World Health Organization
Regional Office for Europe
Copenhagen

Nuclear power:

Accidental releases — principles of public health action

WHO Regional Publications, European Series No. 16

The World Health Organization is a specialized agency of the United Nations with primary responsibility for international health matters and public health. Through this Organization, which was created in 1948, the health professions of more than 150 countries exchange their knowledge and experience with the aim of making possible the attainment by all citizens of the world by the year 2000 of a level of health that will permit them to lead a socially and economically productive life.

The WHO Regional Office for Europe is one of six regional offices throughout the world, each with its own programme geared to the particular health problems of the countries it serves. The European Region has 32 active Member States,[a] and is unique in that a large proportion of them are industrialized countries with highly advanced medical services. The European programme therefore differs from those of other regions in concentrating on the problems associated with industrial society. In its strategy for attaining the goal of "health for all by the year 2000" the Regional Office is arranging its activities in three main areas: promotion of lifestyles conducive to health; reduction of preventable conditions; and provision of care that is adequate, accessible and acceptable to all.

The Region is also characterized by the large number of languages spoken by its peoples, and the resulting difficulties in disseminating information to all who may need it. The Regional Office publishes in four languages — English, French, German and Russian — and applications for rights of translation into other languages are most welcome.

[a] Albania, Austria, Belgium, Bulgaria, Czechoslovakia, Denmark, Finland, France, German Democratic Republic, Federal Republic of Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Malta, Monaco, Morocco, Netherlands, Norway, Poland, Portugal, Romania, San Marino, Spain, Sweden, Switzerland, Turkey, USSR, United Kingdom and Yugoslavia.

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Cover photo: Three Mile Island nuclear reactor near Harrisburg, Pennsylvania, USA.

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Introduction

The World Health Organization has for some time been assisting Member States to develop the capacity to understand the public health implications of the widespread use of radiation. These efforts, which complement those of other organizations such as the International Commission on Radiological Protection (ICRP) and the International Atomic Energy Agency (IAEA), or have been done in collaboration with them, have resulted in a range of WHO publications on the subject (*1–6*).

This report continues the efforts of WHO to provide guidance in dealing with any unexpected event or situation in a nuclear plant that has the potential to release radioactive materials into the environment in excess of the authorized limits. The public health actions considered in this report are those that would be taken to respond to such an accident, including the development and implementation of emergency plans to mitigate the impact on health.

This report is based on the collective knowledge and experience of the members of a Working Group, convened by WHO in collaboration with the Government of Belgium in Brussels on 23–27 November 1981, to discuss and appraise the different actions that might be taken following accidental radioactive releases from nuclear plants. It does not provide detailed technical data, but broadly surveys the rational basis for decision-making, indicating the present position as assessed by members of the Working Group.

The meeting was attended by 22 temporary advisers from 13 countries as well as by representatives from IAEA, the Organisation for Economic Co-operation and Development (OECD), and the International Radiation Protection Association (IRPA). Four major disciplines (radiological protection, health physics, environmental science and technology, and human biology) and three main professional categories (physicians, engineers and physicists) were represented, providing a comprehensive multidisciplinary approach to the topic.

The purpose of this report is to give guidance to national authorities in how to develop the capacity to take action in a nuclear emergency. Emergency planning is often the responsibility of several bodies, and health authorities are not always the only ones who would be involved. Primary guidance is given on measures to mitigate the impact on health of the radionuclide releases that may accompany an accident in a nuclear installation. In this regard, the competent national authorities must consider the following points.

— *Preliminary planning.* Health authorities may serve in an advisory capacity to help ensure that nuclear installations are safely designed, constructed and operated, and that plans exist for coping with any emergencies that may arise.

— *Operational aspects.* Health authorities could ensure that staffing levels are adequate to cope wth the health aspects of accidents, that public health actions needed to respond to accidents are properly coordinated with the various bodies involved, and that the responsible health personnel are properly trained.

