NRPB

DOCUMENTS OF THE NRPB

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Board Statement on Emergency Reference Levels

VOLUME 1 NO 4 1990

National Radiological Protection Board
Chilton, Didcot, Oxon OX11 0RQ

The National Radiological Protection Board was created by the Radiological Protection Act, 1970. The functions of the Board are to give advice, to conduct research, and to provide technical services in the field of protection against both ionising and non-ionising radiations.

In 1977 the Board received Directions under the Radiological Protection Act which require it to give advice on the acceptability to and the application in the UK, of standards recommended by international or intergovernmental bodies, and to specify emergency reference levels (ERLs) of dose for limiting radiation doses in accident situations.

Documents of the NRPB contain both the formal advice of the Board on standards of protection as well as guidance on their application in practice.

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Statement by the National Radiological Protection Board

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

SCOPE

1 The principles given below were formulated primarily in the context of accidental releases of radionuclides to atmosphere from major nuclear installations in the UK, but are also appropriate for use in other radiological emergencies where there is a possibility of significant exposure of sections of the UK population outside areas in which radioactive materials are normally used. The principles apply to protection during the period from the time at which it is recognised that an emergency exists, or will occur, until the time at which conditions have effectively returned to normal, and to persons at or close to the scene of an accident and those further afield. They cover the entire spectrum of accidents, from the relatively minor to the most severe. The principles are intended to be used as one of the major inputs to the establishment of emergency plans and as guidance for actions when an accidental release or other emergency has actually occurred.

PROTECTION OF THE PUBLIC

Principles

2 The basic principles recommended by the Board for the protection of the public should an accident occur are as follows.

(i) Countermeasures should be introduced if they are expected to achieve more good than harm—*justification.*

(ii) The quantitative criteria used for the introduction and withdrawal of countermeasures should be such that protection of the public is optimised—*optimisation.*

(iii) Serious deterministic* health effects should be avoided by introducing countermeasures to keep doses to individuals to levels below the thresholds for these effects.

3 The principles apply to all the countermeasures which could be taken to protect the public, and in particular to sheltering, evacuation, the administration of tablets

*Deterministic health effects are those for which the severity of the effect varies with the dose and there is a threshold of dose below which the effect does not occur.

containing stable iodine, the imposition of restrictions on the consumption of food and water, and relocation.

4 Justification is a requirement that the net harm associated with the countermeasure should be less than the harm associated with the radiation doses that will be avoided if the countermeasure is introduced. Optimisation can be stated more simply as a requirement that countermeasures should be introduced so as to do the most good, ie, so as to minimise overall harm. The word 'harm' is used here in a wide sense and includes not only quantifiable aspects such as detriment to physical health and economic cost, but also less readily quantifiable factors such as anxiety and social disruption. Decisions as to whether countermeasures are justified and protection optimised must therefore always contain a considerable element of judgement. Neither principle implies that a countermeasure should only be taken if it is certain that it will be completely successful. In all practical situations a countermeasure will be aimed at protecting a group of people and should be taken if it is expected to do more good than harm for most of the group.

5 The third principle overrides the other two. However, it should rarely become important because in most accidents the introduction of countermeasures for the public will be justified and protection optimised at levels of individual dose well below those at which serious deterministic health effects could occur.

Emergency reference levels

6 The quantitative criteria recommended by the Board for the introduction of countermeasures to protect the public in the event of an accident are known as emergency reference levels (ERLs), and are in terms of the dose to an individual that could be averted if the countermeasure is taken. The ERLs are specific to each countermeasure because the harm associated with each countermeasure is different.

7 In order to meet planning needs but still retain the flexibility to match actions to conditions at the time of an accident, the Board recommends a lower and an upper ERL for each countermeasure. The lower ERL is the dose level below which the countermeasure should not be introduced because, in the Board's judgement, it would be very unlikely to be justified to do so. If estimated averted doses exceed the lower ERL, implementation of the countermeasure should be considered but is not essential. The upper ERL is the dose level at which the Board expects every effort to be made to introduce the countermeasure unless it would clearly contravene the principles of justification and optimisation to do so.

8 The Board considers that, when emergency plans are prepared for any given nuclear installation or potential accident, account should be taken of, *inter alia*, the nature and magnitude of possible doses and the practicality of implementing each countermeasure, or combination of countermeasures, in order to select specific intervention levels which could be used in most circumstances. These intervention levels are expected to be between the lower and upper ERLs. However, the flexibility to take actions appropriate to the conditions at the time of an accident should be retained because there could be occasions when a countermeasure, even though desirable under most circumstances, is impractical. It is also necessary to check that total doses to individuals will be below the thresholds at which deterministic effects may occur because the ERLs are in terms of averted dose.

9 The Board wishes to emphasise that in applying ERLs, whether for emergency planning or in decisions during an actual accident, it is not necessary to be certain that doses would be received if countermeasures were not introduced. Precautionary actions, based on expected occurrences, are potentially very effective in protecting the public and should therefore be taken if it is probable, but not certain, that they will avert doses.

10 ERLs are conceptually separate from dose limits recommended for application to routine exposure of members of the public to ionising radiation. ERLs relate to doses potentially averted by intervention in people's lives should an accident occur. Dose limits are established within the framework of risks normally tolerated by the majority of the population and apply to exposures which will actually be incurred and which can be controlled in advance by design and planning regular operations.

PROTECTION OF WORKERS

11 For the purpose of providing advice on their protection in the event of an emergency the Board distinguishes between three categories of workers: those involved in urgent actions at the scene of a serious accident, those involved in implementing countermeasures and taking other actions to protect the public, and those involved in recovery operations.

12 Workers in the first category are those who must act to save life, to prevent serious injuries or to prevent a substantial increase in the scale of the accident. It is neither possible nor appropriate to specify maximum levels of dose for such situations. The Board therefore recommends only that substantial efforts be made to keep doses to these workers to levels lower than those at which serious deterministic health effects may occur.

13 The second category includes people whose work routinely involves exposures above normal background levels and those whose work does not; most of the latter are emergency services personnel. Unlike members of the public, who will incur doses unless action is taken to prevent them doing so, workers in this category will primarily incur doses if a decision is taken that they should carry out particular actions. The dose limits for occupationally exposed persons are relevant to these workers because their exposure is deliberate and, to varying extents, controlled. However, such workers would incur doses in directly taking measures to protect the public; also, accidents are not expected to occur very frequently. The Board therefore considers that it would be appropriate to allow workers in the second category to receive doses which are greater than routine doses to occupationally exposed persons. Workers involved in implementing countermeasures and taking other actions to protect the public in the event of an accident should be allowed to receive doses equal to the currently recommended limits for occupationally exposed persons and, in exceptional circumstances, to receive doses which are above these limits, provided that doses are always kept below the thresholds for serious deterministic effects. Detailed optimisation of protection of these workers should not be a major consideration in decisions on the actions they are to take to protect the public.

14 The actions of the workers in the third category are important in restoring normal conditions but they are not so directly concerned with protection of the public as those of workers in the second category. The Board therefore recommends that the full system of dose limitation for occupationally exposed persons should be applied to these workers.

EMERGENCY REFERENCE LEVELS OF DOSE FOR EARLY COUNTERMEASURES TO PROTECT THE PUBLIC

Recommendations for the Practical Application of the Board's Statement

ABSTRACT

Quantitative guidance is given on levels of dose for the introduction of three early countermeasures to protect the public in an emergency: sheltering, evacuation and the administration of stable iodine. A description is given of the countermeasures and their effectiveness under different circumstances. The factors to be taken into account in setting numerical values are described and used to derive upper and lower bounds for each countermeasure which should encompass the range of justified values for most circumstances.

PREPARED BY M D HILL, M E MORREY AND G A M WEBB

INTRODUCTION

1 In August 1977 the Board was given a Direction by the Secretary of State for Social Services, acting on behalf of the Health Ministers, which made it responsible for specifying emergency reference levels (ERLs) of dose for members of the public. The Board was also made responsible for providing guidance to Government Departments and other appropriate bodies on the derivation of ERLs relating to radiation exposure and the radioactive materials in the public environment. The Board issued preliminary advice on these topics in 1978[1], detailed advice in 1981[2] and additional guidance in 1986[3].

2 Board staff have for some years been reviewing the recommendations on ERLs; the new evidence about the risks associated with radiation provided by the re-evaluation of data on the Hiroshima and Nagasaki survivors was taken into account, as it became available[4,5]. At several stages during the review, consultations were held with organisations and regulatory bodies with a role in emergency response. In addition, comments on possible changes to Board recommendations were sought through the publication of papers[6,7], and ERLs were one of the topics covered in Board evidence to the public inquiry into the proposed pressurised water reactor at Hinkley Point[8]. In parallel with the review by Board staff and following the Chernobyl reactor accident, several of the relevant international organisations began to reconsider their advice on protection in the event of an accident, including that on intervention levels of dose[9–11], and Board staff participated in these international discussions.

3 Having considered the comments made during its own review, and taking note of the consensus on matters of principle emerging internationally, particularly the proposed new recommendations from ICRP, the Board has decided to issue revised recommendations on the protection of the public should an accident occur, and to supplement these with recommendations on the protection of workers. The new recommendations are of two types: one is a statement of the basic principles for protection of the public and workers in the event of an accidental release or other radiological emergency[12]; the other type contains numerical dose levels and advice on their application. This document is the first of the latter type and deals with ERLs for members of the public for sheltering, evacuation and the administration of stable iodine. These countermeasures are those which might need to be implemented relatively soon following the initiation of a serious accident and so they are collectively referred to here as 'early countermeasures'. Subsequent documents will deal with ERLs for other countermeasures which affect the public.

4 The principal situation for which these ERLs have been derived is an accidental release of radioactive materials to atmosphere. However, it is recognised that there are other accidents (eg, damaged, exposed sources) in which early countermeasures—in particular, evacuation—may need to be introduced; the ERLs given here are intended for these situations also.

5 In addition to specifying ERLs for early countermeasures, these recommendations provide guidance on how the ERLs should be applied in practice.

