struck between the desire to reduce exposures and the need to conserve resources and enable an area to return to normality.

Prior to this contract, the National Radiological Protection Board (NRPB) had published advice on a framework within which decisions on recovery strategies could be made. This relied, in part, upon a review of decontamination options carried out under contract to the then Department of Environment. In addition, the Nuclear Emergencies Planning Liaison Group had issued guidance on some practical aspects of implementing NRPB's framework, in particular, on the setting up of a Remediation Working Group (RWG) in the aftermath of an accident. The operation of the RWG had subsequently been trialled in some national emergency exercises. In addition, the Ministry of Defence had commissioned NRPB to develop support software for assisting decisions on an appropriate recovery strategy. CONDO v1.0 (CONsequences of Decontamination Options) was released in 1999. It was designed with a simple user interface and estimated consequences by interpolation within a database of unit results.

Main Objectives

The purpose of this contract was to provide the Environment Agency (EA) and the Food Standards Agency (FSA) with recommendations on managing their response during the recovery phase. To achieve this, two principal objectives were specified:

Objective 1: to improve the existing CONDO computer model for estimating the consequences of decontamination options applied after an accident, and

Objective 2: to explore, through application of CONDO and discussions with Local Authority emergency planning officers (EPOs) the wider social and practical consequences of decontamination options.

The improvement of CONDO was required in three areas: enhancement of the user interface, inclusion of additional radionuclide specific decontamination data, and, coding of a dynamic dose model for inhabited areas (EXPURT) within the software, in order to provide more flexibility in the results that could be calculated.

CONDO provides estimates of the dose, resource and waste consequences of decontamination options. However, a number of other factors are also important for developing a recovery strategy: local circumstances (physical, economic, demographic, availability of resources), social acceptability of options, national concerns, interaction with any emergency countermeasures implemented. Enhancement of the CONDO software alone would not provide a sufficient basis on which to develop recommendations for improvement of EA's and FSA's response in the recovery phase. The second objective therefore required the wider exploration of issues relevant to response in the recovery phase.

Although FSA co-sponsored this contract, the consideration of food countermeasures and the decontamination of agricultural land was agreed to be outside its scope, except insofar as the perception of restrictions imposed by FSA might influence the social acceptability and practicality of decontamination carried out in inhabited areas.

Results

Two major releases of CONDO were delivered under this contract: v2.1 and v3.0. Both versions achieved the objectives required by the project. However, following trialling of CONDO v2.1, a major revision to the underlying EXPURT model was undertaken, in order to tailor it more closely for application within CONDO, and so increase CONDO's flexibility of use. CONDO v3.0 incorporates this revised version of EXPURT.

Discussions were held with five EPOs and their colleagues. These discussions were based on, but not constrained by, three postulated accident scenarios: a submarine reactor accident, a weapons' accident and a civil reactor accident. The accidents were similar to ones used in emergency exercises, although modified to suit the needs of this project. They not only spanned the range of accident types, but also were chosen to present a range of dose consequences (with the highest predicted doses ranging from less than 1 mSv to 20 mSv or more). This enabled a range of recovery strategies and issues to be explored, from situations where relatively intensive measures would be considered for reducing dose rates through to situations where the radiation health risk, on its own, would not warrant decontamination measures to be taken.

In addition to the discussions with EPOs, information was obtained on the practical issues encountered during two decontamination events in the UK: the discovery and subsequent clean-up of high levels of contamination at a house in Sellafield, Cumbria, caused by pigeon droppings containing radionuclides, and the clean-up of depleted uranium following an aircraft crash in 1999.

Recommendations

As a result of this work, a number of recommendations have been made with regard to the planning of recovery strategies, the development of support tools, practical guidance for implementation of decontamination measures, and, the training of those likely to be involved during the recovery phase in the relevant issues and application of support tools. In particular, the suggestion is made that EA develops a generic recovery plan that could provide a basis on which Local Authorities could build their strategies. In this regard it is noted that the EPOs strongly supported the structure and content of the proposed development of a Recovery Handbook. Other specific issues for EA to consider are the extent to which EA advice would be perceived by the public as impartial and options for the disposal of wastes.

1 INTRODUCTION

This report summarises the work programme and findings of a contract carried out with funding from the Environment Agency (EA) and the Food Standards Agency (FSA). The objective of this DEWAR contract[1] was to assist these Agencies in their development of plans for responding in the medium and longer term following an accidental release of radionuclides into the environment.

Following an accidental release of radionuclides into the environment, radioactive contamination may persist and be detectable for some considerable time. Such radioactive contamination may expose people directly to external irradiation or to internal irradiation following ingestion or inhalation. Ingestion of contaminated foods may be avoided either by implementing agricultural countermeasures to reduce the contamination in foods or by removing contaminated foods from the market: protection against the ingestion of contaminated foods is outside the remit of this report. Methods for reducing potential exposure via other pathways have been researched, both in the context of experiments and also following major accidents (most notably following the accident at the Chernobyl nuclear power station in 1986). Such methods can be divided into two types: those that fix or shield the contamination in-situ (permanently or temporarily), and those that remove the contamination from its initial environment to a more controlled situation. Strictly, only the latter should be termed decontamination methods. However, for the purposes of this report, and to emphasise the commonality between both types of method, compared with 'restricted access' measures which rely on preventing or reducing the access of people to contaminated areas, both types of methods of dealing directly with the contamination are termed 'decontamination' measures here.

In terms of responding to an accidental release of radioactivity, two distinct time phases may be identified: the emergency response phase and the recovery phase. During the emergency response phase urgent decisions are taken concerning measures required to protect the affected population from short term, relatively high risks. During the recovery phase, decisions are taken concerning the lifting of emergency countermeasures, the implementation of further protective actions to reduce exposures that might occur over the longer term, and measures to promote a return to 'normal living'. It is during the recovery phase that measures such as decontamination or restricted access to more highly contaminated areas might be implemented.

The most obvious way of facilitating the population’s return to normal lifestyles would be the full reinstatement of pre-accident conditions. Unfortunately, this would rarely be a practicable option. Many radionuclides can readily be detected down to extremely low levels, such that their presence can be detected even when the radiation risk they pose is negligible. Removal of all detectable contamination would probably have very damaging environmental consequences, i.e. the removal of all plants, trees, topsoil, buildings and hard surfaces. It is therefore important to recognise that full reinstatement of pre-accident radiation levels might have very great social and environmental costs, as well as monetary costs. In addition, widespread removal of contamination can result in very large quantities of waste requiring appropriate disposal. Full reinstatement of pre-accident conditions, therefore, is unlikely to be a practicable goal.

[1] DEWAR - options for DEcontamination and Waste Arisings following accidental release of Radioactivity.

In determining a strategy for the recovery phase, it is essential to develop practicable goals for intervention which strike a balance between the desire for the maximum reduction of doses and the need to keep all the adverse consequences of intervention to a minimum. To some extent, such decisions cannot be made until the exact circumstances of the accident are known. However, appropriate research in advance of an accident can provide an informed framework within which such decisions can be made. In particular, computer models for investigating the likely consequences of a range of recovery options can be developed, practicable options for intervention measures and waste disposal routes can be identified, and broad criteria for decision-making can be developed.

Significant research and planning development for dealing with the recovery phase of an accident had been undertaken over the past decade, prior to commencement of this project. For example, NRPB had published a framework for decision making during this phase [NRPB, 1997] and the Nuclear Emergency Planning Liaison Group (NEPLG) had circulated detailed guidance on managing the response during this phase [NEPLG, 2001]. Furthermore, under contract both to the then Department of the Environment (DoE) and the Ministry of Defence (MoD) NRPB had published reviews of studies of the effectiveness of decontamination options [Brown *et al*, 1996; Brown and Jones, 2000]. Finally, MoD had funded the development of software (CONDO) to scope some of the consequences of decontamination options, for assisting decisions on recovery strategies in the aftermath of an accident [Charnock *et al*, 2000].

The purpose of the DEWAR work programme was to provide the Environment Agency (EA) and the Food Standards Agency (FSA) with recommendations on managing their response during the recovery phase. To achieve this, two principal objectives were specified:

Objective 1: to improve the existing CONDO computer model for estimating the consequences of decontamination options applied after an accident, and

Objective 2: to explore, through application of CONDO and discussions with Local Authority emergency planning officers (EPOs) the wider social and practical consequences of decontamination options.

This report discusses each of the Tasks in turn and then concludes with recommendations drawn from the findings of the work.

2 TASK 1: CONDO DEVELOPMENT

2.1 Application of CONDO

Decisions on whether to carry out decontamination measures after an accident require information on the likely consequences of such measures, in terms of dose, resources required and the likely social and environmental impact. CONDO v1.0 (CONsequences of Decontamination Options) was developed, under contract to MoD, to enable these consequences of decontamination options to be estimated [Charnock *et al*, 2000]. To do this fully and in detail is both a very complex task and would require much detailed information from the user. As a first step, therefore, CONDO v1.0 provided scoping information, based on limited user input and default data held in a database. The results enabled a decision maker to obtain indicative estimates of the extent and scale of the problem being faced, and so to identify those options which should be excluded from further study and those for which more detailed investigation would be warranted.

CONDO v1.0 estimated, for a wide range of decontamination options, the following consequences:

levels of decontamination achieved
quantities and activities of wastes arising
resources required
residual doses to the public
doses to workers.

These decontamination consequences could be compared with an indicative cost for relocating the affected population for a given period of time (based on NRPB's COCO-1 model [Haywood *et al*, 1991]).

In principle, therefore, CONDO provides the basic calculational functionality for assisting in the investigation of decontamination and waste disposal issues. Being an interactive software tool, it also lends itself to use by accident response staff, both for response planning purposes and in the aftermath of an actual accident. Indeed, CONDO v1.0 has been tested in several emergency response exercises, in particular, MoD's joint UK/US emergency exercise Diagonal Glance (September 1998), and has been found to be a useful tool for feeding scoping information to those responsible for advising on the development of a recovery strategy.

CONDO only provides information on consequences of decontamination that can be physically modelled: doses, levels of decontamination achieved, amounts and types of wastes arising, timescales. These are necessarily modelled at a generic level: site and accident specific factors would need to be taken account of separately and overlaid on the generic information provided by CONDO. Any recovery strategy must also take account of less mathematically quantifiable aspects, such as local social aspirations and perceptions and the wider economic and social context of any actions. These could be obtained from appropriate experts and pro-active dialogue with those affected by any postulated measures: in a generic sense before the occurrence of an accident, and more specifically in the event that one occurred. It would not be possible or appropriate to enhance CONDO to model the impact of these factors.

NEPLG guidance on managing the recovery phase of an accident, recommends the convening of a Recovery Working Group (RWG), comprised of experts in all factors relevant to the response, within which the optimum recovery strategy may be explored and developed [NEPLG, 2001]. One application of the CONDO software is the provision of input to the RWG. It is envisaged that, initially, CONDO would form the main input, in order to group options according to whether they provide relatively cost effective dose reduction[2], significant dose reduction at a much higher cost, or would not be considered on dose reduction grounds alone[3] [NRPB, 1997]. However, the more detailed investigation of these options, in the context of a specific site and accident, would need to be carried out by incorporating information and expertise additional to that provided by CONDO, through discussion in the RWG.

2.2 Development of CONDO

Under contract to EA and FSA, the following enhancements to CONDO v1.0 were planned:

- Additional radionuclide specific data
- Embedding of a dynamic dose model for inhabited areas within the CONDO computer model
- Improvements to the user interface.

In fulfilling these requirements, three versions of CONDO have been released. Version 2.0 was released to EA and FSA in May 2001, as an evaluation version, for testing and comment. As a result of comments received, CONDO v2.1 was released to EA, FSA and MoD in September 2001 [Charnock *et al*, 2001; Charnock *et al*, 2003]. CONDO v2.1 achieved all three of the goals required by the contract: additional radionuclide specific information, incorporation of NRPB's dose model for inhabited areas, EXPURT v2.02, within the software, and an improved user interface. CONDO v2.1 retained the straightforwardness of inputs and assumptions of version 1.0, but provided enhanced flexibility of application and improved presentation of information and report generation. In addition, the CONDO database (version 1.2) was expanded to include consideration of more decontamination techniques (version 2.1). Following a major revision to EXPURT, as discussed in Section 2.2.2 below, CONDO v3.0 was released in February 2003. This third release, agreed between all parties, had not been envisaged in the original contract, but provides a significant enhancement to the project deliverables.

Each of the planned enhancements to CONDO v1.0 is discussed in more detail in the following sections.

2.2.1 Additional radionuclide specific data

The estimates provided by CONDO v1.0 were based on two studies: a survey of decontamination options and their effectiveness, carried out by NRPB, Rolls Royce Nuclear Engineering Services Ltd and the Atomic Weapons Establishment under contract to DoE,

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[2] Where cost is used to include the material and personnel resources diverted to this task and the disruption caused to those living and working in the area, as well as any direct monetary outlay.

[3] This last group of options might still be implemented in response to social or wider economic factors.

which was based mainly on data for caesium-137 [Brown *et al*, 1996], and, a review of relevant data for plutonium-239, carried out by NRPB under contract to MoD [Brown and Jones, 2000]. In order to provide appropriate estimates for other radionuclides, CONDO v1.0 adopted the concept of proxy radionuclides. Radionuclides for which data were not available could be treated as if they behaved chemically in an identical manner to their proxy, whilst retaining their own physical half-life and decay characteristics. Owing to scarcity of other data, all radionuclides had been set with either caesium-137 or plutonium-239 as their proxy. Whilst it was recognised that only limited additional data on other radionuclides had been published, the identification and inclusion of data for other radionuclides formed one goal for the enhancement of CONDO.

During this study, some limited additional information on decontamination effectiveness was found for ruthenium, barium and lanthanum. This is included in the CONDO database, as discussed in Appendix A.2.1. In addition, experimental data on the initial deposition of iodine to different surfaces in inhabited areas, relative to the initial deposition of other elements in particulate form, has been used to determine separate parameters for iodine deposition within the EXPURT database. Appendix B of Charnock *et al* [2003] provides further discussion of the available data, and Appendix C of this report lists the parameter values adopted in both EXPURT v2.02 and EXPURT v3.0.

2.2.2 Embedding of dynamic dose model for inhabited areas

The effectiveness and consequences of decontamination options depends not only on the option itself, but also on how contamination is initially distributed in the environment and then subsequently weathers and is re-distributed. In calculating how contamination is both initially and subsequently distributed in inhabited areas, and also in calculating residual doses, CONDO v1.0 used a set of multiplying factors, based on results provided by a dose model developed by NRPB for inhabited areas, EXPURT [Crick and Brown, 1990]. Ideally, these calculations would have used models specific for the environment being considered. However, in order to do this, it would have been necessary to code the EXPURT model inside CONDO, rather than relying on multiplying factors taken from separate EXPURT runs. The major enhancement planned for CONDO was therefore the incorporation of EXPURT within the CONDO computer model.

CONDO v2 was developed to incorporate EXPURT v2.02. The functionality of the released version, v2.1, is described in Appendix A, with further detail, including a description of EXPURT v2.02, provided by Charnock *et al* [2003].

Following extensive application of CONDO v2.1, it became clear that the functioning of CONDO would be greatly enhanced if a major revision was made to the functioning of the underlying EXPURT model. EXPURT had been developed to provide the likely range of doses and surface contamination following deposition of radioactivity and decontamination in inhabited areas, taking account of the uncertainty associated with the underlying model parameters. To enable this to be practicable, the modelling approach incorporated averaged representations of the composition of inhabited areas (eg building types, ratio of paved areas to grass/soil areas) and assumed population behaviour. Whilst this approach is well suited for carrying out uncertainty analyses, it is less suited to examining the likely consequences of a specific contamination scenario. For this, the ability to model, explicitly, different aspects of inhabited areas (such as high density inner city areas, low density suburbs etc) and different population behaviours is important. Therefore, a revision to the contract goals was agreed between NRPB, EA and FSA, to develop a further version of CONDO, CONDO v3.0, that incorporated a revised version of EXPURT, EXPURT v3.0. CONDO v3.0 functionality is described in Appendix B. EXPURT v3.0 is described in Appendix C.

In summary, the incorporation of EXPURT within CONDO has provided the user with greatly enhanced flexibility of operation, in terms of the timing of decontamination techniques and the times at which results may be calculated. It has also provided the opportunity for indicative individual worker doses to be calculated, instead of the generic collective work dose calculated by CONDO v1.0, and for an improved resuspension dose model to be adopted (as described by Walsh [2002]). In addition, the incorporation of EXPURT v3.0 within CONDO v3.0 has enabled the user to describe the pattern of contamination intuitively, ie by delineating areas according to areas containing similar types of development, rather than according to the more abstract concept of pre-defined mixes of building types modelled within EXPURT v2.02.

2.2.3 Enhanced user interface

CONDO v1.0 had a fairly restricted user interface, particularly with respect to presentation of the results and facilitating 'what if' questions. In order to make it more flexible to use, and to facilitate identification and extraction of key results for wider dissemination, a more interactive user interface was required. Both v2.1 and v3.0 incorporated enhancements to the interface, some cosmetic, others directly linked to the enhanced flexibility provided by the incorporation of different versions of EXPURT.

The main enhancements incorporated in CONDO v3.0, as compared with v1.0, are listed below. More detailed descriptions are given in Appendices A and B.

- When the program is first started, a ‘splash’ screen is presented, identifying the program.

- The user may request numerical information to be presented in either scientific or decimal format.

- The user may specify a region in terms of any combination of up to four different ‘environments’. These environments represent areas with multi-storey buildings, areas with brick housing, areas with lightweight buildings (such as mobile homes), and, areas (within inhabited areas) without any buildings (such as parks and playing fields).

- The user may specify how much time the population spends both indoors and outdoors in each of the specified environments, or simply the relative amount of time spent indoors overall (and the software will apportion the individual occupancies accordingly, see Appendix B).

- The user may specify the population for each defined region, rather than relying on system default population densities.

- More decontamination options are included.

- Results are presented at 2 levels:
  - a list of techniques appropriate to the surface type selected, which can be ordered according to: decontamination factor likely to be achieved, reduction in resuspension likely to be achieved, cost of the technique per unit area, mass of waste per unit area, categorisation according to NRPB's recommended framework for making decisions on recovery countermeasures [NRPB, 1997]
  - detailed results for a single technique/surface type combination in the specified region.

- The user may define the results calculated (CONDO v1.0 always calculated a pre-defined set of results), ie:
  - choice of technique and surface to be decontaminated
  - percentage of each surface type (eg paved, grass/soil) within a region to be decontaminated
  - time when technique starts to be implemented
  - number of teams used in decontaminating or time taken for decontamination
  - times after the initial deposition at which results are calculated.

- The user may ask doses to be calculated assuming either that an individual is permanently outdoors in the environment which gives the highest dose or that the individual spends time indoors and outdoors in each environment as specified for the region.

- The user may provide comments, at most stages of interaction with the software, that will annotate the calculated results when saved to a 'report'.

- Reports may be generated that contain:
  - automatically generated information defining the run time and date, the scenario specified by the user, the technique applied etc
  - any combination of user requested results for a single technique
  - a list of techniques ordered on different evaluation criteria for application to a particular surface type
  - sets of results, sequentially displayed, for any number of technique/surface/region combinations
  - all comments provided by the user, linked to the relevant information in the report.

- The reports may be edited to a limited extent within CONDO, before printing or output to a word processing package.

2.3 Application of CONDO v3.0

CONDO v3.0 is released with three pre-defined contamination scenarios. These are based on contamination patterns that have been used for testing emergency plans, as part of the UK's emergency exercise programme for nuclear sites. However, they have been adapted to meet the needs of this contract, and, as such, should not be interpreted as guidance on either the absolute or relative sizes of release that might occur in different types of accident. The radionuclides considered are believed to be representative of those that would dominate the exposure hazard following three different types of accident, namely: an accidental release from a nuclear powered submarine, a weapons transport accident and an accident occurring at a civil nuclear power plant. The sizes of release assumed have been chosen to provide a range of resulting doses, from doses that are small compared with those from one year's exposure to natural background radiation, to those that are comparable with the annual dose limit for workers. The locations of the releases have been selected to enable consideration of both urban and rural sites. Selection of these sites should not be interpreted as an indication of the scale and composition of release that is most likely for an accident occurring there.

The provision of these contamination scenarios enhances the application of CONDO v3.0 for users in a number of ways. Users can learn how to use CONDO in stages, by exploring the provision of results from existing scenarios, before moving on to learn how to specify the scenarios themselves. These scenarios also enable users to undertake preliminary explorations of key issues and ‘what if?’ questions as part of the development of emergency plans, without the need, initially, to construct site specific contamination scenarios. Once a general understanding of the sort of consequences likely from undertaking different decontamination techniques has been gained, the sensitivity of these general conclusions to site specific issues can be explored by developing a range of site specific scenarios. Finally, in the event of an accidental release, these scenarios can be used as ‘templates’ to be tailored to the actual situation, thus avoiding the need to construct the accident scenario entirely from ‘scratch’. This is particularly helpful at early times before a detailed knowledge of the exact contamination pattern has been built up from monitoring.

In the sub-sections that follow, the pre-defined scenarios are discussed in more detail. This discussion provides an insight into the capabilities and application of the CONDO v3.0 software. It also provides a context for the outcome of the discussions held with Emergency Planning Officers, presented in Chapter 3. In discussing these scenarios, maps are presented which show the contamination patterns being considered. Currently, CONDO does not have the capability to display maps of the contamination. The advantage of working with such maps is obvious: the enhancement of CONDO with this capability requires consideration for the future.

2.3.1 Using CONDO

In this sub-section, some general guidance is provided on the running of CONDO. In the following sub-sections, the three assumed scenarios are discussed.

Defining regions

The basic unit of area within CONDO is the ‘region’. Regions are defined by the user to have:

an area
a composition in terms of the building types found in the region
a uniform level of contamination by one or more radionuclides.

A single region will often be defined as a single discrete area. However, it need not be a contiguous area of land, but could, for example, be defined as the combination of two or three small villages that had a similar level of contamination. For convenience, regions can be grouped together into ‘scenarios’. However, since regions are separately analysed by CONDO, there is no requirement for the regions grouped within a scenario to hold any spatial relationship to one another. For example, a scenario could hold regions that: together, exactly cover the contamination ‘footprint’; overlap; do not cover the whole contaminated area; or, are completely contained within other regions. This flexibility encourages and supports the exploration of ‘what if?’ questions.

The composition of the regions, in terms of building types ('environments'), is specified by the user according to the area associated with each. These environments are defined and analysed by the underlying EXPURT model. As indicated in Section 2.2.3, EXPURT v3.0 provides four environments: 'lightweight houses', 'brick houses', 'multi-storey buildings' and open green areas (ie areas away from buildings). These environments are discussed in more detail in Appendices B and C. The environments with buildings are modelled as a grid of rectangular 'cells', each containing a single building, with the shielding properties appropriate to that building type, surrounded by a mix of soil/grass, trees/shrubs, and paved areas. The open green areas are representative of managed recreational areas (as opposed to more open countryside), comprising mostly soil/grass and trees/shrubs, but with some paved areas. For each region, the user specifies the percentage area of the region that each type of environment represents. The design of CONDO v3.0 is such that new environments can be added, once the necessary modelling data to describe them has been compiled and added to the EXPURT database. (NB: This is not something the user can do. NRPB will provide updated EXPURT databases, as and when these can reasonably be made available.)

Each region is associated with a defined level of deposition of specified radionuclides. In an inhabited area, initial deposition levels will vary between different surfaces, ie between soil/grass, trees/shrubs, paved and building surfaces. CONDO assumes that the measurements available to the user do not provide a detailed understanding of the exact distribution of radionuclides on different surfaces. Rather, it is assumed that the user is most likely to have access either to estimated levels of deposition (based on activity concentration measurements in air or from atmospheric dispersion models) or to direct measurements of deposition on grass, well away from buildings[4]. Therefore CONDO requires only an estimate of deposition to soil/grass for each radionuclide, from which it calculates the levels of deposition to other surfaces. (This is discussed in more detail in Appendix A.) The user may only specify a single deposition level to soil/grass for each radionuclide within a region. If the variation of deposition to soil/grass within a region is judged too significant for the approximation of uniform deposition to be valid, then the user should sub-divide the region into sub-regions, according to the distribution of deposition.

Doses

Having set up the regions, the user may use CONDO to scope the likely impact of the contamination pattern in the absence of countermeasures. This can be achieved by running CONDO for each region, for any surface / decontamination technique combination. One of the results calculated by CONDO is the total (effective) dose that would be received by a 'typical' individual, in the absence of countermeasures[5]. The user may select three times at which this dose is calculated.

In order for the user to correctly interpret the doses reported, it is important to understand how they are calculated. The user may choose between two types of doses: doses typical for people living 'normally', ie spending representative amounts of time inside buildings of different types and also outdoors, and doses to people spending all of their time outdoors in

[4] This is the protocol generally adopted for early deposition measurements made following an accidental release to the air.

[5] In this report the term 'dose' is used to mean the sum of the committed effective dose from inhaling radionuclides resuspended from surfaces during the user specified time period and the whole body external dose from deposited radionuclides, integrated to the user specified time. In general, one of these two pathways will strongly dominate the total dose received. These doses are calculated for adults. No account is taken of exposures from the airborne plume.

the environment that would provide the highest outdoor dose. In setting up the regions, the user is asked to specify the fraction of time that is typically spent indoors and outdoors in each environment. The user may do this explicitly, if the information is available (or if the user wishes to explore the consequences of different assumptions). However, in most applications of CONDO, it is more likely that the user will simply wish to specify the overall fraction of time spent indoors and outdoors in the region as a whole (eg 0.9 indoor occupancy, 0.1 outdoor occupancy). In this case, CONDO interprets the overall indoor and outdoor occupancy fractions specified by the user, as follows. The ratios of occupancy fractions for being outdoors in each environment are set equal to the ratios of the relative outdoor areas of each environment within the region. The fractions are then normalised so that they sum to the overall occupancy fraction specified. For indoors occupancy, the ratios of the fractions are set equal to the ratios of the number of people within each environment. Default population densities are provided for each environment which contains buildings (in CONDO v3.0, 'open green areas' are assumed to have no resident population). Combined with the area given for each environment, these provide default population sizes for the environments specified. These populations may be overridden by the user. In the calculation of indoor occupancy fractions it is only the ratios between the population sizes that are relevant. Therefore, for the purposes of calculating occupancy fractions, it is only necessary to be satisfied that the populations given for each environment are in the correct ratio to each other; their absolute values are not significant.

The assumption made by CONDO v3.0 in determining the outdoor occupancy fractions for each environment requires further discussion. The basis of the assumption for outdoor occupancy fractions is that the size of the outdoor area determines the number of people spending time in it and the amount of time they spend there. This is probably not an unreasonable assumption for environments containing buildings. However, for 'open green areas' which may, for example, be either well used playing fields or less frequented parks, the assumption is less likely to be valid. In particular, it will tend to over estimate the outdoor occupancy fraction for open areas which are not used heavily by the public. If the environment 'open green areas' is used to represent areas outside inhabited areas (eg fields), then it is very likely that CONDO will over estimate the outdoor occupancy fraction for this environment, and will consequently under estimate it for the other environments specified in the region[6].

Analysing decontamination options

Once the user has gained an overall understanding of the scale of the doses likely to be received in the absence of countermeasures, he/she can then consider the options for decontamination in the context of NRPB and NEPLG guidance [NRPB, 1997; NEPLG, 2001]. The Level 1 results form allows the user to order techniques applicable to a given surface according to their likely classification according to the categories (A, B and C)[7]

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[6] Strictly, this 'open green area' environment is not intended to be used for large expanses of fields or semi-natural areas, as 10% of the land area is assumed to be paved or metalled.

[7] NRPB advises that Category A measures are those that avert moderate doses, require relatively low resource, incur relatively little disruption and can be carried out within about one month. These should be considered for implementation in response to any detectable level of radioactive contamination (but only implemented if the overall benefit of implementing them is judged to be greater than the overall benefit of taking no remedial measures). Category B measures avert larger doses, but are consequently more resource intensive and disruptive and take much longer to plan and carry out. NRPB advises that these should not be considered unless the doses expected to be received in the first year following the accident would exceed around 10 mSv. Category C measures would not be carried out on radiation protection grounds, but might be implemented for the purposes of public reassurance.

recommended by NRPB. For a contamination footprint that resulted in doses of less than 10 mSv in the first year, NRPB advises that Category B countermeasures would not normally be considered. In this case, a helpful starting point would be to consider those options labelled Category A on the Level 1 form, for each surface. However, the user is advised not to completely disregard the other options, as, in specific circumstances, techniques that would normally be classified as Category B options, might be better treated as Category A (and *vice versa*). In addition, Category C options might be considered for the purposes of public reassurance or in situations where no other options are possible. Examination of the unit costs, resource requirements and decontamination effectiveness factors for these other techniques will assist in this preliminary checking of the possible feasibility of these options.
Once promising techniques have been selected, the user can run CONDO to identify the likely effect these would have on overall doses and also on the volumes, form (ie liquid or solid) and activity concentrations of wastes arising. Scoping the amount of waste arising is particularly important as a disposal route would have to been found for it. In running CONDO for different techniques and considering different surfaces, it is important to explore the sensitivity both of the likely effectiveness of the decontamination option and of the resources required to the start and end times specified for implementing the measure. The user is advised to begin by specifying a time period within which the decontamination should be completed (a default of 2 days is offered by CONDO). CONDO will then reflect back the number of teams required to achieve this, as well as the decontamination and dose reductions achieved. The user can then consider the likely availability of the required number of teams and amount of equipment, before exploring the option in more detail.