— *Implementation.* Health authorities could ensure that means of assessing an accident are available, that methods for initiating countermeasures can be implemented, and that procedures for recovery and re-entry into contaminated areas can be developed.

The health authorities will be expected to participate to different degrees in these three steps.

This report outlines the general principles and the rationale for responding to an accident in a nuclear plant. The response to a given accident, and particularly the selection of specific countermeasures and the timing of their implementation, will depend heavily on the specific situation, including the nature of the accident, the geography of the area and the weather conditions at the time, and therefore every attempt has been made to maintain flexibility in the recommendations.

The guiding principles are based on the philosophy developed by bodies such as ICRP, of which eight Committee members, including the Chairman and Vice-Chairman of the Main Commission, were participants in the meeting. Chapter 2 deals with the source and timing of releases and their importance with regard to countermeasures; Chapter 3 describes the consequences and identifies the main routes of irradiation. The evaluation of radiological hazards is made in Chapter 4 and individual risk, especially from non-stochastic effects, is emphasized. A list and description of countermeasures that may be applied are given in Chapter 5, including the risks and benefits related to each countermeasure. Chapter 6 deals with the psychosocial aspects of an accident. Chapter 7 deals with the main parameters involved in the decision-making, and indicates how and why reference levels can be defined.

One of the primary problems revealed by the accident at Three Mile Island in the United States was the psychological impact on the public of the accident itself, as well as the confusion associated with the responses of the various governmental authorities. It is the belief of those who prepared this report that many of these problems could have been avoided through better emergency planning, particularly in terms of public education. Through publication of this report, WHO hopes to enable national authorities not only to develop better capabilities of responding to accidents in nuclear installations and thereby to reduce the health impact, but also to avoid unnecessary psychosocial impacts on the affected population groups.

Dr H.P. Jammet was elected Chairman of the Working Group, and Dr J.-C. Nénot and Dr R.H. Clarke acted as Rapporteurs. Dr F. Komarov and Dr M.J. Suess acted as Scientific Secretaries. The composition of subgroups that were formed for the meeting and the list of participants are given in Annexes 1 and 2, respectively.

On the basis of a preliminary draft prepared by the Rapporteurs and subsequent comments from members of the Working Group, a drafting committee consisting of Dr Clarke, Dr Nénot and Dr Suess met in Paris in August 1983 to prepare the final report.

1

Guiding principles

The development of commercial nuclear power can be said to have had a satisfactory record of safety over the last few decades compared with the non-nuclear power industry. No system can be assumed to be totally safe, however, and since an accident resulting in a radioactive release may have a detrimental effect on the health of the population, emergency plans need to be prepared.

The Cost of Countermeasures

The main objective is to reduce the detriment[a] to individual members of the public from the release or potential release of radioactive materials into the environment. This reduction can only be obtained by taking remedial measures that may have their own health risks and social costs. They will be justified if the reduction in exposure and the increased risk of social cost and physical harm result in a positive net benefit.

The dose limitation system recommended by ICRP for exposure resulting from normal operations does not apply to accidental situations (*7–9*). In the case of abnormal situations, the Commission makes this general statement on intervention (*7*):

> The form of intervention suitable for limiting an abnormal exposure to members of the public will depend on the circumstances. All the countermeasures that can be applied to reduce the exposure of members of the public after an accidental release of radioactive materials carry some detriment to the people concerned, whether it is a risk to health or some social disruption. The decision to introduce countermeasures should be based on a balance of the detriment which it carries and the reduction in the exposure which it can achieve. The magnitude of the detriment of countermeasures will vary with their nature and with the circumstances in which they are applied, for example, with the size of the population involved. Their effectiveness, on the other hand, will depend on the speed with

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[a] The detriment to a population is defined by ICRP (*7*) as the mathematical expectation of the harm incurred from an exposure to radiation, taking into account not only the probability of each type of deleterious effect, but also the severity of the effect. These deleterious effects include both the effects on health and other effects.