FEATURES OF COUNTERMEASURES

Sheltering

6 In this context sheltering refers to staying indoors, with doors and windows closed and ventilation systems turned off. It provides protection from external irradiation from radioactive material in the air and that deposited on the ground, and from inhalation of radioactive material. Typical dose reductions for solidly built and reasonably airtight UK housing are by a factor of ten for external exposure and by a factor of three for inhalation of particles[13]. However, the dose reduction for inhalation of vapours (eg, elemental radioiodine) is negligible, and the protection against external irradiation afforded by light constructions, such as caravans, is very small. The factors quoted depend on sheltering being implemented before, or soon after, the start of the release and on the building being thoroughly ventilated as soon as outdoor air concentrations have fallen substantially, and are for a relatively short release of radionuclides to atmosphere (up to a few hours). A more detailed discussion of the dose savings which can be achieved by sheltering is given in reference 13.

7 There are practical aspects which also affect the use of sheltering as a countermeasure, in particular the need to restrict access to the sheltering zone and the inconvenience caused to individuals. The latter may range from insignificant, in the case where the individual had intended to be indoors anyway, to rather high, when important outdoor activities had been planned. Prolonged sheltering may also cause a high degree of stress. Generally, the direct physical risks of sheltering are extremely small, but there may be indirect risks (eg, an individual may be prevented from obtaining necessary food or medical supplies).

8 To a large extent, these adverse effects of the countermeasure are small, particularly if the sheltering period is kept to a few hours. A recent survey[14] found that most people think they could shelter in excess of one day without experiencing significant disruption. Significant problems can be reduced by advising individuals that short periods out of doors, for necessary activities, will not, in many situations, result in very high exposures. External exposures to people inside a building from material in the outside air or on the ground will not be significantly affected by the opening and closing of outside doors, nor will occasional opening and closing of outside doors have a major impact on the radionuclide concentrations in air within the building, and hence on doses by inhalation.

9 Sheltering, as a stand-alone early countermeasure, is only effective against doses resulting from releases to atmosphere, although it could be implemented as a temporary countermeasure to provide protection from external irradiation from radionuclides deposited on the ground, while preparations for evacuation and/or decontamination were made. If a release to atmosphere occurs, there are four main situations for which sheltering is likely to be the optimum countermeasure:

(i) a release consisting mainly of radioisotopes of noble gases (to reduce the external dose);

(ii) a release which would result in relatively low doses;

(iii) a release which would result in very large short-term doses, for which evacuation could not be carried out in advance of the release;
(iv) circumstances in which evacuation either is not possible or would entail considerable risk to the evacuees.

10 For case (i) the dose reduction afforded by sheltering is likely to be as substantial as (or even greater than) that achieved by evacuation, unless the evacuation is carried out before the release begins. In case (ii), the disruption and monetary cost of the evacuation would not warrant the potential additional dose saving which evacuation could achieve (ie, the dose saved by the evacuation would be below the lower ERL for evacuation). Case (iii) is a situation in which the timing of countermeasures may strongly influence the dose received. If evacuation is carried out while concentrations of radionuclides in air are very high, then the evacuating population may receive substantial doses. By sheltering the population until air concentrations have reduced to a lower level and then considering evacuation, greater dose savings may be achieved. The most likely cause of case (iv) would be extremely adverse weather conditions (eg, freezing fog or deep snow). In such conditions the individual health risk posed by the release could well be less than the physical risk entailed by evacuation. In this case, sheltering might be the most effective countermeasure which could be implemented to protect the public.

11 Where radioiodine is known to form a significant part of the release, the administration of stable iodine (to reduce the dose from inhalation of radioiodine) in conjunction with sheltering (to reduce the external irradiation dose) can form a very effective countermeasures strategy, although it is important not to overlook the inhalation dose likely to be received from other radionuclides. It must also be remembered that the benefit of sheltering is strongly dependent on the type of buildings available to accommodate people and the available means of communicating the advice to shelter and cease sheltering. It is therefore important to take these factors into account when formulating emergency plans for specific sites.

Evacuation

12 In the context of ERLs for early countermeasures, evacuation is taken to mean the removal of people from an area in order to avoid (or potentially to avoid) relatively high short-term exposures. The primary purpose of evacuation is to protect the population against the inhalation of radionuclides and external exposure from radionuclides in the air and deposited on the ground. It is distinct from relocation, which is the removal of people from the contaminated area for periods of weeks, months or years to avoid chronic, long-term exposures, although relocation may be carried out as an extension to evacuation.

13 Evacuation is the only countermeasure which has the potential to prevent virtually all exposure to a release. However, this is only achieved if the evacuation is carried out before the release occurs. In other situations partial dose savings will usually be achieved, although it is possible that evacuation may result in higher doses than alternative countermeasures or than no countermeasures, if it is incorrectly implemented. While people are in transit, their protection against external irradiation and inhalation of radionuclides is likely to be very much less than the protection they would receive from remaining inside typical UK buildings. It is therefore not advisable to evacuate people through areas where radionuclide concentrations in air are relatively high, unless it is judged that the dose which they would receive if any other countermeasures strategy were implemented (including taking no countermeasures) would be higher than the dose received during the evacuation.

14 Although the potential advantages of evacuation are great, there are also significant disadvantages, particularly if a large number of people is involved. Evacuation is a very disruptive countermeasure and may be expensive to implement. There are also practical problems concerning feeding and housing the evacuated population and ensuring the security of property in the evacuated zone. Stress may also be a problem, especially if evacuation is prolonged or families are separated. Generally, however, the physical risks of evacuation are not considered to be important (see the appendix).

15 Evacuation can be effective for reducing doses following many different types of accidental release. It can be effective in situations involving an accidental release to atmosphere, or localised contamination of the environment following, for example, the breakage of a radiography source or the crash of a nuclear-powered satellite. Five main situations can be identified in which evacuation is likely to be the optimum early countermeasure:

(i) precautionary evacuation, in response to the threat of a probable release;
(ii) in response to a large release of predictable duration or size, particularly one for which there is sufficient advance warning for people to be moved before it begins;
(iii) in response to an accident for which the release to atmosphere may be prolonged, and the size of the release is very uncertain and potentially large;
(iv) after the cessation of a release to atmosphere, to avoid doses from short-lived radionuclides deposited on the ground;
(v) after the cessation of any release, to avoid external exposure while localised, short-term decontamination is carried out.

16 Case (i) includes situations where conditions at a nuclear installation indicate that a large release of radionuclides to atmosphere is likely, but not certain, and if it does occur it will not start for some time. In this case, it is strongly recommended that precautionary evacuation is carried out, unless other factors, such as adverse weather conditions, preclude this. Case (ii) includes releases where the source of the release can be quickly brought under control and also those where the magnitude of the release will be limited (eg, a ruptured tank containing radioactive material). In such circumstances, the likely evolution of the accident can be predicted with confidence and the dose savings which could be achieved by evacuation compared with the appropriate intervention levels. In case (iii) a release is continuing, but the evolution of the accident is very uncertain, and there is the potential for the release to increase substantially or to continue at a significant level for a long time. Here, the enhanced exposure incurred during the evacuation is likely to be outweighed by the potential subsequent dose saving. The final two situations are linked, but in case (iv) the duration of the evacuation is determined by the decay of the radionuclides, while in case (v) the decontamination of land and property determines how quickly people can return. If large areas are contaminated then it is likely that the decontamination would take months or years to complete, and it would be necessary to relocate the affected population.

17 In situations when evacuation is carried out during the release, it is important to consider carefully the timing of the evacuation, so that the greatest dose saving can be achieved. As discussed for sheltering, in some situations it may be more beneficial to delay evacuation until concentrations of radionuclides in air are lower, and to advise sheltering in the meantime. As with sheltering, where radioiodine is known to form a significant part of the release, the administration of stable iodine in conjunction with evacuation can form a very effective countermeasures strategy. However, it should be noted that it is not necessary to administer stable iodine if precautionary evacuation has been carried out, or the evacuation was achieved very quickly after the start of the release.

Administration of stable iodine

18 The administration of stable iodine reduces or prevents uptake of radioactive iodine by the thyroid, largely by diluting it with stable isotopes; a stable iodine load may also partially saturate the iodine transport mechanism in the body. The level of protection is maximised if administration can be achieved just prior to the intake of the radioiodine; later administrations are less effective, although administration up to several hours after exposure can still achieve a substantial dose saving[15].

19 Stable iodine is potentially effective in reducing doses from intakes of radioiodine by inhalation or ingestion. However, appropriate restrictions on contaminated food can be used to reduce intakes of radioiodine by ingestion, and have the advantage of reducing doses from other radionuclides at the same time. Therefore, the administration of stable iodine is only recommended for reducing doses from inhalation of radioiodine, and it should only be carried out if doses from this pathway are likely to be important. In such cases, the administration of stable iodine in conjunction with sheltering or evacuation is likely to be the most effective countermeasures strategy. Planning for the issue of stable iodine as a stand-alone countermeasure is not recommended, since a release containing radioiodine will also result in exposure from external irradiation, and may well contain other radionuclides which give significant inhalation doses. Since the administration of stable iodine is most effective if it is carried out quickly once a release has started, it is important to plan the necessary distribution arrangements carefully.

20 A working group set up by the Department of Health to consider the WHO guidelines on the use of stable iodine[16] has recently drafted a report[15] which recommends that stable iodine should be administered in the form of potassium iodate tablets. Suggested optimum dosages of iodate are recommended for four age groups: 170 mg for adults, 85 mg for children aged 3–12 years, 40–45 mg for children aged from 1 month to under 3 years, and 20 mg for neonates. These values correspond to equivalent masses of 100 mg, 50 mg, 25 mg, and 12.5 mg

of iodine. The report also discusses possible contraindications to the taking of stable iodine, and the provision of information about these to the public and to medical practitioners.

Combining countermeasures

21 Following an accident, it is unlikely that only a single protective measure will be adequate. Generally, it will be most effective to implement a combination of countermeasures. Examples have already been given in the preceding paragraphs. There are also countermeasures, other than the three discussed above, which could usefully be employed in the early stages of an accident. The one most commonly considered is personal decontamination (usually showering and changing into clean clothes). This countermeasure, implemented alone, is unlikely to reduce doses significantly (and therefore it is not appropriate to develop ERLs for its implementation). However, personal decontamination is useful for preventing the spread of contamination and, carried out in conjunction with sheltering and evacuation, it can provide further dose savings with very little additional disruption or cost.

22 It is recommended that those responsible for developing emergency plans should explicitly consider the effective combination of countermeasures, as well as the implementation of single countermeasures, so that the best protection can be given to the public if an accident occurs.

