Volume 16 No.1 2005

Documents of the NRPB

Protection of On-site Personnel in the Event of a Radiation Accident

National Radiological Protection Board

Headquarters
Chilton, Didcot,
Oxfordshire OX11 0RQ

www.nrpb.org

Working in partnership with the Health Protection Agency

Contents

Protection of On-site Personnel in the Event of a Radiation Accident **1**

Executive Summary **3**

Introduction **9**

Scope **10**

Issues for On-site Contingency Planning **10**

Prior measures 11

Prompt detection 13

Identifying those most exposed 13

Clear, rehearsed procedures 14

Evacuation routes, shelters/mustering locations 14

Communication 14

Protection Principles **15**

Dose–response relationship 15

Emergency planning thresholds for serious deterministic injuries 15

Existing principles for the protection of the public off-site 16

Principles for the protection of on-site personnel 18

Avoidance of serious deterministic injuries 18

Annual dose limits 20

Framework for the Protection of On-site Personnel **20**

Interface with Off-site Planning **24**

References **24**

Appendix: Experience of Past Accidents **26**

PROTECTION OF ON-SITE PERSONNEL IN THE EVENT OF A RADIATION ACCIDENT

ABSTRACT

The National Radiological Protection Board (NRPB) is responsible, in the UK, for advising government and other responsible bodies on the principles for responding to radiological emergencies and for specifying emergency reference levels of dose (ERLs). NRPB has published appropriate advice on the off-site protection of the public and on the protection of workers involved in taking mitigating actions to reduce the exposures of others. However, advice has not yet been provided on the protection of those on-site personnel who are not involved in mitigating actions (hereafter termed 'on-site personnel').

This advice provides a framework for the protection of such on-site personnel in the event of a radiation accident. This framework both dovetails with existing planning for the protection of members of the public off-site and takes account of specific differences between the situations on- and off-site.

PREPARED BY M MORREY AND S J WATSON

This advice from NRPB reflects understanding and evaluation of the current scientific evidence as presented and referenced in this document.

Executive Summary

1 The National Radiological Protection Board (NRPB) is responsible, in the UK, for advising government and other responsible bodies on the principles for responding to nuclear or radiological emergencies involving ionising radiation and for specifying emergency reference levels of dose (ERLs). An accident involving the release of radionuclides could lead to exposures of individuals on the site where the accident occurs ('on-site') and also outside the site ('off-site'). NRPB has published specific principles and ERLs for the protection of the public off-site, together with guidance on the application of off-site countermeasures. NRPB has also published broad recommendations for the protection of workers taking mitigating actions to reduce the exposures of others both on- and off-site. However, advice has not yet been provided on the protection of those on-site personnel who are not involved in mitigating actions. Such people could include direct employees of the site operator, contractors and/or visitors to the site. In this document they are termed 'on-site personnel'.

2 Existing arrangements for the protection of on-site personnel have developed in response to the identification of specific risks and for the circumstances of specific sites. Legislation requires employers to undertake a risk assessment; to identify potential exposure risks from ionising radiation; to take steps to prevent or reduce these potential risks; and to prepare a contingency plan for mitigating the health consequences on-site should a radiation accident occur. However, the types of radiation accidents that need to be considered vary markedly between sites. In the absence of more specific guidance on the appropriate framework for developing detailed contingency plans, it has been difficult to maintain a common approach between different sites with different types of potential accident. The purpose of this advice is to bring all contingency planning within a common framework and to enable employers to plan to a common standard.

3 It is intended that this advice will assist in the development of contingency plans to protect people who are present on a site at the time of a radiation accident from exposure to ionising radiation resulting from the event, and who are not involved in mitigating actions to reduce the exposures of others. This advice provides a framework that both dovetails with existing planning for the protection of other groups and takes account of specific differences between the situations on- and off-site. This advice is not intended to be used to determine whether or not the preparation of a contingency plan is necessary.

4 There are a range of different types of sites at which events leading to exposures of on-site personnel could occur. Some sites have the potential for radiation accidents with significant consequences, both on- and off-site; for others the main concern is the exposure of people on-site. Crucially, some radiation accidents have the potential to expose on-site personnel to very high doses, well above the thresholds for serious deterministic injuries. Advice developed for the protection of on-site personnel must give priority to the protection of those at risk of suffering serious deterministic injury, whilst remaining consistent with existing advice on the protection of the public off-site and providing flexibility for specific differences between sites, types of accident, and situations on- and off-site.

5 From discussion of radiation accidents that have occurred it emerges that there are a few key issues common to all types of radiation accident affecting on-site personnel. These are:

(a) consideration of prior measures by the employer (ie actions taken in advance of an accident occurring),
(b) prompt detection of the occurrence and nature of the event,
(c) robust procedures for promptly identifying those who have received large exposures,
(d) clear response procedures which personnel have the confidence and training to follow appropriately,
(e) clearly signed evacuation routes, sheltering zones and mustering centres,
(f) communication mechanisms.

6 Additionally it is clear that it is difficult to predict the probability with which radiation accidents might occur. It is recognised that the probability of an accident occurring is likely to be a relevant factor in the decision on whether or not a contingency plan is required, and may sometimes be a relevant factor in the development of the contingency plan. However, if theoretical estimates of the low probability of an accident occurring are put forward as a justification for not providing special exposure mitigation measures, then the likelihood of large uncertainties associated with these estimates of probability should not be overlooked.

7 There are two key exposure bands relevant to emergency response plans: those where the doses and dose rates are sufficiently high to lead directly to serious deterministic injuries; and those (lower) doses and dose rates where serious deterministic injuries will not result, but the individual will have an increased risk of developing some later health problems, in particular of developing cancer (stochastic health effects). For exposures in the lower band, it is generally assumed that the size of the (stochastic) radiation risk is directly proportional to the size of the dose, and that there is no threshold dose below which there is no risk. However, serious deterministic injuries may be avoided entirely by preventing doses from exceeding the relevant thresholds for these injuries. NRPB recognises that a distinction should be made between the actual dose thresholds for serious deterministic injury (which vary according to many factors, including individuals, aftercare and exact circumstances of the exposure) and those recommended for contingency (or emergency) planning purposes. The latter need to be set at a (lower) level that provides confidence that no individual would be subject to serious deterministic injury if exposed to this dose. The threshold exposures for contingency planning purposes advised by NRPB are shown below.

8 The absence of a safe/unsafe boundary of dose for the risk of stochastic health effects forms the basis of the principles recommended by both NRPB and the International Commission on Radiological Protection (ICRP) for the protection of the public off-site. These principles are that when all the consequences of taking a countermeasure have been evaluated (including social as well as health and monetary factors) the countermeasure should be expected to do more good than harm (ie be justified) and it should be implemented in such a way as to maximise the net benefit (ie be optimised). Although it is unlikely that the threshold doses for serious deterministic injuries would be exceeded for members of the public off-site, NRPB also recommends, in a third principle, that if it were judged that such doses might reasonably occur following an

Type of radiation	Dose (Gy) [a]	Integration period
Low LET [b]	1 Gy whole body/red bone marrow 2–3 Gy other radiosensitive organs	Fractions of a second up to a few days
Neutron [b]	0.5 Gy whole body	Fractions of a second up to a few days
Alpha	1 Gy lung	Dose integrated to one year from acute inhalation

Notes

(a) These are thresholds recommended for the purposes of contingency/emergency planning; they are deliberately cautious compared with the likely biological thresholds for these injuries.

(b) These whole-body thresholds should be reduced by up to a factor of five for fetal exposure during the first 21 weeks of development.

accident, then every effort should be made to avoid them. NRPB recommends that the principles developed for the protection of the public off-site are adopted for the protection of on-site personnel. There are obvious advantages in the adoption of a common set of principles for the protection of individuals both off- and on-site, and the reasoning underpinning their development for the off-site situation applies equally to the on-site situation. A major difference between the potential consequences of radiation accidents on- and off-site is the much increased potential for serious deterministic injury to result on-site from some events. In order to develop a framework for planning for the protection of on-site personnel in the event of a radiation accident, it is therefore helpful to explore the application of the third NRPB principle in more depth.