> which they can be introduced. For these reasons it is not possible to fix generally applicable intervention levels above which intervention will always be required. However, it might be possible to set levels below which intervention would not generally be considered to be justified. Intervention levels depend on the particular circumstances of each case and can therefore give only general guidance.
>
> As most forms of intervention involve some detriment, the optimal method of intervention depends on a balance between the detriment caused by the intervention and the benefit expected by the reductions of dose achieved by the intervention. Such a balance necessarily depends on local circumstances at the time of the situation calling for intervention but preliminary planning should be done in advance on a contingency basis.

The same general philosophy appears in the *Basic safety standards for radiation protection* (*10*), issued jointly by IAEA, the International Labour Organisation (ILO), the OECD Nuclear Energy Agency and WHO:

> For sources or practices . . . which would lead to accidental or emergency exposures of workers or members of the public, an intervention plan shall be established and approved by the competent authority. The plan shall deal with foreseeable situations and shall include provisions for demonstrating the efficiency of the planned countermeasures.

The Emergency Plan

The public health actions that might be taken in an accident should be part of a complete emergency plan. This emergency plan must be prepared in advance to control and limit effectively the consequences of the accident.

The emergency plan should be designed to deal with a wide range of possible accidents rather than just a few reference accidents. Each type of accident could have different consequences, in both nature and degree, and no single sequence alone can be used for planning (*11*). Their selection for planning purposes must cover a large range, from those that require no off-site action as there are unlikely to be off-site consequences of any importance, to those with important consequences off the site, however improbable. The degree of detail required in the emergency plan decreases as the probability of an accident decreases. The emergency plan should also take into account the most likely radionuclide composition of the releases that might be discharged by the plant. In all cases, the plan must be flexible so that it can be adapted to the particular conditions of any accident. This general philosophy, dealing with a large range of accidents and keeping the plan flexible, appears in many international and national publications (*7,8,12–18*). The *Basic safety standards for radiation protection* clearly states:

> The emergency plan should be based on a study of the radiological consequences of the radioactive releases following a reference accident. The plan should, however, be sufficiently flexible to allow its adaptation to the real situation, since this will generally differ from the reference accident.

The Phases of the Accident

Any accident occurring in a nuclear installation may be divided into successive phases, which are functions of various criteria: the chronology of the accident, and the levels of the hazards to the population or of the countermeasures that can be taken to avert the potential exposure. When establishing the emergency plan, averting exposure is the most important aim, as the first priority is the protection of the population from potential radiation exposure.

It is possible to define a sequence of three phases that are common to most accidents (*12,14,15,19*). In each phase, different considerations will affect the decision to introduce countermeasures.

— *The early phase.* This covers both the period where there is the threat of a release and the first few hours after its beginning.

— *The intermediate phase.* This is expected to start a few hours after the onset of the accident and can last for one or more days; it is presumed that the majority of the release will already have taken place and that activity is likely to have been deposited on the ground.

— *The late phase.* This is the one during which decisions are taken concerning the return to normal living conditions; it may extend over a long period.

Dose Measurements

An accident at a nuclear installation may release anything from a small to a very large amount of radioactive material and the range of possible doses is likewise wide. There will be both stochastic risks and, at higher doses, non-stochastic risks as well. In the early and intermediate phases, countermeasures will be used to avoid non-stochastic effects and reduce individual stochastic risk. For non-stochastic effects, the most suitable dosimetric description of the risk to the individual is the absorbed dose. For stochastic risks, the dose equivalent is a satisfactory description once the levels of dose have reached the point where countermeasures are considered.

Although the risk of the countermeasure itself may depend on how many people are involved, collective dose commitments are not relevant in the early and intermediate phases. During and after the last phase, however, the detriment associated with the accident will have to be quantified and quantities such as collective dose commitment will then be of interest. The collective dose, evaluated over limited areas, may be relevant when selecting countermeasures for the later phases, such as decontamination of land and buildings.