Dose effectiveness of decontamination options

When evaluating decontamination options, it is important to recognise the likely extent to which any single measure can reduce doses. Within an inhabited area that has become contaminated with radioactivity, people will be exposed from contamination on a number of different surfaces. CONDO v3.0 considers six surface types, namely, soil/grass, paved, trees/shrubs, roofs, exterior walls of buildings, internal building surfaces. At a simplistic level, division of the outdoor environment into four main surfaces (buildings, paved, soil/grass, trees/shrubs) would suggest that even full decontamination of one outdoor surface is unlikely to avert more than about 25% of the projected dose. In fact, of course, the situation is more complex than this. The contribution that the radioactivity on each surface will make to the total dose will depend on where an individual spends his/her time, the relative initial deposition of radionuclides to different surfaces, the relative areas of each surface in the region, and the transfer of radioactivity between surfaces over time. For decontamination measures carried out within short times of the initial deposition (days, possibly a few weeks), this last factor can have an important influence on the dose effectiveness achieved, as subsequent transfer of radioactivity within the environment may re-contaminate a ‘cleaned’ surface (eg trees shedding their leaves).

With regard to the relative amounts of radioactivity on each surface, the following points can be noted. EXPURT v3.0 predicts that nearly all the radioactivity deposited, under dry conditions, in the environments offered in CONDO v3.0, will be deposited to the tree/shrub and soil/grass surfaces, in approximately equal amounts. Unsurprisingly, this means that, for deposition occurring under dry conditions, outdoor doses calculated for these environments will be dominated by irradiation from the tree/shrub and soil/grass surfaces (and, in the long term, solely from the soil/grass surface as all trees shed their leaves over time). Decontamination techniques applied to surfaces other than these, however efficient in removing contamination, will therefore only have a small impact on the total outdoor dose.

For deposition under wet conditions, the radioactivity is spread move evenly between (outdoor) surfaces, and so, to a first approximation, the contributions that irradiation from different surfaces make to the total outdoor dose will be related to the relative areas of these surfaces. Again, since the soil/grass surface represents the largest area in each of the environments provided in CONDO v3.0, radioactivity deposited on this surface will still provide the largest component of the total outdoor dose. However, significant contributions will also be provided by radioactivity on other surfaces, particularly paved surfaces.

For normal living doses, the situation is more complex. Depending on the circumstances, all surfaces can contribute moderate components of the total dose. Relevant factors to consider are the occupancy factors used, the mix of environments, whether the initial deposition occurred under dry or wet conditions and for how long into the future the dose is to be integrated. However, for the environments supplied with CONDO v3.0, for a wide range of combinations of these factors, the largest component of the dose will still come from radioactivity deposited on, or weathered onto, soil/grass. Under some combinations of factors, particularly those involving deposition occurring in wet weather, other surfaces can provide moderate contributions to the total dose. The chief exception to this is for regions comprising only multi-storey buildings and where the deposition occurs under dry conditions. In this case, contamination on the building surfaces is much more significant than contamination on the ground[8].

It is important to recognise that these general conclusions have been based on the assumptions in EXPURT v3.0 and its associated database DB2 vA.01 (in particular, the parameters listed in Tables C.1 and C.2 in Appendix C), the assumptions in the resuspension model adopted [Walsh, 2002], and the definitions of the four environments provided with CONDO v3.0. It would be useful to undertake a sensitivity study on EXPURT/CONDO in order to determine the extent to which these conclusions are more widely valid, and to identify those parameters and assumptions to which the results are most sensitive.

Tie-down techniques

The weapons' accident scenario (see Section 2.3.3) enables exploration of another feature of CONDO v3.0: the inclusion of tie-down techniques. These are techniques designed to reduce resuspension, either semi-permanently (eg the application of bitumen to roads) or on a more temporary basis (eg the application of sand or water to roads). Such techniques do not remove contamination, and, generally, would only be employed to reduce the hazard from, and the spread of, the contamination prior to the application of more thorough decontamination. CONDO v3.0 provides estimates of the doses that would be averted during the periods for which these techniques would remain effective. However, CONDO v3.0 cannot link these to the subsequent application of a second technique, although the underlying EXPURT v3.0 program is able to support such a link. Consequently, in order to scope the consequences of applying a tie-down technique followed by a decontamination technique, the user must undertake two separate analyses using CONDO, and manually combine the results. The linking of techniques sequentially is an option that could usefully be considered in future releases of CONDO.

[8] It should be noted, however, that the modelling for multi-storey environments assumes an individual located well above ground level and well below roof level. For individuals located near ground level, it is likely that the soil/grass, trees/shrubs and paved surfaces would contribute a larger component of the total dose than predicted by CONDO v3.0/EXPURT v3.0 (DB1 vA.0 and DB2 vA.01). For individuals located near the roof of a multi-storey building, it is likely that contamination on the roof would contribute a larger component of the total dose than predicted by CONDO v3.0/EXPURT v3.0 (DB1 vA.0 and DB2 vA.01).

Interpretation of CONDO results
When applying CONDO, it cannot be over emphasised that the CONDO results are intended to form only one input into the decisions taken concerning clean-up after an accident. CONDO provides indicative information on the likely effectiveness, costs and timescales of applying different techniques. However, other, local and national, expertise is required to determine the availability of the resources required, the acceptability of each option to those affected, and the significance of specific local features or requirements (whether physical or in response to public concerns) for the interpretation of CONDO's indicative results.

2.3.2 Submarine reactor accident

If an accidental release to the atmosphere were to occur from the reactor in a nuclear powered submarine, it is likely that a range of different radionuclides would be released, in a range of different amounts. For straightforwardness, only four radionuclides are considered in the CONDO scenario: iodine-131, caesium-134, caesium-137 and ruthenium-106. If an accidental release occurred, these radionuclides are likely to dominate the resultant potential exposures to those outside the dockyard. In the scenario, it is assumed that the ratios of the depositions of these four isotopes are constant everywhere, with iodine-131 activity deposited in the largest amounts. The assumed deposition pattern for iodine-131 is shown in Figure 2.1. The ratios assumed for the other isotopes, relative to iodine-131 are as follows:

- iodine-131 : caesium-137 in the ratio 10 : 1
- iodine-131 : caesium-134 in the ratio 20 : 1
- iodine-131 ruthenium-106 in the ratio 20,000 : 1.

The map shows that two plumes of radioactivity have been assumed, the larger one to the north, across part of Plymouth, with a slightly smaller one, in terms of deposited activity, travelling to the south west across Torpoint. Since Torpoint is in Cornwall, whilst Plymouth is in Devon, this pattern of contamination enabled potential 'cross border' issues between two Local Authorities to be explored.

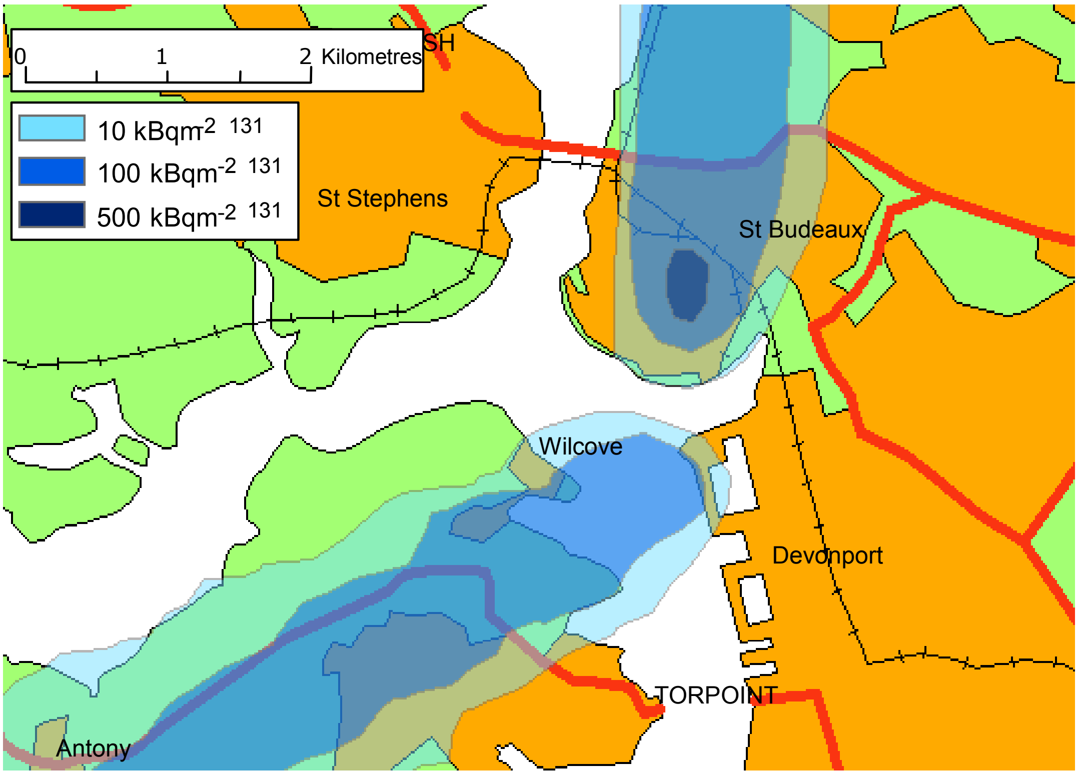


Figure 2.1 Deposition contours for the submarine reactor accident scenario

Figure 2.2 illustrates how the contamination pattern in Figure 2.1 might be encapsulated within CONDO v3.0. In this example, five regions have been identified, based on deposition levels and geography. The northern deposition 'plume' is divided into three regions, one representing the area of highest deposition, one representing the remaining part of Plymouth that is contaminated, and the third covering an area of moderate deposition over land that has few buildings. The south west deposition 'plume' is divided in two regions, one incorporating the village of Wilcove and the other the larger village of Torpoint. Both these regions contain a mix of built up areas and fields. A main road has been used to separate them, and the fields to the north east of this road have not been included in the assessment. This choice of regions could equally well have been determined by the land use, as was done for the northern plume. In this case, three regions could have been specified, two defined by the village boundaries and one containing the fields between them (and also extending to the coast, if desired). Alternatively, a single region could have been used to describe both villages: as discussed in Section 2.3.1, provided an appropriate mix of building types is specified to CONDO and the area associated with them is correctly determined, there is no requirement for regions to comprise solely contiguous land areas. In fact, because a scenario is treated simply as a means of grouping together regions relating to a specific accident, it is possible for the user to sub-divide the south west plume into all of these configurations and to store them all under the same scenario name, provided each defined region is given a unique name.

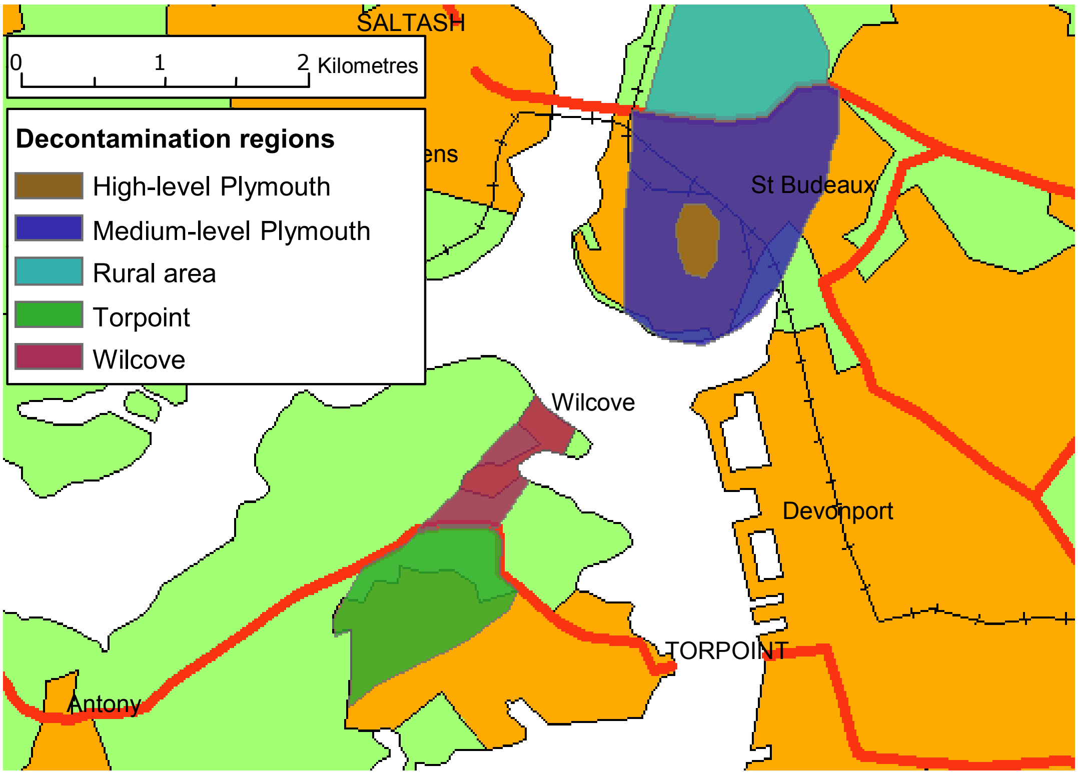


Figure 2.2 Subdivision of the submarine accident deposition contours into CONDO regions

Table 2.1 Regions for the submarine reactor accident deposition pattern

Region	Deposited activity (Bq m^{-2}) ^{131}I	^{137}Cs	^{134}Cs	^{106}Ru	Environments	Area (km^2)
High level, Plymouth	750 000	75 000	37 500	375	50% multi-storey 50% brick	0.11
Medium level, Plymouth	300 000	30 000	15 000	150	50% multi-storey 50% brick	1.7
Rural area	200 000	20 000	10 000	100	80% open green area 10% brick 10% lightweight	1.2
Torpoint	200 000	20 000	10 000	100	50% brick 10% lightweight 40% open green area	0.9
Wilcove	100 000	10 000	5 000	50	50% brick 50% open green area	0.32

Since the scenarios supplied with CONDO v3.0 are intended to be used generically, the mix of environments specified for each of the defined regions is not based exclusively on the detailed composition of the area surrounding the Devonport dockyards. Instead, whilst retaining the general features of that area, the mix is also chosen to reflect what might be expected for similar areas across the UK. Table 2.1 lists the region definitions for the submarine reactor accident scenario held in CONDO v3.0.

Table 2.2 Indicative doses for submarine reactor accident scenario

Region	Deposited activity (Bq m^{-2}) ^{131}I	Total effective dose (mSv)[a] Normal living[b]	Outdoor[c]
High level Plymouth	750 000	First week: 0.02 First year: 0.2	First week: 0.1 First year: 2
Medium level Plymouth	300 000	First week: 0.01 First year: 0.1	First week: 0.04 First year: 0.6
Rural area	200 000	First week: 0.01 First year: 0.1	First week: 0.06 First year: 1
Torpoint	200 000	First week: 0.01 First year: 0.1	First week: 0.06 First year: 1
Wilcove	100 000	First week: 0.005 First year: 0.04	First week: 0.03 First year: 0.5

Notes:

a) Doses given to 1 significant figure, to emphasise the uncertainties inherent in such generic calculations.

b) Doses calculated assuming 90% and 10% indoor and outdoor occupancy, respectively, and default population densities for each environment.

c) Doses represent dose to individual assumed to be permanently outdoors in the environment giving the highest dose.

Table 2.2 gives normal living and maximum outdoor doses integrated to one week and to one year following the deposition, for the regions defined in Table 2.1. As expected, the outdoor doses are around ten times higher than the normal living doses. The outdoor doses corresponding to the region of highest deposition are around 2 mSv in the first year. At first sight, the doses given for the less highly contaminated region of Plymouth (‘Medium level Plymouth’) are a little surprising when compared with those for the ‘Rural area’ and Torpoint. It can be seen that, although these last two regions have lower deposition, the doses calculated are equal to or higher than those for ‘Medium level Plymouth’. This reflects the fact that they are less densely built up (which means there are fewer buildings to shield outdoor doses) and it has been assumed that some of the housing in these regions is of a more lightweight construction than the buildings in Plymouth[9].

2.3.3 Weapons’ accident

The weapons’ accident pre-defined scenario is based on two damaged (un-armed) nuclear warheads releasing part of their radioactive contents into the atmosphere. The assumed location of the accident is just to the east of Weston-super-Mare, in North Somerset. In terms of the potential doses to exposed people, the most significant radionuclide to be released in such an accident is plutonium-239. Figure 2.3 shows the assumed pattern of deposition of plutonium-239. It can be seen that the highest deposition occurs in a thin strip travelling west, just reaching the area of Weston called St Georges. The wider deposition ‘plume’ covers the northern part of Weston, including Worle and Kewstoke. Plutonium-239 also contaminates two major communication highways: the M5 (identified as a blue line travelling north-south) and the main south west railway line, linking Bristol and Exeter.

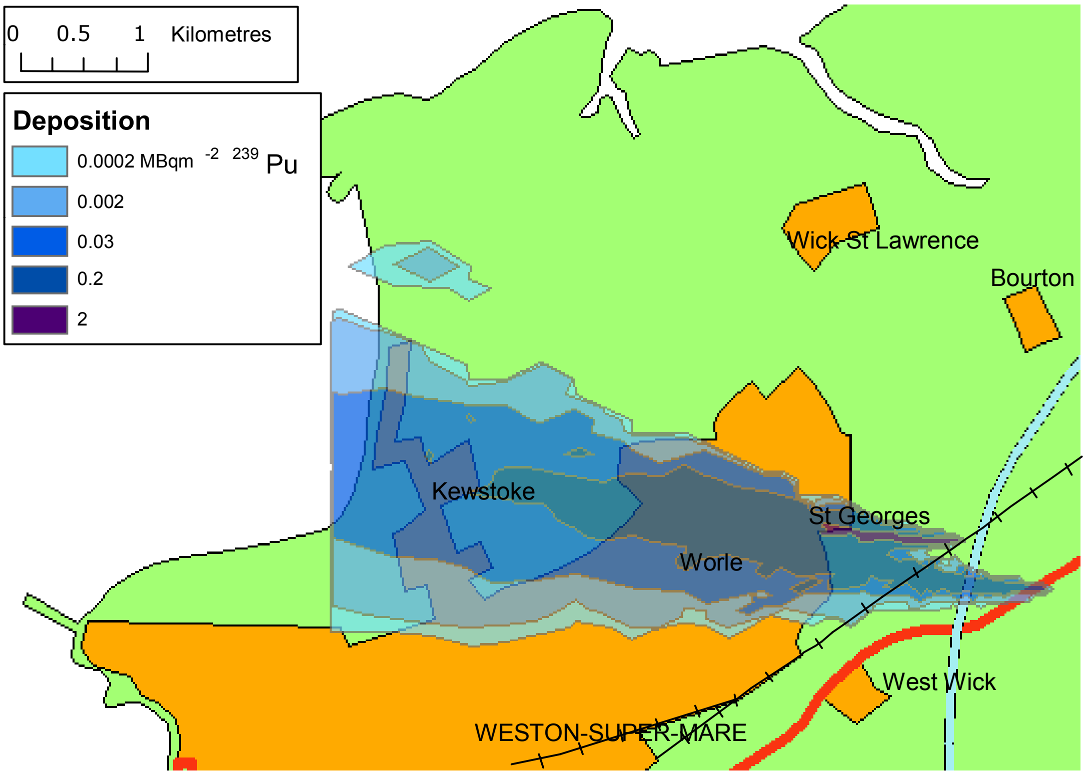


Figure 2.3 Deposition contours for the weapons’ accident scenario

[9] As noted earlier, the assumption of the presence of buildings of lightweight construction may not reflect the construction of the actual buildings in these areas. This assumption has been made partly to illustrate the effect on doses of including this type of housing.

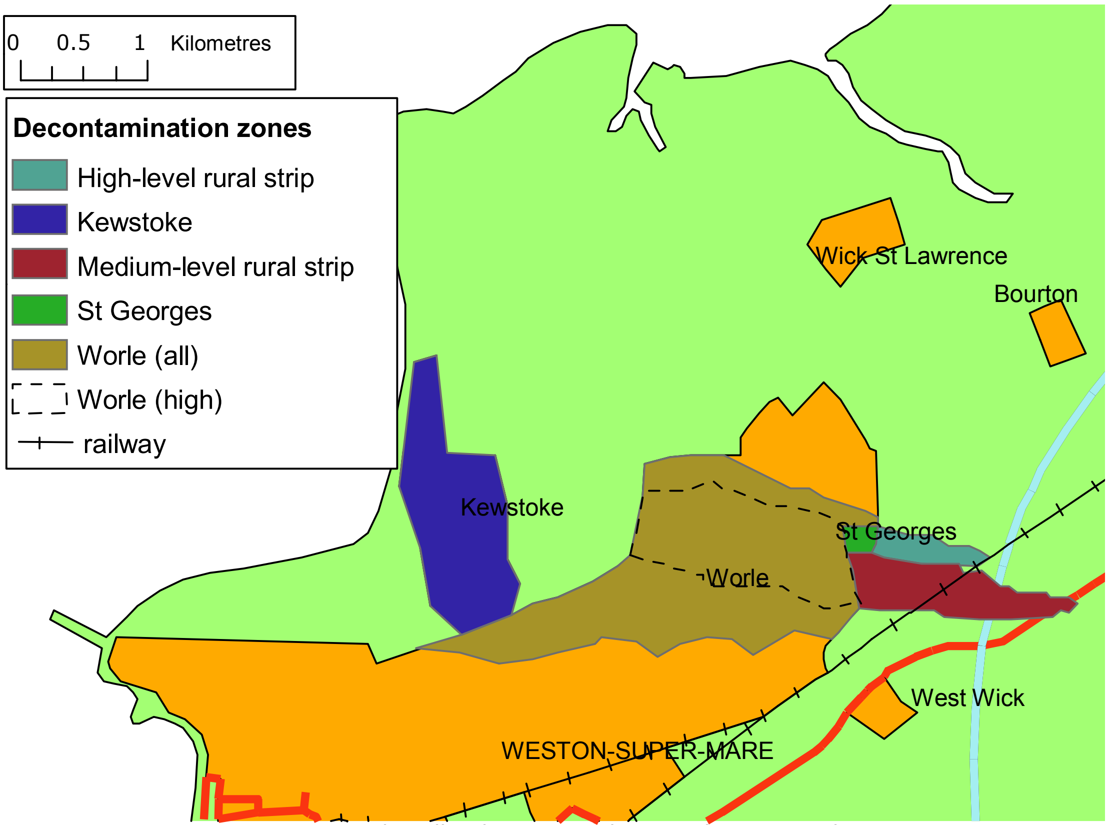


Figure 2.4 Subdivision of the weapons' accident deposition contours into CONDO regions

Figure 2.4 illustrates how the contamination pattern has been sub-divided into regions, within CONDO. Five adjacent, but independent regions have been identified, defined according to their contamination levels and whether the area is mainly urban or largely farmland. In addition, a sixth region, 'Worle (high)', has been defined, which is wholly contained within the larger 'Worle (all)' region. This demonstrates the use of the 'scenario' grouping system to hold overlapping regions, so that 'what if?' questions can be more thoroughly explored (as discussed in Section 2.3.1).

Table 2.3 Regions and doses in the absence of countermeasures for the weapons' accident scenario

Region	Deposited activity, ^{239}Pu (Bq m^{-2})	Environments	Area (km^2)	Total effective dose (mSv)[a] Normal living[b]	Outdoor[c]
St Georges	2 000 000	100% brick	0.05	First week: 0.8 First year: 4	First week: 7 First year: 20
High-level rural strip	3 000 000	20% brick 10% lightweight 70% open green	0.15	First week: 1 First year: 6	First week: 10 First year: 20
Medium-level rural strip	300 000	20% brick 10% lightweight 70% open green	0.5	First week: 0.1 First year: 0.6	First week: 1 First year: 2
Worle (all)	200 000	80% brick 20% open green	2.7	First week: 0.08 First year: 0.4	First week: 0.7 First year: 2
Worle (high)	500 000	80% brick 20% open green	1.0	First week: 0.2 First year: 1	First week: 2 First year: 4
Kewstoke	30 000	60% brick 20% lightweight 20% open green	1.1	First week: 0.01 First year: 0.06	First week: 0.1 First year: 0.2

Notes:
a) Doses given to 1 significant figure, to emphasise the uncertainties inherent in such generic calculations.
b) Doses calculated assuming 90% and 10% indoor and outdoor occupancy, respectively, and default population densities for each environment.
c) Doses represent dose to individual assumed to be permanently outdoors in the environment giving the highest dose.

Table 2.3 gives the definitions of these regions and the resultant doses, assuming no countermeasures are taken. In this scenario, it can be seen that outdoor doses of around 20 mSv are predicted for the first year following the accident, if no remedial measures are undertaken. However, unlike the doses estimated for the submarine accident scenario, very little influence of the environments composing each region can be seen on the resultant doses. This is because the dominant exposure pathway for plutonium-239 (between external irradiation and the inhalation of resuspended radionuclides) is resuspension. Resuspension is a complex process to model in detail, and, at the present time, there are insufficient data to support a detailed model. The model adopted for resuspension in CONDO v3.0 is that recommended by Walsh [2002]. This makes best use of the UK specific data that are available, but is unable to distinguish between resuspension from different surfaces or within different environments, except for indoor and outdoor locations. Consequently, no differences in outdoor dose, except those related directly to deposition level, are discernable between regions in Table 2.3.

2.3.4 Civil reactor accident scenario

The third pre-defined scenario provided with CONDO v3.0 is based on a postulated reactor accident occurring at the Oldbury civil nuclear power station. As with the submarine reactor accident, if a release to atmosphere were to occur, it is likely that a wide mix of radionuclides would be present. However, for the purposes of the pre-defined scenario, the assumed deposition is limited to iodine-131, caesium-137, caesium-134 and ruthenium-106. These radionuclides are assumed to have been deposited everywhere in the same activity ratios, although these ratios are assumed to be slightly different from those assumed for the submarine reactor accident. For the civil reactor accident, caesium-137, caesium-134 and ruthenium-106 are assumed to have been deposited in equal activity amounts, whilst the activity of iodine-131 deposited is assumed to have been ten times this amount. The deposition pattern for iodine-131 is shown in Figure 2.5. It can be seen that the size of release assumed is much smaller than for the submarine reactor accident. This reflects the desire to explore practical issues concerned with recovery following a very small release, rather than a belief that a civil reactor accident would necessarily be expected to result in a smaller release than a submarine reactor accident.

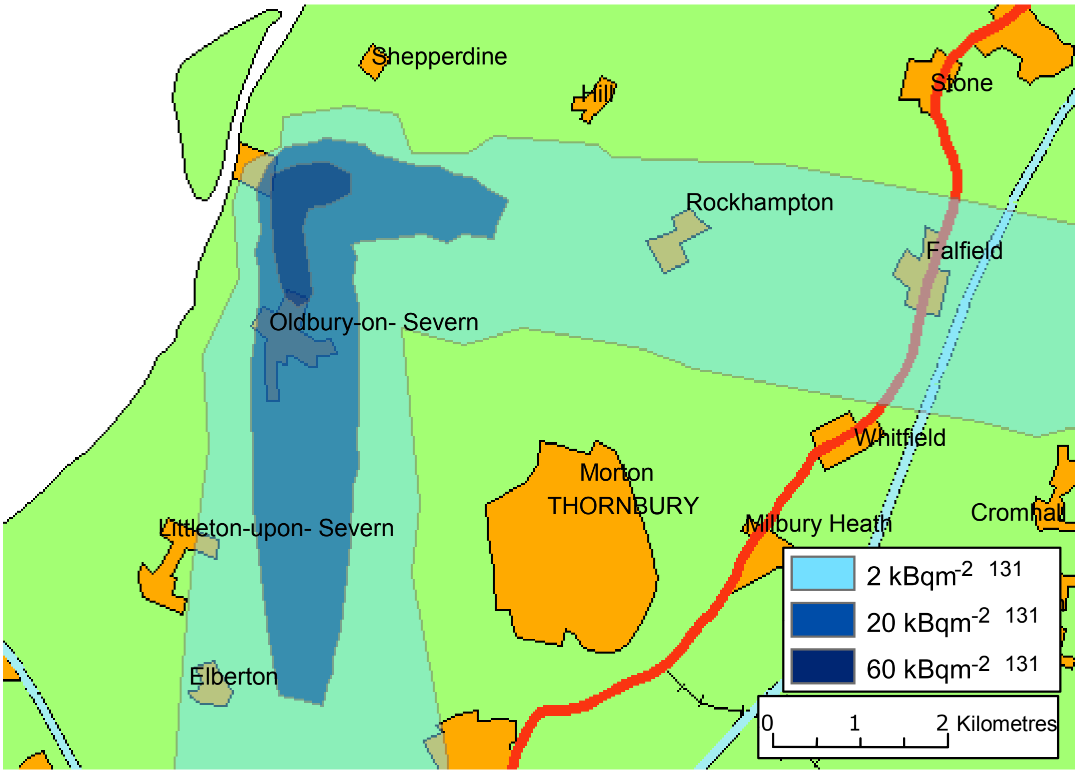


Figure 2.5 Deposition contours for the civil reactor accident scenario

Figure 2.6 shows how the assumed pattern of contamination has been sub-divided into regions within CONDO. It is debatable whether the 'high level rural homes' region would normally be specified as a single area, encompassing much farmland as well as the few scattered houses (especially given the limitations associated with assigning CONDO environments to farmland (see discussion under Section 2.3.1), or whether it would be defined as a single region comprising a set of small discrete parcels of land surrounding each of the houses identified. However, to have sub-divided it in this way would have been to make the regions too closely related to this specific scenario and location, and therefore more difficult to apply and edit for more general use.