9 The third NRPB principle implies a general presumption that any measure that has the potential to reduce exposure to levels where serious deterministic injuries will not occur is justified. However, there may be circumstances where a particular measure cannot be justified, ie the costs (or harmful consequences) of the measure outweigh the expected beneficial consequences. NRPB therefore recommends that the third principle is applied by explicitly considering all options with the potential for avoiding serious deterministic injury and only eliminating options from consideration on the basis of a specific case demonstrating that a measure is not justified. One clear basis for a measure not being justified would be where the risk of severe injury to those implementing the measure was even greater than that being protected against. A second reason could be that implementing the protective measure caused serious disruption to the routine operation of the business (eg the installation of alarms that, as well as guaranteeing to alarm in the event of a criticality accident, also had a very high false alarm rate). A further reason that might be put forward is that the strategy requires very high investment in advance of an accident occurring, whilst the likelihood of the accident is judged to be extremely low.

10 NRPB recognises that the balance of benefits and harms required for justification of a measure may be substantially different between an 'at-time' active measure and a prior measure requiring substantial investment (in terms of both resource and risk to those installing it) in advance of a radiation accident occurring. NRPB recommends that it is reasonable to differentiate between prior measures and at-time measures when exploring whether options for avoiding serious deterministic injury are justified. In situations where much of the cost of implementing the measure is only incurred at the time of the radiation accident, then the presumption of justification is stronger than in situations where most of the cost is borne in advance of an accident occurring.

11 The third principle implies a discontinuity between the protective measures adopted for those who might receive exposures sufficient to cause serious deterministic injury and those whose maximum exposures would solely increase their risk of developing stochastic health effects. A contingency plan that exhibited such a discontinuity would be entirely in accord with this advice. However, it is also possible that the response strategy may involve some blurring of the boundaries between the protection of the two groups of personnel. It is important to note that one factor that may well enter into the balance is a trade-off between the 'ideal' contingency plan for those whose potential exposure might result in serious deterministic injury and the 'ideal' contingency plan for others potentially exposed. NRPB recommends that, in such situations, it is the reduction of dose to those who might receive serious deterministic injury that should take priority.

12 The statutory annual dose limits are intended for application to situations where the source is under control. They do not consider the balance of harm and benefits associated with a one-off exposure resulting from a radiation accident. Although no employer is exempted from the specified dose limits in the event of an accident, the advice provided here is intended to assist employers with the preparation and implementation of contingency plans.

13 The NRPB principles for protection suggest that contingency planning for the protection of on-site personnel should be undertaken as a two-phase process: planning measures to protect those whose potential exposure in the event of a radiation accident might result in serious deterministic injury, and planning measures to protect those whose potential exposure would result solely in increased stochastic risk. Priority should be afforded to the development of those aspects of the plan that aim to protect individuals from serious deterministic injury. This requires:

(a) identification of those individuals at risk of such injury,
(b) identification of the range of measures which have the potential to reduce exposures below NRPB emergency planning thresholds,
(c) determination if there is a case for demonstrating that some of the measures are not justified,
(d) development of the response strategy to be implemented.

This strategy will almost certainly comprise both measures implemented in advance of an accident occurring, in order to support the 'at-time' response, and at-time measures, with the latter comprising reactive actions by the individuals themselves and measures taken on their behalf by others. The focus of this planning is to reduce individual doses to levels below the thresholds for serious deterministic injuries.

14 The second phase, to be initiated after planning the response strategy for those at risk of serious deterministic injury, is planning for measures to mitigate the exposures of those whose potential exposure would result solely in an increased stochastic risk. This would be done by balancing the expected benefits and harms to exposed groups, with consideration of both individual and collective consequences. It would be expected that greater resource would be expended on measures to mitigate the exposures of those potentially exposed at higher levels (ie who would be at higher risk of stochastic effects). Any planning of exposure mitigation measures for those not expected to receive serious deterministic injuries should be reviewed to ensure that the planned measure would not reduce the effectiveness of the measures planned to avoid serious deterministic injuries. Although the optimum strategy for mitigating exposures that would result only in an increase in stochastic risk would almost certainly include some expenditure of resource on prior support measures, it is likely that most measures in the strategy would only involve significant cost in the event of a radiation accident.

15 The framework recommended by NRPB for the identification of justified measures for consideration within contingency plans is summarised in the table below. The subsequent development of an appropriate optimised protection strategy is a matter for each site.

	Justified measures	
Consequence that planned response is protecting against	Planned responses requiring substantial investment prior to a radiation accident occurring	Planned responses for which most of the cost is borne after a radiation accident occurs
Serious deterministic injury	Most measures *(prior costs and probability of accident occurring may exclude measures)*	All measures
Exposure resulting in high individual risk of stochastic health effects	Some measures *(prior costs and probability of accident occurring are important factors in justification)*	Most measures *(protection of those at risk of serious deterministic injury remains first priority)*
Exposure resulting in moderate/low individual risk of stochastic health effects	Measures unlikely to be justified	Some measures *(protection of higher risk groups is priority; averaging harms/benefits across population groups appropriate)*

16 An accident which results in activation of the on-site contingency plan might result in doses off-site which would require an off-site response. Off-site emergency plans are based on the three NRPB principles and associated guidance for implementation of the three off-site countermeasures of evacuation, sheltering and administration of stable iodine. It is clear that, under these circumstances, care should be taken to provide an appropriate interface between the on-site contingency plan and the off-site emergency plan. In particular, any apparent difference between the level of protection provided to on-site personnel and members of the public off-site should be straightforward to explain and justify. In all cases, the presumption would be that the implementation of the emergency plan off-site would result in consequent risks to the public that were no higher than (and probably lower than) those incurred by on-site personnel situated at the site boundary.

INTRODUCTION

1 The National Radiological Protection Board (NRPB) is responsible, in the UK, for advising government and other responsible bodies on the principles for responding to nuclear or radiological emergencies involving ionising radiation and for specifying emergency reference levels of dose (ERLs) (Health Ministers, 1977). A radiation accident* could lead to exposures of individuals on the site where the accident occurs ('on-site')† and also outside the site ('off-site'). In 1990, NRPB published specific principles for the protection of the public off-site, and also broad recommendations for the protection of workers involved in taking mitigating actions to reduce the exposures of others, both on- and off-site (NRPB, 1990a). NRPB has also published ERLs for countermeasures intended to reduce public exposure off-site, together with guidance on the application of off-site countermeasures (NRPB, 1990b, 1997a,b). However, advice has not yet been provided on the protection of those on-site personnel who are not involved in mitigating actions (who would be likely to comprise the majority of those on-site). Such people could include direct employees of the site operator, contractors and/or visitors to the site.

2 Existing arrangements for the protection of on-site personnel have developed in response to the identification of specific risks and for the circumstances of specific sites. Legislation‡ requires employers to undertake a risk assessment; to identify potential exposure risks from ionising radiation; to take steps to prevent or reduce these potential risks; and to prepare a contingency plan for mitigating the health consequences on-site should a radiation accident occur§. However, the types of radiation accidents that need to be considered vary markedly between sites. For example, a criticality accident could be associated with potentially lethal external dose rates to those people close by over very short periods of time. However, a release of radioactive iodine would pose a predominantly carcinogenic inhalation hazard, with the exposure accumulating over a more protracted period of time and over a larger distance from the release point. Alternatively, an exposed radioactive source in an industrial facility or a hospital would pose a protracted external hazard, with dose rates that might vary from relatively small to lethal. In the absence of more specific guidance on the appropriate framework for developing detailed contingency plans, it has been difficult to maintain a common approach between different sites with the potential for different types of accident.

3 HSE has asked NRPB to develop principles and guidance for the protection of on-site personnel in the event of a radiation accident. The purpose of these principles is

---

* The Ionising Radiations Regulations 1999 (IRR99) (GB Parliament, 1999) define a 'radiation accident' as 'an accident where immediate action would be required to prevent or reduce the exposure to ionising radiation of employees or any other persons'.

† Strictly, 'on-site' is taken to mean the area that is under the management control of the activity that led to the accidental release.

‡ Regulations 7 and 12 of IRR99 deal with the requirements for risk assessment and contingency planning for radiation accidents.