Intervention Levels

The plans should include intervention levels, the points at which relevant countermeasures are taken in each time phase. It is the projected dose (i.e. the dose likely to be received if no countermeasure were implemented) that should be considered in the setting of intervention levels, as well as the dose avoided by the countermeasure. There cannot be a unique value of dose at which each countermeasure should be taken, however, and the values will depend on site characteristics, the installation, and the circumstances of the accident. The intervention levels must be flexible, so that they can be adapted for groups of exposed populations according to their size and distribution, and for many other varying conditions, such as local and regional meteorological conditions and the potential escalation of the accident. For these reasons, it will be possible only to define a range of doses within which intervention levels should be set.

For each intervention level, a derived value will need to be calculated for use in practice. Derived intervention levels can therefore be established for inhalation, external irradiation, drinking-water, various foodstuffs such as milk, meat, etc. The introduction of countermeasures will usually be based on derived intervention levels that are compared with predictions before or measurements during the exposure.

The Role of the Authorities

Actions taken to protect the public from the consequences of a nuclear accident are the responsibility of the competent national authorities. The specific role of health authorities in the event of an accident will depend on the divisions of responsibility in each country. They may be involved in the establishment of the emergency plan and may be the appropriate body to provide information and educate the local population. The existence of emergency plans should be made known to the local population in advance, and information should be provided outlining some basic aspects of the emergency response plan and some simple and clear instructions. If the local population has been properly informed, people may well react logically in general when faced with a hazardous event.

If an accident occurs, it is very important to inform the public as quickly as possible, since some countermeasures will have to be taken rapidly. As soon as possible, the public involved in any countermeasures should be given a full explanation of the actions taken for their protection.

In the implementation of an emergency plan, many different authorities are required to take action, including the ministry of the interior, the police department, civil defence, the fire brigade, the ministry of health, the radiation protection department, and the safety department, and there is an absolute need for coordination. The specific public health actions that might be taken should be identified in the different procedures specifying the activities of the emergency support groups.

2

Timing and decision-making

A wide range of accidents must be considered in preparing an emergency plan for a given installation. In most types of accident, radioactive materials would be released into the atmosphere and the potential consequences are examined with a greater degree of detail than those of an accidental liquid discharge.

Accidental releases to the aquatic environment are less likely to occur and are also likely to involve a significant delay before populations are exposed (*20*). Some aspects of decision-making in the event of a release to aquatic environments may be similar to those in the later phases of an atmospheric release. This report is concerned primarily with decision-making in the early phase, however, and exposure by aquatic pathways is not considered further.

The Timing of the Accidental Events

The nature of the release depends on the type of nuclear installation and the severity of the accident. For the preparation of emergency plans different sources of release should be considered, each one being defined by the fraction of core inventory likely to be released, including the probability of its occurrence, the warning time before release and the expected duration of the release (*21,22*).

The time distribution of events is very important when evaluating the feasibility of taking countermeasures and their effectiveness in reducing the potential health consequences of the accident. The times of particular importance are: the time from the recognition of an accident until the release to the environment commences, the warning time, and the duration of the release. These three parameters are interrelated and may have different importance in emergency planning.

The time interval between the recognition of the start of an accident sequence and the emergence of radioactive material to the atmosphere is important. If very short, no countermeasures can be taken before the occurrence of the release. In general, this type of accident has a low probability of occurring at large nuclear installations such as power reactors that have elaborate safety systems. In most cases, there will be a delay before the uncontrolled release occurs. This delay may vary from half an hour to one day, or more (*14,23,24*). In some cases, it may be possible to control the release following an accident.

The warning time is the period between the awareness of an impending accident that has the potential for off-site exposure of the public and the release of radioactive materials. This parameter is important for making decisions, especially about whether countermeasures should be taken or not, and which ones should be chosen.