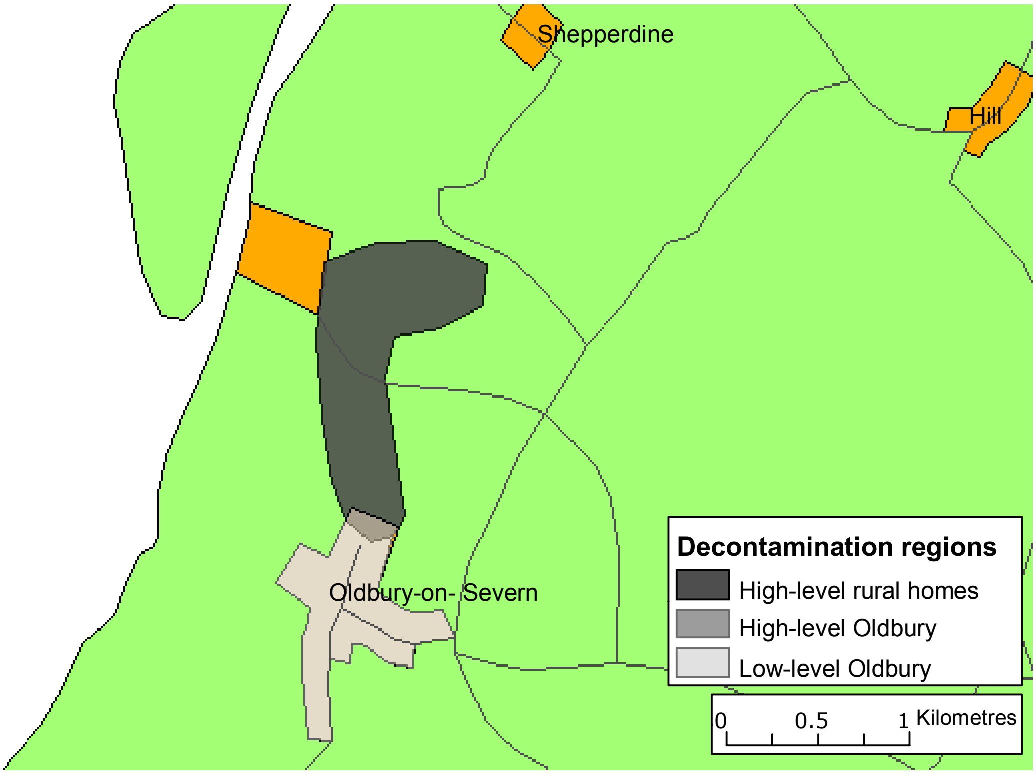


Figure 2.6 Subdivision of the civil reactor accident deposition contours into CONDO regions

Tables 2.4 and 2.5 define these regions and list the associated doses (calculated as discussed in Section 2.3.1). It can be seen that even the highest estimated doses are less than one millisievert over the first year. As with the submarine accident scenario, the shielding effect of brick housing in reducing normal living doses relative to those that would be received in more open areas is apparent.

Table 2.4 Regions defined for the civil reactor accident scenario

Region	Deposited activity (Bq m^{-2}) ^{131}I	^{137}Cs	^{134}Cs	^{106}Ru	Environments	Area (km^2)
High-level rural homes	70 000	7000	7000	7000	90% open green area 10% brick	0.7
High-level Oldbury	60 000	6000	6000	6000	10% open green area 90% brick	0.025
Low-level Oldbury	20 000	2000	2000	2000	10% open green area 90% brick	0.4

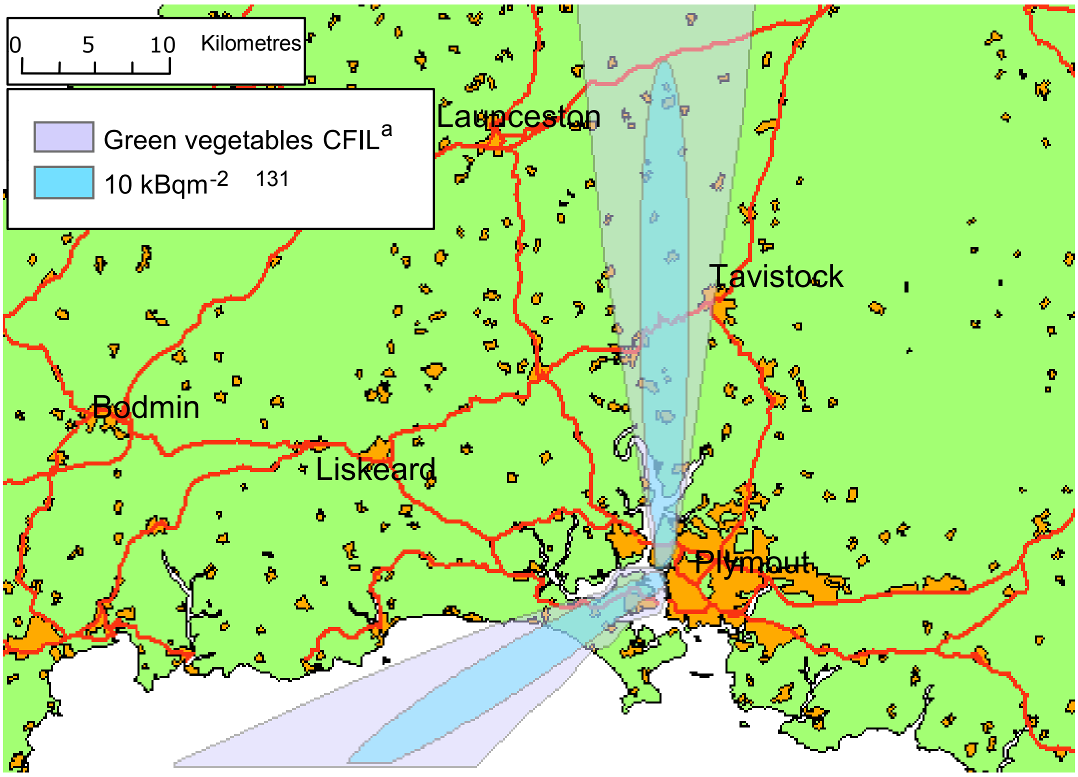
Table 2.5 Doses in the absence of countermeasures for the civil reactor accident scenario

Region	Deposited activity (Bq m^{-2}) ^{131}I	Total effective dose (mSv)[a] Normal living[b]	Outdoor[c]
High-level rural homes	70 000	First week: 0.004 First year: 0.06	First week: 0.03 First year: 0.5
High-level Oldbury	60 000	First week: 0.003 First year: 0.03	First week: 0.02 First year: 0.5
Low-level Oldbury	20 000	First week: 0.001 First year: 0.01	First week: 0.007 First year: 0.2

Notes:
a) Doses given to 1 significant figure, to emphasise the uncertainties inherent in such generic calcluations.
b) Doses calculated assuming 90% and 10% indoor and outdoor occupancy, respectively, and default population densities for each environment.
c) Doses represent dose to individual assumed to be permanently outdoors in the environment giving the highest dose.

2.3.5 Interaction between decontamination measures and food restrictions

Decisions on the best decontamination strategy to be implemented will not only have to take account of physical and practical constraints, but also of public concerns and priorities. These social issues will be, in part, influenced by other actions taken in the longer term with respect to the accident. One such influencing factor is likely to be the imposition of food restrictions. Regulations laid down by the Council of the European Communities [CEC, 1987] require food to be withdrawn from the market if, following a future accident, it contains activity concentrations of radionuclides in excess of stipulated levels (hereafter termed ‘CFILs’ – Council Food Intervention Levels). For most postulated accidents, it is likely that the areas of food restrictions required by the CEC Regulations would be very much larger than the areas in which decontamination measures are likely to be carried out. This is illustrated in Figure 2.7, where the lowest contour for deposition of iodine-131 shown in Figure 2.1 is compared with the likely area of food restrictions. Dealing with public anxieties and perceptions in the context of such a large food restriction area would form an important part of the recovery strategy for such an accident. This is discussed further in Section 3.7.2.



a) CFIL - activity concentration limit as laid down by the Council of the European Communities

Figure 2.7 Comparison of the area of food restrictions with the deposition contours shown in Figure 2.1

3 TASK 2: PRACTICAL ISSUES

Any recovery strategy employed in the longer term to return the environment and people's lives back to 'normality' may be implemented over a number of years. The potential costs of implementing a strategy that is not optimal during this 'recovery' phase are therefore very large. Identification of the optimum strategy will not, however, be straightforward, and it cannot be achieved by considering radiation protection issues alone. The strategy adopted will require acceptance by the affected community and so social issues must be taken into account.

As discussed in Chapter 2, CONDO contains a database of scientific and technical information that can be used to explore the impact of carrying out decontamination and other recovery options in an inhabited area. This impact is presented in terms of the reductions in dose that could be expected, the cost of implementation of the option, the resources required, and, the quantities of waste material produced, its type and its activity concentrations. This information provides a very important input to any decisions on a recovery strategy in an area. However, there are also many other local factors that would need to be taken into account in developing a recovery strategy that would be acceptable to all the stakeholders involved.
It is recognised that these local factors may be very area specific and may be influenced by the public's acceptance of nuclear sites in their area. Also the reaction of people to an accident and the impact on the community and environment can probably not be ascertained fully in advance of an accident occurring. It is important, however, that as a scientific community, we try to understand what the local issues are likely to be, drawing on experience from other non-radiological disasters and incidents and from nuclear emergency exercises carried out in the UK.

Local Authorities (LAs) have a key role in the developing and implementation of a recovery strategy and will be responsible for the management of the process by which the affected area is returned to a state such that people can live normally. In many circumstances they will chair the Recovery Working Group (RWG)[10], which, according to the advice of NEPLG [2001], has the remit to:

- characterise the extent and nature of off-site contamination;
- identify options for clean-up and disposal of wastes;
- propose options for consideration;
- prepare plans for their implementation;
- advise on post-recovery monitoring.

The RWG is a multi-agency group that would comprise representatives of both local and central Government bodies[11]. Local organisations represented would probably include County, District and Unitary Councils, the police force and fire brigade, and water and health authorities. As a starting point in the process of identifying local issues and experience it was considered pertinent, therefore, to hold a series of discussions with Emergency Planning Officers (EPOs) from LAs that have been involved in considering nuclear issues.

[10] Generally, it is expected that LAs will chair the RWG if they have experience in planning the response for a nuclear accident or radiological emergency (ie their area includes a nuclear site). For transport accidents, occurring away from nuclear installations, it is possible that the LA would ask EA to chair the RWG. Either way, the LA will have a significant and key role within the RWG.
[11] Government bodies would include, but not be limited to: DEFRA, EA, FSA, NRPB and, for an accident involving submarines or weapons, MoD. The operator would also provide expertise to this group.

It was felt important to capture the views of EPOs who have different types of nuclear site in the area they are responsible for and who have been involved in emergency planning for different types of accidental release. To focus discussions on the different types of nuclear accident that could be foreseen in the UK, postulated accident scenarios were used. These were the three scenarios provided with CONDO v3.0, as presented and discussed in Section 2.3.

In addition, the views of people that have been involved in recovery following recent incidents involving radioactivity in the UK have been elicited and included in the discussion below. These are the crash of a Korean Air Cargo jet carrying depleted uranium in 1999 and the clean-up of contaminated pigeon droppings in a private garden near the BNFL Sellafield site [Lee, 2001; Emptage, 2001; Parker, 2002].

A number of topics were addressed during the discussions. The following sections present the issues identified and points raised by the EPOs, grouped into common themes. Section 3.1 highlights aspects of the contamination scenarios that were of particular importance for these discussions. It should be noted however, that the discussions were not constrained by these scenarios and generally covered more wide-ranging issues, depending on the concerns and experience of the EPOs involved.

3.1 Contamination Scenarios

The submarine reactor accident scenario (see Section 2.3.2) would have resulted in external outdoor doses in the first year following the accident (excluding the emergency phase) of around a few millisieverts in the most contaminated areas (see Figure 2.1 and Table 2.2). These doses are of the same order as, but a little higher than, annual doses from natural background (outside of high radon areas).

The weapons' transport accident scenario (see Section 2.3.3) provided a much less dispersed contamination pattern, with outdoor doses ranging from extremely small, in the outer area of the contamination, to doses possibly in excess of the annual dose limit for workers, in the most highly contaminated area (see Figure 2.3 and Table 2.3). The highest doses are still small compared with those that would result in deterministic injuries. However, they are high enough to justify the expenditure of significant resource on recovery measures, according to advice provided by NRPB [1997].

Even the highest doses resulting from the civil nuclear reactor accident scenario (see Section 2.3.4) would be less than the dose received on average in the UK from annual natural background (see Figure 2.5 and Table 2.5). This scenario provided an opportunity to explore the likely impact of social responses on decision making in the absence of a significant health hazard.

3.2 Priorities and Criteria for Recovery

LAs have a legal responsibility ('duty of care') to ensure the social, economic and health well being of the local community. The highest priority is the health of the population. However, people's well being would also be affected by lack of access to their jobs, food etc and so the LA also needs to try to return the economy in the area to normal as soon as possible. The protection of the environment is also important and any clean-up would have to provide a balance between available resources, health risks and the 'cleanliness' of the environment.

However, it was generally accepted that, in practice, clean-up of non-residential areas would have to receive a lower priority and restricted access measures might be put in place as an interim.

In general, the EPOs expected that residential areas and/or sensitive sites such as schools and hospitals would receive priority. However, how this prioritisation would be realised would be influenced by the measures implemented in the emergency phase and the extent and scale of the resulting contamination. For example, if schools were closed in the emergency phase of an accident, delaying clean-up would not lead to an increase in possible health consequences. Future acceptance of parents to send their children back to a school in a highly contaminated area, even if extensive clean-up had taken place, would also be a consideration in determining priorities.

Gaining public acceptance was seen as the dominant criteria in making decisions on a recovery strategy. The general view was that having decided on a strategy, it would be important that the LA didn't deviate from it, thus maintaining credibility, and that the LA would have to accept that not everyone would agree with the decision. The view was also expressed that recovery should be based on scientific criteria and that, as long as the advice came from organisations seen as independent of the Government and the operator, these would generally be accepted by the public. So, decisions on the recovery strategy to be adopted would need to strike a balance between the strategy justified on scientific grounds and the measures required to provide public reassurance.

In the 'Sellafield pigeon' incident, only a small area of land required clean-up. The operators took great care to undertake restoration of the property involved in accordance with the occupant's wishes [Emptage, 2001; Parker, 2002]. For example, some clumps of treasured plants were left in-situ and excavation carried out around them. As far as possible the land was returned to the same state as before the contamination event.

3.3 Responsibilities

It was recognised that the Chief Executive of the LA would take the lead role in managing the recovery phase but that a lot of support from outside the LA would be needed. The view was also expressed that a key role of the LA was to interpret the needs of all parties in the local community and to act as a liaison between national organisations, central and local Government and the community whilst maintaining a community lead.

All the EPO's spoken to expressed the opinion that they would be expecting the polluter to pay for recovery with possible additional support from Central Government. Very early on in the development of a strategy, they felt that provisional costs should be estimated and the payee identified. The LA was seen as being responsible for billing the payee for the recovery operation. As an example, the involvement of MoD claims' officers at an early stage in the response, during an emergency exercise at Plymouth, was seen as being essential in providing the necessary immediate authorisation of finances so that positive decision-taking could proceed.

The EPOs felt that the distinction between responsibility and liability was not very clear, with some having the view that those supplying the money for recovery, possibly Central Government and/or the operator responsible, would wish to exercise control over the recovery.

In the case of the 'Sellafield pigeons' clean-up, the operator took responsibility and managed the recovery process. Clean-up following the crash of a Korean Air Cargo jet carrying depleted uranium in 1999 was co-ordinated by Essex County Council. The then DERA Radiological Protection Service (DRPS), which was part of MoD, conducted extensive surveys of the area surrounding the crash.

3.4 Strategies for Recovery

Dividing the affected area into areas of different land use was seen as key to developing a recovery strategy. The types of areas that would be considered include: residential, industrial, schools, hospitals and other sensitive public buildings, and, parks and recreational spaces. It is also important to know how much a particular area is used, where sensitive groups are situated and where community facilities are, as well as knowing population densities in residential areas. The division of an affected area into postcode areas was also viewed as a good way to manage a recovery strategy and a meaningful way to communicate a strategy to the local community. GIS systems, which provide detailed local level information, could also be used to help develop a recovery strategy, taking detailed land use into account. All the EPO's supported the structure proposed for a UK recovery handbook [Brown and Nisbet, 2002], which uses land use as a starting point for developing a recovery strategy.

Although the EPO's accepted that the LA has a responsibility to take a lead in the recovery process, as discussed above, they recognise that they do not have the information needed to develop a recovery strategy for radioactive contamination. They therefore strongly welcomed the intent to provide technical information in a structured manner as an aid to the development of a strategy within the proposed UK recovery handbook.

For the two reactor accident scenarios discussed, the predicted first year outdoor doses were significantly lower than the levels of dose at which disruptive clean-up would be advised in order to reduce radiation doses [NRPB, 1997]. These stimulated discussion concerning whether it would be acceptable to have a strategy that involved undertaking no clean-up, but to rely on public information to address public concerns.

3.4.1 Public expectations

The 'Sellafield pigeon' experience showed that there was a wide range of expectations by the public in terms of the level of remediation expected, ranging from complete decontamination to no concern at all. The discussions on this with the public were aided by the statement by EA that the levels of radioactivity beyond the sanctuary did not warrant intervention. It was difficult, however, to defend a situation that intervention is only required on one side of a garden fence. Careful consideration of the local area and habits of the population was also required (Emptage, 2001). For example, it became apparent that grass cuttings from the contaminated area were being composted and used on a vegetable patch outside the contaminated area.

BNFL was very attentive to requests for monitoring of properties and the provision of the data to all those affected. BNFL also carried out some removal and replacement of turf on adjacent property as a goodwill gesture. It is fair to say that the expectations were lower due to a reasonable level of understanding by the residents affected, many of whom were employed by BNFL.

3.4.2 Early communication of the recovery strategy

The LA needs to be seen to be doing something quickly to address the contamination in an area, particularly in areas where people live. It is important that an outline remediation strategy is available on a short timescale; one EPO suggested that they would want to do this within the first week and preferably within 2 days. The following ideas were put forward.

- Although they recognized that a strategy communicated early on would not be detailed, the EPOs believed that it would be better to be honest, ie to say that the information was not available to develop the strategy fully and that people would be kept informed of further developments, than to say nothing.

- The EPOs thought that a two phase strategy might be appropriate. Immediate clean-up would be carried out where most required and/or where most straightforward to undertake, followed by a longer term phase involving consultation with stakeholders and detailed weighing of the pros and cons of different strategies. This graduated approach might lead to greater public reassurance than a single rushed phase, which might require additional re-cleaning in the future (see also Section 3.4.6).

- The EPOs felt it would be unacceptable not to put forward a recovery strategy in the short term and then to suggest clean-up later.

- The EPOs considered that any statements on a recovery strategy should be linked to the emergency countermeasures that were in place. For example, people could be informed that protective measures were in place in some areas whilst, in other areas, people could live as normal but that further advice might be issued later.

3.4.3 'Do Nothing' option

The 'do nothing' option was viewed as a real option by some of the EPO's consulted, provided the decision could be backed up by scientific argument and could be maintained into the future (ie any future pressure to undertake decontamination could be withstood). Their view was that, if there is negligible risk to the population, doing nothing is preferable to undertaking decontamination and contributes to the provision of a consistent message to the public. The main advantages of the 'do nothing' option given by the EPOs are listed below.

- Doing nothing probably causes less worry for the public than doing something. Carrying out any kind of clean-up may lead to the perception that there is a problem even if there isn't.

- Even simple reassurance options, such as fire hosing roads, could lead to problems if people question why only certain areas are being cleaned. This again could have the opposite effect of reassurance and lead to public pressure to clean everything everywhere.

- Even if an area receives substantial clean-up, the public may be reluctant to go back and the LA would have to provide a lot of reassurance and monitoring to persuade people it was safe. This is an unnecessary step if there was no scientific need to clean-up in the first place.

However, not all EPOs spoken to held this optimistic view of the ‘do nothing’ option. The opposite view was also expressed, that the ‘do nothing’ option would never be acceptable to the public. It was felt that clean-up, even if contamination levels were low, would provide public reassurance and give the message that the LA cared about the community.

It was also noted that the LA may be forced to adopt a strategy of ‘doing nothing’ in some areas due to lack of resources. In this case, care would be needed in the presentation of this information to the public. A possible alternative to ‘doing nothing’ in these circumstances would be to try to reduce the level of resources required elsewhere by asking the public to help themselves, eg by washing their cars.

3.4.4 Restricted access

Restricting access to an area was seen as being acceptable to the public. This was done extensively in rural areas during the Foot and Mouth outbreak in 2001. One advantage of this form of countermeasure is that it can be implemented relatively quickly. For example, following the Foot and Mouth outbreak, about 500 miles of public rights of way in West Berkshire were marked with signs within a few days. However, if the intent is to exclude people from an area, rather than simply to advise them to keep out, then physical barriers would be required as well as signs. This would clearly require more resources and more time to implement than the provision of signs alone.

In the event of a major contamination event, the most highly contaminated areas would be expected to be evacuated during the emergency phase. In the example of the weapons’ accident scenario, the EPOs felt that the area immediately surrounding the damaged weapons would remain restricted for a prolonged period and that the level of contamination in that area would result in most buildings being demolished. One EPO felt that, even in the short term, in addition to fencing off this area, it would need to be made aesthetically pleasing (eg using trees) in order to present some reassurance to the local population. He felt that, in the longer term, the local population might be willing for a contaminated area to remain restricted to public access, provided all direct evidence of the ‘hazard’ had been removed (ie the visual impact of the site was pleasing).

3.4.5 Partial clean-up

Partial clean-up of an area is a potential issue in developing a recovery strategy. In terms of cost/dose effectiveness, a strategy might reasonably be developed in which large open areas (eg playing fields) were decontaminated, but small enclosed areas (eg private gardens) were not. In general, it was felt that such a strategy would not find acceptance with the public because the local population would relate their health risk to the existence of contamination, rather than their resulting level of exposure from it. For example, the EPOs felt that decontaminating public roads and pavements in residential areas but on not private property was likely to lead to anxiety and hence pressure to clean-up the whole area. Similarly, if invasive techniques (eg ploughing) were used in open areas such as parks and playing fields, then there would be pressure for similar techniques to be carried out in people’s gardens. The use of apparently less invasive techniques in private gardens would raise concerns about the effectiveness of the techniques used. However, it is unlikely that techniques appropriate for large open spaces would be suitable for use in gardens. Even if public spaces were just closed until they could be monitored, the EPOs felt this would probably lead to the expectation that all gardens should also be monitored.

3.4.6 Prioritisation

For the two scenarios where the first year outdoor doses were estimated to be a few mSv or more, close to the site of the accident, (the weapons' and submarine accidents) prioritisation of the clean-up strategy was discussed.

It was felt that if a large inhabited area were contaminated, it might be sensible to address areas with relatively low contamination first. It might be possible to undertake reassurance monitoring and/or simple decontamination in such areas fairly quickly and so avoid the need to relocate the people living there. This would leave a much smaller (ie more manageable) number of people requiring extended accommodation outside the area, and so would make it easier for the LA to investigate all options in detail before deciding on the recovery strategy to be adopted for the more highly contaminated areas. This approach might also enable experience to be gained in some decontamination / clean-up techniques before they were implemented in highly contaminated areas. Furthermore, there might be psychological benefits gained from moving people back, quickly, into a previously contaminated area as it sends out the message that is safe to live there.

3.4.7 Specific decontamination options

The options of grass cutting, tie-down of material to surfaces and fire hosing were discussed in more detail.

Grass cutting

For gardens, cutting grass on its own may not be a viable option. People would question whether plants, shrubs and trees would also be contaminated and so there would be pressure to remove all vegetation. The view was that either all vegetation or no vegetation would have to be removed. People might also expect that all the turf is removed and not just the grass. The EPO said that the population would need to feel safe about letting their children play in the gardens before they would accept that the recovery measures taken were adequate.

Although LAs are likely to have a good supply of grass cutting equipment that could be used, very few have the capability for grass cuttings to be collected. This, therefore, restricts the practicability of this option, as grass cuttings need to be removed if the technique is to be effective in reducing doses.

Tie-down

If tie-down of activity to surfaces is used as a means to reduce doses from resuspension and to prevent spread of contamination (particularly useful for actinide contamination, eg plutonium), then public perception will probably only allow this to be used as a temporary measure. In the longer term, there will be pressure for full removal of the contamination, together with the tie-down material. This needs to be addressed in developing the overall strategy, as the presence of tie-down materials can greatly increase the amount of waste material produced.

Firehosing

The LA would be looking to the Fire Brigade to carry out fire hosing, if required. It is recognised that this would be resource intensive and that the Fire Brigade would also need to maintain their normal service, thus restricting the amount of equipment available. For example, Brown and Jones [2000] suggest that teams of 2-3 people can fire hose about

8000 m^2 of roads per 8 hour shift, equivalent to about 800m of roads, including any pavements.

3.4.8 Self evacuation

Self evacuation was seen as an issue by several of the EPO's. People are likely to self evacuate rather than shelter or wait for instructions to evacuate. Large-scale self-evacuation may occur from all areas, not just those affected by the plume. However, the EPOs felt that people who lived in areas that were subsequently declared 'clean' would start to return quite quickly.

3.5 Management of Recovery Implementation

For refuse, cleaning and maintenance services, the LAs either employ their own staff, contract the work out to specialist companies or do both. The general view was that there would be significant resistance by all staff to enter contaminated areas, although it may be possible to use this workforce if they were paid sufficiently highly. Most LAs have access to contractors who specialise in hazardous materials who may be prepared to help with clean-up and disposal issues. However, the consensus view was that the LAs would be looking for support from outside the local area, as any resources they had access to would be quickly utilised. For large areas, the EPOs expected they would ask Central Government and the operator to organize and undertake the clean-up and to provide the necessary resources.

In general, the LAs have verbal or written agreements with neighbouring Authorities to assist each other in the event of an emergency. In the context of the submarine accident scenario, the area of contamination crossed several administrative borders. The EPO of Plymouth County Council felt that co-operation was good between the neighbouring organisations and that each would work as part of a central team, whilst also directing operations within their own areas. In the context of the civil reactor accident scenario, the possibility of whether priorities for neighbouring LAs might differ was raised. For example, had the assumed accident been much larger (ie with a contamination footprint extending as far as Bristol), it could be envisaged that the rural area around the site might be a priority for the Authority responsible locally, whilst the LA responsible for Bristol might want to give priority to sensitive inhabited areas, schools, hospitals etc even if contamination levels were much lower than those around the site.

The view expressed by most of the EPOs was that, in general, it would not be possible to undertake any substantial clean-up in residential areas if people were still in their homes. Others thought that some non-invasive techniques that did not affect people's property, such as road sweeping, might be possible, but that communication with the public and the media would need to be very good if people were to accept this.

It was agreed that, in general, clean-up could not take place with people *in situ* if workers implementing the clean-up were required to wear protective clothing and/or personal protection equipment (PPE).

The following specific points were also raised.

- Leaving people in their homes would restrict the options that could be implemented.

- If people were left in the area, clean-up would need to be implemented quickly, thus requiring substantial resources in the short term. As a ‘rule of thumb’ one EPO thought that if clean-up couldn’t be implemented within 24 hours then people would want to be moved out of the area. Normally it would be desirable to monitor contamination levels both before and after clean-up in order to record the effectiveness achieved. However, if the aim were to implement clean-up measures quickly, then it might be better not to monitor in advance of carrying out the decontamination measures and so avoid any delay in their implementation.

- Experience has shown that the longer people are kept out of their homes the more unlikely they are ever to return, even if their homes are fully cleaned.

- For an accident resulting in widespread contamination, particularly if much of the contaminated area was inhabited, it was thought that fire hosing or vacuum sweeping of roads could not be done fast enough to enable people to stay in their homes. Therefore, the benefit of implementing these techniques, which should be done relatively quickly to maximize their effectiveness, might be limited for such situations.

- If the planned clean-up would be destructive to homes and gardens, it would be better to decontaminate the area having moved people out first, thus reducing disruption and anxiety.

- Experience with a chemical incident in Bristol showed that people were prepared to stay in houses neighbouring those requiring decontamination even though workers wore PPE. It is recognised however that public perception of the dangers of radiation may lead to a different response.

3.6 Monitoring

The LAs would want extensive monitoring of all areas to help to convince people it is safe to remain in the area and that life can return to normal. Monitoring needs to be carried out by organisations independent of the polluter and the Government to ensure public trust and acceptance of the recovery strategy. Most LAs have access to independent monitoring resources at Universities, scientific services and laboratories in the area.

The following views and issues were expressed.

- The process of monitoring in an area could be to give publicity to the LA’s recovery strategy. Having a media team following the monitoring teams around in areas of low contamination might help show the public that monitoring is taking place and that the results produced are accurate.

- Monitoring results would need to be presented in terms that the public could understand, for example, ‘the activity is lower now than measured last week’[12].

- Monitoring carried out while people remained in the area, including in their gardens etc, would lead to reassurance that the situation was ‘safe’[13].

- Monitoring carried out by workers wearing PPE might cause concern. Careful communication of the situation would be needed. This view is supported by those involved in the ‘Sellafield pigeon’ incident, who suggest that careful consideration should be given to the use of PPE and that protective items should only be used if and where absolutely necessary [Emptage, 2001].

- Monitoring would be needed to demonstrate that any clean-up had been effective. Even if levels were not believed to be of concern, restrictions on sensitive buildings, such as schools, would not be lifted until monitoring had taken place. Similarly, monitoring would be required before the lifting of automatic restrictions on water extractions, for example.

- The provision of personal monitoring for reassurance would be very critical. Many people would want this even if they were not in the area directly affected. The EPOs saw this as an important means of telling people that they were not at risk. A facility for carrying out personal monitoring would need to be set up independently of the operator.