§ Throughout, the phrase 'contingency plan' – as required by IRR99 – is used to refer to the plan for the protection of on-site personnel in the event of a radiation accident, and the phrase 'emergency plan' – as required by the Radiation (Emergency Preparedness and Public Information) Regulations 2001, REPPIR (GB Parliament, 2001) – is used to refer to the corresponding off-site plan.

to bring all contingency planning within a common framework and to enable employers to plan to a common standard. This advice provides a framework that both dovetails with existing planning for the protection of other groups and takes account of specific differences between the situations on- and off-site.

SCOPE

4 The purpose of this advice is to assist in the development of contingency plans to protect all people present on a site at the time of a radiation accident from exposure to ionising radiation resulting from the event, except those involved in mitigating actions to reduce the exposures of others*. In this context, the term 'site' is taken to mean any premises for which a contingency plan has been prepared under the requirements of Regulation 12 of IRR99 (GB Parliament, 1999) and/or the site licence conditions. This advice is intended as providing a framework for the development of the contingency plan. It is complementary to previous advice published by NRPB on emergency planning for the protection of the public off-site (NRPB, 1990a,b, 1997a) and to the requirements of REPPIR (GB Parliament, 2001), which deal with protection of the public off-site and the protection of intervention personnel.

5 As with the current NRPB advice for the protection of members of the public in the event of radiological emergencies, the proposed advice provided here is intended for application wherever the need for contingency planning has been identified. This advice is not intended to be used to determine whether or not the preparation of a contingency plan is necessary. This advice is also not intended to be used to determine measures for the prevention of radiation accidents. Such preventive measures are considered at an earlier stage in safety assessments (GB Parliament, 1999).

ISSUES FOR ON-SITE CONTINGENCY PLANNING

6 There are a range of different types of sites at which events leading to exposures of on-site personnel could occur, including nuclear licensed sites, hospitals, and industries using radiography sources, each with their own particular features. Some of these sites have the potential for radiation accidents with significant consequences, both on- and off-site, such as accidental releases from nuclear power reactors, reprocessing plants and large stores of radioactive materials (whether intended as waste or for use). For other types of radiation accident the main concern is the exposure of people on-site. Such situations include criticality accidents, large actinide or tritium releases within a confined space, accidents involving large x-ray/neutron generators, sources trapped outside their shielding, and a range of more limited spills, exposures and releases. Crucially, some radiation accidents (eg uncontrolled criticality, large airborne releases of radioactivity within laboratories, and failure of shielding around solid sources with

* For example, the scope of this advice does not include individuals defined as 'intervention personnel' under REPPIR (GB Parliament, 2001). It should be noted that the protection advice for those involved in mitigating actions provided by NRPB (1990a) has a wider scope than the REPPIR legislation.

high dose rates) have the potential to expose on-site personnel to very high doses, well above the thresholds for serious deterministic injuries*.

7 It is clear from the above that advice developed for the protection of on-site personnel must be consistent with existing advice on the protection of the public off-site. It should also be adaptable to specific differences between sites, types of radiation accident and the situations on- and off-site. With regard to differences between the on- and off-site situations, the greater likelihood (at some sites) of accidents resulting in on-site exposures above thresholds for serious deterministic injury must be addressed.

8 In the appendix some of the different types of radiation accidents that have occurred and that have exposed on-site personnel to doses above the relevant dose limit are discussed. These events cover those involving unshielded sources, airborne releases into confined areas and uncontrolled criticality events, as well as large accidental releases from nuclear sites involving significant off-site exposure. From this discussion it emerges that there are a few key issues that seem to be common to all types of radiation accident affecting on-site personnel. These are:

(a) consideration of prior measures by the employer (ie measures implemented in advance of an accident occurring),
(b) prompt detection of the occurrence and nature of the event,
(c) robust procedures for promptly identifying those who have received large exposures,
(d) clear response procedures which personnel have the confidence and training to follow appropriately,
(e) clearly signed evacuation routes, sheltering zones and mustering centres,
(f) communication mechanisms.

9 Another lesson that can be learned from the review of past events is that it is difficult to predict the probability with which radiation accidents might occur. It is recognised that the probability of an accident occurring is likely to be a relevant factor in the decision on whether or not a contingency plan is required, and may sometimes be a relevant factor in the development of the contingency plan. However, if theoretical estimates of the low probability of an accident occurring are put forward as a justification for not providing special exposure mitigation measures, then due account should be taken of the uncertainties associated with these estimates of probability.

Prior measures

10 Prior measures are measures put in place before a radiation accident occurs, that contribute to the reduction of exposures in the event of an accident. The term 'prior measures' may be used to cover two groups of measures. Prior *support* measures are put in place before a radiation accident occurs in order to facilitate or support an *active* response at the time of a radiation accident. Prior *passive* measures are also put in place before a radiation accident occurs, but they provide *passive* protection to individuals at risk without any active response being initiated.

---

* Deterministic injuries or deterministic health effects are those for which the severity of the effect varies with dose and there is a threshold of dose below which the effect does not occur. In this document, *serious* deterministic injuries are taken to be those deterministic health effects that are irreversible in nature, and which significantly impair the future quality of life of the individual.

11 Prior *support* measures form an integral part of the contingency plan. Most, if not all, measures that could be implemented to reduce exposures in the event of a radiation accident require some form of planning or infrastructure to be in place beforehand. Prior support measures range from physical measures, such as the provision of specialist equipment (eg detection and alarm systems, signed evacuation routes, specific monitoring equipment, stockpiles of stable iodine tablets and a suitably equipped emergency control centre) to the development of protocols, call-out registers and agreements with other emergency response organisations. In fact, the contingency plan itself could be viewed as a type of prior support measure. Similarly, emergency response training and emergency exercises would fall within this category of measure.

12 The role of prior *passive* measures within contingency planning is not so clear cut. Measures such as the construction of additional shielding, the design of adequate plant and processes or the fitting of automatic extraction devices might well serve to reduce exposures in the event of a radiation accident. However, such measures might also reduce exposures during routine operations or during abnormal, but not 'accident', situations. Alternatively, such measures might pose disadvantages during normal operation of the plant. It is also clear that measures that involve structural alteration to an existing plant might have been introduced more cost effectively at the design stage. These reasons provide a strong argument for prior passive measures to fall within the remit of the prior risk assessment required by Regulation 7 of IRR99 (GB Parliament, 1999) rather than the contingency plan. As part of the prior risk assessment, employers are required to demonstrate that all reasonable measures have been taken both to avoid radiation accidents and to reduce the resultant exposures from those that cannot reasonably be avoided. The contingency plan, however, is required to detail what mitigating actions can be taken in the event that the protective measures developed as part of the risk assessment fail (GB Parliament, 1999, Regulation 12; USDoE, 2000). NRPB judges that placing decisions on prior passive measures within the remit of the contingency plan, rather than the prior risk assessment, would be an erosion of the employer's responsibility to plan a safe operation. Thus the consideration of prior passive measures would not normally form part of contingency (or emergency) planning.

13 Whilst it is acknowledged that prior passive measures are, in general, outside the scope of this advice, NRPB advises that there are two areas where the process of contingency planning might reasonably instigate a review of the judgements developed within the risk assessment. The first area concerns development of operations and activities beyond the immediate vicinity of a plant that has been the subject of a risk assessment. It is important that staff are not placed at unnecessary risk in the event of a radiation accident. Therefore, unless it is essential that staff are present, it is preferable not to have staff located in, or close to, potentially hazardous areas. This employs similar considerations to off-site planning regulations that restrict inappropriate development (eg of housing estates or of commercial activities having high occupancy) close to the site boundary. Historically, risk assessments have often been plant focused, rather than covering all the operations on a single site (or adjacent sites). In such cases it may be that review of the contingency planning highlights a need to revise the risk assessment using a wider focus, including a review of the benefits of implementing prior passive measures. However, NRPB recognises that the decision on whether to implement prior passive measures will only be taken as a result of a revised risk assessment. The second area in which consideration of prior passive measures may be appropriate is when passive protection can be demonstrated to contribute substantially to the active response. For example, the provision of additional shielding in a particular location might not be assessed as a net benefit within the scope of the prior risk assessment. However, if a key group of intervention personnel were either normally located there, or were required to muster there under the contingency plan, the provision of additional shielding might then be considered a form of prior support measure for the active response, and so justified under the contingency plan.