The duration of release is variable, from a few minutes to several days (*10*). In general, it can be expected that the most important fraction will be released during the first hour for releases lasting a few hours, at least for the most probable accidents. In other cases, where the release may be protracted and could last several days, most activity will be released on the first day; releases can have peaks with variable time intervals that cannot be predicted. The duration of release is always an important parameter, however, since if it is lengthy, changes of wind direction and velocity may occur. This may well reduce the doses received, but may also affect population groups who were not identified in the early stages.

Taking into account these three main parameters, the time delay before release, the duration of release and the warning time, releases may be schematically divided into three categories that may be combined in different ways:

— short or prolonged

— controlled or uncontrolled

— with or without warning.

Two other parameters have an impact on potential doses to the public.

— *The height of the release*: atmospheric disturbance and the resulting consequences will vary depending on whether the release emerges from a well defined source or not, and whether it is entrained in the flow of air around the buildings or not.

— *Buoyancy*: plume rise could be an important parameter leading to a reduction in risk to local individuals. The heat content of the release, its orientation, size and momentum all have an important influence on plume rise. Models for this process have not yet been sufficiently developed, however, to allow accurate predictions of plume rise to be made.

The Timing of Countermeasures

In each of the three phases of an accident (early, intermediate and late) different considerations apply to the decision the authorities may take to introduce countermeasures (*14,19,22,25–30*). In practice the distinction between the phases is not clearly defined and some overlap may occur.

Early phase
The early phase is defined as the period that begins when the potential for off-site exposure is recognized and extends into the first few hours after the beginning of the release. The time interval between the recognition of an accident sequence and the start of the release can be as short as half an hour or less, and the duration of the release may also be as short as half an hour. This timing makes it difficult to take decisions about the introduction of countermeasures, since there is a need to forecast the future course of the accident and situations that have not yet arisen. The evaluation of off-site exposure and the possibility of reducing it by appropriate countermeasures is thus a difficult and speculative exercise.

The common feature of the warning period and the first few hours of release is that operational decisions are based on the same criteria: data from the nuclear installation itself and local meteorological data. Provisional estimates of the nature and quantity of radioactive materials that might be released, as well as the chronology of the release, will need to be revised later by successive steps. As the installation will also, in most cases, provide the first meteorological data relevant to decisions, it is important that there should be a reliable and accurate system for measuring meteorological conditions.

The risks to be considered in the early phase include direct external irradiation from the nuclear installation, external exposure from the plume, from the early deposits on the ground and from deposition on clothing and skin, and inhalation of radioactive material from the plume.

Intermediate phase
The intermediate phase covers the period from the first few hours after the commencement of the release and can last for one or more days. In this phase it is assumed that the majority of the release will already have occurred and significant amounts of radioactive material may already have been deposited on the ground, unless the release consisted of noble gases only. There is no clear time boundary in emergency planning between the first and second phases. In the second phase, however, the first results from environmental monitoring will gradually become available. These results together with predictions of any future releases will confirm or modify those decisions already reached to introduce countermeasures.

During the intermediate phase, the population can be exposed to various sources of radiation: radionuclides deposited on the ground, and internal irradiation related to the ingestion of water and foodstuffs directly or indirectly contaminated and to the inhalation of radioactive materials resuspended from contaminated areas, such as the ground, roads and buildings.

Late phase
This phase is concerned with the return to normal living conditions. It may extend from some weeks to several years after the accident; its duration will depend on the nature and importance of the release. The risk to the population is related to the consumption of contaminated food in general and to external irradiation from a contaminated environment. During this phase

the data obtained from environmental monitoring can be used to make the decision to return to normal living conditions, by the simultaneous or successive lifting of the various countermeasures imposed during the first two phases of the accident. Alternatively, the decision could also be made to continue certain restrictions for long periods of time, affecting, for instance, the agricultural production of land, interdiction of certain areas or buildings, and the consumption of certain foodstuffs (vegetable, animal or dairy produce) from certain areas.