- Some EPOs expressed the view that the LA would need to monitor the affected area over a protracted timescale in order to demonstrate that environmental contamination was as expected. Although the LA would be responsible for carrying out this programme, it would require funding to be provided.

- In contrast to the above point, other EPOs felt that extensive monitoring in the long term might cause public concern, particularly in areas where contamination levels were relatively low. For example, they felt that views such as ‘Is something expected to happen that will worsen the situation?’ or ‘Why can I live here if there is still a problem?’ might be expressed. Their view was that it would be appropriate to monitor for a few weeks but not over a prolonged period. If contamination levels were low, no remediation had been carried out and the public had been told that there was no risk, then the area should be left alone and no further monitoring done.

- Any monitoring strategy would need to be made public as part of the overall recovery strategy.

The monitoring resource required was significant for the ‘Sellafield pigeon’ incident but was easily available from the large resource at Sellafield. Specialist contractors were also used to assist in the extensive environmental sampling to avoid disruption to the statutory monitoring programme. Analytical resources had to be re-deployed which raised the interesting point of needing to ensure that the workers handling the samples had classified worker status [Parker, 2002].

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[12] In the opinion of the authors, this approach might be a useful supplementary method of presentation, but should not be used as a substitute for providing the actual measurements.

[13] This should not, however, be used as an argument to avoid moving people out of an area where the hazard posed by the contamination is high.

3.7 Communication with the Public and Other Stakeholders

Public information was viewed by the LAs as being critical in dealing with any accident and in the acceptance of any nuclear site in an area. The main issue for the EPOs was how to elicit and gain acceptability of the recovery plan by the public. However, they were unclear how to tackle it. They identified two aspects of the problem: determining the information that is relevant for the public and identifying sources for that information.

According to the EPOs, a very important aspect of communicating with the public is that a consistent message should be given to them. Clear and honest information would be essential for maintaining trust and credibility. It would not be acceptable to avoid telling the public what is happening. The LA would therefore need to have a key role in ensuring communication happened in order to maintain the trust of the public. It would need to 'sell' its message proactively to the public and the media, otherwise others would appear to gain control of the situation and the 'ear' of the media. Some of the EPO's felt strongly that there should be one authoritative voice, giving independent advice and information directly to the public. The public's trust of the organisations giving advice is essential. LAs would be looking for advice from independent organisations and specialists. It was felt that people would accept scientific advice on clean-up etc if it came from a recognised independent source eg NRPB. However, the EPOs felt that advice from MoD or other bodies that are perceived as being linked to the government would not be taken up so readily[14].

EPOs with responsibility for licensed nuclear sites generally felt that the population living immediately around the sites would be easier to deal with than those living further away. Local populations already have regular dealings with the LA and the site operator, through local liaison groups, community activities of the operator, direct employment by the site etc. Furthermore, under REPPIR[15], the LAs issue leaflets to those in the detailed emergency planning zone describing the emergency plans. This general acceptance by local populations is thought to be strongest in rural areas, where people have a commitment to staying in the area. The EPOs felt that people with reduced ties to a particular area, and those further away from the site, tend to have different expectations of the site and also tend to be more concerned about the hazard it poses.

The EPOs thought that education of the public in the event of an accident would be very important. They felt that the public should receive early information concerning the practicalities of options for clean-up. This would include information on the differences between a complete return to pre-accident conditions and the achievement of a 'safe' environment in which some contamination by radioactivity was still measurable. If this were not provided at the beginning of the recovery phase, the EPOs felt that public expectations would be unrealistically elevated and that, consequently, any recovery strategy that did not achieve 'total' clean-up would prove unacceptable. Education about exposure to natural background radiation might also aid the acceptance of residual contamination in the environment.

[14] This has implications for the roles of EA and FSA following an accident – and particularly for EA, since, under current arrangements for the RWG, the EA is envisaged as taking a significant role in the development of any recovery strategy. This is discussed further in Chapter 4.
[15] Radiation (Emergency Preparedness and Public Information) Regulations [HSE, 2001].

The EPOs felt that the public would need early information on the extent of clean-up that was likely. This would help them prepare themselves for what followed. Mechanisms suggested for engaging the public included:

- REPPIR leaflets
- the provision of early information about the accident, eg using television and radio
- newspapers
- LA web sites
- LA information lines
- a public emergency help line, staffed with volunteers from LA staff and also public health workers
- the existing Local Liaison Committees
- public meetings
- direct links to parishes, to facilitate consultation over local issues
- information leaflets – circulated via libraries and mail-drops.

The EPOs also discussed the possibility of more ambitious communication mechanisms. One such possibility is a password protected Inter-Agency web site, where emergency services, health services, EA, LAs etc can input information. In the event of an emergency, this would help the LA media team digest all the relevant information and provide consistent advice via press statements. This facility could be extended to include public access to specific areas of the web-site, or specific categories of information.

A second idea discussed was the option of having an independent reporter in the help-line room (with restrictions) so that they could hear the major concerns of the public and the most commonly asked questions. This might enable frequently asked questions to be discussed on the radio, allowing answers to be passed to more people and freeing up phones for other enquiries.

3.7.1 Presentation of quantitative information to the public

The way in which graphical information was presented to the various stakeholders, particularly the public, would be very important. Maps would be very useful for providing the LA and others who would be responsible for the management of the accident with detailed information. However, the general view of the EPOs was that significant care would be needed when using maps to present information to the public. The concerns they raised are summarised in the following bullet points.

- Representation of an affected area on a map without careful communication with the public might lead to more panic and self-evacuation.

- If contours were presented on a map (especially deposition levels), this would be understood to indicate areas of concern, regardless of the actual hazard. For example, some action might be expected by the public inside the whole area encapsulated by the outermost contour. This would be independent of what the contours were expressing, eg ground deposition or doses.

- If presented in isolation, numbers on a map would be essentially meaningless to most people and so would need to be related to something they understood. In particular, presenting maps of deposition without careful interpretation would be likely to be confusing as the numerical values of deposition would be high compared to the resulting doses. It might be helpful to relate doses to those received from every day experiences e.g. ‘you need to fly on a plane 3 times before you get the same dose’. Putting the accident into context with known accidents (Chernobyl) could also be used especially if the accident were significantly less severe than this.

- Some EPOs thought that it might be better to avoid using numbers on maps. For example, areas could be delineated according to where emergency actions had been taken. This would not only link the need for recovery measures to the hazard identified in the emergency phase, but already put in people’s minds the idea that further measures would only be required in limited areas.

- In contrast to the above, the view was also expressed that people would be entitled to be informed where the contamination was and of its health significance. They felt it would be up to the LA and others to convince people that there was not a problem in areas of low contamination. Restricting access to detailed information, or releasing partial maps which did not show the full extent of the plume, could lead to a breakdown in public confidence in the LA as wider information would soon be in the public domain from other sources (eg Greenpeace).

- If there were a public demand for maps then these should be issued through the LA so that appropriate interpretation could be disseminated with them.

- People living around nuclear sites are used to seeing maps with contours, sectors etc. In these cases, the EPOs felt that presenting information on maps would be an appropriate way to communicate the extent of the problem to the public and shouldn’t result in problems so long as people understood what the contours were representing. Presenting information to the public in postcode areas might be more meaningful to people than contours; these would probably be the same areas that would be used to delimit where any clean-up would take place.

- Careful use of colours on maps would be needed. The use of red, which is likely to be viewed as indicating ‘dangerous’, should be avoided. The use of hatching to fill areas might be easier to interpret than contour lines.

The importance of careful consideration of presentation is supported by the views of those involved in the ‘Sellafield pigeons’ incident. In the Sellafield case, presentation in terms of dose rate was favoured [Emptage, 2001]. Detailed maps of contamination levels were not seen as being required in this case [Parker, 2002]. However, this was probably because the contamination was understood by the public to be limited to the immediate area of a particular house.

3.7.2 Food restrictions

Even following a relatively small accidental release, not requiring emergency countermeasures like sheltering or evacuation of the population, it is likely that food restrictions would be required, under European Community regulations [CEC, 1987]. For nearly any size of release requiring food restrictions, the restricted area for food would be expected to be much larger than the area in which sheltering, evacuation or recovery measures would be carried out. The possible exception is the release of plutonium in a weapons' accident. In this case, the link between the accident and military uses of radioactive materials might result in clean-up measures that covered a far wider area than would reasonably be expected based on the hazard posed. In the weapons' accident scenario considered here (Figure 2.3), food restrictions would not be expected outside the lowest contamination contour indicated. For the reactor accident scenarios, the area within which food restrictions would be required is much larger than the areas in which recovery countermeasures would be considered. This is shown explicitly in Figure 2.7, for the submarine accident scenario. For the civil reactor accident scenario explored, the area requiring food restrictions would correspond approximately to the outer contour in Figure 2.5.

Despite significant efforts in recent years between FSA, EA and NRPB to address ways of communicating the reasons for this apparent discrepancy, the EPOs still felt vulnerable with respect to explaining why food restrictions would be required in areas where other countermeasures were not. All the EPOs expressed concern about how they would be able to maintain public support when carrying out clean-up in a much smaller area than that in which the FSA would be implementing food restrictions. This could be interpreted that they were not taking as much care of the public as the FSA. They recognised that the protection of the public from different exposure pathways would need careful explanation and presentation and it was felt that ways to do this should be discussed further in emergency exercises and other fora.

3.7.3 Experience of liaison with the public in radiation incidents in the UK

In the 'Sellafield pigeon' incident, public relations were kept very local and low-key. The occupants of the sanctuary and the surrounding properties and the parish council were kept well informed. Recovery plans for the sanctuary were not promulgated any wider. The management of remediation of the sanctuary property and the culling of the pigeons was immeasurably facilitated by the intermediary services of an ex-BNFL employee, resident in Seascale and known to the occupants [Parker, 2002].

Public perception of the magnitude of the contamination problem was tempered by the fact that the pigeons were already seen as a problem and residents were glad to see their numbers reduced as part of the remediation carried out. The link between the physical presence of the pigeons and the resulting contamination probably also helped the residents to rationalise the problem because they could see where the greatest contamination was likely to be [Parker, 2002]).

Publicity was limited and mostly at press release level. There were no public meetings, only a single meeting with local residents and parish councillors. In this case this was sufficient.

After the Korean Air Cargo jet crash, there was a great deal of public concern over the presence of depleted uranium on the aircraft and liaising with the public took a significant amount of time. DRPS made a number of presentations at local meetings to concerned parties including the public, the emergency services that responded to the crash, local farmers whose land was affected, National Trust representatives and the company undertaking the environmental clean-up [Lee, 2001]. The perception of DRPS staff was that people living near to the crash site received insufficient information from LAs and often came to the site to ask questions [Lee, 2001].

3.8 Management of Waste

The management of waste arising from any clean-up and also from potentially contaminated domestic waste was seen by the EPOs as a significant issue. They observed that both the environmental and the social impact of disposing of any waste material generated would need to be addressed.

The EPOs felt that gaining public acceptance for even the temporary storage of waste would be difficult. Gaining public acceptance for permanent disposal of contaminated wastes would be even more difficult. Some of the LAs have landfill sites in their areas whilst others have contracts with sites in neighbouring Authorities, which might well be called into question in the context of contaminated wastes. Some EPOs suggested that the waste should be moved far enough away for it to become anonymous (if that were possible). However, the general view was that there would be extreme public resistance to the keeping of any contaminated waste in the area. In any event, the EPOs said that the LA would be looking to the responsible operator and national organizations for advice on waste storage and disposal arising from clean-up, recognizing that the decision on final disposal options is likely to be political.

Much of the waste water in inhabited areas goes directly to the local sewage works. This might impact on the type of recovery options chosen. Concerns about controlling waste water and any other debris carried by the water into the sewage system, which could lead to the build up of contamination, would need to be considered carefully before waste generating options such as hosing were used.

West Berkshire has an agreement with Thames Water that two local sewage plants could be used for handling contaminated waters. These plants could be isolated from the general water treatment process and so could safely store the waste, pending any ultimate disposal. They recognized that, if used to hold contaminated wastes, these sewage works would be written off and not used in the future for normal water treatment.

The majority of the volume/mass of waste arising from the clean-up of the sanctuary property contaminated with ^{137}Cs from the ‘Sellafield pigeons’ was soil and tarmac with some timber. Sellafield has a soil disposal site and the average concentration in the contaminated material fell within the limits for the disposal site. This greatly facilitated the disposal operation as the waste material was only handled twice (to load and dispose). The material was transported on lined and covered lightweight trucks which were monitored clear at the end of the operation.

Waste arising from the Korean air crash was fairly small. The depleted uranium weights were nearly all intact and easily removed from the soil; the few vials containing radiopharmaceuticals that were broken required the removal of a small amount of contaminated soil (Lee, 2001). Interim storage of the radioactive materials was not a problem, an iso-container placed in a secure compound at Stanstead airport being used to hold the material until disposal was arranged.

3.8.1 Household Refuse

The EPOs recognised that it is the responsibility of the LAs to manage refuse collection. However, at present, there are no plans for dealing with large quantities of household waste that might be contaminated with radioactivity. The following views were expressed about the management of potentially contaminated domestic refuse.

- For ordinary domestic waste, some LAs employ contractors to collect and handle the waste. These contractors are often large national companies who are known to handle other special wastes. It was therefore felt that they should have no problem handling any potentially contaminated domestic refuse. However, other operators would not be prepared to collect the waste unless assurances could be given that it was uncontaminated.

- Some LAs, such as West Berkshire, use ‘wheely bins’ for domestic refuse and so it is unlikely that the refuse in the bins would become contaminated. It was recognized, however, that all refuse collected would need to be temporarily stored until full monitoring had been carried out.

- Where an area was significantly contaminated (ie people would not be allowed to continue living there without substantial decontamination of land and property) one suggestion was that the area could be used as a temporary repository for contaminated waste from elsewhere in the region. However, in order to provide reassurance for local people living near the site, measures would be needed to make the site not only ‘safe’ from leakage and inadvertent access, but also aesthetically pleasing (eg the use of a tree/shrub screen) in order to reduce its adverse visual impact.

- People would expect the LA to remove any household waste regardless of contamination levels. If it were not collected, people were likely to dump their own waste at municipal tips or just ‘fly tip’.

- If domestic waste had to be specially managed, this might lead to people questioning why it was safe for them to stay in their homes.

The issue of domestic waste was also discussed in more detail in the context of the weapons’ accident scenario affecting Weston-Super-Mare. In Weston-super-Mare, about 200 tonnes per day of normal household refuse is collected and this would be left on the street until it was collected. Normally, refuse goes to a collection point and then onwards to two disposal sites. The EPO said that these sites would not accept the waste, if there was any chance of it being contaminated, unless forced to do so by legislation[16]. However, the local community would want the refuse taken out of the area. The LA has no incinerators that could be used. The elected members also would not want any waste sites in the area, as it is a tourist area.

Several options for managing refuse were discussed. One was that people would be asked to look after their own waste on a temporary basis. Practically this is unlikely to work because people would just dump the waste somewhere and there would be no control. Another option would be to build a temporary site that was lined, although this, also, would be unlikely to be acceptable.

[16] In practice only the refuse sacks would be contaminated; however, all the waste would be perceived as being contaminated.

3.9 Impact on Tourism

The impact of an accident on tourism would, of course, be very dependent on the scale of the tourism industry in the area. For those LAs in tourist areas, it was felt that the tourism industry would be seriously affected in the short term. Moreover, the area affected by the downturn in tourism would probably be larger than the area in which recovery countermeasures were required. For example, the whole of the southwest of England might be affected initially if an accident happened at Plymouth. However, the EPOs felt that the provision of sound, widespread information to the public could, relatively quickly, reduce this area to one more nearly corresponding to the area of significant contamination.

The EPOs considered that the time taken for the tourist industry to recover would depend to a large extent on how long it took the local community to be seen to be functioning as normal. Once normality had returned to an area, it was likely that tourism would gradually return. The return of tourism would be one aim of the LA as part of its responsibility for the economic well being of the area.

4 IMPLICATIONS OF DEWAR FINDINGS FOR EA & FSA

Whilst this project was necessarily exploratory in nature, the information generated by CONDO, the experience of using CONDO in emergency exercises and the discussions held with Local Authority Emergency Planning Officers have provided some useful insights into how EA and FSA might focus their planning for managing the recovery phase of an accident. The discussion of these insights has been structured according to the topics of planning, tools, advice for 'on the day' response, and, training.

4.1 Planning

In terms of planning, the discussions with EPOs have identified a number of issues that would benefit from prior consideration and outline arrangements.

- It would be useful to develop a generic strategy that could be tailored to the specifics of the accident, on the day. This would have the advantages of providing an objective foundation for informing public expectations and of enabling early communications regarding the recovery measures to be implemented. The generic strategy would identify priorities and likely timescales, rather than specific measures. For example, it might outline a two-phase approach in which less contaminated areas are dealt with promptly, whilst people living in more contaminated areas are re-housed for a period of weeks or months allowing their homes and local environments to be decontaminated over a longer timescale. It might also be helpful for this generic strategy to make reference / linkages to countermeasures implemented in the emergency phase.

- Some of the EPOs questioned whether the high profile involvement of government agencies in the development of recovery strategies would tend to undermine their acceptability to the public. The NEPLG guidance on accident response, and, in particular, on the formation and working of the Remediation Working Group envisages a major role for EA in the development of any recovery strategy. For accidents occurring in areas where the relevant LA lacks the experience to chair the RWG, EA would even expect to chair the group. At face value, the EPO comments would seem to suggest that such a high profile role for EA would be unhelpful, in terms of gaining public confidence. It is therefore important that EA explores this issue more fully and more widely with LAs. The same issue may also be relevant for FSA, but probably to a lesser extent, insomuch as FSA is likely to be seen as implementing more extensive protective measures for food production than will appear to be the case for 'inhabited' areas.

- The software tool, CONDO, further developed under this contract, is intended to provide one input to the RWG. Its aim is to provide scoping information on the dose, resource and waste consequences of decontamination options. However, other inputs, in terms of social acceptability, the wider local and regional economic impact, the relationship of recovery measures to emergency countermeasures, monitoring and food restrictions, and, factors specific to the accident and local circumstances requiring local knowledge and expertise, will all require integration within the development of the recovery strategy. At present, national guidance from NEPLG envisages that this is achieved through dialogue within the RWG. It would be helpful to explore more thoroughly whether there are additional mechanisms that could be developed to support this process.

- The strength of support for the 'do nothing' option, in situations where doses are low should be further explored. First it is necessary to determine how representative this view is, and whether there are some circumstances (eg contamination affecting rural communities?) that are more favourable for the 'do nothing' option than others. If it is found that there are circumstances in which the optimum strategy would be to return to normal promptly, following adequate monitoring, then the generic strategy should encompass this guidance. It may also be appropriate for NRPB to modify its existing framework of advice to incorporate an intervention level of dose below which it may well be justified not to undertake remediation measures.

- It is important that there is clear guidance concerning the extent of LA responsibilities, and the agencies to whom LAs can turn for resources and wider (executive) decisions. In particular, the concern of LAs over whether contracted staff would be available for decontamination work should be investigated. It is recognised that NEPLG guidance has provided some information, but it would be helpful for this guidance to be developed further.

- Mechanisms for disposal of waste clearly require further consideration. Whilst those participating in emergency exercises to date have concentrated largely on the disposal of wastes arising from clean-up measures, it is clear that the disposal of household and normal commercial wastes generated in areas perceived as contaminated will also require specific decisions. The generic recovery strategy needs to address whether existing landfill sites or incinerators should be required to accept such wastes (and perhaps then closed), or whether the preferred option would be to construct a dedicated repository.

- It would be helpful if all agencies involved in accident response could agree a common approach to the provision of quantitative information, particularly with regard to contamination levels and their interpretation. It is clear that further work is required on this, in order to identify methods that provide an appropriate balance between the need to be open in the provision of information, the need to provide information in a form that is meaningful to a lay audience, and the need to recognise the public's desire for the delineation of 'safe/unsafe' boundaries.

- Further consideration could also usefully be given to developing methods for rapid communication of relevant information following an accident, both between response agencies and to the public. During the discussions held with EPOs, two suggestions were put forward: the use of a dedicated web-site, with password protected areas for restricted communication; and, the acceptance of a designated reporter within the local emergency centre.

- In the light of the comments made by the EPOs regarding the use of personal protective equipment during clean-up, it would be helpful to identify what remediation measures could reasonably be carried out without the use of specialised PPE. The generic recovery plan should recognise that if specialised PPE is required, then accommodation will need to be found for those living in the area to be decontaminated.

- Despite considerable effort already put in to handling the apparent discrepancy between the likely scales of decontamination measures and food restrictions, it is clear that further work still is required on this. The EPOs voiced continuing concern over how to present these discrepancies to the public in a meaningful and acceptable way.

- Finally, further consideration could be given to the quantification of the consequences of clean-up options on the local and regional economies. From this, it would be useful to group measures according to the likely scale of their subsequent economic impact, and possibly even to seek to identify measures that would help to counteract any negative impact.

4.2 Tools

In addition to appropriate planning, an effective response 'on the day' requires dedicated tools for assisting decision making and the interpretation of information. CONDO is one such tool. Its specific remit is the provision of scoping information on the likely scale of physically quantifiable consequences of decontamination options. It has been noted that the detailed evaluation of promising options would require the input of specific expertise and local knowledge, 'on the day'. In addition, the likely social acceptability and detailed economic consequences of options, both on the local and wider scale, would need separate evaluation and consideration[17]. However, CONDO is proving a powerful tool for exploring the likely consequences of recovery options. Version 3.0, encompassing a dynamic dose model for inhabited areas, provides considerable flexibility of use and is specifically designed for helping the user obtain an overall understanding of the scale and impact of the contamination and for answering 'what if?' questions. For example, CONDO enables the user to:

- identify those surfaces leading to the highest contributions to doses over given timescales
- compare and rank the dose, cost and waste consequences of different decontamination options
- compare the benefit received by the public in terms of averted dose with the doses likely to be received by decontamination workers
- explore the sensitivity of decisions on the 'optimum' decontamination strategy to underlying assumptions concerning the sub-division of the contaminated area and the time frame within which remediation should be completed
- obtain and disseminate copies of selected results.

Dose modelling for inhabited areas is a complex process, for which only limited experimental and 'real' data exist. It is important that priority is given to exploring the sensitivity of CONDO results to the underlying modelling assumptions and parameter values[18]. This will enable improved guidance on the likely consequences of decontamination options to be provided. In addition, the following three enhancements would also improve CONDO's effectiveness.

- The incorporation of new experimental data, both on the initial distribution of radioactive material within an area of different types of buildings and on the effectiveness of decontamination options for a wider range of radionuclides. Some of these data may be available in unpublished form from other laboratories in Europe (in particular, the Riso National Laboratory in Denmark). Others require new experimental work to be carried out.

[17] CONDO provides indicative costs, but these are based on very general assumptions concerning labour costs, work rates and equipment availability, all of which are likely to be strongly dependent on the exact circumstances of the accident and subsequent contamination.

[18] This work could be included, for example, within the Recovery Handbook project.

- The addition of different types of buildings to the ‘environments’ CONDO is able to represent. This requires further mathematical modelling and also research to determine which aspects of buildings and their associated environments are important in terms of the dose, resource and waste consequences of decontamination options.

- The incorporation of mapping software (ie a GIS). This would provide a much improved user interface, allowing the delineation of areas according to a precise map of the contaminated region, and the presentation of results in a spatial format. Mapping is available from a number of sources, appropriate for different applications, and includes digitised land use data, maps showing individual buildings and even maps providing information on building heights[19]. The incorporation of mapping software within CONDO would also assist both the sharing of information between response agencies and the presentation of information to the public.

In addition to CONDO, the EPOs recognised the need for a step-by-step guide to decision making in the recovery phase, ie a recovery handbook. The EPOs endorsed the structure proposed for the recovery handbook about to be funded by EA and FSA in conjunction with other Government Departments. It is proposed that this handbook will comprise best practice advice, relevant generic data, site specific questions to be addressed and relevant background information. It is intended to be helpful to all response agencies involved in the recovery phase of an accident. It should be of particular value for those response agencies that do not currently have a nuclear licensed site within their jurisdiction, but who, nevertheless, might become involved in a recovery strategy, whether as a result of a transport accident within their area or a very large accident at a fixed site.

4.3 On the Day

A number of useful points emerged concerning response ‘on the day’.

- All agencies should be careful to promise only those measures that can actually be achieved. Loss of public trust will be swift if measures either take much longer than originally estimated or only occur in part.

- Restricting access to more highly contaminated areas is likely to be acceptable, particularly if it is accompanied by efforts to minimise the negative visual impact of the area or activities taking place there.

- Planning to undertake clean-up measures in communal/public areas, but not in private homes and gardens is unlikely to be acceptable. Similarly, adopting measures in communal areas that appear to be more stringent than those adopted for private homes is unlikely to be acceptable.

- Generally, it is better to plan to relocate people temporarily whilst decontamination of their homes and/or environments is carried out.

[19] Note that although steps are being taken at Government level to explore the possibility of sharing mapping data between all Government Departments and Agencies, at the time of writing, most mapping data of the detail 00required for application after accidents is not freely available to NRPB.

- Detailed monitoring in the early days/weeks following the accident is essential, both for providing information on the extent of the contamination and for determining whether or not the decontamination measures have been successful. In this regard, it would normally be considered best practice to monitor an area both before and after decontamination and/or tie-down measures have been carried out. However, for those measures that need to be carried out promptly following the accident, particularly in situations where people will remain in the area during the remediation, it may be necessary to implement the measures without waiting for detailed monitoring to be undertaken first. In the longer term, some EPOs felt that so called 'reassurance' monitoring, continued over a protracted period of time after an area has been declared 'safe', may create anxiety rather than allay it.

Specific comments were also made concerning individual decontamination options. Further discussions would undoubtedly elicit additional practical information of this type.

4.4 Training

It is not possible to respond effectively to an accident in either the emergency or recovery phases, without adequate training of the staff involved. Training is required in a number of areas (many outside the focus of this contract), including: understanding of the nature and scale of potential accidents, use of dedicated support tools, access to appropriate resources and expertise, specific roles and authorities, legislation. In this section, those specific aspects of training that have been highlighted as a result of this contract are discussed.

4.4.1 Training for development of recovery plans

If Government Departments/Agencies are to develop a generic recovery plan, it is necessary for appropriate staff to receive training and exchange ideas on the legislative, health, resource and practical issues relevant to developing a recovery strategy. To some extent, this may be furthered within the workshop(s) proposed under the Recovery Handbook project. However, currently, the aim of this project is to develop a detailed framework for assisting decision making, particularly at a local level, ie it is not to develop a generic UK recovery plan. Therefore it is important that staff at EA/FSA review the aims and initiatives being undertaken within the Recovery Handbook project, in order to identify how other training needs, necessary for the development of a generic recovery plan, might be met within it.

The EPOs suggested two currently untested approaches towards the wider dissemination of information following an accident: the sharing of a website with other Government Departments/Agencies and the inclusion of a local reporter within the LA's a public helpline team. Clearly these ideas need closer examination and possibly trialling. However, neither would be workable without specific training, and the development of appropriate guidelines and procedures for all staff involved. Moreover, in order to develop the necessary training programmes, it is first necessary to explore the structures and procedures that would be necessary to support these initiatives.

It is clear from the EPOs' comments that further exploration is required of the issues involved in recovery after an accident. Whilst this can be carried forward through discussion of scenarios, similar to the mechanism employed in this contract, the authors recommend that the benefit to be gained through learning within an emergency exercise setting should not be underestimated. Currently, the emergency phase of accident response is exercised regularly within the UK, precisely to hone emergency planning through trial application of the plans to a range of different scenarios. Whilst the resource implications of holding extended exercises over several days cannot be ignored, the authors believe there would be substantial benefits to be gained from a regular programme of such extended exercises. These would be in terms of both the sharing of expertise and the understanding and development of improved response planning for the recovery phase. This learning and improvement cannot be so effectively gained through reliance only on workshops or 'time shifts' part way through an emergency exercise, as these divorce those participating from the important dimension of time and its strong influence on decision making. One way of reducing the resource impact of playing in 'real time' might be to avoid overnight play, eg by holding the emergency response part of the exercise on the first (extended) day, followed by a second day of planning detailed monitoring and initial recovery measures, and by a third day focussed on the development of the detailed recovery strategy, initiated by the provision of detailed contamination maps.

4.4.2 Training in the use of support tools

Developing a recovery strategy following an accident is a complex task. It also involves issues and assessments that many of the respondents are unlikely to deal with in their every day jobs. Whilst an obvious aim of any tool intended to support such decision making is that it should be as straightforward to use as possible, it is unlikely that such tools can simply be picked up 'on the day' by any decision maker and instantly applied. For this reason, training (both initial training and refresher training) in the use of available tools is essential. With direct application to this contract, training is required, in the short term, in the use of CONDO, and, in the longer term, will be required in the use of the Recovery Handbook.

With respect to CONDO, two levels of training are identified: one for direct users of CONDO and one for those who might make use of CONDO results. The direct users of CONDO require training in loading and running the software, and also in how to frame the questions likely to be asked by decision makers in order to obtain the most useful support from CONDO. They particularly need to acquire an understanding of the implications of their inputs to CONDO in terms of the results generated, and how to test the robustness of these inputs in terms of the information sought. Those who might use CONDO results require a more general understanding of what CONDO can provide for them, what are the associated uncertainties in any results generated, and what information is necessary in order to apply CONDO most effectively.

In respect of the Recovery Handbook, it is too early to define the associated training needs in detail. However, it is possible to observe that it is intended for application by users from different decision communities: eg, Government Departments and Agencies; those involved in food and water production; those responsible for the remediation of inhabited areas; those involved in waste disposal processes. Is it unlikely that a single training programme will be appropriate for all these groups, and so the training needs of each group (and possibly other groups) will need to be identified.