Prompt detection

14 Prompt detection that a radiation accident has occurred clearly enables those at risk of exposure to take actions to reduce or prevent their exposure (such as evacuating the immediate area or seeking appropriate shelter). However, there are a number of other issues that need consideration. Firstly, if triggering an active response by those at risk relies upon detection, it is important that the system is as reliable as is reasonably practicable, both in terms of always detecting events that should trigger the response and also in terms of avoiding false alarms. Furthermore, whilst the detectors must be located so as to detect enhanced dose rates promptly, the alarms need to be located, and to be of a specification, such that all those needing to take protective actions can hear them (ie both inside relevant buildings and out of doors). On sites or within buildings that could have different types of radiation accident, for which different responses would be required, it is also important that the detection and alarm systems clearly distinguish both the location of the release and its nature. This can be difficult, particularly for accidents that result in high gamma dose rates, which can be detected at some distance from the location of the accident. In setting the trigger dose rate level for detectors, it may, for example, be necessary to adopt a trade-off between the detection of small releases versus the better identification of the source of very large releases. It is also recognised that practical factors (such as the possible unreliability of electronic instruments in the presence of high fluxes of radiation) must be considered in making decisions regarding such a trade-off.

Identifying those most exposed

15 Given the potential for some radiation accidents to expose individuals to very large doses, it is important that response procedures enable highly exposed individuals to be promptly identified. This requires not only that appropriate rapid dose estimation methods are available to those responding to the situation, but that the numbers of people requiring initial measurement, in order to identify any who have been highly exposed, are kept to a minimum. A plan that requires large numbers of personnel to evacuate and present themselves for measurement, including many who are unlikely to have been exposed significantly, may not necessarily offer the optimum response, since it may result in delay in providing appropriate treatment for those most at risk. It follows that the contingency planning needs to take account of the likelihood that individuals in different locations would have received high exposures, to enable those most likely to have been highly exposed to be separately identified for initial measurement.

Clear, rehearsed procedures

16 It is clearly essential that, for the contingency plan to be effective in the event of a radiation accident, it should be fully understood and appropriately rehearsed by all who might need to follow it – as required by Regulation 12(2)(c) of IRR99 (GB Parliament, 1999). The frequency and scope of these rehearsals should be linked to the range of identified radiation accidents and their likely consequences. On sites where there is the potential for different types of radiation accident requiring different responses, the triggers for those different responses need to be easily distinguishable (eg different alarm sounds).

Evacuation routes, shelters/mustering locations

17 However well-rehearsed the contingency plans, those taking urgent action to reduce their own exposure in a real event may be under considerable stress. It is therefore important that evacuation routes are clearly marked and straightforward to follow, and that any mustering or sheltering locations are also clearly marked as such. As far as possible, the distances people need to travel before reaching a location of relative safety should be kept to a minimum. However, the possible consequences of the additional emotional and physical stress induced by long evacuation routes need to be balanced against possible advantages, eg of having people mustered together in specially equipped buildings. In this respect, the provision (where reasonably practicable) of specially designed shielded areas within buildings as protection against external exposure might offer an initial alternative to long evacuation routes. Similarly, the contingency planning should take account of the physical mobility of individuals, whether because of personal disability or because of the clothing being worn at the time of the accident. The ability to isolate and demarcate areas in which a radioactive source had become exposed or an airborne release had occurred could be effective both in reducing exposures outside the sealed area and in preventing unintentional re-entry to the area.

18 As well as being clearly signed and constructed, or located to provide appropriate protection, sheltering/mustering locations need to be appropriately equipped. Where there is the possibility of highly exposed or badly injured individuals mustering at a location, it is important that those individuals can be rapidly identified and appropriate care provided (whether by care provided in that location or by the safe removal of the individual(s) to an alternative location). For those who are expected to remain within the shelter, facilities appropriate to the likely length of stay are required (eg chairs). It is also important either that intervention personnel meet those mustering, or that it is clear who, of those mustering, is the contact person for information and instruction. Where a shelter is intended as a temporary protective measure, eg where a shielded area has been provided within a building, then the contingency plan should address the means of withdrawing the people mustered there.

Communication

19 As with off-site accident response, one of the most important aspects of contingency planning must be ensuring that effective and prompt communication can be established and maintained with those requiring protection. Where this cannot easily be achieved by the presence of specially trained intervention personnel then other methods, eg telephone communication with the emergency controller, need to

be clearly identified. Moreover, the provision for communication needs to be two-way: those managing the response can learn much about the incident and the scale and nature of likely exposures from those evacuated from the area; the planned procedures need to facilitate appropriate collection and collation of this information.

PROTECTION PRINCIPLES

Dose–response relationship

20 There are two key exposure bands relevant to emergency response plans: those where the doses and dose rates are sufficiently high to lead directly to serious deterministic injuries; and those (lower) doses and dose rates where serious deterministic injuries will not result, but the individual will have an increased risk of developing some later health problems, in particular of developing cancer (stochastic health effects)[*].

21 For exposures in the lower band, it is generally assumed that the size of the (stochastic) radiation risk is directly proportional to the size of the dose, and that there is no threshold dose below which there is no risk (NRPB, 1995). Within the dose range of up to a few hundred millisieverts whole-body dose, the same increment in dose gives the same increment in risk, regardless of the dose already received. (For example, increasing an exposure from 101 to 121 mSv gives the same *additional* risk – of 10^{-3} risk of fatal cancer[†] (NRPB, 1993a) – as increasing an exposure from 1 to 21 mSv.) This means that for whole-body doses below about 1 Sv delivered during the first few days following an accident there is no safe/unsafe boundary of dose on which to base decisions on countermeasures. NRPB therefore recommends that decisions on protective measures for reducing these exposures should be based on an evaluation of the relative levels of benefits and harms expected to result from different courses of action (NRPB, 1990a).

Emergency planning thresholds for serious deterministic injuries

22 In contrast to stochastic effects, serious deterministic injuries may be avoided entirely by preventing doses from exceeding the relevant thresholds for these injuries. In order to develop plans that address the prevention of such exposures, it is necessary to determine appropriate dose thresholds against which exposure scenarios and mitigation measures can be judged.

* In order to cause deterministic injuries, exposures need to exceed both dose and dose rate thresholds in the organ or tissue that receives the injury. Criteria used to define thresholds for serious deterministic injuries must therefore specify both the dose and dose rate that apply and the relevant organ. Such doses are measured in gray (Gy). In order to quantify the stochastic risk caused by exposures, the dose unit sievert (Sv) is used. The resulting dose quantity is related to the dose in gray via a weighting factor that represents the likelihood of a certain type of radiation in a certain tissue causing a stochastic effect. To calculate the stochastic risk resulting from an exposure, it is conventional to sum the external (whole-body or organ) exposure and the committed (effective or organ) dose from intakes of radionuclides over the relevant period. To avoid over-complicating the text, this document uses the term dose with both meanings. Wherever the precise meaning (ie dose in Gy or in Sv) is not clear from the context, further clarification is provided.

† Strictly, 10^{-3} average risk of fatal cancer for a population of adults of working age.

23 NRPB recognises that a distinction should be made between the actual dose thresholds for serious deterministic injury – which vary according to many factors, including individuals, aftercare and exact circumstances of the exposure (NRPB, 1996) – and those recommended for contingency (or emergency) planning purposes. The latter need to be set at a (lower) level that provides confidence that no individual would be subject to serious deterministic injury if exposed to this dose. NRPB advises that the relevant threshold exposures for contingency planning purposes are acute doses of 1 Gy whole body (which may result in deterministic injury to the bone marrow) and 2–3 Gy to the other most radiosensitive organs*, for low LET radiation, and 0.5 Gy whole body for acute exposure to neutrons. In this context, acute doses are those delivered over a period of up to a few days. An appropriate threshold for an acute inhalation of alpha-emitting radionuclides is more difficult to specify. It is likely that the actual threshold for deterministic injuries in the lung is in excess of 10 Gy lifetime dose to the lung. However, there is a very large uncertainty associated with the models for serious deterministic injuries resulting from acute intakes of alpha-emitting radionuclides. Therefore, for the purposes of developing contingency plans, NRPB recommends the prudent adoption of a threshold of 1 Gy lung dose, integrated to one year, from an acute inhalation of alpha-emitting radionuclides. These emergency planning threshold doses are summarised in Table 1.