During the late phase, which may also be called the recovery phase, the aim is to return to normal living conditions. Decisions on the protective measures (health as well as socioeconomic measures) to be maintained or undertaken during this phase will be based on considerations that differ from those used for the first two phases. The rationale for decision-making may therefore differ from the one used in the early phases of the emergency plan. For instance, the main consideration in the early phase is the projected individual doses that might be received if no protective measure is taken. In the early phase, members of the public for whom rapid countermeasures might need to be taken represent, in most cases, well defined and relatively small groups. Low-level doses received by large numbers of people living far from the nuclear installation would contribute the majority of the collective dose from the radioactive release and it may be impractical to introduce measures to avoid the receipt of these doses. On the other hand quantities of dose, such as collective dose equivalent and committed collective dose equivalent, and their distribution are relevant in the assessment of the total health detriment associated with the release. Collective doses received above certain individual dose criteria will form the basis of decision-making using cost–benefit analysis in the recovery phase.

Decision-making

The characteristic of decision-making in the early phase of an accident sequence is that it is most likely to be made on the basis of information coming from the plant rather than any comprehensive environmental monitoring. If there is sufficient warning time, precautionary sheltering or evacuation may be instituted depending on the magnitude of the potential release. This demonstrates the need for preplanned action levels to be established at the nuclear installation based on an analysis of a wide range of accidents and their consequences.

In the intermediate phase, it is presumed that most of the activity to be released will already have been discharged to the atmosphere, and unless the release consisted mainly of noble gases there is likely to be residual contamination on the ground. Decisions to introduce countermeasures will be made in this phase on the basis of environmental monitoring. If it is a severe accident and the external dose rates from ground deposition are very high in some areas close to the plant, or if rain has washed out excess amounts of activity, then urgent evacuation will be required. At lower levels of dose there will be more time to establish dose rates and projected lifetime doses, making allowance for natural weathering or decontamination measures, before deciding whether to relocate population groups to avoid receipt of further doses. These levels of dose are likely to be lower than those at which more urgent evacuation would be undertaken.

In the intermediate phase, consideration will also have to be given to introducing restrictions on the sale and consumption of foodstuffs produced in contaminated areas. Decisions will be based on how easy it is to ensure alternative supplies of foodstuffs and water. Where alternative supplies can be ensured there may be little hardship in banning the consumption of foodstuffs and a great deal of public reassurance.

In the recovery phase, the aim is to try to return areas that have been affected by countermeasures back to normal living. Again, the decisions will be based on the dose rates and the projected lifetime doses to the individuals who are allowed to return and recommence their lives in contaminated areas. The level of dose at which return is permitted will be decided after consideration of collective doses and by using cost–benefit analysis. Thought will have to be given to decontamination as well as to the importance of the activity taking place in the affected area. For example, if industrial activity taking place in an affected area is important to the national interest, then it could be appropriate to allow a resumption of normal living while projected doses are higher than would be acceptable in, say, a predominantly rural area.

3

Assessing radiation exposure

Routes of Exposure

The exposure of individual members of the public may arise by various pathways including external exposure to the radionuclides in the plume and to the activity deposited on the ground, internal exposure by inhalation of activity in the plume and material resuspended into the air from contaminated surfaces, and by consumption of contaminated foodstuffs. It is important to identify each pathway, and to evaluate its importance relative to the others. The various routes by which populations are exposed affect the decision the authorities take to decrease or prevent exposure.

After an accidental release into the atmosphere, the most important routes of exposure are the following.

External exposure to airborne activity. Gamma radiation from noble gases, iodines and particulate fission products leads to whole-body irradiation during the passage of the plume. The resulting dose depends on the characteristics and duration of the release. If only noble gases are released, the plume will be the main source of population exposure. Direct exposure from the facility itself may be ignored in most cases, in comparison with the direct exposure from the plume.

Internal exposure following inhalation of radionuclides from the plume. This leads essentially to the irradiation of organs and tissues, the dose depending on the isotopic composition of the release, its characteristics and duration (*31,32*).