5 SUMMARY

This contract has extended understanding of how to respond to accidental releases of radioactivity in the recovery phase, ie after emergency countermeasures have been initiated and the source of the release has been brought back under control. It has achieved this in two ways: by enhancing the CONDO software tool for scoping the dose, resource and waste consequences of decontamination options, and, through dialogue with Local Authority Emergency Planning Officers. As a result of this work, recommendations have been made for improvements to the current effectiveness of UK planning and preparedness for the recovery phase. These cover the areas of planning, development of support tools, guidance for the practical implementation of a recovery strategy in the event of an accidental release, and training. In particular, the desirability of the development of a generic UK recovery plan has been discussed.

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APPENDIX A: TECHNICAL DESCRIPTION OF CONDO v2.1

This appendix describes the functionality of CONDO v2.1. Compared with v1.0, developed under contract to the Ministry of Defence (MoD) [Charnock *et al*, 2000] it provides enhanced flexibility of application and improved presentation of information and report generation. A major part of the increased flexibility comes from the incorporation of NRPB's external dose model for inhabited areas, EXPURT [Crick and Brown, 1990], directly within the software. In addition, the database (formerly version 1.2, now version 2.1) has been expanded to include consideration of more techniques. This appendix provides details of changes implemented since CONDO v1.0 was released. Where discussion of the models and assumptions used in Condo v1.0 is necessary for understanding of the new features, these are summarised; a full description of the models and assumptions in CONDO v1.0 is provided by Charnock *et al* [2000]. A detailed description of the models and data used in CONDO v2.1 is provided in a separate report [Charnock *et al*, 2003]. A User Guide, describing the operation of CONDO v2.1, is also published separately [Charnock *et al*, 2001].

A.1 Overview

The minimum input required by CONDO v2.1 is: an estimate of the area contaminated, sub-divided into user defined regions; and, estimates of the average deposition level of each radionuclide in each region. In order to estimate the required outputs, CONDO processes this user information together with default environmental data and information on decontamination options held in a database. The user may optionally replace some or all of the default information with location specific data, as appropriate.

Information on the likely consequences of each decontamination technique included in the database is provided to the user in two stages (here termed 'output levels'). The first output level is provided to enable an initial, rapid comparison of techniques for the purpose of selecting the most promising. This level contains information (mostly radionuclide independent) that is directly associated with the techniques, namely:

- a list of possible decontamination options that could be applied
- the decontamination effectiveness of each option[20]
- the unit cost of applying each option (£/km^2)
- the normalised time and manpower required (km^2/day/team)
- the equipment requirements
- the waste arising (kg/km^2)

The second output level is intended for further exploration of a particular chosen technique. It contains the detailed results calculated for the application of a specified technique to a specified surface. For perspective, it also provides a broad estimate of the cost of relocating the population. The results calculated are listed below:

- initial and post-decontamination activity levels on different surfaces
- estimates of doses (worker and public) and dose reductions (public)[21]

[20] This is radionuclide dependent and is expressed in two ways, 'decontamination factor', DF, and 'factor for the reduction of resuspended respirable material', RRF, as discussed in Section A.2.4. The user requires different expressions for decontamination effectiveness, depending upon the endpoint of interest.

- estimates of activity concentrations of each radionuclide in waste
- estimates of total costs and time required
- estimate of the monetary costs of relocation (for perspective).

CONDO v2.1 output can be saved to a text file, for subsequent printing, editing or transmission.

A.2 Data

The scientific basis of the software is derived from the results of three reviews. The first review was carried out by NRPB, Rolls Royce Nuclear Engineering Services Ltd and the Atomic Weapons Establishment under contract to the Department of the Environment (now the Department of the Environment, Foods and Rural Affairs, DEFRA) [Brown *et al*, 1996]. The second review was carried out by NRPB under contract to MoD [Brown and Jones, 2000]. The third review was carried out as part of the development of CONDO v2.1, under this contract to EA and FSA [Charnock *et al*, 2003].

These reviews have provided information on decontamination techniques applied to different types of surface and for different radionuclides, following deposition occurring under both wet and dry conditions. This information is listed below, for each technique, and key items are discussed in more detail in the following sub-sections:

- surface to which it is applicable
- likely decontamination factor (DF) to be achieved, by radionuclide
- likely reduction in respirable resuspended material (RRF), by radionuclide
- whether contamination ‘tie-down’ is required prior to applying the technique
- equipment requirements and likely availability
- minimum/maximum size of discrete area over which it is appropriate for application (‘fragmentation’)
- monetary costs per unit area
- work rate per unit area
- team size required
- type and amount of waste created per unit area.

Table A.1 lists the decontamination options for which data are held.

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[21] In this Appendix the term ‘dose’ is used to mean the sum of the committed effective dose from inhaling radionuclides resuspended from surfaces during the user specified time period and the whole body external dose from deposited radionuclides, integrated to the user specified time. In general, one of these two pathways will strongly dominate the total dose received. These doses are calculated for adults. No account is taken of exposures from the airborne plume.

Table A.1 Decontamination options considered in CONDO v2.1

Technique	Technique
Grass/soil surfaces	
Tie-Down: vinamul (soil/grass)	Turf removal (25mm) and returfing
Tie-Down: water (soil/grass)	Turf removal (25mm) and reseeding
Grass cutting and collection	Turf and top soil removal (50mm)
Rotovating	Turf and top soil removal (50mm) with soil replacement
Double digging	Turf and top soil removal (50mm), soil replacement and returfing
Ploughing	Turf and top soil removal (50mm), soil replacement and reseeding
Skim and burial ploughing	Plant and shrub removal
Turf removal (25mm)	
Tree/shrub surfaces	
Tree felling	Tree felling and incineration (small scale)
Tree felling and replacement	
Paved surfaces	
Tie-Down: water	High pressure hosing (waste collected and filtered before disposal of water to drains)
Tie-Down: sand (1mm)	Sandblasting (disposal directly to drains)
Tie-Down: bitumen	Sandblasting (waste collected and filtered before disposal of water to drains)
Vacuum sweeping (dry road, waste collected)	Peelable coatings
Vacuum sweeping (paved surfaces; wet surface, disposal direct to drains)	Foam
Vacuum sweeping (wet surface, waste filtered prior to disposal of water to drains)	Surface removal
Fire hosing (disposal directly to drains)	Surface removal and replacement
High pressure hosing (disposal directly to drains)	
Exterior walls	
Tie-Down: vinacryl (walls)	High pressure hosing (waste collected and filtered before disposal of water to drains; less specialised equipment, on a small scale)
Vacuum cleaning	Sandblasting (disposal directly to drains)
Fire hosing (disposal directly to drains)	Sandblasting (less specialised equipment)
Fire hosing (waste collected and filtered before disposal of water to drains)	Sandblasting (waste collected and filtered before disposal of water to drains)
High pressure hosing (disposal directly to drains)	Peelable coatings
High pressure hosing (disposal directly to drains; less specialised equipment, on a small scale)	Foam
High pressure hosing (waste collected and filtered before disposal of water to drains)	
Roofs	
Tie-Down: vinacryl (roofs)	High pressure hosing (waste collected and filtered before disposal of water to drains; less specialised equipment, on a small scale)
Brushing	Sandblasting (disposal directly to drains)
Fire hosing (disposal direct to drains)	Sandblasting (less specialised equipment)
Fire hosing (waste collected and filtered before disposal of water to drains)	Sandblasting (waste collected and filtered before disposal of water to drains)
High pressure hosing (disposal directly to drains)	Peelable coatings
High pressure hosing (disposal directly to drains; less specialised equipment, on a small scale)	Foam
High pressure hosing (waste collected and filtered before disposal of water to drains)	

Technique Indoor surfaces	Technique
Vacuum cleaning	Washing

In order to provide perspective for the decontamination results, CONDO also provides crude estimates of the costs of relocating the population away from the area, based on the methods and assumptions of the COCO-1 model [Haywood *et al*, 1991] and an estimate of the number of people involved. In CONDO v1.0, the population affected was calculated from default population density data, held for three scales of urbanisation: rural, semi-urban (ie villages and residential areas of towns) and urban (ie city areas with high building densities and heavily industrial areas). In CONDO v2.1 these defaults may be overridden by the user.

The data are stored in a Microsoft ACCESS database [Microsoft, 1997]. The database v2.1 has been streamlined compared with v1.2, released with CONDO v1.0, with consequent advantages of improved speed of access and ease of maintenance. The data in the database are split into two basic categories. The first category comprises the basic resource data regarding decontamination methods, radionuclide properties, costs etc. These data are summarised in the following sub-sections and described in detail by Charnock *et al* [2003]. The second category comprises the data specific to the accident being considered, eg the radionuclides involved, the level of contamination etc. A key feature of CONDO is that all data items (in both categories) are associated with information describing their status and origin: where data are provided by the user, he/she has the facility to enter this accompanying reference information.

A.2.1 Radionuclides

The database holds information for the radionuclides listed in Table A.2. Some simplifying assumptions are made concerning the handling of daughter radionuclides: this is discussed in Section A.5.3.

Table A.2: Radionuclides for which information is held in the database

Radionuclide		
‘Alpha’	Ruthenium-103	Caesium-137
‘Beta-gamma’	Ruthenium-106	Barium-140
Cobalt-60	Iodine-131	Lanthanum-140
Zirconium-95	Caesium-134	Plutonium-239
Niobium-95	Caesium-136	Americium-241

The amount of information available on the effectiveness of decontamination techniques for specific elements is quite limited, with the exception of caesium and plutonium. Some additional information was found on the effectiveness of fire hosing surfaces contaminated with ruthenium, lanthanum and barium, but little else. In CONDO v1.0, the concept of proxy radionuclides was adopted: radionuclides for which no element specific information was available were assigned a proxy element, for which information had been obtained[22]. The reason for adopting this approach was to ensure transparency of the underlying assumptions. However, it was found that this proxy concept led to complicated programming structures. Therefore, in CONDO v2.1, this use of proxies has been removed and information is stored

[22] These ‘proxies’ are proxies for the data assigned to specific radionuclides held in the database and are distinct from the use of the generic radionuclide categories, ‘alpha’ and ‘beta/gamma’.

explicitly for each radionuclide in the database. The assumptions used to generate this full set of radionuclide data are discussed by Charnock *et al* [2003], and summarised in the comment fields of the database. Generally, all beta/gamma emitters use caesium data modified for half-life, whilst the alpha emitters adopt the plutonium data, again modified as appropriate for half-life. For ruthenium, barium and lanthanum, the limited element specific data obtained were supplemented with those for caesium to provide the full set of information required. The inclusion of two generic radionuclides, 'alpha' and 'beta/gamma' provides for situations where the user wishes to scope the impact of the presence of additional radionuclides not explicitly included in the database. The properties adopted for the generic radionuclides are plutonium-239 and caesium-137, respectively.

A.2.2 Surface type

The effectiveness of a decontamination technique is modelled by removing, adding to or re-distributing the activity present in different parts of the environment, according to the action of the technique. For example, ploughing large areas of grass/soil will have no effect on the distribution of activity on buildings or metalled surfaces, but will redistribute activity within the soil profile of the areas ploughed. Conversely, fire hosing of streets will reduce the activity on metalled surfaces, but, unless the contaminated water is collected for special disposal, will increase the activity in drains. Within the CONDO software, these different parts of the environment are called 'surfaces', although, strictly, some are 'volumes' rather than surfaces. Condo v2.1 recognises six surface types:

- soil/grass
- tree/shrub
- metalled surfaces
- roofs
- exterior walls of buildings
- interior building surfaces

Within CONDO these surfaces are combined together in either default or user-specified proportions to describe the physical make-up of the area (or 'environment') being modelled. Three default environment types are provided in CONDO, selected to correspond to the three scales of urbanisation, ie urban, semi-urban and rural. The exact proportions assumed are given by Charnock *et al* [2003]; in summary, the rural environment has relatively more surface area assigned to soil/grass, and relatively less area assigned to metalled surfaces and buildings, compared with the urban environment.

A.2.3 Information on possible decontamination options

The database holds information on the range of applicability of each of the decontamination options considered. For straightforwardness within CONDO, a decontamination technique is assumed to be applicable to one surface type only. In reality some techniques might be applied to several different surfaces, for example, firehosing can be applied to roofs and to metalled surfaces (eg roads). If this is the case the technique is recorded in the database twice, for example, once for roads and once for roofs.

A.2.4 DF and RRF

The term ‘decontamination factor’ (DF) has been defined elsewhere [see Brown *et al*, 1996] to be the (dimensionless) ratio between the amount of activity present before implementation of the decontamination technique to that following its implementation. A DF of 10 indicates that 90% of the radioactive contamination is removed by the technique, whereas as a DF of 1 indicates that all of the contamination is left *in situ* (ie the technique achieves a dose reduction by shielding, fixing or diluting the radioactivity).

Version 1.2 of the database only provided values for the DF for each technique. In order to provide more information about the efficacy of those techniques which achieve a dose reduction without actually removing any of the radioactive contamination, a second factor has been defined, the ‘factor for the reduction in respirable resuspended material or RRF [Brown and Jones, 2000]. This factor is defined analogously to the DF, but refers to the ratio of the amount of radioactivity available for inhalation via the resuspension pathway before and after implementation of the technique. For example, ploughing, digging and rotovating have the effect of mixing surface deposited radioactivity throughout a certain depth of soil, hence reducing the amount in the surface layer that might later be resuspended. Although, in these cases, the DF would be unity, the RRF might attain a high value, depending upon the depth of soil mixing.

A.2.5 Tie-down prior to decontamination

In some circumstances it can be advantageous to carry out temporary ‘fixing’ or tie-down measures prior to implementation of the main decontamination technique, in order to prevent the further spread of contamination and/or to reduce the resuspension hazard. Examples of such measures are:

- water (small volumes, to avoid run-off)
- sand
- bitumen (only when resurfacing of metalled surfaces is intended, otherwise this measure is permanent)
- vinyl acrylic paint
- peelable coatings

Since it will not always be desirable to implement temporary tie-down measures, the costs and resource implications of these measures are identified separately in the database. CONDO v2.1 is limited (by the underlying EXPURT model [Crick and Brown, 1990], see Sections A.3 and A.4) to presentation of the consequences of implementing each technique separately. Therefore, evaluation of a strategy comprising temporary tie-down measures combined with other decontamination techniques requires separate assessment of the consequences of the tie-down and other measures, with manual combination of the results.

A.2.6 Fragmentation

Many of the techniques considered in the database are appropriate to certain scales of application. For example, ploughing requires large machinery and would not be practicable for use in suburban gardens, whilst double digging is a manual task, and so inappropriate for large-scale application in parks or sports fields. Some of the techniques are defined more generically, such as grass cutting. In this case, the method employed would almost certainly depend on the intended scale of the application: garden mowers for gardens, tractor mowers for parks and sports fields. Similarly, decontamination of two or three storey buildings may be achieved by using ladders or scaffolding, whereas decontamination of high buildings will require different equipment for reaching the upper areas. Clearly, the resource and monetary cost consequences of implementing a general technique will depend not only on the total area to be decontaminated, but also on the type of equipment required and the labour-intensiveness of the measure.

In CONDO v1.0 information was held on the monetary costs, manpower and equipment required for each of two scales of application of the technique: the decontamination of large, 'continuous' units of a given surface (such as parks), and the decontamination of multiple small, 'fragmented' units of the surface (such as suburban gardens). For buildings, these terms were interpreted broadly to mean 'low rise' for 'fragmented' and 'high rise' for 'continuous'. Results were presented for both scales of application, for the user to interpret in a manner appropriate to the situation under consideration.

In CONDO v2.1, information is again held on the costs and resources required for each of two scales of application. However, the user is now enabled to define the proportion of each surface type that is amenable to the application of large-scale (or 'high rise') decontamination methods and the proportion that is more appropriate for the application of smaller scale (or 'low rise') decontamination methods, by specifying the fraction of 'fragmentation' of each surface type. For example, a fragmentation of 30% for soil/grass means that 30% of the soil/grass area is made up of small sub-units (each with an area less than about 300 m^2) whilst 70% is made up of larger units (each in excess of about 300 m^2). The threshold area of 300 m^2 is indicative of the minimum discrete area for which large-scale techniques would be applicable, and of the maximum discrete area for which small-scale techniques would be practicable. For buildings, a fragmentation of 30% would indicate that 30% of the area covered by buildings comprised buildings low enough to be decontaminated using 'low rise' equipment such as ladders and scaffolding, whilst 70% would require equipment that enabled decontamination to be undertaken high off the ground (eg fire-tenders). CONDO calculates separately the total area for which large-scale (or 'high rise') and small-scale (or 'low rise') techniques would be applied, combines each with the appropriate information in the database, and then sums the results to present the user with the appropriate total cost and resource information.

A.3 Incorporation of EXPURT

CONDO uses the dose model for inhabited areas, EXPURT [Crick and Brown, 1990], to model the movement of radioactivity within inhabited areas as a function of natural processes and its loss from the environment as a consequence of the application of decontamination techniques. CONDO v1.0 used EXPURT remotely, via pre-calculated tables of results. The use of pre-calculated results limited the flexibility of application of CONDO to those scenarios and endpoints that had been specified in the EXPURT runs. For example, the EXPURT calculations had modelled application of decontamination techniques at specific times, and the resultant doses and surface activities were also only reported at certain times. A major feature of CONDO v2.1 is that EXPURT v2.02 has been incorporated within the code, so that it is run dynamically, as required, with the user's chosen inputs. This means that a number of factors, such as decontamination times and dose integration times, can be set interactively by the user, enabling both better representation of the scenario being explored and also facilitating a series of 'what if?' calculations to be undertaken. EXPURT v2.02 is described by Charnock *et al* [2003]. The primary purpose of CONDO is to enable decision makers to undertake scoping calculations: the facility to undertake a series of 'what if?' calculations contributes an important component to this aim.

A.4 User Interface

A.4.1 Inputting the scenario

The CONDO v1.0 user interface was designed to enable rapid, scoping estimates to be made of the consequences of applying different decontamination techniques. For this reason, entry of the contamination footprint was kept simple and default information was provided wherever possible. In providing for the enhanced flexibility of CONDO v2.1, much of the original straightforwardness has been retained. The flow of the interface screens is shown in Figure A.1, which also indicates the changes made to this interface in CONDO v2.1 compared with CONDO v1.0.

As can been seen from Figure A.1, entry of the contamination footprint is largely unchanged. The user defines an accident on the basis of a *scenario*, either using or modifying a pre-defined scenario or creating a new scenario entirely from scratch. A scenario is all the information relating to the initial contamination of the environment, and the properties (demographic, geographic etc) of the contaminated area. The user divides the scenario area into one or more *regions*. These are chosen by the user for several reasons. They may have significantly different levels of contamination, may be comprised of different types of surfaces (eg predominately soil/grass or predominantly metalled) or may be of interest for some socio-economic reason. Each region is assigned an *environment type* and a proportion of the scenario area. Each environment type is defined in terms of the relative proportion of different surface types contained in it (as described in Section A.2.2). The user also defines the average level of contamination for each region and radionuclide considered. CONDO v1.0 was supplied with two pre-defined weapons' accident scenarios. CONDO v2.1 is supplied with three further contamination footprints, two based on reactor accident scenarios and the third based on another weapons' accident scenario. These can be used as 'templates', to be edited appropriately for the accident scenario under consideration, thus reducing the effort required to input a scenario from 'scratch'.

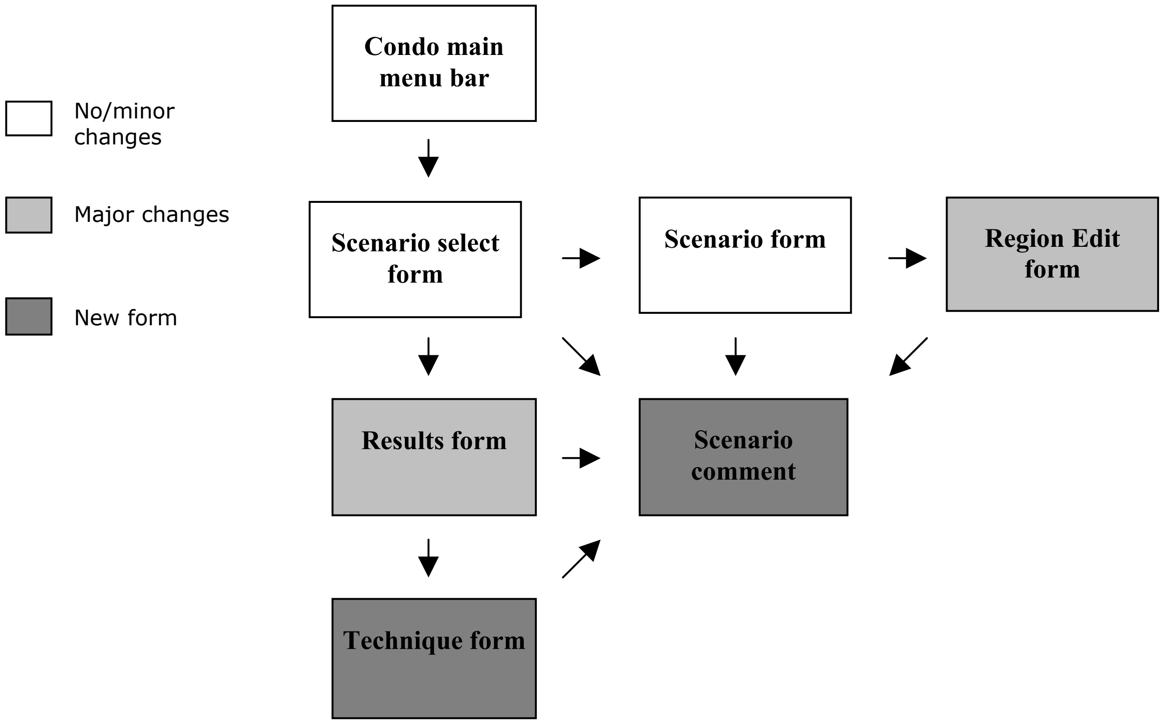

Figure A.1: User Interface Screens in CONDO v2.1 compared with CONDO v1.0

The definition of the scenario supplies most of the user input required. The remaining information required from the user is the time at which a chosen technique is applied, the time period over which relocation costs should be calculated, the number of teams available to undertake the decontamination measure under consideration and a factor to adjust the efficiency at which they are able to operate. Whilst default values are stored in the database for the proportions of each surface type comprising the three default environment types (rural, semi-urban and urban), the incorporation of EXPURT [Crick and Brown, 1990], directly within CONDO v2.1 enables the user to specify more appropriate proportions of each surface if necessary, together with the percentage of area of each surface type that is 'fragmented' (ie for which small-scale decontamination equipment/techniques would be applied, see Section A.2.6). The user may also specify the population directly for each region, instead of using the numbers calculated from default population densities for each environment type.

A.4.2 Interaction with the results screens

CONDO v1.0 calculated a pre-defined set of results for all techniques stored in the database in a single run, from which the user could select those results of interest. CONDO v2.1 both incorporates many more techniques and enables the user considerable freedom in defining the results required. For these reasons, the interface for presentation of the results has been re-designed and a new interface for specifying the results required has been introduced. As indicated in Figure A.1 and summarised in Section A.1, the user interacts with the results screens at two levels. On the first level, the user is presented with information about the decontamination techniques which is not radionuclide dependent. This information can be ordered according to DF, RRF, monetary cost of the technique per unit area or mass of waste per unit area. Based on this information, the user selects a single technique/region/surface combination for further exploration. At this point EXPURT [Crick and Brown, 1990] is called and radionuclide specific results are produced. They are presented via the second level results screen. The user may then request different results for this technique (eg doses integrated to different times) or return to the first level screen and request that calculations are carried out for a different technique/region/surface combination. The user may iterate through this process as many times as required, before either exiting the program or returning to the scenario input screens to modify the scenario.

A.4.3 User comments and report writing

The greater flexibility afforded the user of CONDO v2.1 makes it imperative that all results can be uniquely and fully commented and defined. CONDO v2.1 therefore provides this facility. Comments are added to output results in two ways: automatically and interactively. The automatic facility ensures that if the user asks to record results, these are always prefaced with a summary of the scenario data and other user input information. The interactive facility provides the user with the opportunity to record comments at all stages of the calculation. These are reported together with the associated inputs and/or results.

CONDO v2.1 also provides for customisation of the results that are output to a text file. CONDO v1.0 had only the option to write out all the results calculated; the user had to edit these outside the program. Under CONDO v2.1 the user can select which results are output, and even carry out limited editing of the text from within the program. The user can also add additional results to an existing text file, and so record only those 'what-if' results that prove of interest.

A.5 Calculational methodology

The detailed calculational methodology is given in a separate report [Charnock *et al*, 2003]. In this Section, an overview of the assumptions and models used is given.

A.5.1 Initial and post-decontamination activity levels

If a radioactive plume passes over an area, then, in dry conditions, different surfaces will intercept the radionuclides to differing degrees, depending on the weather conditions, the nature of the surface and the physical and chemical form of the radionuclide. This is commonly modelled using a parameter called the dry deposition velocity, which expresses the ratio of the concentration of the radionuclide in the air just above the surface, to the contamination level of the radionuclide on the surface. This ratio can vary by several orders of magnitude, depending on the factors mentioned above. In wet conditions, the situation is further complicated because, not only does the rain increase the rate of deposition, but it also causes some redistribution of radioactivity in the environment, owing to runoff. The user is asked to indicate whether the deposition occurred during wet or dry conditions. However CONDO assumes that the user does not know the exact distribution of radionuclides between surfaces, as a result of these processes. Therefore, it takes the contamination level entered by the user as the level that would have been measured on grass or soil, assuming the measurement was taken well away from other surfaces. (This is the same value as most atmospheric dispersion models would estimate for deposition at a certain distance and angle away from the source of the release). CONDO then uses EXPURT [Crick and Brown, 1990] to redistribute the contamination according to the processes discussed above. It is the resulting contamination levels for each surface that are then considered in the calculations performed. In CONDO v1.0, default ratios expressing the initial redistribution of contamination were used for the three defined environments of 'heavy urban', 'urban' and 'rural'. In CONDO v2.1, EXPURT is used to calculate this redistribution explicitly[23].

In order to calculate the residual contamination levels on each surface type, as a function of time following decontamination, CONDO v1.0 used tabulated values obtained from prior EXPURT calculations. In CONDO v2.1, EXPURT is called from within the program to calculate values explicitly, taking account of weathering from one surface to another, loss via sewers and down the soil column, and radioactive decay. This means that the user is free to define the time of implementation of the technique, and the times for which results should be calculated. It should be noted, however, that the effectiveness of many techniques is not constant with time, but often reduces if the radionuclides have remained *in situ* long enough to have become chemically bonded to the surface. Where this is the case, the database holds information on the time window for which the stated DFs and RRFs are valid: it is assumed that the technique has no effect outside this time window (see Section A.5.6). This information can be viewed by the user by directly accessing the database, and used to inform decisions on the maximum delays which can be afforded before implementation of each technique.

The user is also able to specify the fraction of the surface area to which the technique is to be applied. This latter input provides the user with the ability to model decontamination of, say, roads and pavements, but not drives, patios etc. The fraction of surface area to be decontaminated may be separately input for both the continuous and the fragmented areas of the specified surface type (see Section A.2.6).

One restriction of the EXPURT model is that decontamination is assumed to be instantaneous. The residual levels of surface contamination therefore take no account of the time it would take to carry out the decontamination: they are calculated as if the measure were completed immediately after the time specified by the user for commencing implementation of the technique.

A.5.2 Estimates of doses

The calculation of external doses in an environment that contains a mixture of surface types and buildings is not straightforward. The dose received by an individual will comprise exposures from a range of contaminated surfaces, each contaminated to different levels and each more or less effectively shielded by intervening barriers, such as walls. Moreover, natural weathering and human activities (including deliberate decontamination) will re-distribute the contamination over time, in a manner which will depend strongly on the type of environment. Finally, the total exposure will depend on how much time an individual spends in different locations (‘occupancy’). The incorporation of the EXPURT dose model for inhabited areas within CONDO v2.1 means that external doses can be calculated explicitly for the time periods, environments and decontamination regime specified by the user. CONDO v2.1 does not support changing the default occupancies (see later).

[23] Note: Whilst there is no reason to assume that the ratios of deposition between different surfaces in inhabited areas are constant, irrespective of dry deposition velocity to grass or of rainfall rate, the available data do not provide a basis for estimating different deposition ratios as a function of these parameters. Therefore, in EXPURT, only two sets of deposition ratios are adopted: one for the component of deposition due to dry deposition, and one for the component due to wet deposition.

As stated in Section A.5.1, EXPURT assumes that decontamination is completed instantaneously, once started. With this restriction, EXPURT calculates external doses taking into account the time dependence of all factors relevant to this calculation. In order to avoid over-estimation of the reduction in external doses achieved, CONDO v2.1 passes EXPURT the time decontamination is completed to represent the time of decontamination (ie the implementation time entered by the user plus the time calculated by CONDO for the decontamination to be carried out, see Section A.5.6), thus adopting the assumption that no dose reduction benefit is gained until the end of the intervention. The doses calculated are adult normal living doses, ie the dose to an adult spending specified proportions of his/her time outdoors and within buildings providing different degrees of shielding. The user may specify up to three integration times for calculation of the doses. The proportions of time assumed for occupancy in differently shielded buildings, and outdoors, are not, however, available for alteration by the user, except by changing the default information held in the database. It is recognised that this may lead to some inconsistency between the proportions of surfaces specified, by the user, for the environment and the assumptions made concerning occupancy. However, given CONDO is intended as a scoping tool, and considering the additional complexity and possibility for serious inconsistency that would be introduced by inviting the user to specify occupancy data for each environment, this restriction is judged the best compromise.