TABLE 1
Emergency planning threshold doses for serious deterministic injuries[a]

Type of radiation	Dose (Gy)	Integration period
Low LET[b]	1 Gy whole body/red bone marrow 2–3 Gy other radiosensitive organs	Fractions of a second up to a few days
Neutron[b]	0.5 Gy whole body	Fractions of a second up to a few days
Alpha	1 Gy lung	Dose integrated to one year from acute inhalation

Notes

(a) These are thresholds recommended for the purposes of contingency/emergency planning; they are deliberately cautious compared with the likely biological thresholds for these injuries.

(b) These whole-body thresholds should be reduced by up to a factor of five for fetal exposure during the first 21 weeks of development, see NRPB (1993b).

Existing principles for the protection of the public off-site

24 The absence of a safe/unsafe boundary of dose for the risk of stochastic health effects forms the basis of the principles recommended by both NRPB and the International Commission on Radiological Protection (ICRP) for the protection of the public off-site, following a nuclear or radiological emergency (NRPB, 1990a; ICRP, 1991a). These principles are that when all the consequences of taking a countermeasure have been evaluated (including social as well as health and monetary factors) the countermeasure should be expected to do more good than harm (ie be justified) and it should be

* It should be noted that skin burns from beta irradiation were implicated in the deaths of a number of intervention personnel following the accident at the Chernobyl nuclear plant. If significant beta contamination of skin is considered likely, then a separate assessment of the risk from skin exposure should be made in order to determine whether serious skin burns could result.

implemented in such a way as to maximise the net benefit (ie be optimised). Although it is unlikely that the threshold doses for serious deterministic injuries would be exceeded for members of the public off-site, NRPB also recommends that if it were judged that such doses might reasonably occur following an accident, then every effort should be made to avoid them. The three NRPB principles of intervention for the protection of the public off-site are given formally in Table 2 (NRPB, 1990a). The intended application of these three principles in the development of off-site emergency plans is discussed below.

Justification	Countermeasures should be introduced if they are expected to achieve more good than harm
Optimisation	The quantitative criteria used for the introduction and withdrawal of countermeasures should be such that the protection of the public is optimised
Avoidance of serious deterministic injuries	Serious deterministic injuries should be avoided by introducing countermeasures to keep doses to individuals below the thresholds for these injuries

TABLE 2 *NRPB principles of intervention for the protection of the public off-site (NRPB, 1990a)*

25 The purpose of justification is to restrict the detailed process of optimisation to consideration of those dose mitigation measures which are expected to do more good than harm. The process of justification therefore is conceptually straightforward: it is the identification and approximate quantification of all the benefits and costs (in the widest sense of the word*) likely to result from implementing a measure or combination of measures (ie a response strategy), in order to scope whether the expected benefits are likely to outweigh the expected harm. The level of resource allocated to the quantification of the factors will depend on how readily it can be demonstrated that the benefits outweigh or do not outweigh the harm (and, for those where this is more difficult to demonstrate, whether sufficient justified response options exist to enable some measures not to be considered further). The detail of the process of justification, in itself not a simple task, will vary, depending on a number of factors. In this regard, two of the most important factors are the nature of the likely health effects, should an accident occur, and the extent to which the costs can be deferred until after an accident has occurred (ie whether the planned response can largely rely upon paper planning and training, or whether specialised equipment, eg alarm systems, must be purchased and/or installed in advance). NRPB also recognises that the practicability of implementing a mitigation measure is relevant to determining whether that measure is justified.

26 The principle of optimisation, as applied to off-site emergency planning, requires a detailed balancing of the expected benefits of introducing a dose mitigating measure (including the expected averted individual dose) and the expected 'costs' (including social and health costs as well as monetary costs). The factors appropriate to consider within this balance are potentially very wide-ranging. NRPB advice for the protection of the public off-site specifically identifies the categories of health, monetary cost and social

* Throughout this document, the balance of benefits against harm or cost is to be understood in a wide sense (ie including social, economic and practical consequences as well as health consequences), except where explicitly stated otherwise.

factors (NRPB, 1990b). The advice further states that whilst both individual and collective factors* should be taken into account during the process of optimisation, the relative weight accorded to collective and individual factors should vary depending on the magnitude of the individual risk: when the expected individual risks are high, the importance accorded to collective factors should be significantly reduced.

27 If the (off-site) emergency plan considers radiation emergencies expected to result in serious deterministic injuries, then the third principle implies a general presumption that any measure that has the potential to reduce doses to levels below the relevant thresholds is both justified and optimised. An alternative way of expressing this is that, in the process of balancing the beneficial and harmful consequences of the measure, an exceptionally high weight is placed upon the beneficial consequences of reducing the exposure.

Principles for the protection of on-site personnel

28 NRPB recommends that the principles developed for the protection of the public off-site are adopted for the protection of on-site personnel. There are obvious advantages in the adoption of a common set of principles for the protection of individuals both off- and on-site, and the reasoning underpinning their development for the off-site situation applies equally to the on-site situation.

29 A major difference between the potential consequences of radiation accidents on- and off-site is the much increased potential for serious deterministic injury to result on-site from some events. In order to develop a framework for planning for the protection of on-site personnel in the event of a radiation accident, it is therefore helpful to explore the application of the third principle in more depth.

Avoidance of serious deterministic injuries

30 The third NRPB principle implies a general presumption that any measure that has the potential to reduce exposure to levels where serious deterministic injuries will not occur is justified. However, there may be circumstances where a particular measure cannot be justified, ie the costs associated with the measure outweigh the expected beneficial consequences. NRPB therefore recommends that the third principle is applied by explicitly considering all options with the potential for avoiding serious deterministic injury and, subject to reasonable practicability, only eliminating options from consideration on the basis of a specific case demonstrating that a measure is not justified.

31 One clear basis for a measure not being justified would be where the risk of severe injury to those implementing the measure was even greater than that being protected against. A second reason could be that implementing the protective measure caused serious disruption to the routine operation of the business (eg the installation of alarms that, as well as guaranteeing to alarm in the event of a criticality accident, also had a very high false alarm rate). A further reason that might be put forward is the very low likelihood of the radiation accident occurring, in combination with very high costs of prior support measures.

---

* In this context, monetary cost can be considered to be a 'collective' factor, inasmuch as the costs will ultimately be borne by a wider population group than those for whom the measure to reduce exposure to ionising radiation is being taken.

32 NRPB recognises that the balance of benefits and harms required for justification of a measure may be substantially different between an 'at-time' active measure and a prior measure requiring substantial investment (in terms of both resource and risk to those installing it) in advance of a radiation accident occurring. The implementation of an at-time dose mitigation measure results in most of the benefits and the harms being realised at the same time, ie after the event has occurred. In considering the justification of such measures, therefore, the likelihood of the radiation accident occurring is not an important factor. For measures that require substantial prior investment, most of the costs will be borne in advance of a radiation accident happening, whilst most of the expected benefits would not be realised unless the accident actually occurred*. For prior measures that involve very significant 'up-front' cost it will be appropriate to take some account of the likelihood of the event when considering whether or not the measure is justified. In any case, NRPB recommends that it is reasonable to differentiate between prior measures and at-time measures when exploring whether options for avoiding serious deterministic injury are justified. In situations where much of the cost of implementing the measure is only incurred at the time of the radiation accident, then the presumption of justification is stronger than in situations where most of the cost is borne in advance of an accident occurring.