External direct exposure to ground deposits. This leads to a whole-body dose due to deposited fission products on the ground, buildings and roads. This exposure decreases with time, because of radioactive decay and removal by wash-off and seepage. If the release consists of short-lived nuclides the dose rate will rapidly decrease; this will not be the case if significant quantitities of long-lived fission products are deposited.

Internal exposure by inhalation of radionuclides resuspended from the deposited activity.

Internal exposure following ingestion of contaminated food and water. The ingestion of activity arises either as a result of its being deposited directly on foodstuffs consumed by the population or indirectly through foodstuffs and animal or dairy produce derived from contaminated ground. This kind of exposure may affect very large population groups that may live far from the installation and may not have been exposed through the other pathways. The ingestion of vegetables is a long-term mechanism of exposure and is relatively unimportant in comparison with the pathways during the early phase, especially for population groups living near the installation.

The first three pathways can be of differing importance depending on the conditions. As the plume of radioactive material travels downwind from the installation, the airborne activity may be removed by different means. These include radioactive decay, and removal by deposition processes such as impaction on obstacles (i.e. dry deposition) and precipitation (i.e. wet deposition). These deposition mechanisms are difficult to predict with accuracy. Removal rates depend on many parameters, among which the most important are: particle density and size distribution, ground characteristics, and weather conditions. As a first rough approximation, it may be assumed that the dry deposition velocity, i.e. the ratio of the deposition flux to the air concentration at a given height above the ground, is constant. Wet deposition depends on the rate of rainfall and may be assumed to be uniform in the time interval considered. Noble gases are assumed to be non-reactive and they are therefore not removed either by dry or wet deposition. The ground deposition of other radioactive materials such as vapours and particulates can be related to the air concentration of the materials using a deposition velocity. The effect of rain at the time of release would be to increase the exposure of the population living in that area but to decrease the amount of activity in the plume available to expose more distant populations.

Other factors that influence exposure to the atmospheric release include the atmospheric stability, the height of the point of release, the wind speed, and the heat content of the release.

These three modes of exposure — direct radiation from the plume, inhalation of airborne material (volatiles, aerosols, particulates) and direct radiation from deposit — are those likely to occur during the early phase. As activity may also deposit on the individual, exposure may arise from the contamination of clothing and skin.

The final two pathways affect the later phases mainly, and the countermeasures that might be taken will differ from those taken during the early phase.

The main modes of exposure that may be identified are: whole-body exposure and exposure of a given organ, particularly the lung, thyroid, bone marrow and skin. Any of these modes may predominate, depending on the radionuclide composition of the release. The potential consequences increase generally as the releases progress from noble gases only, to volatile and finally non-volatile fission products. This emphasizes the importance of identifying the source as precisely as possible, which will define the relevant pathways (*23*).

Levels of Exposure

The prediction of the doses liable to result from an accidental release can be based on two methods that may be complementary (*33*). The first is a theoretical assessment of the amount and nature of the radioactive release during the early phase of the accident. In general this assessment will have to be made on the basis of information from the plant combined with the current meteorological data. The second method is to use the results of early off-site measurements of radionuclides made after the release to the environment has begun.

Theoretical assessment

Only data from the installation instrumentation will be available before the release to the atmosphere has actually begun. To be able to make decisions on countermeasures, it is imperative to estimate as quickly as possible the magnitude of the doses that are liable to be delivered during the early phase. Such a decision can be made in a short time only if actions specific to the installation are planned in advance and cover a wide range of accidental situations and meteorological conditions. Thus, to make a provisional assessment of population exposure, the installation managers must plan to provide, at regular intervals, estimates of the likely magnitude and composition of activity that might released.

Local meteorological data such as wind velocity and direction, atmospheric diffusion conditions, rainfall or sunshine will be required in an atmospheric dispersion model suited to the site characteristics (*22,34–38*). These data enable predictions to be made of time-integrated atmospheric concentrations of activity and ground and building deposition. In the early phase of the accident, the only meteorological data likely to be available will be wind direction and velocity, and the main requirements of the dispersion model will be its easy use. Most of the simple dispersion models are valid for distances of a few tens of kilometres, and since countermeasures taken during the early phase will cover an area within a few kilometres of the nuclear installation, the models should be valid.