Doses resulting from the inhalation of resuspended radionuclides (resuspension doses) are estimated for all radionuclides. In CONDO v1.0 the simplifying assumption was made that resuspension only took place in the absence of decontamination countermeasures, ie if a decontamination option was implemented it was assumed that all remaining activity on that surface was fixed and therefore unavailable for resuspension. In CONDO v2.1 the empirical formula developed by Garland [1979] has been adopted to calculate resuspension doses, implemented according to the advice provided by NRPB on the calculation of resuspension doses after an accident [Walsh, 2002].

Garland's formula provides an empirical description of the time dependence of resuspension over open grassland in UK conditions. Given the large uncertainties associated with resuspension dose modelling (orders of magnitude), Garland's formula has been adopted here as appropriate for UK conditions in inhabited areas. For doses up to the time of decontamination, the formula is used to estimate radionuclide specific time-integrated air concentrations directly, based on the deposition level to soil/grass. The ICRP average adult breathing rate and appropriate dose coefficients are then used to calculate doses. For the calculation of resuspension doses following decontamination it is assumed that resuspension of the activity remaining available for resuspension (ie all activity remaining on exposed surfaces) continues with the same time profile as it would have done in the absence of decontamination. The ratio of the total activity available for resuspension after decontamination to that before decontamination, summed over all exposed surfaces (metalled, soil/grass surface, trees, exterior walls, interior walls, roofs)[24], is calculated and applied to reduce the prediction of time-integrated air concentration from Garland's formula for times after the decontamination has been initiated. As with external dose, the decontamination is assumed to take place instantaneously, at the end of the period, to avoid overestimating the benefit achieved.

[24] This approach results in a significant over-estimation of indoor resuspension doses in CONDO v2.1. Caution should be exercised when interpreting the results for the effectiveness of indoor decontamination techniques for this exposure pathway.

When calculating the external and resuspension doses to the public the assumption is made that the population spends the whole period of integration within the region. For the calculation of resuspension doses, the time spent by individuals in different locations within the region is not relevant, as the modelling approach links resuspension doses to the level of initial deposition onto grass/soil surfaces (ie the deposition level entered by the user). For the calculation of external dose there are factors in the database that describe the proportion of the time individuals spend in buildings with different shielding properties and outdoors. If only a part of the surface is decontaminated – because the technique is only suitable for a part or because the user has directly specified that only a proportion of the surface is decontaminated – the population is assumed to spend time in the parts of the region decontaminated and not decontaminated in proportion to their relative sizes.

In CONDO v1.0, worker doses were estimated only for the external pathway. Furthermore, only collective worker doses were calculated. In CONDO v2.1, collective doses are no longer presented, but doses to individual workers from both external irradiation and resuspension of activity are calculated. These are calculated in a similar way to those for the public, with direct calls to the EXPURT model, except that the doses are calculated from the start of decontamination until it is complete, assuming that the workers are subject, during working hours only, to exposures unmodified by the decontamination process. The time required by each worker to complete the decontamination is calculated from the work rate associated with the technique and the number of teams specified as available by the user. Where techniques are applied to outdoor surfaces, outdoor external doses only are calculated. Similarly for decontamination carried out indoors, external doses are calculated for indoors occupancy (in buildings with a range of shielding factors) only. In the case of resuspension doses, Garland's formula is applied to the initial deposition density onto grass/soil surfaces in the area, in the same way as for the calculation of resuspension doses for the public. This approach results in identical estimates for workers working indoors or outdoors. However, the uncertainties associated with estimating resuspension doses, particularly for workers, do not support differentiating between the two.

A.5.3 Treatment of daughter radionuclides

Six of the radionuclides considered by CONDO v2.1 have radioactive daughters, as listed in Table A.3. Since EXPURT v2.02 cannot model daughter in-growth explicitly, three sets of approximations have been used to estimate external doses, surface activities and activity concentrations in waste. The choice of approximation depends on the halflife of the daughter relative to that of the parent, and the respective emission energies of the parent and daughter. For the calculation of resuspension dose, a single approximation is used: that the parent and daughter radionuclides are inhaled in their equilibrium ratio amounts. The inhalation dose coefficients adopted explicitly take account of subsequent in-growth of daughters. A detailed discussion of the approximations used and their consequences is provided in a separate report [Charnock *et al*, 2003]. A summary of the key issues of relevance to the user are presented here.

Table A.3 Parent-Daughter chains in CONDO v2.1

Parent	Daughter (equilibrium ratio[a])	Halflife	Gamma Energy (MeV)[b]	Beta Energy (MeV)[b]	Alpha Energy (MeV)[b]
caesium-137		30 y	-	0.2 (0.9)	-
	barium-137m (1:1)	2.6 m	0.7 (0.9)	-	-
ruthenium-106		368 d	-	0.01 (1.0)	-
	rhodium-106 (1:1)	30 s	0.5 (0.2)	1.5 (0.8)	-
zirconium-95		64 d	0.7 (1.0)	0.1 (1.0)	-
	niobium-95 (1:2.22)	35 d	0.8 (1.0)	0.04 (1.0)	-
barium-140		12.7 d	0.5 (0.2)	0.4 (0.6)	-
	lanthanum-140 (1:1.15)	40 h	1.6 (0.95)	0.5 (0.8)	-
plutonium-239		$2.4\ 10^{4}$ y	0.01 (0.1)	-	5.2 (0.7)
	uranium-235 (n/a[c])	$7\ 10^{8}$ y	0.1 (0.1)	-	4.4 (0.7)
americium-241		432 y	0.06 (0.4)	-	5.5 (1.0)
	neptunium-237[d] (n/a[c])	$2\ 10^{6}$ y	0.09 (0.1)	-	4.8 (0.7)

Notes:
(a) ie the ratio of the activity of the parent to that of the daughter at equilibrium.
(b) The energy listed is the highest energy that occurs with a frequency greater than 0.1 (frequency given in brackets); where two or more emissions with frequencies greater than 0.1 are close in energy, the weighted average and summed frequencies are presented.
(c) Equilibrium ratio not given, as equilibrium is not reached on a timescale of interest to users of CONDO.
(d) The decay chain beyond neptunium-237 is not shown.

The daughters of caesium-137 and ruthenium-106 are both very short-lived. Therefore, it is assumed that the daughters are in permanent equilibrium with their parents. These chains are treated as single, hybrid radionuclides, with the emission energies of the daughter, and the halflife and name of the parent. For the user, the only considerations are that CONDO v2.1 does not allow the separate entry of the daughter radionuclides, and the surface activities and the activity concentrations in waste (reported as those of the parent) should be interpreted as the sum of the activities of the daughter and the parent in equilibrium.

The daughters of zirconium-95 and barium-140 have halflives of days. Although equilibrium between the parents and daughters will be established relatively quickly, it will take some days (tens of days for zirconium/niobium) for equilibrium to be established. In order to avoid a substantial error in the estimation of doses and activities in the period before equilibrium is established, CONDO v2.1 assumes that the parent and the daughter are deposited in the environment in their equilibrium ratio activities. Thereafter, a similar approach to that described for caesium-137 and ruthenium-106 can be adopted. Owing to the assumption that the parent and daughter have been deposited in their equilibrium ratio, it is important for the CONDO user to check the validity of this assumption for the scenario under study. If a greater activity of the daughter is measured in the environment than that expected from the equilibrium ratio, then CONDO v2.1 supports input of the additional activity of the daughter as a radionuclide in its own right. If there is less activity of the daughter measured, then the doses reported by CONDO v2.1 at early times will be over-estimated.

For the alpha emitting chains, the daughters have very much longer halflives than the parents. The contribution to dose and activity from these daughters on the timescales of interest to CONDO users (at most, some tens of years) will therefore be very small compared with that of the parent radionuclides. For this reason, the contribution to both external dose and inhalation of resuspended material from in-growth of the daughters is ignored in Condo v2.1.

A.5.4 Direct costs of decontamination

The reviews of decontamination techniques [Brown *et al*, 1996; Brown and Jones, 2000; Charnock *et al*, 2003] provided estimates of the resources required for each technique and surface type. The resources required may cover a number of different items - eg, fire engines, lawn mowers, road scrapers etc, as well as monetary costs. The monetary costs of implementing each technique are stored for decontamination of unit area, sub-divided between equipment, labour and materials costs. As discussed in Section A.2.6, some techniques are suited to application in relatively small-scale discrete units, whilst others are suited to larger areas. CONDO v2.1 calculates the total surface area within a region, described by the user as ‘fragmented’, and the remaining surface area (by implication ‘continuous’) and calculates costs accordingly. In calculating the direct costs of decontamination, CONDO sums these monetary costs; other direct costs, in particular, the cost of disposing of waste, are not estimated quantitatively, but are presented qualitatively, eg as amount of, and activity concentration in, waste.

A.5.5 Equipment requirements

The reviews on which the information in the database is based [Brown *et al*, 1996; Brown and Jones, 2000; Charnock *et al*, 2003] included review of the equipment requirements of each of the decontamination techniques listed in Table A.1. The CONDO database (v2.1) holds this information, together with comments on the likely local and national availability of the equipment, and CONDO displays it together with the other results for each decontamination technique.

A.5.6 Timescales and manpower required

There are four aspects to the generic quantity 'timescale': (1) the timescale constraints for a given decontamination technique to be effective; (2) the time required to muster the necessary physical resources; (3) the time required to carry out the decontamination technique itself (in days); (4) the time to restore the environment to its pre-decontamination state (ie, mature trees etc). Information on the first, second and fourth timescales is held in the database as text, as a function of decontamination technique, surface class and, for the first timescale, as a function of radionuclide and deposition mechanism (wet or dry). This information may be accessed by the user via the results forms.

Regarding timescale 1 above, CONDO v2.1 specifies a time ‘window’ for optimum implementation of each technique. The information in the database concerning the reduction of activity and dose achieved by each technique, and waste activity levels expected to result from them is appropriate to implementation of each technique during its optimum time ‘window’. A technique may well still reduce activity after this time (and the user is free to request later implementation times), but CONDO v2.1 assumes that any technique started after its appropriate time ‘window’ has no effect. A technique started within the time ‘window’, but completed after it, is assumed to reduce activity as if it had been carried out entirely within the optimum time ‘window’.

The time required to muster the equipment (timescale 2) is not provided directly by CONDO. However, the user can estimate this from the information provided about the equipment requirements, as described in Section A.5.5 above.

The time to carry out the countermeasure is calculated from the number of teams, specified by the user, available to carry it out. A team is defined as the number of people in a single unit needed to carry out the countermeasure (a team would consist of more than one person, for example, where equipment is used that requires more than one person to operate it, or where a measure consists of more than one process, each needing an individual skill). In CONDO v2.1, the number of teams available for decontaminating continuous and fragmented areas (see Section A.2.6) are specified separately by the user. CONDO assumes that the resources appropriate to the number of teams specified are available. The database holds estimates of the work rate (km^2/team.day) that could be expected from each team, and this, together with the number of teams, is used to calculate the time it would take to carry out the decontamination option. CONDO assumes that each team works for 8 hours per day: 24-hour shift-working can be represented by trebling the number of teams available. The user also has the option, for both continuous and fragmented areas, of specifying an efficiency factor to account for factors that might substantially alter the work-rate achieved from that held in the database, eg if respiratory equipment were used which reduced the rate at which members of the team could implement the decontamination.

In addition to the absolute timescale for carrying out a decontamination measure, the man days of work required is also calculated and is presented to the user in the second level results screen. This provides a comparator between decontamination options.

A.5.7 Waste arising

The database holds information on the amounts (kg km^{-2}) of wastes arising as a result of applying each decontamination technique, as indicated by reviews [Brown *et al*, 1996; Brown and Jones, 2000; Charnock *et al*, 2003]. In CONDO v1.0, waste activities were calculated from information held in the database. The activity concentrations were only given for caesium-137. With CONDO v2.1, activity concentrations are calculated directly from the surface concentration immediately before and immediately after decontamination (assuming decontamination to be instantaneous) and thus the reported waste activity and surface activity are always consistent and tied directly into the DF of the radionuclide. However, in order not to underestimate the activity concentration in waste, the time of generation of the waste is taken to be the start of the decontamination. This is in contrast to the calculation of doses, where decontamination is assumed not to reduce doses until the measure has been fully completed (see Section A.5.2).

As discussed in Section A.5.3, six of the radionuclides considered within CONDO have radioactive daughters. The methods adopted for estimating the contribution of these daughters to total activity concentration in the waste are as described in that Section.

CONDO also generates comments regarding the form of the waste, the type of activity (beta/gamma or alpha) and an indicative classification: ie, high level waste (HLW), intermediate level waste (ILW), low level waste (LLW), very low level solid waste (VLLW) or exempt waste.

A.5.8 Relocation costs

CONDO v2.1 uses the same methodology as CONDO v1.0 to calculate relocation costs, ie the COCO-1 methodology [Haywood *et al*, 1991]. According to this model, the monetary cost of relocation comprises six components: loss of income, capital stock, land, dwellings and consumer durables, and transport costs. A single set of cost data are held in the database for general application to the UK. These are those recommended in the COCO-1 model. The duration of relocation is supplied by the user and is assumed to include an average resettlement time. However, after a period of time the model assumes that the economy adjusts and people acquire new permanent jobs. Thus the relocation duration specified by the user is subject to a cut-off point for the calculation of costs. This cut-off time is set to 2 years, as recommended by Haywood *et al*.

A.6 References

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APPENDIX B: DESCRIPTION OF CONDO v3.0

This appendix describes, at a high level, the methodology that CONDO v3.0 follows. A detailed technical description of the model will be published separately by NRPB in its W series. CONDO v3.0 is, in many respects, the same as v2.1, except that a new EXPURT model (v3.0, see Appendix C) has been included. This has required some modification to the way that the CONDO user specifies the composition of a region (see Appendix A, Section A.4.1), and has required alterations to the database, in that information on environments and surfaces within those environments is now obtained directly from EXPURT. In addition, during the development of CONDO v3.0, further changes were made to the endpoints provided and some additional enhancements have been made to the interface.

B.1 Changes Required by the Incorporation of EXPURT v3.0

EXPURT v3.0 calculates doses for a particular ‘environment’ or housing type, whereas EXPURT v2.02 calculated doses for an area comprising a mix of housing types (also called ‘environments’ in CONDO v1.0 [Charnock *et al*, 2000] and CONDO v2.1). Tables B.1 and B.2 summarise the main differences between the ‘old’ and ‘new’ style environments.

Table B.1 Default environments in CONDO v2.1 / EXPURT v2.02[a]

Environment	Fraction of area by building shielding			Fraction of area by surface type			
	Low[b]	Medium[c]	High[d]	Soil/grass	Paved	Buildings[e]	Tree/shrub
Rural	0.2	0.75	0.05	0.6	0.15	0.25	0.0
Semi-urban	0.05	0.8	0.15	0.2	0.4	0.4	0.0
Urban	0.05	0.6	0.35	0.1	0.4	0.5	0.0

Notes:

(a) In CONDO v2.1, the user was presented with default surface proportions for the environments, but was allowed to vary them. The user was not allowed to vary the proportions of different types of shielded buildings.

(b) Low shielded houses are representative of buildings of lightweight construction, eg timber framed houses; mobile homes.

(c) Medium shielded houses are representative of buildings of brick construction, typically two storeys high, eg detached, semi-detached or terraced brick built houses.

(d) High shielded houses are representative of multi-storey, solidly built buildings, eg blocks of flats, office blocks, buildings above 4 storeys.

(e) This is the fraction of the area covered by the ‘footprint’ of the buildings.

Table B.2 Environments in CONDO v3.0 / EXPURT v3.0[a]

	Fraction of area by surface type (default % fragmentation[b])			
Environment	Soil/grass	Paved	Buildings[c]	Trees/shrubs
Lightweight houses[d]	0.54 (90)	0.32 (50)	0.14 (100)	0.1[h] (0.5)
Brick houses[e]	0.52 (80)	0.30 (50)	0.18 (100)	0.1[h] (0.5)
Multi-storey buildings[f]	0.47 (50)	0.28 (50)	0.25 (60)	0.1[h] (100)
Open green areas[g]	0.90 (20)	0.10 (50)	0	0.1[h] (50)

Notes:

(a) In CONDO v3.0 the user is not allowed to change the proportions of the surfaces within an environment. This is because the underlying EXPURT and CONDO databases (DB1 vA.0 and DB2 vA.01 for EXPURT v3.0 and database v3.0 for CONDO v3.0) were created based on the parameter values in the table.

(b) The designation of areas of a surface type as 'fragmented' or continuous' indicates the techniques and type of equipment that would be appropriate for decontaminating them, as discussed in Appendix A, Section A.2.6.

(c) This is the fraction of the area covered by the 'footprint' of the buildings. The land area covered by buildings in the EXPURT v3.0 environments is about half of that assumed in the EXPURT v2.02 environments. Subsequent releases of the EXPURT database may alter this. It is unclear at present exactly how sensitive the doses calculated are to the relative land area covered by houses and outdoors surfaces, since a number of factors, interacting in a complex manner, contribute to the doses calculated. Comparisons with the doses calculated using EXPURT v2.02 suggest that, overall, the re-specification of environments has not resulted in substantial changes to either the overall doses nor the relative importance of different surfaces.

(d) Lightweight houses are representative of buildings of lightweight construction, eg timber framed houses; mobile homes. They have the same shielding properties as 'low shielded' buildings in EXPURT v2.02.

(e) Brick houses are representative of buildings of brick construction, typically two storeys high, eg detached, semi-detached or terraced brick built houses. They have the same shielding properties as 'medium shielded' buildings in EXPURT v2.02.

(f) Multi-storey buildings are assumed to be solidly built, eg blocks of flats, office blocks (above 4 storeys high). They have the same shielding properties as 'high shielded' buildings in EXPURT v2.02.

(g) Doses in open green areas are assumed to be unaffected by the presence of buildings. As is clear in the table they are assumed to contain some paved component. Examples of open green areas are parks and playing fields. There is no equivalent 'environment' in EXPURT v2.02.

(h) The value given for foliage in this table is the fraction of soil/grass area, not the fraction of the overall environment area, as foliage is assumed to be associated only with the soil/grass surface. The fraction of foliage does not affect the summation of the other surfaces to unity, as foliage is assumed to contribute additional surface area to the soil/grass surface, not to replace it.

Each of the new-style EXPURT environments is made up of a set of identical rectangular cells, each containing a building of specified dimensions and shielding properties, surrounded by a specified mix of paved, soil/grass and tree/shrub surfaces. The CONDO user constructs a CONDO region by specifying the proportions of the region that comprise each environment type (eg 50% brick buildings, 10% multi-storey buildings, 20% lightweight buildings and 20% open green areas). The user no longer has the option to directly change the proportion of different surface types, although this can be done indirectly (to some extent) by changing the proportions of new style environments within a CONDO region[25].

In calculating doses, CONDO assumes each individual spends a proportion of his/her time in each of the environments that make up the region[26]. Each environment in this release of the

[25] Strictly, the limitation on the user with regard to changing building dimensions, shielding properties and spacing between buildings, within an environment, is imposed by EXPURT. The limitation on the user with regard to changing the relative proportions of paved, soil/grass and tree/shrub surfaces is imposed by CONDO.

[26] In this Appendix the term 'dose' is used to mean the sum of the committed effective dose from inhaling radionuclides resuspended from surfaces during the user specified time period and the whole body external dose

software is assumed to have up to two locations within it where individuals may spend their time: indoors and outdoors. The environment ‘open green areas’ has only one such location: outdoors. From information on the assumed proportions of time spent in each location, CONDO calculates indicative doses to the public (see Section B.4.7).

As with CONDO v2.1 a distinction is made between techniques and equipment appropriate for small scale and ‘low rise’ application, and those appropriate for large scale and ‘high rise’ application (see Appendix A, Section A.2.6). Areas within which small scale / ‘low rise’ techniques and equipment are appropriate are designated ‘fragmented’, whilst areas within which large scale / ‘high rise’ techniques and equipment are appropriate are designated ‘continuous’. CONDO v3.0 provides default proportions for the area of each surface within an environment that is ‘fragmented, which the user may change.

CONDO v3.0 requires certain information about the environments used by EXPURT in order to run. Some of this information is derived from the EXPURT data libraries, some is obtained from the user (see two paragraphs below). In order to avoid asking the user to input the same information every time CONDO is re-started, this information is stored in CONDO’s own database, linked to the other information relevant to that environment using an ‘Environment ID’ that matches the Environment ID in the EXPURT database. Although the user is not required to re-enter user-supplied data about the environment for each run of CONDO, this option is available, should the user wish to change what has been previously entered. In this case, CONDO overwrites the original set of user specified environment data.

EXPURT v3.0 has been written so that additional new-style environments can be added to its libraries. The libraries themselves are now databases instead of flat files. There is a need therefore for CONDO to be able to respond to new environments as they are made available, and also to modify existing ones. On starting, CONDO scans the EXPURT databases, checking not just the Environment ID, but also the other relevant environment data, in case a correction has been made to information used by CONDO in the EXPURT database. If any of the relevant environment data is changed for an existing ID or a new Environment ID is detected, then CONDO directs the user to check these new data and, if necessary, to modify the related information that the user may change. If any of the environment IDs currently in the CONDO database are not located in the EXPURT database, or any of the EXPURT data for an existing environment ID has been changed, CONDO’s entry for this Environment ID is deleted and a warning issued[27].

There are some environment attributes that CONDO is not able to acquire from the EXPURT database. EXPURT has no concept of surface fragmentation, and neither does it have a concept of land value (needed for the costing of relocation). As new environments are identified and written into the CONDO database, CONDO adds default values for these attributes. The user is then presented with a window that enables him/her to modify the default values and to see the attributes derived from the EXPURT database.

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from deposited radionuclides, integrated to the user specified time. In general, one of these two pathways will strongly dominate the total dose received. These doses are calculated for adults. No account is taken of exposures from the airborne plume.

[27] Note: when new EXPURT environments are made available in the future, detailed guidance on the procedure for installing the new information within CONDO will be provided at that time.

B.2 Additional Endpoints Calculated

The following endpoints have been added to the endpoints calculated by CONDO v3.0:

- a ‘typical’ category (A, B and C) for each technique in the database, according to the framework recommended by NRPB for recovery decisions [NRPB, 1997]
- outdoor doses that represent extreme behaviour (in addition to ‘normal living’ doses, as provided in CONDO v2.1)
- the number of teams required to carry out a decontamination option within a time period specified by the user (in addition to the functionality of CONDO v2.1 that allows the user to set the number of teams from which the time required is calculated).

B.2.1 Technique categories

The framework recommended by NRPB for recovery decisions specifies three categories of countermeasure: A, B and C [NRPB, 1997]. These categories are based on an assessment of how dose effective a technique is likely to be and its potential for disruption and cost. In summary, they are defined as follows:

A moderately dose effective and only moderately disruptive or costly; can be completed within one month of the accident

B relatively highly dose effective but also costly or highly disruptive; unlikely to be completed within one month of the accident

C either only weakly dose effective or moderately dose effective but costly.

A given technique may be categorised differently depending on local circumstances. However, for the purposes of CONDO v3.0 a typical category has been assigned to each technique to provide initial assistance in scoping options for decontamination. The results are presented as a column on the 1st Level Results form. The user is able to order the results on this field, thereby grouping the techniques according to their broad NRPB category. Users are intended to refine this initial, scoping, categorisation in the light of specific circumstances.

B.2.2 ‘Normal living’ and outdoor doses

CONDO v2.1 calculated only ‘normal living’ doses, ie average doses to an individual spending part of the time indoors and part of the time outdoors in the mix of environments specified by the user as comprising the region. CONDO v3.0 retains the concept of a ‘normal living’ dose endpoint, but allows the user to specify the occupancy factors used to define the fraction of time spent in each indoor and outdoor location in the region (see Section B.4.7).

The option of outdoor dose is intended to be used to represent the ‘worst-case’ dose, i.e. the dose to a member of the public should he/she adopt extreme behaviour, such as remaining outdoors continuously. Because of the configuration of surfaces and the movement of radionuclides between surfaces, different new-style EXPURT environments give different outdoor doses at different times. CONDO returns the dose of the environment that is highest for each integration period, together with the environment for which this applies.

B.2.3 Number of teams and duration of decontamination work

By default, in CONDO v3.0 the numbers of teams in both ‘fragmented’ and ‘continuous’ areas (see Appendix A, Section A.2.6) are calculated from the amount of time the user specifies that the decontamination work will take. Alternatively, the amount of time needed can be calculated from the number of teams available for the work, as specified by the user. This second option is the same as that in CONDO v2.1.

B.3 Methodology Changes

The methodology for calculating resuspension doses to the public and workers has been improved.

B.3.1 Resuspension doses

In CONDO v2.1, all resuspension doses were calculated according to Garland’s methodology for resuspension above soil/grass surfaces [Garland, 1979]. The method for estimating the dose reduction achieved by implementing decontamination or tie-down techniques was based on the amount of initial deposition to soil/grass surfaces and the total amount of radioactivity in the environment, available for resuspension, both before and after application of the technique. This method made no distinction between the relative reduction of radioactivity on indoor and outdoor surfaces. It also assumed that the appropriate rate for reduction of resuspended radioactivity with time was that provided by Garland’s empirical formula. For simplicity, and recognising the high degree of uncertainty associated with resuspension estimates, no attempt was made to compare and, if necessary, to harmonise, the Garland formula with the time variations of activity densities on surfaces predicted by EXPURT.

In CONDO v3.0 indoor and outdoor resuspension doses, for both workers and the public, are calculated differently, as recommended by Walsh [2002]. Outdoor resuspension doses and the effect on doses of decontaminating outdoor surfaces is modelled in the same way as in CONDO v2.1. However, indoor resuspension doses are calculated using a constant resuspension factor, as recommended by Walsh [2002].

The resuspension factor recommended by Walsh for calculating indoor resuspension doses does not decrease with time: the assumption is made that radioactivity present on indoor surfaces is always available for resuspension. In order to account for the rate of loss of radioactivity from indoor surfaces (through domestic cleaning etc), which is modelled in EXPURT with a 30 day half life, a dose cut-off at six months is adopted. The effect of decontamination is calculated using a dose reduction factor based on the total activity on indoor surfaces before and after decontamination, in the same way as for the calculation of outdoor resuspension dose.

B.4 Interface Design

Some significant interface changes have been introduced between CONDO v2.1 and CONDO v3.0. Some of these have been required as a result of the incorporation of EXPURT v3.0, whilst others have been introduced following extensive use of earlier versions of CONDO. This section summarises those changes.

B.4.1 Design overview

Figure B.1 shows the connections between forms.

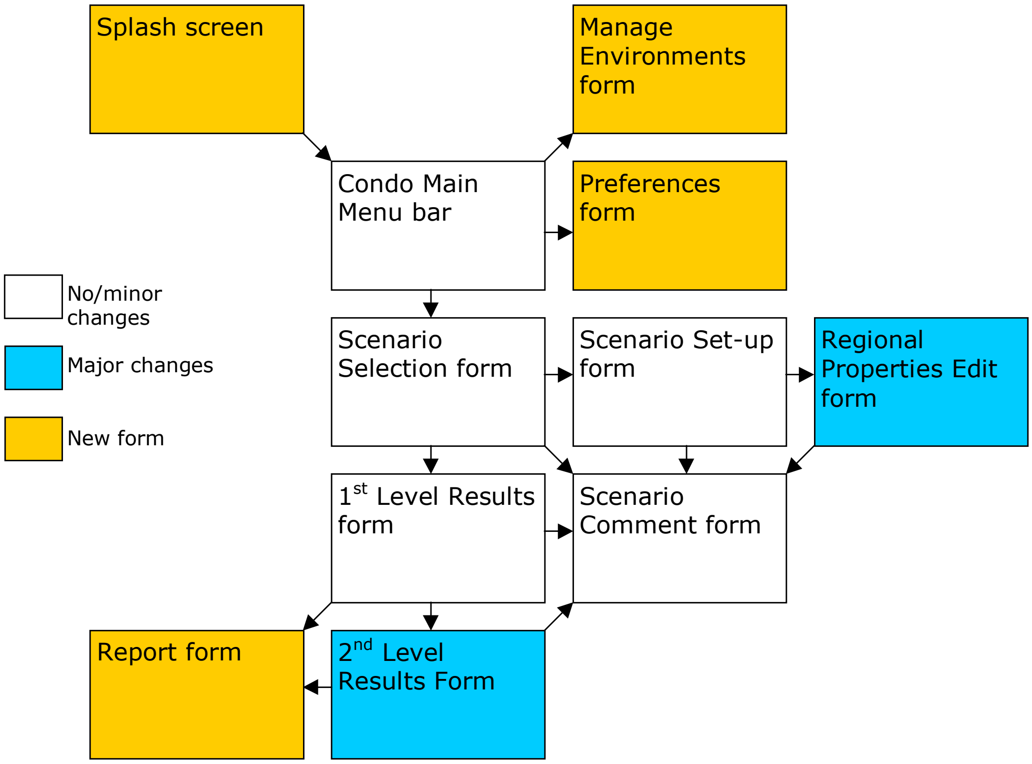


Figure B.1 Connections between new and existing forms.

B.4.2 Splash screen

The Splash screen appears as CONDO3.0 is starting. It performs no functions. The Splash screen contains the name of the program, the version of the program and of the database, and, the NRPB logo.

B.4.3 CONDO Main Menu bar

This is positioned along the top of the screen as it allows the user to navigate between forms and to access the help and other forms that are available globally, e.g. the new Preferences form.

B.4.4 Manage Environments form

The Manage Environments form is displayed automatically should any new environments be found in the EXPURT database. The user can also browse this form by calling it from the main menu. The form displays all the environments available and the various associated attributes. For each EXPURT environment, the user may change the degree of fragmentation of each surface, the population density and the economic value of the area.

B.4.5 Preferences form

The Preferences form allows the user to specify the way numbers are displayed (ie scientific notation or decimal) and the whether outdoor or ‘normal living’ doses are to be calculated. The choice for the display of numbers will apply to all numbers except those that refer to proportions (e.g. proportions of different environments within a region).