33 The third principle implies a discontinuity between the protective measures adopted for those who might receive exposures sufficient to cause serious deterministic injury and those whose maximum exposures in the event of a radiation accident would solely increase their risk of developing stochastic health effects. A contingency plan that exhibited such a discontinuity would be entirely in accord with this advice. However, it is also possible that the response strategy may involve some blurring of the boundaries between the protection of the two groups of personnel. This is because the principles of justification and optimisation allow for a different balance to be struck between competing factors, depending on the level of additional individual stochastic risk that would be incurred by the potential exposure at different locations. At locations where this individual stochastic risk may be high, then those potentially exposed may well be treated very similarly to those for whom the potential exposures might result in serious deterministic injuries, because the stochastic risk to these individuals will be the dominant factor in the optimisation of the response planning. However, at locations where the individual stochastic risk associated with the potential exposure is much lower, the effective inclusion of many other factors in the optimisation process is likely to result in a different balance, and therefore a different response strategy being adopted (NRPB, 1990b, appendix). It is important to note, in this regard, that one factor that may well enter into the balance is a trade-off between the 'ideal' contingency plan for those whose potential exposure might result in serious deterministic injury and the 'ideal' contingency plan for others potentially exposed. NRPB recommends that, in such situations, it is the reduction of dose to those who might receive serious deterministic injury that should take priority.

* It is recognised that for at-time measures, there are always likely to be some up-front costs (eg stockpiling stable iodine tablets), whilst for prior measures there are likely to be some up-front benefits (eg the reassurance provided to the workforce). However, the key point is that there is a shift in the balance of the timing of when the majority of the costs and benefits are incurred between at-time and prior measures.

Annual dose limits

34 The annual dose limits recommended by ICRP (1991b) and endorsed by NRPB (1993c) are intended for application to situations where the source is under control. They do not consider the balance of harms and benefits associated with a one-off exposure resulting from a radiation accident. No employer is exempted from the specified statutory dose limits in the event of an accident. The advice provided here is intended to assist employers with the preparation and implementation of contingency plans.

FRAMEWORK FOR THE PROTECTION OF ON-SITE PERSONNEL

35 The NRPB principles for protection, taken together with the discussion about their application, suggest that contingency planning for the protection of on-site personnel should be undertaken as a two-phase process: planning measures to protect those whose potential exposure in the event of a radiation accident might result in serious deterministic injury, and planning measures to protect those whose potential exposure would result solely in increased stochastic risk. Priority should be afforded to the development of those aspects of the plan that aim to protect individuals from serious deterministic injury. This requires:

(a) identification of those individuals at risk of such injury,
(b) identification of the range of measures which have the potential to reduce exposures below NRPB emergency planning thresholds,
(c) determination if there is a case for demonstrating that some of the measures are not justified,
(d) development of the response strategy to be implemented.

This strategy will almost certainly comprise both prior support measures and at-time measures, with the at-time measures comprising reactive actions by the individuals themselves and measures taken on their behalf by others. The focus of this planning is to reduce individual doses to levels below the thresholds for serious deterministic injuries.

36 The second phase, to be initiated after planning the response strategy for those at risk of serious deterministic injury, is planning for measures to mitigate the exposures of those whose potential exposure would result solely in an increased stochastic risk. This would be done by balancing the expected benefits and harms to exposed groups, with consideration of both individual and collective consequences. It would be expected that greater resource would be expended on measures to mitigate the exposures of those potentially exposed at higher levels (ie who would be at higher risk of stochastic effects). Any planning of exposure mitigation measures for those not expected to receive serious deterministic injuries should be reviewed to ensure that the planned measure did not reduce the effectiveness of the measures planned to avoid serious deterministic injuries. Although the optimum strategy for mitigating exposures that would result solely in an increase in stochastic risk would almost certainly include some expenditure of resource on prior support measures, it is likely that most measures in the strategy would only involve significant cost in the event of a radiation accident.

37 This two-step framework is illustrated in the figure. A radiation accident is assumed to have occurred in building A. In this example, the main hazard is assumed to be direct

gamma exposure, with elevated dose rates emanating in all directions from the building. However, the framework is equally applicable to other scenarios, such as an airborne release, except that the pattern of dose rates would be more focused in direction. The shading indicates the pattern of reducing dose rate, primarily as a function of distance from building A, but modified by the shielding properties of other buildings. The inner area, inside the broken line, represents the area within which individual doses in excess of the recommended emergency planning thresholds for serious deterministic injury, listed in Table 1, have been estimated, on the basis of radiation accidents considered within the scope of the plan*. The first priority is the development of a strategy of dose mitigation measures to reduce the doses to those personnel, present within the marked contour at the time of the event, to levels below the emergency planning thresholds†. Once this strategy is identified, the development of contingency plans to mitigate the doses to those who would be outside the contour can be implemented. Here, the scope

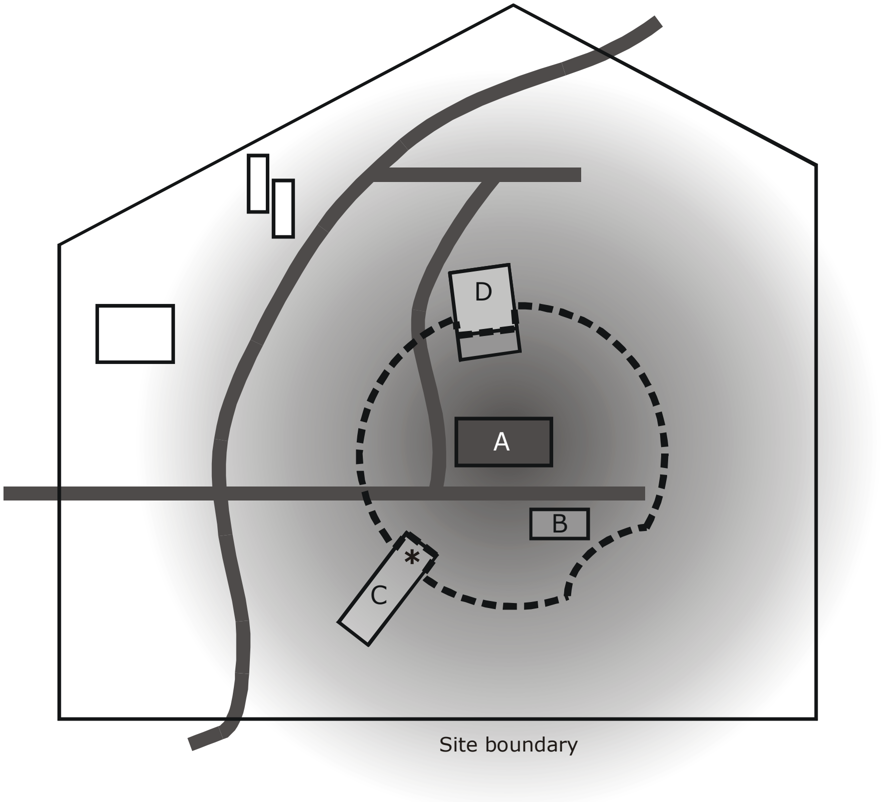

Illustration of framework for application of the NRPB principles for protection (see paragraphs 37–42)

* Such contours should be determined on the basis of potential individual exposure; it is inappropriate to average potential exposures over groups of people when dealing with exposures above the thresholds for serious deterministic injury.

† In principle, measures capable of reducing doses below serious deterministic thresholds should be sought for all situations covered by the plan that could potentially expose people above the relevant thresholds. However, it is reasonable that priority would be given to situations where larger numbers of people might suffer these injuries.

of factors considered in the optimisation process increasingly broadens as the expected individual doses reduce. In particular, for potential individual exposures well below the emergency planning thresholds in Table 1, it is appropriate to consider collective factors averaged over groups of people who would be exposed to relatively widely varying stochastic risk. Table 3 summarises this framework in the context of the range of measures likely to be justified for different expected levels of risk.