APPLICATION OF PRINCIPLES

Purpose of ERLs for early countermeasures

23 If a countermeasure is implemented, then in addition to any dose saving it may achieve, it will have other benefits (principally reassurance) but it will also lead to some harm (eg, social disruption and monetary cost). The Board's principles[12] state that no countermeasure should be implemented unless it is expected to produce more good than harm and that the level of dose at which it is introduced (the intervention level) should be chosen so that the most good is achieved. It is therefore necessary to balance the likely benefits of a countermeasure against the possible harm it will cause, in order to determine the optimum intervention level for its introduction.

24 The optimum intervention level of dose for introducing a particular countermeasure will be very dependent on the nature of the accident, the weather conditions, the available resources and site specific factors, such as the characteristics of the population, housing and industry. However, the purpose of early countermeasures is to provide rapid protection against relatively high, short-term exposures. There will not be time to carry out a detailed analysis and quantification of all the relevant factors influencing the optimum intervention level of dose for each countermeasure at the time of an accident. It is therefore necessary to carry out a range of such analyses for different assumed accident scenarios, in advance of an accident, in order to formulate guidance on appropriate intervention levels in different situations. These may then be incorporated into emergency plans.

25 The purpose of the Board advice on ERLs for early countermeasures is to provide generic guidance on the determination of, and appropriate values for, intervention levels. It is intended that the primary use of this guidance will be in emergency planning, as an aid for the determination of intervention levels which are optimum for particular sites and circumstances. The Board therefore recommends upper and lower ERLs which, in its judgement, bound most of the range of possible optimum intervention levels. The lower ERL is chosen to be an appropriate intervention level in situations which are favourable for the introduction of a countermeasure, while the upper ERL is appropriate for situations which are much less favourable. The ERLs are not intended to bound the total range of possible optimum intervention levels, since, if very extreme situations are considered, this range could be very large. However, for most situations, it is likely that the optimum intervention level would fall within the range provided by the upper and lower ERLs.

26 The ERLs are specified in terms of dose averted by the countermeasure. This is because the dose incurred before a countermeasure is implemented entails a risk which will occur whether or not the countermeasure is introduced. Thus, provided that the total doses (incurred and projected) are below the thresholds for serious deterministic health effects, the dose incurred prior to the countermeasure does not, in principle, enter into the decision.

27 It is recognised that the overall reduction of stochastic risks is also an important aim of emergency response; the specification of ERLs in terms of dose averted should not be seen to be in conflict with this aim. It is considered that the primary way in which overall reduction in stochastic risks should be achieved is by appropriate emergency response planning. The Board places emphasis on the development of emergency plans which enable countermeasures to be implemented quickly, so that substantial parts of the potential dose are not received prior to implementation of a countermeasure. The specification of ERLs in terms of dose averted should not be taken to mean that there is benefit in delaying the implementation of countermeasures. In most circumstances, countermeasures should be implemented as quickly as possible; the only reason for delaying implementation should be that higher doses will be averted if there is a delay. However, it is recognised that despite careful planning, there may arise unavoidable circumstances where a substantial dose is received prior to possible implementation of a countermeasure. In such circumstances, the specification of intervention levels in terms of dose averted does not preclude account being taken of doses already received in the assessment and balance of harms and benefits resulting from implementation of the countermeasure. For example, it may be judged that the benefits (particularly in terms of reassurance) of taking the countermeasure are increased relative to those that would have resulted if very little dose had already been received, and so a lower intervention level than would otherwise have been chosen may be appropriate. However, account taken in this way of doses already received should not be confused with the treatment of ERLs and intervention levels as some form of total dose limits; it is not right that an individual who has already received most of the potential projected dose

should suffer further by undergoing a countermeasure which averts very little additional risk.

28 The derivation of intervention levels should, in principle, take account of the possibility of combining countermeasures. However, this is a complex process requiring specific details of the characteristics of the site and the accident. The ERLs have therefore been derived for each countermeasure independently, but it is recommended that the potential advantages of combining countermeasures (as discussed in paragraphs 21 and 22) are recognised when emergency plans are developed.

Factors which influence decisions on countermeasures

29 A number of factors could potentially influence decisions on countermeasures. These can be grouped into three categories: health factors, monetary cost factors, and those, much less easily quantified, which are social factors. The factors which have been considered in determining the ERLs for early countermeasures are given below.

Health factors

Averted individual risk from exposure to radiation ('averted individual risk')

Averted collective risk from exposure to radiation ('averted collective risk')

Individual physical risk introduced by the countermeasure ('individual physical risk')

Collective physical risk introduced by the countermeasure ('collective physical risk')

Risks incurred by workers implementing the countermeasure ('worker risk')

Monetary cost factors

Monetary cost ('monetary cost')

Social factors

Reassurance provided by the countermeasure ('reassurance')

Anxiety caused by the need to introduce the countermeasure ('countermeasure anxiety')

Disruption to the individual ('individual disruption')

Disruption to society ('social disruption')

30 Some of these factors (benefits) tend to reduce the intervention level at which the countermeasure should be introduced, while others (harm) tend to increase it. This division of the factors is illustrated in Figure 1. The appropriate intervention level of dose for a given countermeasure, in a given situation, is determined by a comparison or balancing of these factors. The countermeasure will be justified for all intervention levels of dose for which the benefits outweigh the harm, and the optimum intervention level will be the value at which the difference between the

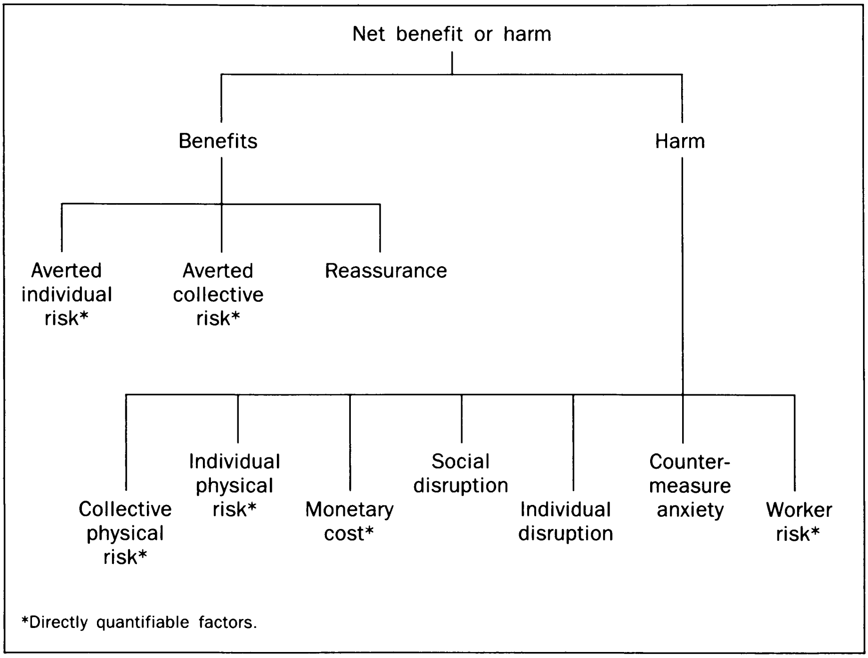

FIGURE 1 *Factors relevant to early countermeasures decisions*

benefits and the harm is greatest. This balancing may be achieved intuitively, or may be carried out more formally using decision-aiding techniques[17]. In either case, the factors considered relevant are first quantified ('valued') and then weighted according to their perceived importance. The harm and benefits can then be compared, and a decision taken concerning whether or not the countermeasure should be implemented at that intervention level of dose. Although this process is conducted whether the decision is taken intuitively or aided with more formal techniques, the use of these formal techniques has the advantage that the process is clearly structured and the reason for the decision is explicit. It should be stressed that the use of these techniques does not replace the responsibility of those who must make decisions or their judgement of the factors involved. The purpose of these techniques is solely to enable those making decisions to address each factor explicitly, and to understand clearly the basis of their decisions.

31 In determining the ERLs, use has been made of a form of multiattribute value analysis (MAVA). This was preferred to the use of cost–benefit analysis, since MAVA allows the inclusion of social factors directly into the analysis, and does not constrain the user to convert the values of all factors to monetary costs. Although MAVA techniques are very useful in establishing intervention levels for emergency planning purposes, and for specifying ERLs, decisions on early countermeasures following an actual accident would need to be taken quickly, and at such times more intuitive judgements would be necessary, based on the guidance in the emergency plan.

Population group considered in the derivation of ERLs

32 It is important to recognise that no population group is homogeneous. The aim of emergency planning and the implementation of countermeasures must be to ensure 'the most good for the most people', not to attempt to provide uniform net benefit to everyone. For every countermeasure and population group it will always be possible to identify individuals who gain less benefit from (or who are even disadvantaged by) the countermeasure. An example is elderly people who are at far less risk from exposure to radiation than younger people, and who are probably more at risk from physical injury, disruption and anxiety from implementation of a countermeasure. Another example is those individuals who suffer disruption or monetary loss as a result of the countermeasure, but who themselves do not benefit from the countermeasure.

33 The population group for which dose savings and risks should be evaluated for the determination of intervention levels should exclude extreme and unusual individuals with characteristics which place them at significantly different risk (whether from radiation exposure or from the countermeasure) than the rest of the population. If such individuals are included, then it is likely that too much weight will be accorded to their risks or benefits, and so the resulting intervention level will not ensure the most good for the most people. The population group chosen should comprise (or be likely to comprise) at least a significant minority of the potentially exposed population; they should have conventional habits and live in conventional dwellings. The protection of individuals engaged in activities which, although unusual for the UK population as a whole, are customary practices in a particular area (eg, campers), should be considered in the development of site specific emergency plans. However, explicit consideration of such people is not appropriate for the specification of the ERLs.

34 If an evaluation of all the benefits and harm is carried out for every individual in the population group for which the countermeasure is being considered, then a distribution of optimum intervention levels would result. In order to ensure the most good for the most people the intervention level chosen should be the value corresponding to the average of the distribution. If each individual's optimum intervention level were determined solely with regard to the physical well-being of that individual, then the intervention level chosen would correspond to the dose averted for an individual who was average in all respects for the population group being considered. Such a procedure would, however, neglect social factors, which are particularly important at low levels of individual risk. People's perception of personal disruption and risk is often influenced by their perception of the risk to others in the group, particularly children. Considering the factor of reassurance alone, most people would not be reassured by an emergency plan which did not explicitly protect children. For this reason, the ERLs are intended for application to the averted dose for young children.