B.4.6 Scenario set-up form

This form has only slightly changed.

Unlike in CONDO v2.1, the user is not able to set the time of ‘first rain’ in CONDO v3.0. This is because of the revision to EXPURT; it is now not a useful parameter to make available to the user. It is also no longer possible to set the number of regions on this form. This was found to be both unnecessary and confusing in CONDO v2.1.

In other respects this form has stayed the same.

B.4.7 Regional Properties Edit form

As before the Regional Properties Edit form is divided into four parts: a region section, an environment section, a radionuclide section and a commit/cancel section.

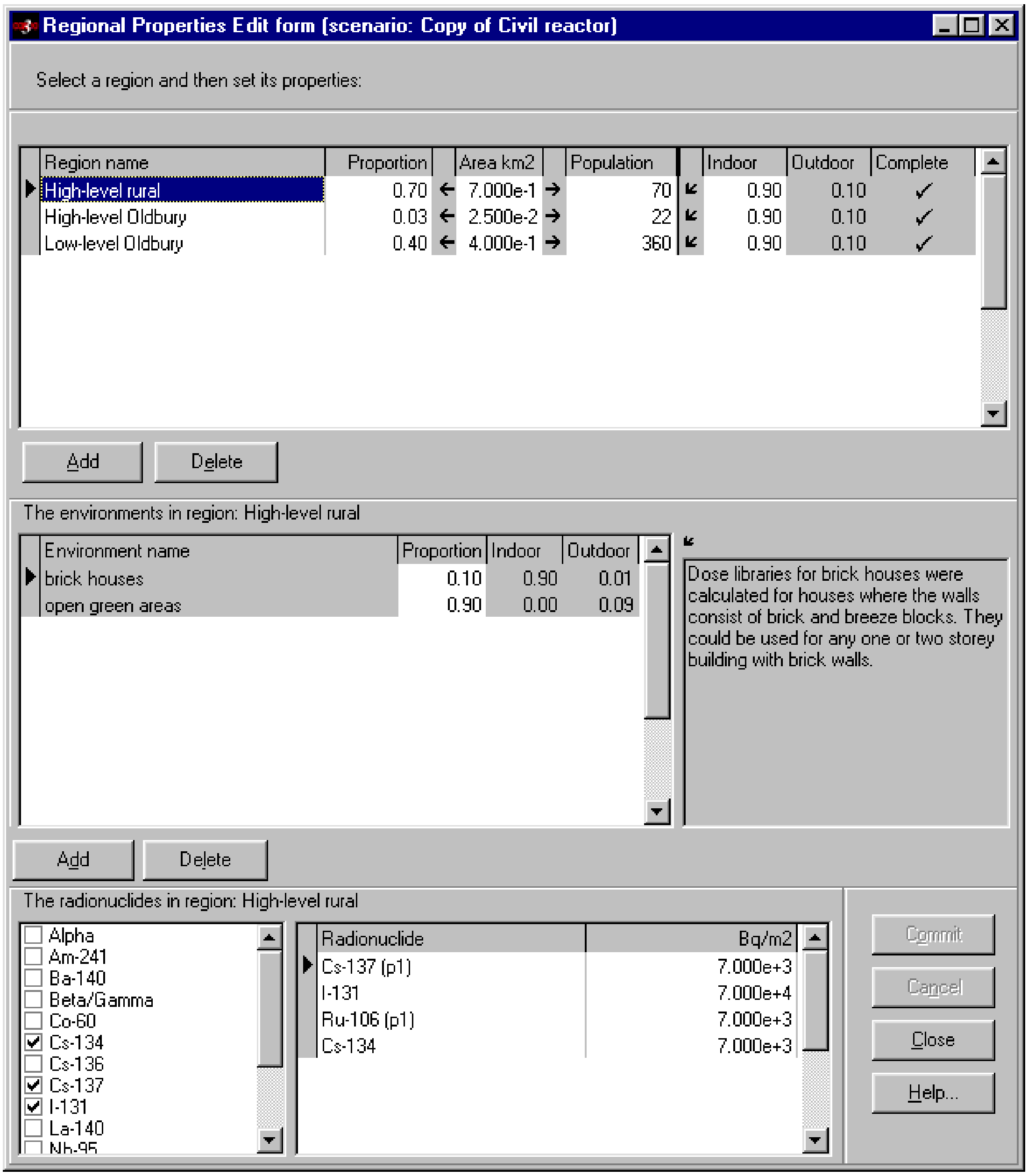


Figure B.2 Regional Properties Edit form

Region section

In this part of the form the user enters details about each region (for the definition of a CONDO region, see Appendix A, Section A.4.1 and Section 2.3.1 of the main text), in particular, areas and populations.

CONDO v2.1 required the user to ensure that the summed areas of the regions within a scenario summed to the scenario area. As discussed in Section 2.3.1 of the main report, this is no longer required. CONDO v3.0 allows regions to be specified without reference to the size of other regions or to the size of the scenario area. This form allows the user to specify the region area either as a proportion of the scenario area or as an absolute value (in which case the proportion will be calculated by CONDO). Both values are linked so that changing one results in the other being updated. Arrows in this section indicate which value has been set and which value has been derived from it. CONDO issues a warning if proportions do not sum to unity, however this will not prevent the user from performing an analysis.

Each new-style environment has a default population density associated with it. These are used to calculate a default population for the environment and hence the default population for the region as a whole. Populations are used for two purposes in CONDO v3.0. The first purpose is the estimation of the cost of relocating the population. The methodology for this is unchanged from CONDO v2.1 (see Appendix A, Section A.5.8). The second purpose is the apportionment of occupancy factors between indoor locations in each environment (as discussed below). As with CONDO v2.1, the user is able to overwrite these defaults. An arrow indicates whether a population has been derived from a default population density and the region area. If the population has been directly set by the user the arrow will be absent.

In this section of the form, the user may enter the overall indoor and outdoor occupancy factors for the region. If these are provided, then CONDO apportions them between the environments specified on the 'environment' section of the form as follows. For indoor occupancy, the overall indoor occupancy factor is apportioned according to the relative population sizes in each environment. For outdoors occupancy, the overall outdoor occupancy factor is apportioned according to the relative sizes of the environments. (The method used for indoor occupancy cannot be used for determining outdoor occupancy factors because the 'open green areas' environment is given a population density of zero, by default.)

Environment section
In this section of the form, the environments within each region are specified, together with the detailed occupancy factors, if overall occupancy factors have not been provided in the 'region' section of the form. The environments must be selected from those provided by the EXPURT database, as listed in a drop-down box on the form. The user also specifies the proportion of the region that comprises this environment type.

The user may specify indoor and outdoor occupancy factors explicitly for each environment (except for open green areas for which only an outdoor occupancy factor may be specified). The user must ensure that these values sum to unity. A region is treated as incomplete until these occupancy factors sum to unity, and a scenario is treated as incomplete until all regions are complete (ie the user is unable to close the form).

Radionuclide section
In CONDO v3.0, the user specifies the deposition levels of radionuclides in the same way as in CONDO v2.1.

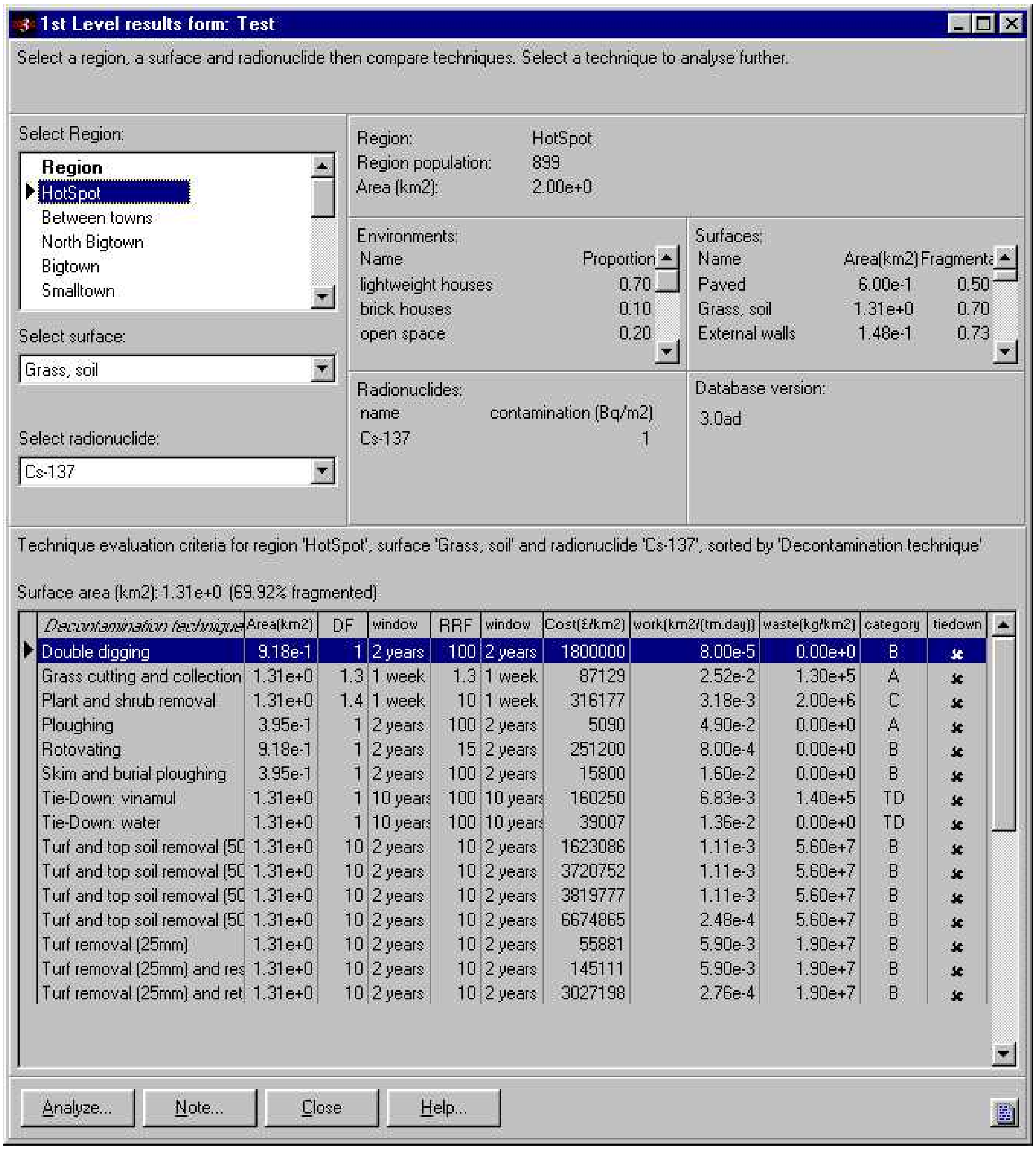
Commit section
The process of committing changes to the database is unchanged from CONDO v2.1.

B.4.8 Scenario Comment form

The Scenario Comment form enables the user to enter any notes about the scenario that they feel are appropriate. They can enter notes about the scenario as a whole or about an individual region. The notes are put on a separate form in CONDO v3.0, to provide for extensive notes being made. Forms that call the Scenario Comments form link automatically to the notes appropriate to the region under investigation.

B.4.9 1st Level Results form

The 1st Level Results form is only slightly changed. The format of results is determined by whether the user has specified scientific or decimal notation (see Section B.4.5). A report button has been added to enable selected options to be written to the new Report form.



Decontamination technique	Area(km2)	DF	window	RRF	window	Cost(£/km2)	work(km2/(tm.day))	waste(kg/km2)	category	tiedown
Double digging	9.18e-1	1	2 years	100	2 years	1800000	8.00e-5	0.00e+0	B	
Grass cutting and collection	1.31e+0	1.3	1 week	1.3	1 week	87129	2.52e-2	1.30e+5	A	
Plant and shrub removal	1.31e+0	1.4	1 week	10	1 week	316177	3.18e-3	2.00e+6	C	
Ploughing	3.95e-1	1	2 years	100	2 years	5090	4.90e-2	0.00e+0	A	
Rotovating	9.18e-1	1	2 years	15	2 years	251200	8.00e-4	0.00e+0	B	
Skim and burial ploughing	3.95e-1	1	2 years	100	2 years	15800	1.60e-2	0.00e+0	B	
Tie-Down: vinamul	1.31e+0	1	10 years	100	10 years	160250	6.83e-3	1.40e+5	TD	
Tie-Down: water	1.31e+0	1	10 years	100	10 years	39007	1.36e-2	0.00e+0	TD	
Turf and top soil removal (50	1.31e+0	10	2 years	10	2 years	1623086	1.11e-3	5.60e+7	B	
Turf and top soil removal (50	1.31e+0	10	2 years	10	2 years	3720752	1.11e-3	5.60e+7	B	
Turf and top soil removal (50	1.31e+0	10	2 years	10	2 years	3819777	1.11e-3	5.60e+7	B	
Turf and top soil removal (50	1.31e+0	10	2 years	10	2 years	6674865	2.48e-4	5.60e+7	B	
Turf removal (25mm)	1.31e+0	10	2 years	10	2 years	55881	5.90e-3	1.90e+7	B	
Turf removal (25mm) and res	1.31e+0	10	2 years	10	2 years	145111	5.90e-3	1.90e+7	B	
Turf removal (25mm) and ret	1.31e+0	10	2 years	10	2 years	3027198	2.76e-4	1.90e+7	B	

Figure B.3 1st Level Results form

As with CONDO v2.1, the user selects the surface type of interest, and the area of the surface and its degree of 'fragmentation' are displayed. Again, as with CONDO v2.1, each technique appropriate for this surface is listed, together with relevant summary information concerning unit costs and likely consequences. In addition, the techniques are assigned an initial category, A, B or C, according to the framework recommended by NRPB, as discussed in Section B.2.1. This categorisation is indicated on this form as an additional column against which techniques can be ordered. A time window for each technique is also listed, which indicates the time from deposition over which the technique can be expected to be effective.

B.4.10 The 2nd Level Results form

The 2nd Level Results form is for analysing the consequences of applying a single technique to a single surface.

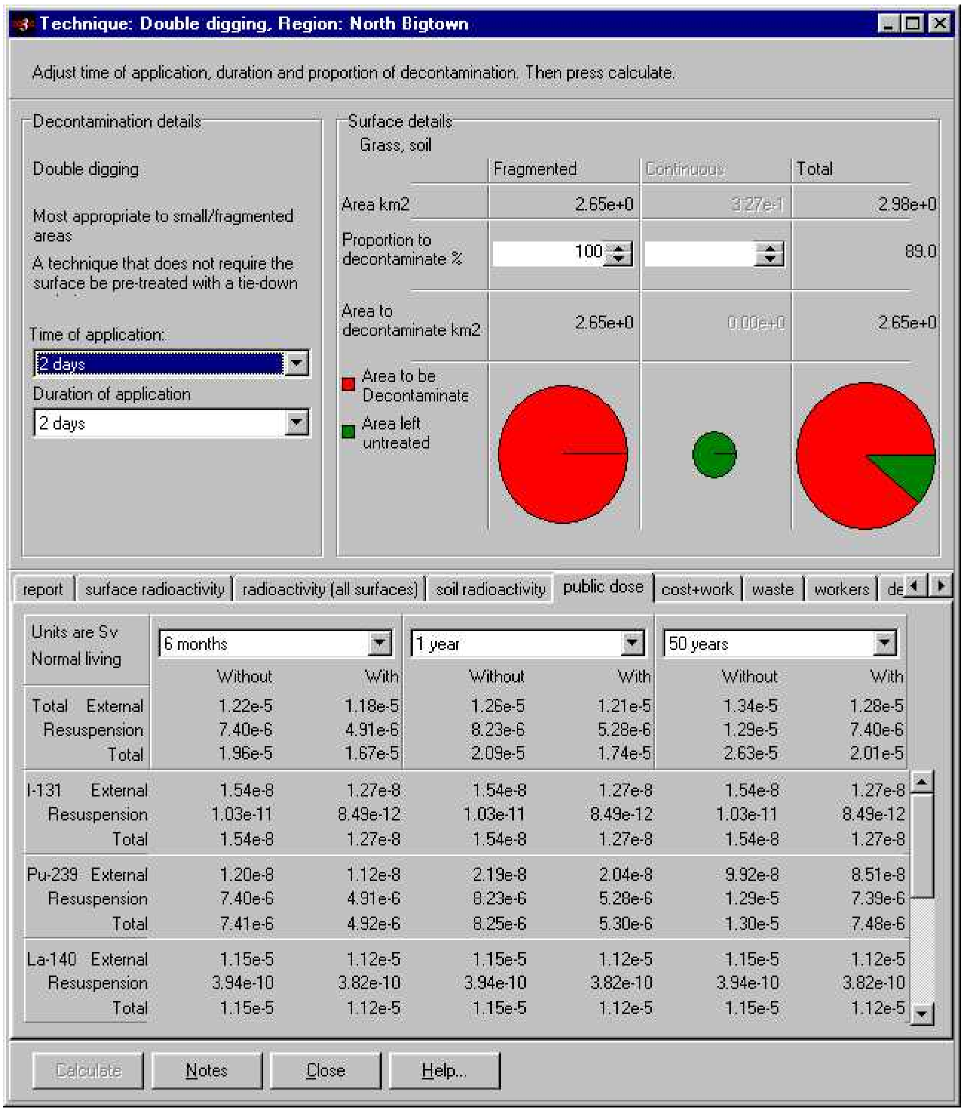


Figure B.4 2nd Level Results form

Changes from CONDO v2.1

In appearance the 2nd Level Results form has changed very little. The main difference is the addition of a drop-down menu to allow the user to enter the time estimated for the decontamination work to be carried out. In addition, most of the functionality on the CONDO v2.1 Report tabsheet has been exported onto the CONDO v3.0 Report form.

Overview of 2nd Level Results form

The 2nd Level Results form is divided into four areas.

Top left: This provides details about the technique. It also allows the user to specify when the technique will be applied and how long it is estimated it will take to implement.

Top right: This provides information about the surface: its area and how 'fragmented' it is. It also allows the user to specify the proportion of the area which is to be decontaminated.

Centre: This comprises a set of tabsheets on which most of the results are presented.

Bottom: This provides the buttons for controlling the form.

Technique section
CONDO v3.0 adopts a default start time for the decontamination of 2 days and a default duration for the implementation of the technique of 2 days. When the 2nd Level Results form is first entered, the results on the tabsheets are presented for these defaults. The user is then free to vary either or both of these and to re-calculate the results. If the user prefers to specify the number of teams available to carry out the work, rather than the time the decontamination work will take, then this is achieved by altering the number of teams on either the Worker or the Cost+Work tabsheet. Since these two quantities (number of teams and time taken to implement the work) are directly linked, the user may only specify one, and CONDO will automatically calculate the other.

Surface section
This section provides information to the user about the composition of the surface, both numerically and using pie charts. The user is able, separately to specify the proportions of the 'fragmented' and 'continuous' areas of the surface that will be decontaminated (see Appendix A, Section A.2.6 for a discussion of the terms 'fragmented' and continuous').

Tabsheets
The tabsheets provide the following results.

- Amount of radioactivity on surfaces: the amount of radioactivity with and without decontamination on the surface being decontaminated at up to two user-specified times (the default times are 1 week and 1 year), and also immediately before and immediately after decontamination. Information is also available about the changing levels of radioactivity with time on all surfaces, as a result of both natural processes and the decontamination work.

- Public dose: individual external and resuspension doses integrated to up to 3 user-defined times (defaults are 6 months, 1 year and 50 years). The same integration times are used for both external and resuspension doses.

- Worker dose: individual external and resuspension doses calculated over the period of the decontamination work, assuming that the worker works in the place that gives the highest exposure throughout his/her shift.

- Cost and man-hours required to carry out the work: the cost and man-hours required to decontaminate the area specified, and either the time required to apply the technique or the number of teams required, depending on which of these quantities the user has specified. Results are provided for both 'fragmented' and 'continuous' areas of the surface.

- Details about the technique: the comments from the database which describe the techniques and equipment requirements etc.

- Notes: user entered notes about the scenario and the region.

- Waste: the amount of waste, the activity concentration within it and the waste classification.

- Relocation: the population within the region (based on default population densities, or the user entered value), the time for which they are to be relocated (the default is 5 years, but the user may change this) and the cost of relocating these people for the specified time period (according to the COCO-1 model [Haywood *et al*, 1991]).

In addition, the Report tabsheet enables the user to select results and comments for compilation within a report. This report may be edited to a limited extent within CONDO, using the Report form, printed or exported to another word processor. All reports generated by CONDO v3.0 automatically contain the time and date that the report was generated and information about the technique, the region and the surface being decontaminated.

B.3 Database Design

The main changes that have been made to the database have been to accommodate the new-style EXPURT environments. Additional changes have also been made to accommodate minor changes to the CONDO methodology and general improvements to the database design. Some of the results tables have been discarded as it has proved simpler to generate the results as SQL queries rather than calculating them in the Delphi code and storing them in the database.

B.4 References

Charnock, T, Prett, AJ, Brown, J, Higgins NA and Morrey M (2000). CONDO: Software for estimating the consequences of decontamination options. Report for CONDO version 1.0 (with database version 1.2). Chilton, NRPB-R313.

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APPENDIX C: TECHNICAL DESCRIPTION OF EXPURT v3.0

Arthur Jones and Lucia Singer

This appendix describes the EXPURT model included in CONDO v3.0. EXPURT v3.0 is included in the CONDO package as a DLL which is called from other parts of the program. Some of the information required to use EXPURT is obtained from two databases supplied with the system, while other parts are obtained from input to the CONDO system. One database (DB1) holds information relating to the calculation of dose rate from the predicted surface activities; the other (DB2) holds information relating to the initial deposition and subsequent movement of material around the environment.

This appendix briefly describes the models included in EXPURT v3.0, together with DB1 vA.01 and DB2 vA.01, its two associated databases. An earlier version of the EXPURT model is described by Crick and Brown [1990]. The current version differs in some ways from that version, although the general features described by Crick and Brown are relevant to the current version of the model.

C.1 Environments and Exposure Pathways

EXPURT v3.0 separately models environments containing a single type of building (or no building) and sums the results according to the mix of environments specified by the user[28]. Dose rates and relative areas of different surfaces are intended to represent average values in inhabited areas. Each environment is modelled as a regular grid of rectangular cells, as illustrated in Figure C.1 for 4 cells[29]. Each cell contains a single building of the specified dimensions and construction material, surrounded by an appropriate mix of outdoor components (ie paved, soil/grass and tree/shrub surfaces). Information describing the environments is stored in the EXPURT databases DB1 and DB2. Some of this information has been used to generate base dose data and so cannot be altered by the user during a run of EXPURT. This information is stored in DB1. Some information describing the environment is modelled dynamically within EXPURT and so it is possible for an informed user to vary it. Default values for these data are stored in DB2.

DB1 vA.01 and DB2 vA.01 provide for four environments, those containing: lightweight, timber framed buildings, brick built houses, multi-storey buildings and open green areas away from buildings. The buildings are those identified as low, medium and high shielded in Crick and Brown [1990]. Each of the environments containing buildings assumes the buildings are spaced at regular intervals with 20 m between the faces of adjacent buildings. Within these environments, EXPURT models the initial deposition and transfer of radioactivity with respect to up to six surface types: paved, soil/grass (also representing plants and small shrubs), tree/shrub (representing trees and large shrubs), roofs, exterior walls and internal surfaces. The dimensions of the buildings and the area of the environment 'cell' (ie the

[28] Although EXPURT v3.0 provides the option of summing results across environments, as implemented in CONDO v3.0 it is CONDO that provides the summation.

[29] The environments adopted clearly represent a very idealised description of inhabited areas. However, the detailed modelling of more 'realistic' environments requires substantial resource and computer time, and hence needs careful justification and planning. The provision of these stylised environments provides a foundation for scoping the likely doses and consequences of decontamination in inhabited areas, following deposition from a radioactive release. It also provides a basis on which sensitivity analyses can be undertaken, in order to focus development work on the most important parameters and modelling assumptions.

building plus outdoor surfaces extending to 10 m from each face of the building) are listed in Table C.1. These cannot be changed during a run of EXPURT and so are stored in DB1. The relative fractions of paved and soil/grass surfaces comprising the outdoor surfaces, and factors describing the degree of tree/shrub cover, are listed in Table C.2. These can be changed during a run of EXPURT and so are stored in DB2[30].

EXPURT calculates doses and dose rates to individuals, both indoors and outdoors, from radioactivity deposited on each of the six surfaces, and also calculates doses and dose rates outdoors in an area where the dose from material deposited on building surfaces can be neglected. Therefore EXPURT considers:

- dose rates indoors from activity on the internal surfaces and external walls and roof of the building considered
- dose rates indoors from activity on paved, soil/grass and tree/shrub surfaces
- dose rates outdoors from activity on external walls and roofs of the nearest buildings
- dose rates outdoors from activity on paved, soil/grass and tree/shrub surfaces.

The database DB1 includes values for dose rate per unit deposition from each of the surfaces mentioned above. It is assumed that all buildings contributing to dose rates at a location have similar shielding properties and sizes, ie they are all within the same EXPURT environment. The assumptions used in calculating the dose rates per unit deposition are discussed in a later section.

C.2 Model for Deposition and Transfers within the Environment

EXPURT models the transfers in the environment following deposition of material to surfaces in residential or open areas, and calculates doses and dose rates at a range of times following the initial deposit. Following initial deposition to the surfaces specified for the environment (some or all of soil/grass, tree/shrub, paved, internal, external walls and roof surfaces), EXPURT models the transfer of radioactivity between these surfaces with time and the removal of radioactivity into drains and sewers.

The model is illustrated in Figure C.2, which shows the transfers between building surfaces and paved areas and the run-off to soil and drains, and Figure C.3, which shows the transfers for radioactivity onto and from the leaves of trees and shrubs and the movement of radioactivity down the soil column. The movement of material is modelled using first order differential equations, and so the assumption is made that a specified fraction (represented by the transfer coefficient) of the total amount of activity on any surface transfers in unit time to the other surfaces as indicated in the figures. EXPURT thus requires information on the total amount of material in each of the compartments indicated in Figures C.2 and C.3. This is obtained from the relative deposition to the different surfaces (expressed in Bq m^{-2} of the actual surface), the relative amounts of the different surfaces in the area under consideration (expressed in m^2 of surface per m^2 of environment 'cell' area), and the rates at which material transfers between surfaces following its deposition. The default values for these quantities are stored in the EXPURT databases. As discussed above, the default values for the fractions of the overall area covered by each surface are obtained from DB1 and DB2; those in DB1 vA.01 and DB2 vA.01 are listed in Tables C.1 and C.2. Database DB2 contains values

[30] Whilst it is possible for the user to change the information listed in Table C.2 when running EXPURT directly, CONDO v3.0 does not offer the user this option.

for the relative dry deposition to the different surfaces and the interception factors adopted for deposition occurring under wet conditions; the relative wet deposition to walls is calculated from the angle at which rain is assumed to fall. DB2 also stores information used to calculate the transfer coefficients between the surfaces. The default values for these parameters in DB2 vA.01 are given in Table C.3. The values are the same for all environment types in this version of the database. The justification for the numbers adopted is provided in Appendix B of a report describing CONDO v2.1 [Charnock *et al*, 2003].

Part of the radioactivity initially deposited on external walls, roofs and paved areas in dry conditions is firmly fixed to the surface, while the remaining activity is more readily removed; this is modelled by splitting the deposition between 'mobile' and 'fixed' components on the appropriate surfaces. However the mobile component rapidly becomes more firmly fixed. Any activity remaining in the mobile form is removed by the first rain which falls after deposition; these transfers are marked as dotted lines in Figure C.2. Default values for the fraction of the initial deposit which is firmly fixed, and the rate at which material is fixed after deposition are included in the database. Material deposited in rain either becomes firmly attached to the surface or is carried off the surface with the run-off water. The fraction that becomes firmly fixed is defined by the interception factor, a default value for which, as indicated in the previous paragraph, is held in DB2. Experimental data suggest that the transfers from walls, roofs and paved areas are largely caused by the action of rain on the deposited material. The transfer coefficients are calculated from a value for the fraction removed per mm of rain and the annual average rainfall rate, for which default values are included in DB2, as listed in Table C.3.

The transfers within the soil column are expressed directly in terms of the fraction of the activity from each compartment transferring per unit time. Default values are included in the database DB2 (see Table C.3); they are the same as those used for transfer in undisturbed pasture in the food chain model FARMLAND [Brown and Simmonds, 1995].

EXPURT also considers the dose from material deposited onto the leaves of trees and shrubs. The deposition to trees and shrubs, relative to that to soil/grass areas, for both wet and dry deposition is specified in the database DB2 (see Table C.3 for default values in DB2 vA.01). Material is lost from the external part of the leaves as a result of weathering and leaf-fall. EXPURT v3.0 does not include a detailed description of the loss of leaves in autumn, instead it uses a constant loss rate that reflects the average retention period on leaves of plants that do and do not lose their leaves in autumn.

The EXPURT model also includes the possibility of root uptake from soil to the internal parts of trees and shrubs. However, the mathematical techniques used to solve the equations in EXPURT v3.0 cannot handle the inclusion of root uptake. DB2 vA.01 therefore holds parameter values which exclude consideration of root uptake. It is intended, in future releases of EXPURT, to replace the method used to solve the equations by a different technique that is capable of handling the full model. Unpublished calculations have suggested that the dose from radioactivity in trees and shrubs resulting from root uptake is small compared to that from radioactivity deposited directly onto the leaves.