TABLE 3
Framework for identifying justified measures for the protection of on-site personnel

	Justified measures	
Consequence that planned response is protecting against	Planned responses requiring substantial investment prior to a radiation accident occurring	Planned responses for which most of the cost is borne after a radiation accident occurs
1 Serious deterministic injury	Most measures *(prior costs and probability of accident occurring may exclude measures)*	All measures
2 Exposure resulting in high individual risk of stochastic health effects	Some measures *(prior costs and probability of accident occurring are important factors in justification)*	Most measures *(protection of those at risk of serious deterministic injury remains first priority)*
3 Exposure resulting in moderate/low individual risk of stochastic health effects	Measures unlikely to be justified	Some measures *(protection of higher risk groups is priority; averaging harms/benefits across population groups appropriate)*

38 It is helpful to discuss each entry in Table 3 in more detail, beginning with the development of a strategy for mitigating the exposures of those who might receive serious deterministic injuries. As already stated, it is necessary to identify those individuals who, in the event of a radiation accident, might receive exposures in excess of the emergency planning threshold doses for serious deterministic injuries (ie those in Table 1). The highest priority is afforded to the protection of these individuals (inner area in the figure, Group 1 in Table 3). The identification of justified dose mitigation measures for these individuals should be carried out as a separate process within the contingency planning, with the presumption being in favour of planning for measures that would protect against serious deterministic injuries as discussed in paragraphs 27 and 30–33. It is recognised that, in general, contingency planning to avoid exposures leading to serious deterministic injury (for example, automatic detection alarm systems) will require significant investment prior to an accident taking place, owing to the relatively short timescales available for introducing at-time responses following detection of a release. As discussed earlier, NRPB recognises that considerations of monetary cost and any severe risks to those installing the equipment are important factors to be considered within the overall justification process for these measures, as is the recognition that the costs will definitely be incurred, whereas the benefits might never be realised. For this reason, the Group 1 entry in Table 3 for planned responses requiring substantial prior investment specifies a caveat on the general presumption that every dose-effective measure is likely to be justified. By contrast, the entry for planned responses that do not require so much prior investment has no such caveat. The specific measures to be planned for could then be selected through a process of optimisation, although selection of any option that enabled the avoidance (or the potential to avoid) serious deterministic injuries would be in accord with this advice.

39 Once appropriate contingency planning has been determined for those at risk of serious deterministic injury, the potential levels of exposures for other people on-site should be estimated. The stochastic risks associated with these exposures may cover a wide range from very small to relatively high (ie potential doses just below the threshold doses proposed in Table 1). The basis for planning measures for these people is indicated by Groups 2 and 3 in Table 3. As with its advice for the protection of the public off-site, NRPB advises that appropriate exposure mitigation measures for these people should be determined by a full balancing of the expected benefits and harms of each option, including those benefits and harms expected to result prior to a radiation accident occurring. Also, in accord with its advice for the protection of the public off-site, NRPB advises that the extent to which averaging assumptions and collective risks should be considered in the balance depends on the likely level of individual risk resulting from the potential exposure. Where the expected individual exposures will be high, then averaging assumptions and collective considerations will be relatively less important. For low expected individual exposures, the process of justification and optimisation should take a wide range of factors into account, with averaging of harms and benefits across groups of individuals forming an integral aspect of this. Furthermore, it would not normally be expected that exposure mitigation measures requiring substantial investment prior to an accident would be justified for the sole protection of those whose potential exposures would result in low stochastic risk, except in situations where the corresponding potential collective stochastic risk would be high.

40 One important aspect of planning for protective measures for on-site personnel is the need for flexibility to accommodate local circumstances. This flexibility should be reflected directly within the planning process itself, in terms of the expected benefits and harms of implementing each protective option at different locations within the site. However, it is helpful to provide some explicit guidance on this, with respect to the location of buildings. This is illustrated in the figure, where four buildings are shown (labelled A, B, C and D). As noted earlier, the area enclosed by the broken line indicates the area within which the relevant emergency planning threshold dose given in Table 1 is calculated to be exceeded for a given accident occurring in building A. This contour has been calculated realistically, in that it has taken account of the shielding properties of buildings B, C and D. Building B has insufficient shielding to reduce doses inside to below the emergency planning threshold, but causes distortion of the contour in its 'shadow'. Personnel located in building B at the time of the accident would need to be treated in the same manner as those in building A and as those outdoors within the contour. Building C has sufficient shielding to reduce the dose to those inside to levels that do not exceed the relevant emergency planning threshold. These people would need some special attention in the planning process (eg to be warned not to exit their building at the asterisked end), but would not automatically be considered as part of the group at risk of serious deterministic injury. Building D represents the situation where the shielding provided reduces the doses to levels below the relevant emergency planning threshold in some parts of the building, but not in all. Personnel within this building would clearly require special consideration, but a decision as to whether to treat all the people in building D as if they were at risk of serious deterministic injury, or solely those who would actually lie within the contour, would be a matter for local decision making. Potentially relevant factors in such a decision might include the degree of caution incorporated in the type(s) of radiation accident considered, the caution in the estimation of doses and the practicability of adopting different responses for those in one part of a building compared with others.

41 The figure only illustrates a situation in which dose rates are reduced in specific locations as a result of the shielding provided by buildings. In developing the contingency plan, it is important to recognise that, depending on the type of radiation accident considered, local variations in dose rate and/or activity concentrations in air – both increases as well as decreases – may occur at specific locations for a wide range of reasons. It is important that the contingency plan takes appropriate account of the likely spatial pattern of potential exposure in recommending the measures to be taken.

INTERFACE WITH OFF-SITE PLANNING

42 An accident which results in activation of the on-site contingency plan might result in doses off-site which would require an off-site response, under the terms of REPPIR (GB Parliament, 2001). Continuation of the shading in the figure outside the site boundary to the east and south is intended to illustrate this point. Off-site emergency plans are based on the three NRPB principles and associated guidance for off-site countermeasures (NRPB, 1990a,b). It is clear that, under these circumstances, care should be taken to provide an appropriate interface between the on-site contingency plan and the off-site emergency plan. In particular, any apparent difference between the level of protection provided to on-site personnel and members of the public off-site should be straightforward to explain and justify. In all cases, the presumption would be that the implementation of the emergency plan off-site, near the site boundary, would result in consequent risks to the public that were no higher than (and probably lower than) those incurred by on-site personnel situated at the site boundary.

REFERENCES

GB Parliament (1999). Ionising Radiations Regulations. London, HMSO, SI(1999) 3232.

GB Parliament (2001). Radiation (Emergency Preparedness and Public Information) Regulations. London, HMSO, SI(2001) 2975.

Health Ministers (1977). Direction by the Health Ministers under the Radiological Protection Act 1970. 1977 specification of emergency reference levels of dose. *Reproduced in Doc NRPB, **1**(1), 13 (1990).*

ICRP (1991a). Principles for intervention for protection of the public in a radiological emergency. ICRP Publication 63. *Ann ICRP,* **22**(4).

ICRP (1991b). 1990 recommendations of the ICRP. ICRP Publication 60. *Ann ICRP,* **21**(1–3).

NRPB (1990a). Statement by NRPB. Principles for the protection of the public and workers in the event of accidental releases of radioactive materials into the environment and other radiological emergencies. *Doc NRPB,* **1**(4), 1–4.

NRPB (1990b). Emergency reference levels of dose for early countermeasures to protect the public: recommendations for the practical application of the Board's Statement. *Doc NRPB,* **1**(4), 5–33.

NRPB (1993a). Estimates of the late radiation risks to the UK population. *Doc NRPB,* **4**(4), 15–157.

NRPB (1993b). Diagnostic medical exposures: exposure to ionising radiation of pregnant women. *Doc NRPB,* **4**(4), 5–14.

NRPB (1993c). Statement by NRPB. 1990 recommendations of ICRP. *Doc NRPB,* **4**(1), 1–5.

NRPB (1995). Risk of radiation-induced cancer at low doses and low dose rates for radiation protection purposes. *Doc NRPB*, **6**(1), 1–77.

NRPB (1996). Risk from deterministic effects of ionising radiation. *Doc NRPB*, **7**(3), 1–31.

NRPB (1997a). Application of emergency reference levels of dose in emergency planning and response. *Doc NRPB*, **8**(1), 21–34.

NRPB (1997b). Intervention for recovery after accidents. *Doc NRPB*, **8**(1), 1–20.

USDoE (2000). Comprehensive emergency management system. Order DOE 0 151.1A. Washington DC. www.oa.doe.gov/emo/directives/o151-1a.pdf.