35 It has been recognised that during the early stages of development, the embryo and fetus may be at significant risk of serious mental retardation from exposure to high levels of radiation[5]. However, more recent research[18–20] suggests that this effect of irradiation on the fetus is in terms of a downward shift of

IQ of 30 points Sv^{-1}. At the levels of dose likely to be received by the public following a civil nuclear accident, this risk is thus very small. In addition, application of the third principle (that of limitation of the total dose received to levels below those at which deterministic effects may occur) will avoid the potential exposure of pregnant women to levels of dose where the risk to the fetus is substantial. Therefore it is not appropriate to take special account of pregnant women when specifying ERLs.

Role of dose limits

36 The dose limits recommended for application to routine exposure of members of the public, and targets related to these limits, are not relevant should an accident occur. Dose limits and related targets are established within the framework of risks routinely tolerated by the majority of the population, and apply to exposures which can be controlled in advance by design and in planning regular operations. The limits and targets are conceptually separate from ERLs, and relate to doses actually incurred from a specified group of practices rather than doses potentially averted by intervention. Thus the existence of dose limits for the public should not have any influence when intervention levels are established.

RECOMMENDED ERLs

37 Approximate values for the upper and lower ERLs for each of the early countermeasures of sheltering, evacuation and the administration of stable iodine are derived in the appendix and shown in Table 1. They have been obtained by comparing the benefits and harm associated with each countermeasure in circumstances favourable (lower ERL) and unfavourable (upper ERL) for its introduction. It should be noted that the approach used determines intervention levels which are justified, in the sense that more good then harm is expected to be achieved by the countermeasures in the postulated scenarios. However, the levels do not represent the optimum for any specific site or scenario; the determination of optimum intervention levels needs to be carried out as part of site specific emergency planning. The ERLs obtained from the justification approach are approximate because many of the factors which would influence decisions on countermeasures are very difficult to quantify, and because quantification of these

TABLE 1 *Approximate ERLs for early countermeasures*

		Dose equivalent level (mSv)	
Countermeasure	Body organ	Lower	Upper
Sheltering	Whole body	Few	Few tens
	Thyroid, lung, skin	Few tens	Few hundreds
Evacuation	Whole body	Few tens	Few hundreds
	Thyroid, lung, skin	Few hundreds	Few thousands
Stable iodine	Thyroid	Few tens	Few hundreds

Note ERLs as derived in the appendix, for young children.

factors requires site specific and accident specific information. The major factors which influenced the choice of these values are summarised below.

38 In conditions favourable for the implementation of sheltering (eg, a few people are involved and individual disruption is low), the only major drawback is likely to be the anxiety introduced by the need to take the countermeasure. The lower ERL is therefore set at a relatively small, but not negligible, dose level. In conditions which are unfavourable for implementing sheltering (eg, where many people are involved for a long time), there are likely to be increased social disruption and monetary costs, but it is unlikely, even in these unfavourable conditions, that sheltering would introduce significant physical risks. Therefore the upper ERL is judged to be about ten times higher than the lower ERL. In determining this upper ERL it is assumed that the dose averted is achieved during a period no longer than 1 or 2 days. If a longer period of sheltering is indicated, then serious consideration should be given to additional or substitute countermeasures. The lower ERL for evacuation represents the balancing of a number of factors, including individual disruption, monetary costs and dose averted. It is judged that the appropriate level of averted dose for intervention is about the same as that corresponding to the upper ERL for sheltering, ie, a whole body dose of a few tens of millisieverts. The upper ERL for evacuation is taken to be at a level of averted dose of a few hundred millisieverts, whole body.

39 The Department of Health Working Group advises[15] that the health risks associated with the administration of its recommended dosage of stable iodine are very small for most people. Therefore, in conditions favourable for the administration of stable iodine, the only major drawback is likely to be the anxiety introduced by the need to take the countermeasure. In unfavourable conditions, monetary costs and social disruption may form additional drawbacks. In contrast, the reassurance provided by the countermeasure is likely to be high. The appropriate levels of dose averted for administering stable iodine are judged to be a few tens of millisieverts and a few hundred millisieverts to the thyroid for the lower and upper ERLs, respectively.

40 While the approximate values of ERLs given in Table 1 are useful as generic guidance, those responsible for emergency planning need clearer and more straightforward advice. Single values of the upper and lower ERLs have therefore been selected from the indicative ranges in order to provide a coherent set of recommended values. These are given in Table 2. For simplicity, they are based on

TABLE 2
Recommended ERLs for early countermeasures

		Dose equivalent level (mSv)	
Countermeasure	Body organ	Lower	Upper
Sheltering	Whole body	3	30
	Thyroid, lung, skin	30	300
Evacuation	Whole body	30	300
	Thyroid, lung, skin	300	3000
Stable iodine	Thyroid	30	300

a single number, the number three, and at present it is advised that the quantity 'effective dose equivalent' is appropriate for comparison with the ERLs of dose to the whole body.

APPLICATION OF ERLs

Derivation of site specific intervention levels

41 In this document, upper and lower ERLs have been derived which, it is judged, bound the range of intervention levels at which a particular countermeasure would be justified in a realistic range of accident scenarios. In planning emergency response at a particular site, it is important to determine the intervention levels which would be optimum for this site for a range of postulated conditions. Generally, it would be expected that these would fall between the upper and lower ERLs. It is not expected that these levels would usually coincide with the lower ERL, since these correspond to the lowest level which would be justified in the most favourable conditions (in particular, for situations in which relatively few people would be affected by the countermeasure).

42 Since it is important to make decisions on early countermeasures quickly, it is not possible to carry out a detailed determination of the optimum intervention levels during an actual accident. Predetermined levels are therefore very important for providing guidance, should an accident occur. Given the uncertainties immediately following an accident, these predetermined intervention levels should be somewhat stylised, following similar arguments to those set out in paragraphs 37–40. The number of predetermined intervention levels should be strictly limited, with clear guidance on the circumstances which would indicate the choice of each.

Precautionary countermeasures

43 It is strongly recommended that the use of precautionary (or automatic) countermeasures is considered when preparing emergency plans. Although the Board has specified ERLs of averted dose for the introduction of countermeasures, these are not intended to imply that no countermeasures decisions should be taken until detailed estimates of the likely averted doses can be made. The ERLs are primarily intended for guidance in the preparation of emergency plans, and it is intended that these plans should provide advice on situations for which the introduction of precautionary countermeasures would be the best course of action.

44 If a decision to implement a countermeasure is delayed until it is certain that a given level of dose will be averted, then the potential benefit of introducing that countermeasure may be severely reduced (see, for example, paragraph 13). This is particularly important for sheltering and evacuation. Therefore if it is judged that there is a significant threat of exposure exceeding the intervention levels determined for the site, even if no increased radioactivity has been measured offsite, then the decision should be taken to carry out the planned countermeasures. This may result in countermeasures being implemented when no offsite release actually occurs. However, the potential advantages of taking such precautionary action are likely to be much greater than the potential costs. Therefore it is recommended that serious consideration is given to the taking of precautionary countermeasures in advance of a probable release of a scale such that it is likely that the relevant intervention level may be exceeded, even if with hindsight they may be shown to be unnecessary.

Population groups which do not include young children

45 The ERLs are intended for application to young children. However, some population groups may not contain children (eg, workers on industrial estates). In principle, it would not be correct to implement countermeasures based on notional averted doses for an age group which was not represented in the exposed population. Ideally, intervention levels should be developed for such sites, which are expressed in terms of doses averted for the population group likely to be exposed. However, the averted doses for adults and children are likely to be very similar for some radionuclides, and even for radioiodine the difference in averted dose is only a factor of between two and three. Given the likely magnitude of the uncertainties in dose estimates, the use of notional doses for comparison with the ERLs is unlikely to result in countermeasures being implemented when it would be unjustifiable to take action.

Dose estimation at the time of an accident

46 Generally, immediately following an accident, the making of any dose estimate is a very uncertain procedure, requiring many assumptions and judgements. In order to make informed decisions on countermeasures, estimates of averted dose are required for comparison with the appropriate intervention levels. It is important to recognise that these estimates should be 'best estimates', since the intervention levels represent a balancing of benefits and harm; the use of pessimistic dose estimates would invalidate this balance. However, even 'best estimates' will be subject to large uncertainty, and so it is reasonable to make simplifying assumptions when calculating averted doses, if these assumptions do not significantly increase the overall uncertainty.

47 It is strongly recommended that doses are calculated using assumptions which reasonably characterise the behaviour and likely exposure of the population. For example, in bad weather or during the night, it would be reasonable to assume that young children are indoors, while in the middle of summer, they may well be playing outdoors. However, it is also recommended that calculational refinements which alter projected doses (ie, doses predicted for individuals in the absence of countermeasures) by less than a factor of two should not be undertaken since the dose estimate is likely to be uncertain by a greater margin than this. Equally, countermeasures which are likely to avert more than half of the projected dose may reasonably be assumed to avert all of the dose for the same reason. Therefore, when estimating the dose averted by any of the three early countermeasures of sheltering, evacuation and the administration of stable iodine, it is reasonable to assume that the whole of the dose projected for the period between the full implementation of the countermeasure and the lifting of it, is averted. If the doses received during the implementation of a countermeasure are likely to be very significant, then it would be reasonable to estimate the averted dose from a time mid-way in the implementation of the countermeasure, or to divide the population into groups, according to the order in which they will be notified of the countermeasure, and calculate the averted doses separately for each group.

48 These approximations could conceal important features of the countermeasures, such as the need for solidly constructed and reasonably airtight buildings if sheltering is to be effective, the need for prompt administration of stable iodine if significant doses from radioiodine are to be saved, and the likely temporary increase in exposure for an evacuating population. It is important that these features are addressed in determining the intervention levels for inclusion in the emergency plan and are borne in mind at the time of an accident. It is therefore recommended that dose calculations performed in support of the emergency plan should not incorporate the simplifying assumptions suggested here for dose estimation at the time of an accident. It is important that in order to develop the emergency plan, realistic and thorough estimates are made of the projected doses and averted doses which could result assuming different accident scenarios and different countermeasures strategies.