C.3 Dose Calculations

In addition to specifying the environments, database DB1 also holds values for the dose rates in each environment from unit deposition density on each of the surfaces modelled as contributing to dose. This section briefly summarises the assumptions and methods used for the dose calculations in DB1 vA.01. Values are given for each of the pathways identified above, for the four environments specified. For the environments with buildings, it was assumed that all buildings considered in the dose calculations were of similar size and thickness; the three environments provided in DB1 vA.01 and DB2 vA.01 represent the buildings described by Crick and Brown [1990] as low, medium and high shielded.

C.3.1 Environment model for calculating dose rates indoors

In order to calculate dose rates indoors, the environment shown in Figure C.1 was simplified slightly, and the dose rates were calculated assuming that the building is surrounded by land which extends 20 m from each face of the building (ie the nearest building wall in each direction is 20 m away). This is illustrated in Figure C.4. Dose rates were calculated for a location within the building that gives an estimate of the average indoor dose rate for that type of building. Dose rates indoors from material on paved, soil/grass and tree/shrub surfaces predicted for this approximation may be smaller than those obtained if the full description of Figure C.1 were to be used. This is partly because the calculations truncate the area of contaminated land and tree/shrub surfaces included in the calculation and partly because the contribution from radioactivity deposited on the external surfaces of adjacent buildings has been omitted. The effect of these modelling approximations will be small, however, as the activity that is not considered in the calculation is at a relatively large distance from the building, and the contribution to dose rate decreases rapidly with distance from the source.

Dose rates in lightweight buildings were calculated for houses where the walls consist of a timber framework with facing wood and plaster. They could also be used for other buildings where the walls offer relatively little shielding, such as mobile homes. Dose rates for brick houses were calculated for houses where the walls consist of brick and breeze blocks. They could be used for any one or two storey building with brick walls. Dose rates for multi-storey buildings were calculated for a block of flats with eight storeys. They could be used for other multi-storey buildings, such as office blocks or shops, but doses in three storey houses would be better represented by using the values for brick houses.

Dose rates indoors from radioactivity on the surfaces of the building being modelled were calculated using a detailed description of the building, allowing for the shielding effects of internal and external walls, floors and roofs. The dose is calculated to a person on the ground floor of the lightweight and brick houses and on a middle floor of a multi-storey building.

C.3.2 Environment model for calculating dose rates outdoors

For the calculation of dose rates outdoors, the configuration for the three environments containing buildings, shown in Figure C.1, would have resulted in outdoor doses being, in general, accrued from spaces bounded by buildings on two sides and extended open areas on the other two sides. In order to model the dose rates outdoors, this configuration was approximated to a square of side 20 m, bounded by buildings on all four sides, as shown in Figure C.5. Dose rates were calculated at the centre of the square. This approximation clearly underestimates, to some extent, the dose rates from radioactivity on paved, grass/soil and trees/shrub surfaces. Conversely, the dose rates from material on outdoor building surfaces are likely to be overestimated. However, in assessing the likely significance of these approximations, it is important to remember that the stylised configurations assumed for the three environments are also approximations to the wide mix of configurations that would be found in inhabited areas. In particular, the dose rate in real inhabited areas will vary at different locations in the environment, depending on the relative positions of different surfaces to the location being considered and the degree to which each is contaminated. In this context, the approximations are considered adequate for scoping the doses likely to be received, and the consequences of carrying out decontamination measures in these areas.

Dose rates in the environment identified as ‘open green areas’ were calculated assuming that the surfaces are infinite in extent. This environment is intended to represent typical park areas or playgrounds within inhabited areas. The dose calculations for this environment do not include any contribution from material on walls of buildings. Dose rates in open areas which are less than about 40 m across are probably better represented by using the outdoor dose in one of the environments with buildings.

C.3.3 Dose rate calculations

The values for dose rates indoors from material on the internal and external surfaces of the building were generated using the NRPB program GRINDS [Crick and Dimbylow, 1985]. GRINDS uses a point-kernel method for calculating dose rates. This program was also used to calculate the dose rate indoors and outdoors from material deposited on paved areas. The NRPB program GRANIS [Carey *et al*, 2003], which also uses a point-kernel method, was used to calculate the dose rates outdoors away from buildings from material in the different layers of soil considered in EXPURT. Dose rates indoors from radioactivity on soil/grass and tree/shrub surfaces were calculated by reducing the dose rate outdoors from those surfaces by the ratio of dose rates indoors and outdoors for a paved area. The values from GRANIS were modified to give the dose rate from finite areas of soil/grass using results from the Monte Carlo code MCNP [LANL, 2001]. This program was also used to calculate the dose rates outdoors from material on building surfaces.

Dose rates from radioactivity on trees and shrubs were calculated assuming that the dose rate per unit deposition of activity on trees and shrubs is the same as that from activity on soil/grass areas. This will tend to underestimate the contribution from activity on trees and large shrubs to dose indoors, as this activity may be at a similar height to the position of windows, and so there could be lower overall shielding provided by the buildings. Work is in hand to explore the significance of this potential underestimate.

C.4 Modelling Decontamination

EXPURT v3.0 considers three ways in which decontamination measures may affect the material in the area in which they are undertaken, namely:

- decontamination, where part of the radioactivity on a surface is removed from the area or transferred to other parts of the environment (eg drains)
- tie-down, which does not reduce the amount of radioactivity on the surface but alters the rate at which it subsequently transfers to other surfaces
- actions in soil which do not remove activity but redistribute the activity within the soil column.

If a surface is decontaminated, the user of CONDO v3.0 specifies a decontamination factor, which is the ratio of activity on the surface before and after the action is taken. EXPURT reduces the activity on the surface by the decontamination factor. EXPURT v3.0 includes two options; either the activity may be totally removed from the system or some part of it may be deposited on certain other surfaces, to model the possibility of transfer of material within the environment as a result of the action. This second option is not included in CONDO v3.0.

If the CONDO v3.0 user specifies a tie-down technique, this is modelled by changing the transfer coefficient for the surface affected. The amounts of activity on the surface are not altered.

Two types of action are included in soil: decontamination by the removal of activity, and dose reduction by redistributing the activity in the soil profile. As seen in Figure C.3, EXPURT models the movement of activity down the soil column using compartments representing the amounts of activity in the layers 0-1, 1-5, 5-15, 15-30 and 30-100 cm. The removal of radioactivity is modelled by removing all soil and a specified proportion of the radioactivity down to one of the depths corresponding to the depths of the soil compartments. Under this option EXPURT assumes that the transfer in the new soil column is at the same rate as in the original soil column, and so the amounts of radioactivity in depths 1, 5, 15, and 30 cm below the new soil surface are calculated from the remaining soil profile. These activities are allocated to the various compartments representing soil, and the subsequent movement of activity in the soil column is modelled. Radioactivity left behind from the removed soil layers is added to that in the new top soil layer. To model the redistribution of activity within the soil profile, the user specifies the fraction of the activity that is in each of the soil compartments after the action has been undertaken. EXPURT then replaces the original soil profile with this new soil profile.

C.5 References

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Crick M J and Brown J (1990). EXPURT: A model for evaluating exposure from radioactive material deposited in the urban environment. Chilton. NRPB-R235.

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LANL (2001) http://laws.lanl.gov/x5/MCNP/index.html

Table C.1 Values for the surface areas and fractions of different surfaces, in DB1 vA.01

Quantity	Values for environment type[a]			
	Lightweight buildings	**Brick buildings**	**Multi-storey buildings**	**Open green areas**
Surface area of building walls within an environment ‘cell’ (m^2)	240	360	2 240	0
Surface area of roofs within an environment ‘cell’ (m^2)	162	243	400	0
Surface area of internal building surfaces within an environment ‘cell’ (m^2)	1 240	1 952	14 240	0
Projected ground area of building within an environment ‘cell’ (m^2)	140	224	400	0
Total area within an environment ‘cell’ (m^2)	1 020	1 224	1 600	10 000
Ratio of area of building walls to total area of environment ‘cell’[b]	0.24	0.29	1.40	0
Ratio of area of building roof to total area of environment ‘cell’[b]	0.16	0.20	0.25	0
Ratio of area of internal surfaces to total area of environment ‘cell’[b]	1.22	1.59	8.90	0
Ratio of projected area of building to total area of environment ‘cell’[b]	0.14	0.18	0.25	0
Ratio of outdoor area to total area of environment ‘cell’[b]	0.86	0.82	0.75	1.00

Notes:

(a) EXPURT v3.0 models environments as a regular grid of rectangular cells, each containing a single building surrounded by an outdoor area extending to 10 m on each side.

(b) Database DB1 vA.01 only holds the areas of each surface, these ratios are calculated within EXPURT v3.0.

Table C.2 Values for the fractions of different surfaces and the behaviour of run-off water in the different environments, in DB2 vA.01

Quantity	Values for environment type			
	Lightweight buildings	**Brick buildings**	**Multi-storey buildings**	**Open green areas**
Fraction of ground area of environment 'cell' (excluding buildings) covered by paved areas	0.37	0.37	0.37	0.1
Fraction of ground area of environment 'cell' (excluding buildings) covered by trees and large shrubs	0.063	0.063	0.063	0.09
Sheltering factor for soil/grass surfaces[a]	0.9	0.9	0.9	0.9
Sheltering factor for paved areas[a]	1.0	1.0	1.0	1.0
Fraction of water running off walls that goes to paved areas rather than soil/grass	0.5	0.5	0.5	0.0
Fraction of water running over paved areas that goes to drains rather than soil/grass	0.7	0.7	0.7	0.5

Note:
(a) The sheltering factor enables the total initial deposition to soil/grass and paved surfaces modelled in wet conditions to be modified to account for the interception of radioactivity by overhanging trees and shrubs. The defaults offered here represent an outdoor area in which 10% of the soil/grass surface is covered by trees and shrubs, but where no part of the paved surfaces are sheltered by trees and shrubs. In CONDO this results in a modification of the user entered initial deposition to soil/grass (at time zero) under wet conditions, ie multiplication by the sheltering factor.

Table C.3 Default values of the parameters describing the initial deposition and rate of movement of material within the environment, in DB2 vA.01

Quantity	Units	Iodine	Other elements
Time of first heavy rain[a]	years	0.00342	0.00342
Mean annual rainfall rate	mm	920	920
Mean residence time of activity in drains	days	7	7
Mean residence time of activity on internal surfaces	days	30	30
Angle at which rain falls from the vertical	degrees	5	5
Mean retention time of water on walls	seconds	60	60
Mean retention time of water on paved areas	seconds	50	50
Migration rate in soil, 0-1 cm compartment to 1-5 cm compartment[b]	day^{-1}	$6.65\ 10^{-4}$	$6.65\ 10^{-4}$
Migration rate in soil, 1-5 cm compartment to 5-15 cm compartment[b]	day^{-1}	$1.72\ 10^{-4}$	$1.72\ 10^{-4}$
Migration rate in soil, 5-15 cm compartment to 15-30 cm compartment[b]	day^{-1}	$1.07\ 10^{-4}$	$1.07\ 10^{-4}$
Migration rate in soil, 15-30 cm compartment to 5-15 cm compartment[b]	day^{-1}	$4.03\ 10^{-6}$	$4.03\ 10^{-6}$
Migration rate in soil, 15-30 cm compartment to deep soil compartment[b]	day^{-1}	$3.\ 80\ 10^{-5}$	$3.\ 80\ 10^{-5}$
Fraction of mobile component fixed by roofs, walls and pavements per day	day^{-1}	1.4	1.4
Fraction of fixed component on roofs removed per mm of rainfall	mm^{-1}	$3\ 10^{-4}$	$3\ 10^{-4}$
Fraction of fixed component on walls removed per mm of rainfall	mm^{-1}	10^{-4}	10^{-4}
Fraction of fixed component on pavements removed per mm of rainfall, for "paved fixed fast" and "paved fixed slow" components	mm^{-1}	$3\ 10^{-3}$ $3\ 10^{-4}$	$3\ 10^{-3}$ $3\ 10^{-4}$
Fraction of dry deposition to roofs, walls and paved areas which is mobile		0.1	0.1
Ratio of dry deposition on roofs to soil		0.7	0.4
Ratio of dry deposition on walls to soil		0.06	0.05
Ratio of dry deposition on internal surfaces to soil		0.07	0.07
Ratio of dry deposition on paved areas to soil		0.1	0.1
Fraction of fixed paved component in the fast clearance compartment.		0.67	0.67
Ratio of dry deposition on trees and large shrubs to soil		10	10
Interception factor for wet deposited activity on roofs[c]		0.4	0.7
Interception factor for wet deposited activity on walls[d]		0.25	0.25
Interception factor for wet deposited activity on paved areas[e]		0.4	0.7
Interception factor for wet deposited activity on trees and large shrubs[f]		1.0	1.0
Retention coefficient for trees/shrubs[g]	years	0.7	0.7
Fraction of activity weathering from trees and large shrubs that goes to paved rather than soil/grass areas		0.0	0.0

Notes:

(a) These values correspond to 1.25 days.

(b) EXPURT also allows the use of a constant migration rate in soil. A default of 0.25 cm y^{-1} is provided in this database. However, CONDO v3.0 does not offer this option.

(c) This is the ratio of the fraction of activity deposited by rain that remains on the roof after the rain water runs off. The modelling assumptions in EXPURT v3.0 do not take account of the slope of roofs, and so EXPURT v3.0 models this ratio to be numerically equal to the ratio of activity deposited by rain and retained on roofs to that deposited by rain and retained on an open soil/grass surface (well away from other surfaces).

(d) This is the ratio of the fraction of activity deposited by rain that remains on the wall after the rain water runs off. Using the modelling assumptions in EXPURT v3.0 concerning the angle of rainfall and consequent sheltering of some of the walls, this interception factor results in a ratio of total activity deposited by rain and retained on walls to that deposited by rain and retained on an open soil/grass surface (well away from other surfaces) of 0.01for both iodine and other elements.

(e) This is the ratio of the fraction of activity deposited by rain that remains on paved surfaces after the rain water runs off. For the environments specified in DB1 vA.01 and DB2 vA0.2, it is numerically equal to the ratio of activity deposited by rain and retained on paved surfaces to that deposited by rain and retained on an open soil/grass surface (well away from other surfaces) as calculated in EXPURT v3.0.

(f) This is the ratio of the fraction of activity deposited by rain that remains on trees and shrubs after the rain water runs off. It is numerically equal to the ratio of activity deposited by rain and retained on trees and shrubs to that deposited by rain and retained on an open soil/grass surface (well away from other surfaces) as calculated in EXPURT v3.0.

(g) This corresponds to a half life of 6 months.

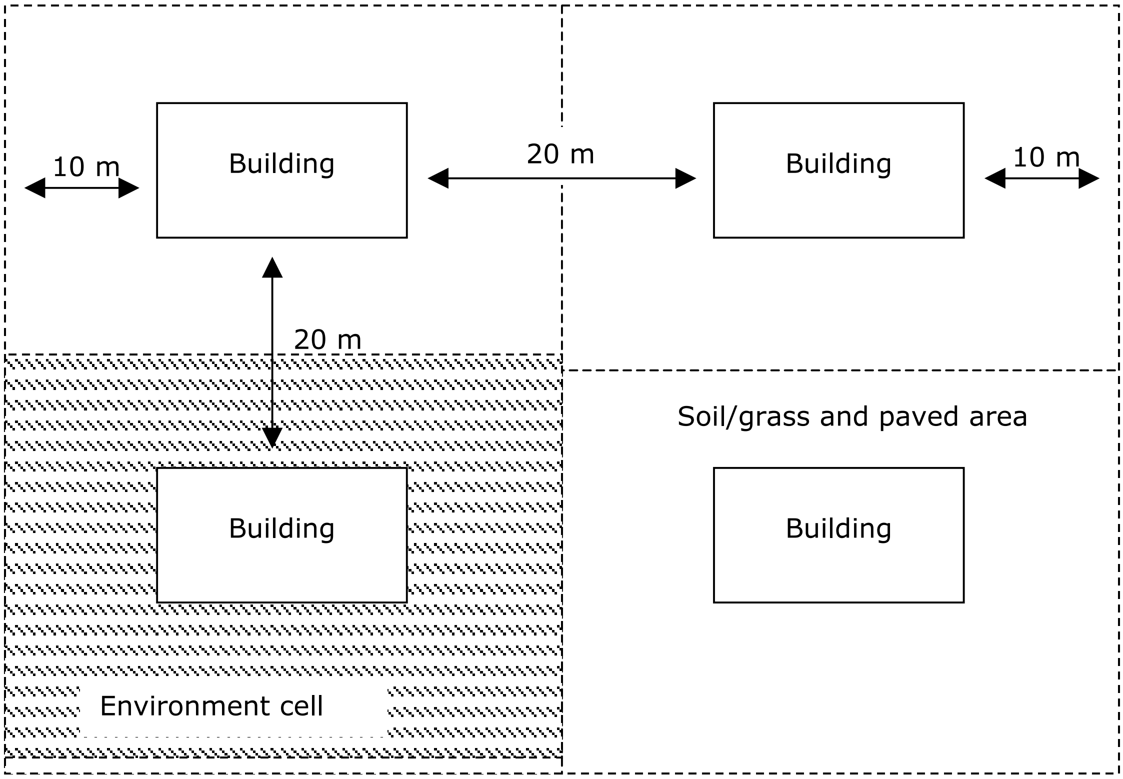

Figure C.1 The environment adopted to represent inhabited areas

Flows marked as dotted lines only occur at the time of first rain

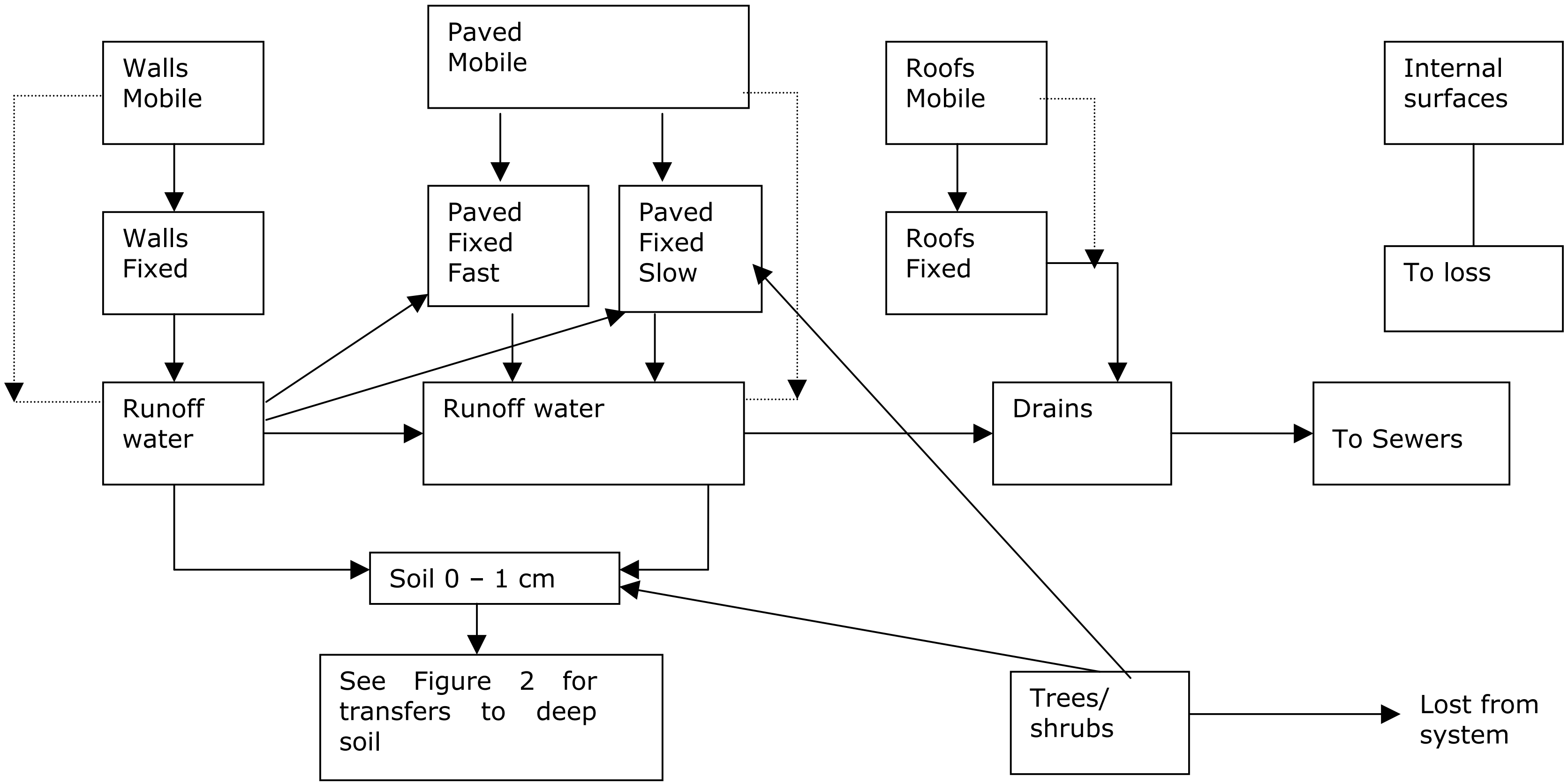

Figure C.2 Model for Transfer between Building Surfaces and to Soil

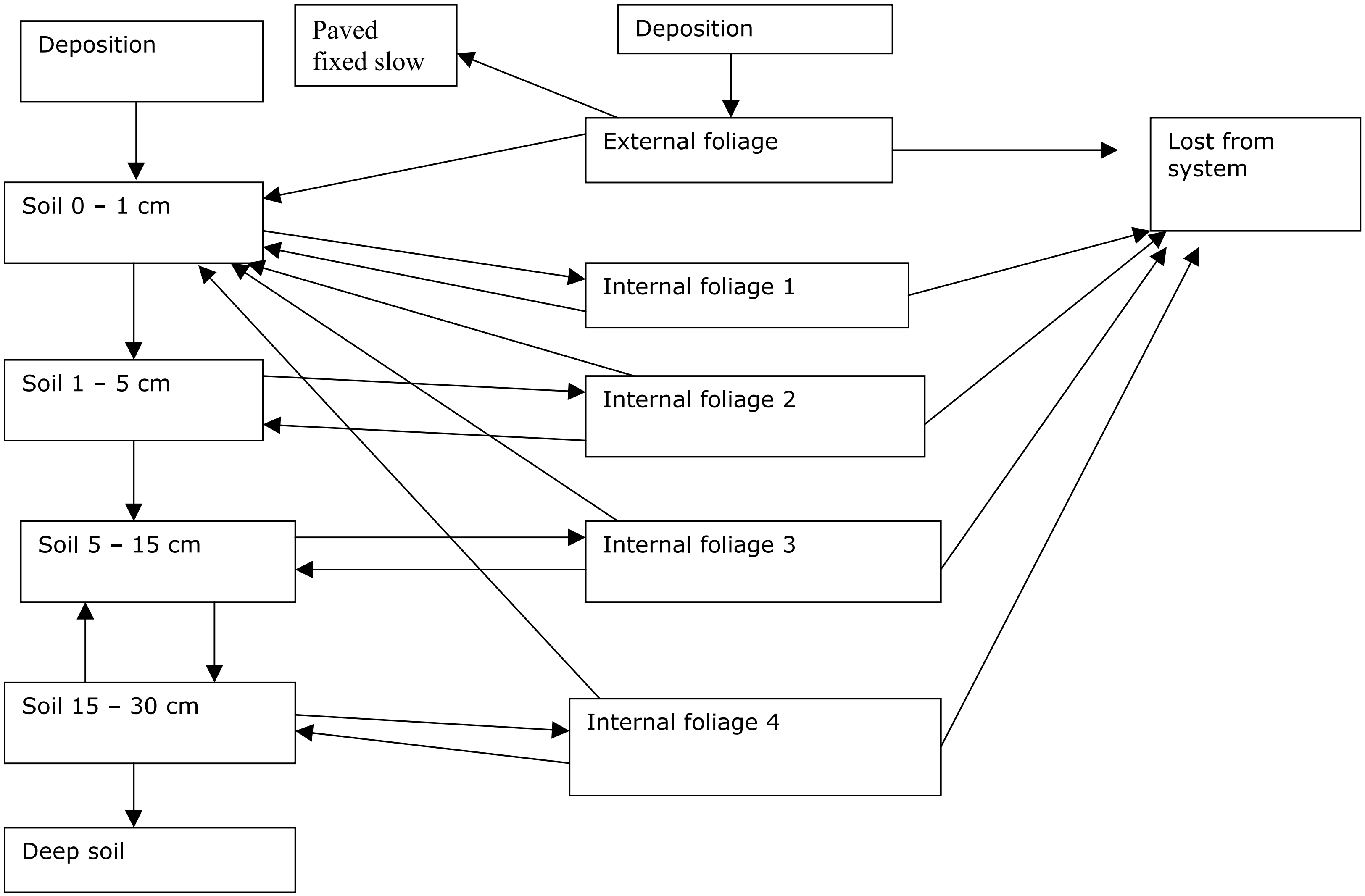

Figure C.3 Model for Transfers in the Soil and to Trees/Shrubs

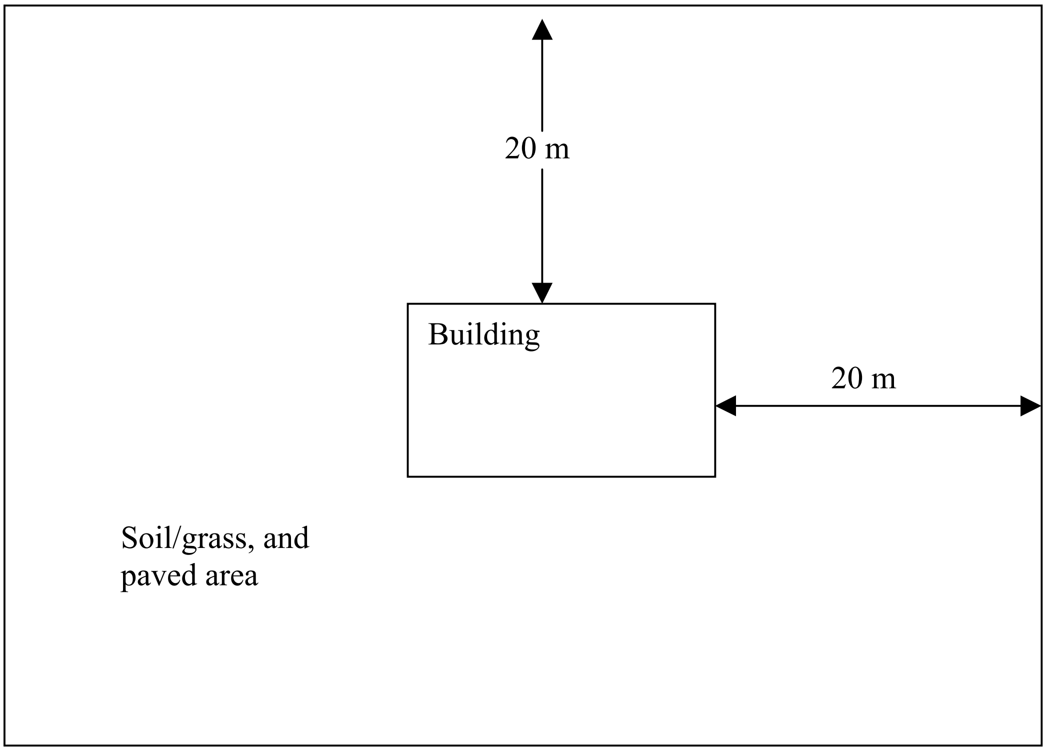

Figure C.4 The environment assumed for calculating dose rate indoors

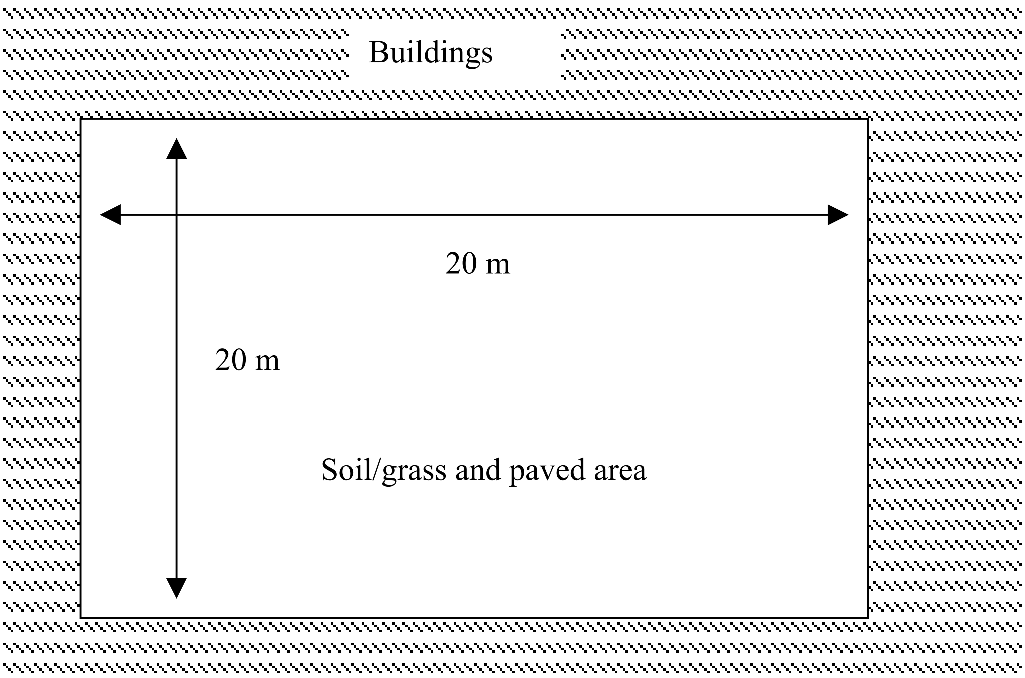

Figure C.5 The environment assumed for calculating dose rate outdoors