Appendix

EXPERIENCE OF PAST ACCIDENTS

Unshielded sources

By far the most commonly occurring accidents, both in the UK and worldwide, are those involving sealed sources that fail to be returned to their shielded enclosures. This may occur in industrial radiography processes, sterilisation units, hospital treatment units, at nuclear industry sites and elsewhere. Such accidents can be divided into two groups: those where the unshielded source remains in the vicinity of its original application (eg it gets 'stuck' in the tubing leading from the shielded enclosure to the location of irradiation, or a failure of the designed shielding occurs); and those where the source is inadvertently carried away (eg having been 'orphaned' – ie lost – and subsequently retrieved by someone ignorant of what it is, or one that has been located within a patient who subsequently leaves the ward or hospital). Accidents involving sealed sources that get 'stuck' in the exposed position have the potential to cause significant exposures to the operator or patient and anyone else who enters the immediate vicinity. Similarly, ill-informed entry to areas where sources are exposed (eg deliberate bypassing of safety interlocks) has the potential to result in significant exposures and, in other countries, has resulted in fatalities (Croft et al, 1990). Those sealed sources that are inadvertently moved from their original locations have the potential to expose a larger number of people over a protracted period of time and may also cause fatalities (Rozental et al, 1990).

Issues for contingency planning that are relevant for these types of accident are listed below.

(a) Prompt detection is likely to be key in limiting exposures. In the case of inadvertent removal of sources, strategically placed detectors and alarm systems may have a role to play.

(b) Clear procedures, appropriately rehearsed and enforced, underpinned by relevant training for staff likely to encounter unshielded sources is key to preventing inappropriate entry to areas where sources might be exposed.

(c) Human error (or unpredicted behaviour) must be considered when assessing the potential for accidental exposure.

Criticality accidents

The accident at Sarov in Russia in 1997 (Punin et al, 1997), which resulted in one fatality, and that at Tokai Mura in Japan in 1999, which resulted in the death of two employees (Nuclear Safety Commission, 1999), have recently focused attention on the risks associated with criticality accidents. The only criticality accident that has occurred in the UK, at the Windscale Works in 1970 (Daniels et al, 1971; Evans, 1984), did not result in serious injury. However, a recently revised review of criticality accidents worldwide catalogues twenty-two process accidents, five of which led to fatalities (McLaughlin et al, 2000). The significance of reporting these accidents is that process facilities carrying out operations with fissile material avoid criticality accidents through physical and administrative controls. These controls are intended to prevent critical or near-critical configurations from ever occurring in the facility. The fact that a process accident occurred as recently as 1999 and resulted in fatalities indicates the importance of continuing review of design and administrative controls, as well as thorough contingency planning.

The review of criticality accidents draws a number of conclusions, many of them concerning design, management and operational issues. However, two of the points raised have relevance for contingency planning. These are listed below.

(a) Most of the twenty-two accidents involved criticality events that were not terminated after a single burst.

(b) Prompt detection and immediate evacuation of personnel within several metres of the accident have been significant in saving lives and limiting exposures. Personnel should therefore be familiar with the emergency procedure and have confidence in responding to the 'triggers' for that procedure.

Releases into confined areas

Sites where large quantities of radioactive materials are stored and processed have the potential for activity to be released into the air in a confined area and consequently to be inhaled by personnel working in that area. Some sites/processes have the potential to cause serious deterministic injuries to the lung, or even fatalities, following such accidents. Most attention, with respect to contingency planning for workers on-site, focuses on potential releases of actinides (notably plutonium-239) and tritium. When present in very high concentrations, tritium poses a particular hazard, owing to its propensity to be absorbed through the skin, as well as being taken into the body through inhalation. An accidental release of ruthenium-106 at the Windscale Works in 1973 resulted in a maximum estimated lung dose (using the dosimetry of the time) of 10–15 Gy (received over a few years) (NII, 1974). This dose was not high enough to cause serious deterministic injury, but was, nonetheless, a significant exposure. Its cause was not a mechanical failure or defect, nor a failure by the operating personnel to follow procedures, but a mechanism for release that had not been previously postulated, and hence not guarded against.

The issues for contingency planning that are relevant for these types of accident are listed below.

(a) Prompt detection and immediate evacuation of personnel from the area are likely to be key in saving lives and limiting exposures. Personnel should therefore be familiar with the emergency procedure and have confidence in responding to the 'triggers' for that procedure.

(b) Prompt isolation of the area will limit the spread of the contamination and potential exposure.

(c) Automatic venting of the area has the potential to reduce the highest exposures, but, unless an effective filtration system can be implemented, risks spreading the contamination and exposing a larger number of people (albeit at a much lower level).

(d) Since processes that handle radioactive materials are designed to prevent releases occurring into the workplace, and at least one has occurred as a result of an unforeseen circumstance, it would seem prudent to consider contingency planning for such accidents, even if the apparent probability of occurrence of such accidents is very low.

Large releases triggering off-site response, also giving on-site exposures

Emergency plans for the protection of the public off-site are based on the presumption of a large release with the potential to give a dose over one year in excess of 5 mSv off-site (GB Parliament, 2001). In the event of such a release, there is the potential for much higher exposures on-site. Moreover, whereas the predominant concern for the reduction of off-site exposures is the inhalation pathway, on-site the potential for significant exposures resulting from direct shine from the damaged plant itself must also be considered. For large accidental releases, wind direction and dispersion fluctuations caused by buildings may also be important in determining the locations of highest potential exposure to those on-site. A further major issue for these types of accident is that potential exposures may be more widespread than other accidents, resulting in a much larger number of personnel requiring protection.

Issues for contingency planning that are relevant for these types of accident are listed below.

(a) Prompt detection and clear procedures for response will be key in reducing exposures.
(b) Emergency procedures must address the possibility of very large numbers of personnel requiring protection. This has implications for the management of the response and the communication of information to those affected.

High external radiation

The Windscale vitrification plant shield door incident (HSE, 1991) demonstrated the potential for high external doses to employees in spite of modern protection systems being in place. The source of radiation was a container of highly active vitrified waste which gave external dose rates up to 20 Sv h^{-1}. Employees were protected by an initial design based upon twin interlocked shield doors which were designed to open only one at a time using a system of four engineered and two procedural protective systems. This was subsequently modified to allow both doors to open simultaneously to allow for a means of escape with a key for this purpose. Further modifications were made following operational experience. All protection systems failed to prevent the incident which could have resulted in the legal dose limit (50 mSv per annum at the time) being exceeded in 10 seconds. Fortunately, no personnel were involved but the potential for a serious accident was recognised.

The review of the incident draws a number of conclusions, many concerning design, management and operational issues relevant to contingency planning: some of these are listed below.

(a) So far as reasonably practicable, safety systems should be independent of control systems. The design should be as simple as possible.
(b) Designers should ensure that audible and visual warning information is clearly presented.
(c) Adequate procedures should be in place to control plant modifications.
(d) Safety systems should be fully challenged during commissioning and subsequent maintenance.

REFERENCES

Croft JR, Zuniga-bello P and Kenneke A (1990). The radiological accident in San Salvador. IN Recovery operations in the event of a nuclear accident or radiological emergency: proceedings of a symposium, Vienna 1989. Vienna, IAEA.

Daniels JT, Howells H and Hughes TG (1971). Criticality incident – Aug 24, 1970, Windscale Works. *Trans Am Nucl Sec,* **14,** 35–6.

Evans MC (1984). A review of criticality accidents within the European Community. *Trans Am Nucl Sec,* **46,** 462–3.

GB Parliament (2001). Radiation (Emergency Preparedness and Public Information) Regulations. London, HMSO, SI(2001) 2975.

HSE (1991). Windscale vitrification shield door incident: 15 September 1991. London, HMSO.

McLaughlin TP, Monahan SP, Pruvost LP, Frolov VV, Ryazanov BG and Sviridov VI (2000). A review of criticality accidents, 2000 revision. Los Alamos National Laboratory, LA-13638.

NII (1974). Report by the Chief Inspector of Nuclear Installations on the Incident in Building B204 at the Windscale Works of British Nuclear Fuels Limited on 26 September 1973. London, HMSO, CMND 5703.

Nuclear Safety Commission (Japan) (1999). Report of the accident investigation committee on a critical accident in uranium fuel fabrication plant.

Punin VT, Smirnov IG and Zykov SA (1997). The accident of the RFNC-VNIIEF criticality test facility. *Atomnaya Energia,* **83.2,** 154–6.

Rozental JJ, de Almeida CE and Mendonca AH (1990). Aspects of the initial and recovery phases of the radiological accident in Goiania, Brazil. IN Recovery operations in the event of a nuclear accident or radiological emergency: proceedings of a symposium, Vienna 1989. Vienna, IAEA.