Avoidance of serious deterministic effects

49 The ERLs are specified in terms of averted dose. However, the third principle for the protection of the public should an accident occur[12] states that serious deterministic health effects should be avoided if at all possible, and clearly refers to total projected dose. The threshold doses for such health injuries in young children are about 1 Gy absorbed dose to the whole body and 2–3 Gy to the most radiosensitive organs[5]. Therefore every effort should be made to keep total exposures of children below these levels. In most situations, the implementation of countermeasures to avert levels of individual dose between the lower and upper ERLs given in Table 2 will also avoid serious deterministic health effects (unless there is a significant delay in implementing them). However, in situations where intervention levels towards the upper ERL for evacuation are considered, then estimates of total exposure should be made, in order to check compliance with the third principle. Ensuring that total doses are below the threshold for serious deterministic effects also prevents total risks of stochastic effects becoming extremely high.

Selective countermeasures

50 No countermeasure can be expected to benefit all members of a population group equally and, indeed, it may disadvantage some, particularly the elderly. For this reason it has sometimes been suggested that countermeasures might be planned selectively, using different intervention levels for different groups within the population. In practice, this is rarely possible. It is not practicable to alert some members of a population group and not others. Moreover, families will not wish to be separated and individuals may experience enhanced anxiety if countermeasures are taken which include neighbours and not themselves. For this latter reason it is wise to include whole communities in emergency plans, accepting that the implementation of a countermeasure may not be optimum for some members,

rather than deliberately excluding some members because of their location or age. However, where certain population groups which are likely to be more at risk can be readily contacted (eg, schools) priority can be given to informing such groups of the need for a countermeasure.

Timing and combining of countermeasures

51 When implementing countermeasures, it is important to remember the points made in paragraphs 6–22 concerning the effectiveness of countermeasures. In particular, if the decision to evacuate is not taken until the release has started, careful consideration should be given to the timing of the evacuation, and whether it would be better to shelter the population for a while until the radionuclide concentrations in air have reduced. Equally, it is important both to recognise that sheltering cannot be prolonged indefinitely, and to ventilate houses thoroughly once the outside air concentrations have returned to near normal.

52 If stable iodine has been administered then it can be assumed that protection is effective for 24 hours. Only if the release is likely to continue at a significant rate after the first day should consideration be given to a second administration of iodine. However, in such circumstances, serious consideration should have been given to evacuating the population, and only in very extreme circumstances would a second administration of stable iodine be necessary. The advice given in the Department of Health Working Group's report[15] that multiple dosages of stable iodine administered to new-born babies may entail significant health risks, should be noted.

53 As discussed in paragraphs 21 and 22, there are some subsidiary countermeasures which could usefully be implemented in conjunction with sheltering and evacuation (eg, personal decontamination). Consideration should always be given to these if the major countermeasures are required. If neither sheltering nor evacuation is to be advised, then, in general, it is recommended that no other early countermeasure should be planned, since to take other countermeasures could create anxiety in the population, for very little dose saving.

WITHDRAWAL OF COUNTERMEASURES

54 It is important to recognise that the withdrawal of countermeasures is a positive action in its own right, and not just a lifting of restrictions. Prolonged evacuation could cause unnecessary stress and disruption to families, and increased monetary cost; while prolonged sheltering, without further advice on restoring ventilation after the passage of a plume, could cause unnecessary, additional radiation exposure of the occupants of buildings.

55 Generally, early countermeasures should be lifted as soon as practicable following the cessation of the release, provided that residual contamination in the environment does not indicate otherwise. If the residual dose rates from deposited, short-lived radionuclides are such that the lower evacuation ERL would be exceeded over a few days, then evacuees should not be allowed to return until these have substantially reduced. In addition, consideration should be given to the evacuation of individuals who were not evacuated while the release was continuing. If residual dose rates are lower, then the population should be allowed to return as soon as practicable, provided that relocation is not justified and decontamination of land and buildings is not necessary. Further guidance on the determination of dose levels for relocation and decontamination will be provided in a subsequent issue of *Documents*.

56 Apart from decisions on the return of the evacuated population, other positive actions will be necessary. In particular, thorough ventilation of all houses in the area affected by the release is advisable, as soon as the release has stopped and contamination levels in outside air have fallen. Since it should very rarely be necessary to administer more than one dose of stable iodine, advice on withdrawal of this countermeasure is not necessary.

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Appendix

DERIVATION OF EMERGENCY REFERENCE LEVELS FOR EARLY COUNTERMEASURES

Introduction

In this appendix the factors which influence the determination of intervention levels are discussed in detail. Using these factors the upper and lower ERLs for each of the three early countermeasures of sheltering, evacuation and the administration of stable iodine are determined. The ERLs for sheltering and evacuation are derived as averted whole body doses for a child. The ERLs for the administration of stable iodine are derived as averted doses to the thyroid of a child. Since ERLs of averted dose to single organs can also be useful in aiding decisions on the introduction of sheltering and evacuation, values for these are also derived.

Factors which influence decisions on countermeasures

In paragraph 29 of the main text, factors were identified as being potentially important for decisions on countermeasures following an accident. These are summarised in Figure 1 of the main text and are discussed in turn below, in an order which reflects the similar characteristics of some of the factors.

Individuals and populations

Before discussing each factor, some general comments are useful concerning those factors which relate to individuals and those which relate to populations (collective factors). The relative importance attached to these two types of factor depends primarily on the level of individual harm (or benefit). Here, the terms harm and benefit are used in the widest sense, encompassing risk of radiation-induced health effects, physical risk, disruption, and reassurance. Generally, at high levels of individual harm or benefit, it is the individual-related factors which most strongly influence any decision on countermeasures. Conversely, where individual levels of risk or benefit are very low, a decision on countermeasures is likely to be dominated by consideration of the collective risks and benefits.

The magnitude of any collective harm or benefit is dependent on the population group considered. Many countermeasures affect a larger number of people than those directly subject to the countermeasure. For example, a decision to evacuate has implications, not only for the evacuees, but for all those required to manage the evacuation, for those providing food, accommodation and medical attention for the evacuees, and for all those who had planned to visit the area or make contact with individuals within it. If consideration were restricted to the collective harm experienced by the evacuated population only, then the total collective harm caused by the countermeasure could be significantly underestimated. Therefore, an intervention level determined by considering only the population group undergoing the countermeasure could be different in value from an intervention level determined by considering the whole of society. (Equally, the definition of 'the whole of society' could affect the decision. For example, the optimum value based on the UK may well be different from that for all Europe.) Wherever collective harm is identified as forming an important input to a decision on countermeasures, then the population group for which it is evaluated should be chosen carefully to ensure that all the significant components are included in the evaluation.

Averted health risk

The health risks resulting from exposure to radiation range from very debilitating injuries (in the extreme, death) to treatable cancers, and also include damage to the developing fetus and hereditary defects. There is also a wide time variation in the incidence of these injuries, ranging from weeks to decades for the individual exposed, and occurring over generations in the case of hereditary defects. In principle, all these aspects should be taken into account when assessing the health risk averted by taking a countermeasure, particularly when determining an intervention level which will optimise the protection given.

In the context of specifying ERLs, some observations can be made on the health risks to be considered. Firstly, it is virtually impossible to imagine a plausible situation where countermeasures would only be implemented to save doses in excess of those which could give rise to serious deterministic health effects. ERLs are thus based on avoiding stochastic health effects and it is not necessary to take account of deterministic health effects when deriving them. It follows from this that ERLs can be expressed in terms of dose equivalent, rather than absorbed dose. Secondly, for whole body irradiation the risk of fatal cancer is likely to be twice the risk of non-fatal cancer[1]. Therefore, bearing in mind the uncertainties in the quantification of many of the factors in Figure 1, it is reasonable to omit consideration of non-fatal cancers when deriving ERLs for whole body exposure. However, the majority of skin and thyroid cancers are non-fatal and so the ERLs developed for these organs should take explicit account of their incidence. Thirdly, the risk of hereditary effects over all generations should be taken into account; for the purposes of specifying ERLs, the same weight is assigned to these health effects, regardless of when they occur. The time distribution of the likely incidence of health effects is not considered relevant in this context.

It should be noted that the relationship between averted individual risk and averted collective risk is not necessarily simple. Throughout the following discussion the averted individual risk is taken to be equal to the risk associated with the ERL of dose. For a given accident scenario and site, raising an intervention level (and hence increasing the minimum averted individual risk for which the countermeasure would be considered) would decrease the averted collective radiation risk because fewer people are affected by the countermeasure, and conversely lowering an intervention level would increase the averted collective risk. Whether these decreases or increases are significant depends on the circumstances. In the case of the Board's ERLs for early countermeasures, averted collective radiation risk is not an important factor. For the lower ERLs, where the circumstances are assumed to be favourable for the introduction of early countermeasures, the number of people involved is small and hence the averted collective risk is small both in absolute terms and as a fraction of the total collective radiation health risk of the accident. In the case of the upper ERLs, the circumstances are assumed to be unfavourable for the introduction of early countermeasures, so averted individual risk is assigned greater weight and averted collective risk is again not a major factor.

Physical risk

Generally, in the UK, the physical risks associated with countermeasures are small. A recent survey of individuals in southwest England concluded that most people could shelter for 1 or 2 days with little difficulty[2]. For the administration of stable iodine, a Department of Health Working Group has recently concluded that, generally, the health risk from this countermeasure is very low[3]. Even for evacuation, which is carried out frequently for hazards other than radiation, there have been very few documented injuries either in the UK or in the USA[4]. However, it is always possible to postulate scenarios where the individual physical risks might become a dominant factor in determining the intervention level for which protection was optimised. For example, in very hot weather, prolonged sheltering of the young or elderly might pose health problems, while in extremely bad weather conditions, evacuation might endanger lives.

Even though the individual physical risks involved in early countermeasures are generally small, the collective risks may not be trivial. The magnitude of the collective risk is, at least partly, dependent on the number of people affected by the countermeasure, while the magnitude of the individual risk is largely unaffected by this. This means that as the intervention level for the countermeasure decreases (resulting in an increasing number of people being involved), the collective physical risk increases proportionately. At some low level of individual risk, the collective physical risk may become a major factor in a countermeasures decision.

Individual disruption, reassurance, countermeasure anxiety

Social factors relating to the individual are discussed here; the collective aspects are considered on p. 29. The three factors of individual disruption, reassurance and countermeasure anxiety are very difficult to quantify, and they may well be very different for each individual. Each of these factors will tend to be most significant in determining intervention levels at levels of dose intermediate between those entailing significant individual health risk and those for which the individual health risk is small.

The level of disruption experienced by individuals will be related, to some extent, to their lifestyle, health and intended activities during the period of the countermeasure. For example, the advice to shelter for a few hours, given to a mother of several young children on a wet and cold winter evening may cause her negligible disruption. The same advice to that mother on a very hot summer's day might cause her significant disruption, particularly if her home was small. However, evacuation will always be very disruptive.

The reassurance afforded to an individual by the introduction of a countermeasure depends on his perception of the risk to which he is exposed and the extent to which he perceives the countermeasure to protect him from that risk. An individual's perception of risk will be determined by a complex set of interacting factors, including the general nature of the risk (in this case, exposure to ionising radiation), and the degree to which the individual can himself quantify the risk and make his own decisions concerning the need for protective actions (in this case, the individual must rely upon information given by the operator of a nuclear installation or by Government agencies). In a situation involving potential accidental exposure to radiation, an individual has little chance for independently assessing the risk and generally perceives that risk to be relatively high. He is therefore unlikely to be reassured by advice that little protective action is required. However, if evacuation is advised, then the level of reassurance afforded to most individuals will be substantial (although, of course, the personal disruption each individual experiences will also be high). A complicating factor here is that the reassurance afforded by implementing a countermeasure will also be strongly influenced by the level of control and competence the authorities are perceived to have in the management of the accident. For example, advice to shelter from authorities who are trusted will provide more reassurance than advice to evacuate from authorities who are perceived to have lost control of the situation. However, considerations of this kind are outside the scope of this document.

Finally, countermeasure anxiety is the anxiety experienced by individuals as a result of knowing that the countermeasure is considered necessary. It is likely that this anxiety will be strongly influenced by the level of risk that would exist in other circumstances where that countermeasure would be implemented. For example, evacuations are often carried out for bomb-scares and, less frequently, for hurricanes and severe flooding. Sheltering is often recommended to avoid acute symptoms following a release of toxic chemicals. Generally, it is only for nuclear accidents that plans are made for urgent countermeasures to protect against late, stochastic health effects. Therefore it is likely that if countermeasures are taken after a nuclear accident, individuals will overestimate their personal health risk.

Monetary cost

Monetary cost is a factor which, some might argue, should not be taken into account when determining intervention levels for early countermeasures. Clearly, for situations where the individual health risks are high, the monetary cost of introducing countermeasures will not be a major factor in decisions on intervention levels. However, monetary cost forms, for many situations, a very significant contribution to the harm introduced by a countermeasure. Moreover, this cost is rarely borne solely by those benefiting from the countermeasure, nor is it necessarily shared equitably throughout the UK population. For the countermeasure of evacuation, the decision to implement it will involve a significant monetary cost, however few people are evacuated. This is because a decision to evacuate people requires the organisation and mobilisation of a number of supporting services; additional police (both to organise the evacuation and to ensure security of property in the evacuated region), transport, accommodation, food supplies, counselling services, monitoring services and general administration. This step increase in monetary cost is much less significant for the other early countermeasures, although the decision to implement any countermeasure is bound to require the mobilisation of some support services. Therefore, at intervention levels of dose which do not represent a significant health risk, it is reasonable that the monetary cost has more weight in the decision on whether to implement countermeasures. The weight which is accorded to this factor relative to the other factors discussed here will, however, be very dependent on the situation and the value of the intervention level being considered.

Social disruption

Social disruption is the collective disturbance to the normal or expected lifestyles of those affected by the countermeasure. As with monetary cost, it is likely to be experienced by a larger population group than those benefiting from the introduction of a countermeasure. It will also increase rapidly with decreasing intervention levels, particularly for accident locations near major towns. As with monetary cost, social disruption is likely to become a significant factor in determining intervention levels at low levels of dose.

Worker risk

The factor 'worker risk' encompasses individual and collective health risks incurred by workers as a result of exposure to radiation and also any physical risks involved in implementing the countermeasures. Where it is possible, the doses to workers implementing early countermeasures should be kept within the dose limits set for planned exposures[5], and in general the risks to individual workers involved in implementing early countermeasures can be assumed to be within normally tolerable levels. They are therefore not considered an important factor in the determination of ERLs for early countermeasures.

Although the individual dose received by workers is unlikely to be a major consideration in the specification of ERLs, the collective dose may well be. The intervention level used for implementing a countermeasure should clearly take account of the collective exposure expected in the work force asked to implement it. For example, it would rarely be justified to ask emergency services personnel to experience a greater collective exposure in the course of introducing a countermeasure than the collective dose averted by that countermeasure.

Worker risk, as defined here, includes physical risks as well as radiation risks. Some accident situations may be hazardous for workers (eg, very bad weather conditions). It is thus important to take account of the magnitude of the physical risk faced by individuals in implementing countermeasures. Where this is significant, then the expected individual risk saving in the exposed population should be at least commensurate with it, or else the countermeasure will not be justified.

ERLs of whole body dose for sheltering

Lower ERL

As discussed in paragraph 25 of the main text, the lower ERL for sheltering is determined assuming favourable circumstances. Such circumstances are assumed to be those where very few people would be involved in the countermeasure, the dose saving could be achieved over a short period, the time of day and year was such that the people asked to shelter would have intended to be indoors during that period anyway, and the resources (including monetary costs) and worker risks required to implement the countermeasures were minimal. Given this scenario, most of the factors discussed above as potentially influencing the ERL would be unimportant. Only three significant factors remain: the benefit of the individual averted health risk, the benefit of reassuring the public by taking the countermeasure, and the anxiety which the public would experience because such a countermeasure was deemed necessary. Of these, the benefit of the health risk averted is directly related to the level of dose averted, while the other two factors are independent of this dose level. The lowest level of dose at which sheltering would be justified is then the dose at which the weighted sum of the two positive factors (risk averted and reassurance) equals the weighted value of the negative factor (anxiety). The weights represent the relative degree of importance attached to each factor. If the values of both reassurance and countermeasure anxiety are assumed to be independent of the intervention level, then their weighted values may be combined to give a net value of harm. The lower ERL is then the weighted averted dose which corresponds to this level of harm.

The ERLs are generic and it is not possible to assign precise quantitative values to each of the three factors. However, it is likely that the value of countermeasure anxiety would be equivalent to a significant risk of serious harm. The value of reassurance is likely to be related to the level of perceived risk, and it is likely to be somewhat lower than the value of the countermeasure anxiety, since sheltering leaves people in a situation involving potential exposure to radiation. Most certainly it will not be greater. Therefore the net equivalent value of these factors is likely to be less than the value of countermeasure anxiety alone, but significantly greater than zero. The level of dose averted which corresponds to this level of harm is judged to be fairly low, but significantly greater than the doses received in normal living (ie, a dose of a few millisieverts).

Upper ERL

The upper ERL is derived assuming conditions which are unfavourable for sheltering. Here the number of people involved is large and the duration of the sheltering is long (ie, 1 or 2 days), so social disruption is large and the monetary cost may no longer be insignificant. Individual disruption will increase with the duration of sheltering but, as shown by a recent survey[2], most people would not find the requirement to shelter for 1 or 2 days severely disruptive. Therefore it is judged that it is the societal factors which will dominate the determination of the intervention level—ie, the upper ERL for sheltering will be determined by balancing social disruption and monetary cost against individual risk averted.

The negative factors of monetary cost and social disruption are likely to have a combined value which is significantly higher than the net value of countermeasure anxiety and reassurance discussed for the determination of the lower ERL. It is judged that an appropriate increase in the level of dose averted, compared with the lower ERL, is about a factor of ten. Therefore, the upper ERL for sheltering is determined to be a few tens of millisieverts.

ERLs of whole body dose for evacuation

Lower ERL

The derivation of the lower ERL for evacuation is probably the most complex because nearly all of the factors in Figure 1 have an influence on the resulting level. Bearing in mind that the lower ERL is derived assuming conditions favourable for evacuation, the physical risks are assumed to be insignificant and social disruption is assumed to be less significant than individual disruption (ie, the number of people involved is small). Although it can be assumed that the monetary costs are only those associated with the evacuation of a small number of people, these may not be trivial, as discussed on p. 28. Thus monetary costs may still have a significant influence on the determination of the ERL. The significance of countermeasure anxiety and individual disruption will be essentially independent of the intervention level. Reassurance is clearly another input, and it is likely to be a higher value than the reassurance provided by sheltering (because people are removed from the hazardous situation). Assuming favourable conditions, worker doses should be kept within dose limits and the number of workers involved in implementing the evacuation will be relatively small. Therefore the risks to workers involved in implementing countermeasures will not form an important factor in determining the lower ERL.

The lower ERL will therefore be determined by the appropriate balancing of the positive factors of individual risk averted and reassurance against the negative factors of monetary cost, individual disruption and countermeasure anxiety. Countermeasure anxiety and reassurance can be taken to be of a similar magnitude, and so offset each other. The balance can thus be reduced to one between individual risk averted, monetary cost and individual disruption. This may be compared with the balance determined for the upper ERL for sheltering, between dose averted, monetary cost and social disruption. Depending on the exact circumstances, either individual or social disruption may be afforded the greater value. Since the ERLs are generic values, it seems reasonable that the value of the lower ERL for evacuation should be of the same order as the upper ERL for sheltering, ie, a few tens of millisieverts.

Upper ERL

Evacuation under unfavourable circumstances could result in very significant levels of disruption, worker risks and, for some members of the public, physical risks, so the upper ERL for evacuation must represent a saving of very significant radiation risks. In this context, the level of dose averted which is considered to be very significant is of the order of a few hundred millisieverts, whole body exposure.

ERLs for the administration of stable iodine

Stable iodine should only be issued if there is the potential for reducing exposure by inhalation to radioiodine. Therefore the ERLs developed here are in terms of doses to the thyroid of a young child from inhalation.

Lower ERL

The Department of Health Working Group advises[3] that the health risks associated with the administration of its recommended dosage of stable iodine are very small for most people. This is interpreted here to mean that the risks are not great enough to influence significantly the decision on the value of the lower ERL. Therefore the important factors for determining the lower ERL will be very similar to those for sheltering, namely dose averted, reassurance and countermeasure anxiety, for the same reasons as discussed on p. 00. However, timely administration of stable iodine can avert practically all of the dose from inhaled radioiodine, so it is judged that the anxiety associated with the introduction of this countermeasure is completely offset by the reassurance provided. Thus the health risk averted by the lower ERL for the administration of stable iodine should be slightly lower than that averted by the lower ERL for sheltering to reflect the higher reassurance. The risk of fatal cancer from irradiation of a child's thyroid is about 200 times less than that resulting from the same whole body dose[1]. However, the incidence of fatal cancer only comprises 10% of the total thyroid incidence. The thyroid dose which presents a risk corresponding to the lower ERL for sheltering (a few millisieverts, whole body exposure) is therefore between a few tens and one-hundred millisieverts, and the lower ERL for administration of stable iodine is taken to be a few tens of millisieverts to the thyroid.

Upper ERL

The main factors which are judged to influence the value of the upper ERL are averted individual risk, monetary cost, social disruption and reassurance. Individual disruption is not increased as the extent of the administration of stable iodine increases, and any anxiety introduced is judged to be offset by the reassurance provided. With the addition of reassurance, these are the same factors as those determining the upper ERL for sheltering. Therefore it is concluded that the health risk averted by the upper ERL for the administration of stable iodine should be slightly less than that averted by the upper ERL for sheltering. Using the same risk factors as discussed for the lower ERL for the administration of stable iodine, this implies that the upper ERL should be of the order of a few hundred millisieverts to the thyroid.

ERLs for single organs

In addition to specifying sheltering and evacuation ERLs in terms of whole body doses, it is helpful to provide ERLs of dose for individual organs that are potentially most at risk following an accident, ie, thyroid, lung and skin. Unlike most cancers, thyroid and skin cancers are usually non-fatal[1]. It is considered appropriate to include the risks of total cancer incidence when determining ERLs for these organs. For total thyroid cancer incidence, the risk is approximately 20 times lower than the risk of fatal cancer incidence from whole body exposure. For the lung and skin the risk of cancer induction (including non-fatal cancers) is somewhat closer to the whole body risk for fatal cancer (ie, probably between a factor of two and five).

For reasons of ease of application, it is not helpful to have different ERLs of dose for each organ. Moreover, given the generic nature of the ERLs and the judgements inherent in their derivation, the choice of slightly different values for each organ would not be very meaningful. Therefore, a single, representative ratio of ten between the ERLs of dose to the whole body and ERLs of dose to single organs has been adopted.

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RADON AFFECTED AREAS: CORNWALL AND DEVON

ABSTRACT

Board advice on radon in homes issued in 1990 specifies that areas of the UK where 1% or more of homes exceed the Action Level of 200 becquerels per cubic metre of air should be regarded as Affected Areas. Results of radon measurements in homes in Cornwall and Devon are mapped and used to show that the whole of the two counties should be regarded as an Affected Area. The Department of the Environment is advised to consider which localities should be delimited for precautions against radon in future homes. Advice on other areas will be proffered as data become available.

PREPARED BY J C H MILES, B M R GREEN, P R LOMAS AND K D CLIFF

INTRODUCTION

1 In January 1990 the National Radiological Protection Board issued revised advice on radon in homes[1]. The Board recommended that a new Action Level should be set for present homes; its value, expressed as the annual average of the radon gas concentration in the home, should be 200 Bq m^{-3}. Parts of the country with 1% probability or more of present or future homes being above the Action Level should be regarded as Affected Areas; such areas should be identified from radiological evidence and periodically reviewed. Present homes in Affected Areas should have radon measurements, and home owners with radon concentrations above 200 Bq m^{-3} should reduce them before the occupants receive a further time-integrated concentration of 1500 Bq m^{-3} y; the annual average of the concentration should then become as low as reasonably practicable.

2 The Board further recommended that, within Affected Areas, localities should be delimited for precautions against radon in future homes. Such localities should be established by the appropriate Government authorities and periodically reviewed; for such localities, Government authorities should decide whether all homes should be constructed with precautions against radon or constructed in the ordinary way, tested for high radon levels, and remedied if necessary. Homes with precautions against radon should be constructed in accordance with approved guidance issued by the appropriate Government authorities: compliance with the guidance should offer reasonable assurance that concentrations would be as low as reasonably practicable and at least below the Action Level.

3 This document is the first assessment of Affected Areas as defined above and covers the counties of Cornwall and Devon. Details are given of the proportions of homes in Cornwall and Devon estimated to exceed the Action Level, and an Affected Area is identified. Further documents assessing Affected Areas in other counties will be issued as sufficient information becomes available.

DATA COLLECTION AND ANALYSIS

4 The Board has carried out various surveys of radon in homes in Cornwall and Devon (see Table 1). All of the measurements were made using passive etched-track detectors[2] in order to determine the long-term average radon concentration. More than 8000 homes have been surveyed variously for 3, 6 or 12 months. The

TABLE 1 *NRPB surveys of homes in Cornwall and Devon as of May 1990*

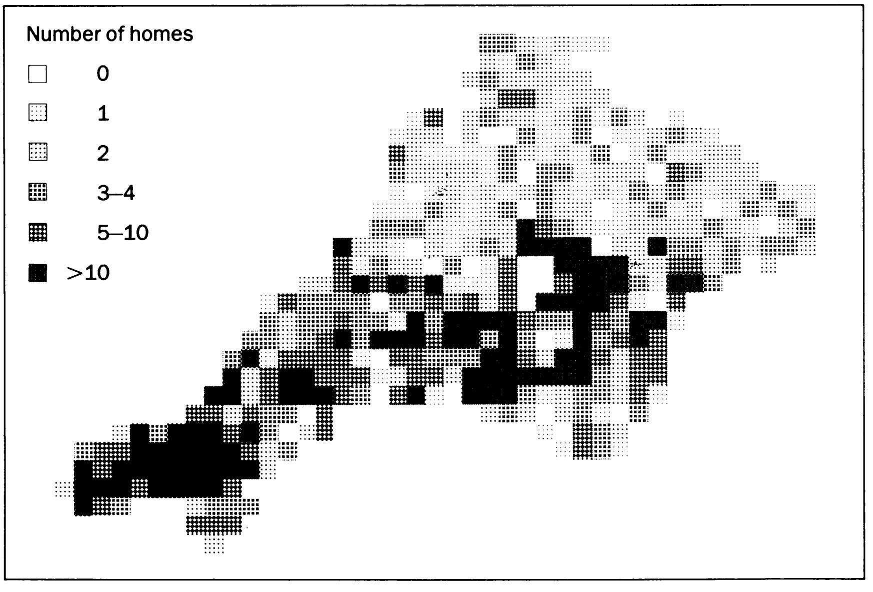
Survey	Sponsor	Number of homes	Survey period (months)
National	National Radiological Protection Board	61	12
Regional	National Radiological Protection Board	365	12
Directed	Department of the Environment	2835	12
Public request	Department of the Environment	1878	3
Grid-square filling	Department of the Environment	391	3
Navy homes	Ministry of Defence	2665	6
Total	All	8195	

number of homes measured in each 5 km grid square in Cornwall and Devon is shown in Figure 1. In all cases, except the Ministry of Defence survey, measurements were made in a living room and bedroom of each home. For the present analysis, the MOD results, which were for living rooms only, were corrected to obtain a whole-house average concentration using data on living room to bedroom radon concentration ratios.

5 Radon concentrations depend on indoor and outdoor temperatures, winds, ventilation conditions and other factors[3]. The average radon concentrations in the living rooms and bedrooms of 2000 homes for each month are shown in Figure 2. If a radon measurement is carried out for less than 12 months, the average concentration over a full year can be calculated with a correction factor derived from the figure. This type of correction was applied to all the results presented here where measurements were made for less than a year.

6 The distribution of radon concentrations in homes has been found to approximate to a log-normal distribution, whether the whole country or smaller areas are considered. To determine the proportion of homes in a grid square above a given threshold, it is therefore necessary to estimate the geometric mean (GM) and geometric standard deviation (GSD) of the results in that square. In many squares, there were too few results to estimate the GSD, so an investigation was undertaken of the variation in GSD in groups of results. Twenty-three of the 5 km grid squares contained 100 results or more. It was found that in these grid squares there was a small range of GSD values which did not vary significantly with GM. The mean GSD value was 2.4, and 80% of the values were between 1.9 and 2.9; the mean value was therefore applied to all grid squares in the later calculations.

FIGURE 1 *Number of homes in which radon was measured in each 5 km grid square in Cornwall and Devon*



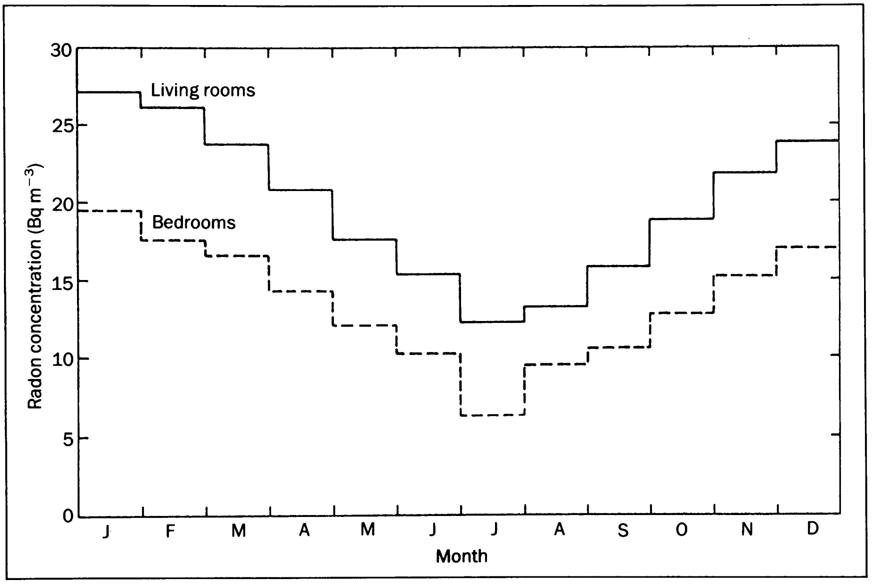


FIGURE 2 *Annual variation in radon concentrations in ground-floor living rooms and first-floor bedrooms*

7 Techniques of arithmetic infilling and smoothing of grid-square data have been described elsewhere[4]. To estimate a value for a grid square where there are no data, a weighted mean is taken of the results in the surrounding eight squares. Similarly, to smooth data, a revised estimate for each square is derived by taking a weighted mean of the nine squares centred on the square of interest, the greatest weight being given to the central square.

8 In the present case, estimates of geometric means are required. To allow infilling and smoothing of the geometric means with the procedures described above, the logarithm of the geometric mean in each grid square was used in the calculations. After the arithmetic infilling and smoothing routines had been applied, antilogarithms of the results were taken, so that, in effect, geometric infilling and smoothing were achieved.

9 To estimate the proportion of homes in each grid square which exceed the Action Level, the formula

$$Z = [\ln(x) - \ln(\mathrm{GM})]/\ln(\mathrm{GSD})$$

was used, where x is the threshold value, in this case 200 Bq m^{-3}. Z is a transformed threshold for use with the standard normal curve; it may be thought of as the difference between the threshold and the GM in units of GSD. For any value of GM a value of Z can be calculated. Tables of the area under the standard normal curve as a function of Z then allow the proportion of homes exceeding a threshold to be calculated[5].

10 The proportions of homes exceeding 200 Bq m^{-3} are shown in Figures 3–5. Three data points have been removed where it was found that a single high result in an otherwise low area caused significant distortion of the resulting maps. These

FIGURE 3 *Estimated proportion of homes exceeding the Action Level in each 5 km grid square in Cornwall and Devon. Blank squares not infilled, data not smoothed*

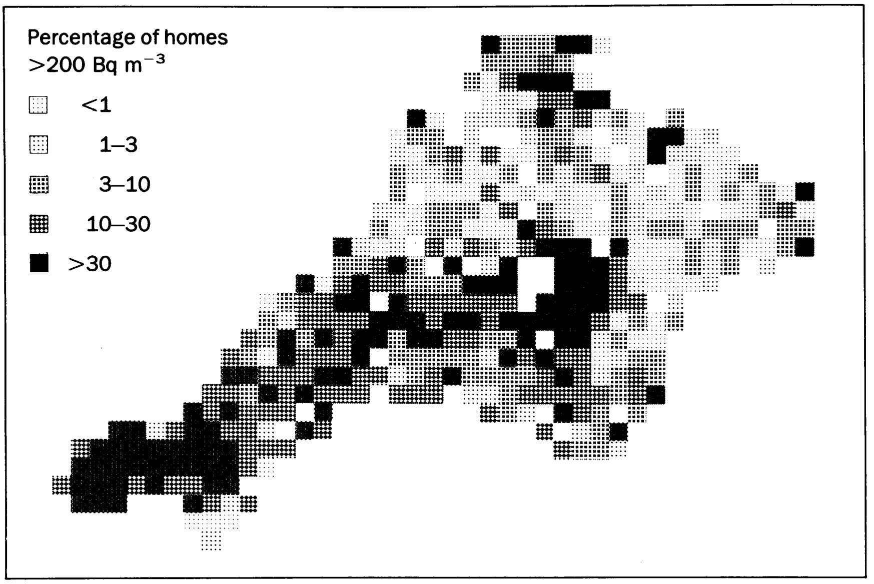
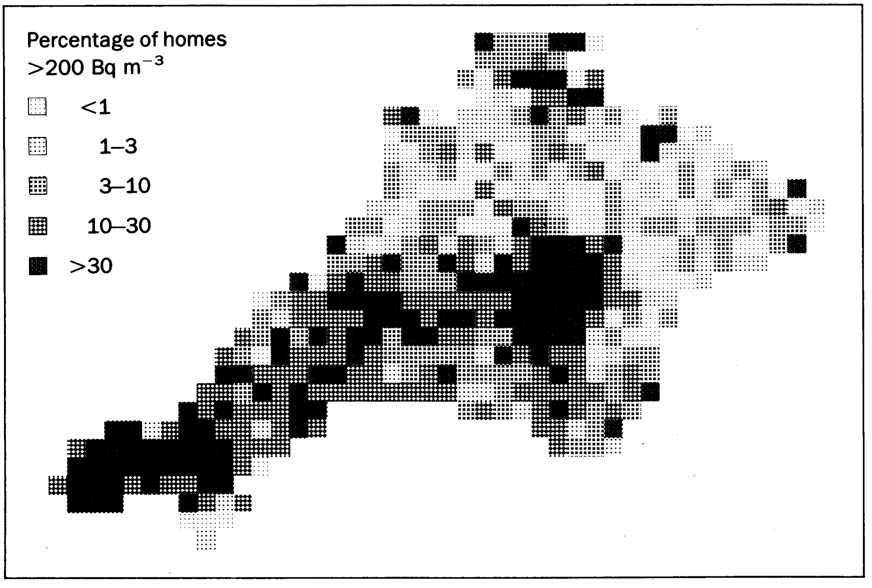


FIGURE 4 *Estimated proportion of homes exceeding the Action Level in each 5 km grid square in Cornwall and Devon. Blank squares infilled, data not smoothed*



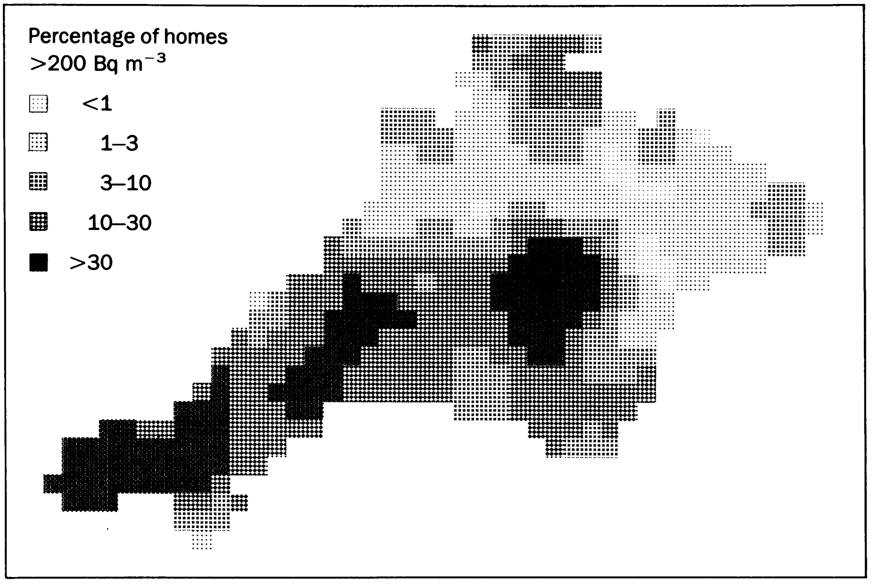


FIGURE 5 *Estimated proportion of homes exceeding the Action Level in each 5 km grid square in Cornwall and Devon. Blank squares infilled, data smoothed*

anomalous points will be investigated by making further measurements in the surrounding areas. The likelihood is that the areas genuinely have relatively low proportions of homes exceeding the Action Level, but by chance a home with a high radon concentration has been selected for measurement. Figure 3 shows the data before infilling and smoothing, Figure 4 shows the data after infilling of blank squares, and Figure 5 the same data after smoothing. Squares with fewer than ten results have been smoothed twice, and squares with ten or more results have been smoothed once.

INTERPRETATION

11 In order to allow the data in Figure 5 to be used to define Affected Areas and delimit localities where precautions against radon are required in new homes, they have been redrawn in Figure 6 on a map showing the outlines of the counties. Here, the borders of areas with >10% and >30% of homes above the Action Level have been drawn by eye on the basis of the data in Figure 5. It should be noted that the positions of these borders cannot be defined to an accuracy better than about 5 km, particularly in sparsely populated areas, because of the wide spread in radon concentrations even within areas that are geologically homogeneous. Nevertheless, correlations with the local geology are clear: in particular the granite masses of Dartmoor, Bodmin Moor and Blackmoor, Wendron Moors and west Penwith and, to some extent, the underlying granite are associated with the highest proportions of homes exceeding the Action Level. The Devonian rocks in Cornwall, south Devon and Exmoor generally underlie areas where 10%–30% of homes exceed the Action Level, whereas carboniferous and other rocks are found in areas where 1%–10% of homes exceed the Action Level.

12 The data in Figure 5 on areas with around 3% of homes above the Action Level are based on relatively sparse measurements, except in Exeter and Plymouth. The data were not considered sufficiently accurate to define the borders of areas with >3% of homes above the Action Level in Figure 6, so this border has been omitted. However, the data are sufficient to show that no significant area of Cornwall and Devon has less than 1% of homes above the Action Level. The whole

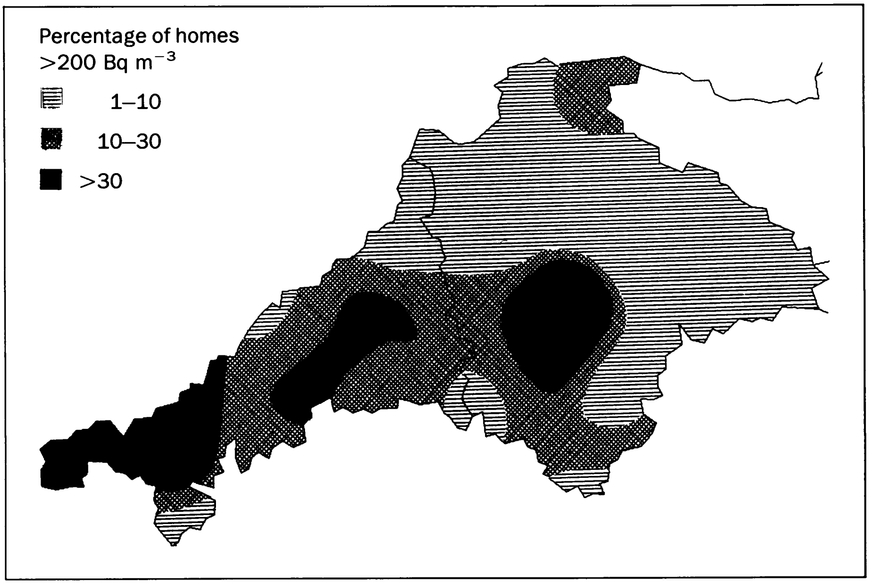


FIGURE 6 *Estimated proportion of homes exceeding the Action Level in areas of Cornwall and Devon*

of these two counties should therefore be regarded as an Affected Area. It is not possible at present to define the limit of the area outside the county boundaries, as systematic surveys covering adjacent counties have not yet been completed. Figure 6 will also allow the appropriate Government authority, in this case the Department of the Environment, to consider which localities should be delimited for precautions against radon in future homes.

RECOMMENDATION

13 The whole of the counties of Cornwall and Devon should be regarded as an Affected Area for the purposes of the Board statement on radon in homes[1]. The appropriate Government authorities should delimit localities within this area for preventive measures against radon in future homes.

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ISBN 0-85951-329-7

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