The most widely used system for predicting atmospheric dispersion is based on the Gaussian plume model. The plume model is easy to use, especially when limited meteorological data are available.

The model applies only to open, flat terrain while in many countries nuclear sites are situated in areas where the topography affects meteorological conditions (such as valleys). In these areas specific models will have to be used that include the local dispersion characteristics (*39*).

Any atmospheric release will result, to some extent, in the contamination of land unless noble gases only are released. In addition, water can be contaminated directly by deposition and by the runoff and leaching of activity from contaminated land (*40*). This will probably happen over longer periods of time but needs to be considered because of the possible contamination of drinking-water sources.

Monitoring

As soon as the release has begun, it is possible to monitor the levels of environmental activity (*15,41–44*). The results obtained from these environmental measurements will confirm or modify the theoretical assessments made during the early phase and, in addition, help in assessing the exposure at locations where measurements cannot be satisfactorily carried out quickly.

Monitoring should be done by well trained teams with specifically adapted, reliable equipment that can easily be transported. These teams should be able to mobilize very rapidly, their number being dependent on the sites. They may be based in different places to avoid all being blocked or delayed by the same conditions due to the release or to other outside factors such as weather. The first measurements should be carried out as soon as possible after the beginning of the release in the immediate vicinity of the installation. In most cases, the mobile environmental monitoring team from the nuclear installation itself will be the first to be called since it is already on-site, immediately available and trained to carry out this type of monitoring.

The monitoring plan, gathering all environmental measurements, has four succesive parts. The first part of the plan takes place in the first hours after the accident. Measurements are made with two objectives: to validate the theoretical predictions by sampling, and to assess further exposure to the plume by placing dosimeters at given points along a predetermined route. These dosimeters can supply data on exposure to the plume only if placed and removed at proper times. The route and the points at which sampling measurements are made, or dosimeters placed, should be planned in advance taking geographic and demographic conditions into account.

The second part of the monitoring plan deals mainly with an assessment of the deposit when gaseous releases include significant amounts of iodines and other fission products. Measurements will be made of dose rate and surface contamination, and an analysis will be made of samples taken from water, plants, soil and surfaces.

During the third part of the monitoring plan, if significant contamination has been identified by sampling measurements, then additional sampling of milk, if produced, becomes necessary. This additional sampling will principally be put into action if the preceding measurements indicate the presence of iodine in the deposits, but it can also be applied to monitor the transfer of other radionuclides deposited onto the ground.

The fourth and last part of the monitoring plan is put into action later, after countermeasures have been taken, to make an assessment of population detriment. There will normally be a need to monitor the residual levels of ground contamination and the activity in foodstuffs at distances well beyond those at which countermeasures have been considered.

4

Assessing the effects of exposure

To prepare emergency plans it is necessary not only to evaluate the exposure of the individuals affected by the accident, but also to consider the deleterious health effects that may result from this exposure. There are three kinds of effect that must be considered: early and continuing somatic effects, late somatic effects, and genetic effects. The biological effects of ionizing radiation on living organisms have been studied by many organizations all over the world. A large amount of scientific effort has been devoted to understanding the fundamental processes by which radiation interacts with human tissues and to providing a solid basis for general guidelines on radiation protection (*7,8,45–52*).

Irradiation can result from external radiation from the plume from activity on the ground, or from radioactive materials that have been inhaled or ingested through contaminated foodstuffs. Radiation can cause early or late health effects depending on the level of dose. The early effects follow acute irradiation and high doses and appear within days or weeks of exposure. By comparison, the late effects appear many years after the exposure. There may be several long-term effects in an exposed population, including the incidence of malignant diseases, fatal and non-fatal, and benign thyroid nodules. There is also the possibility of the abnormal development of fetuses, and inherited abnormalities in the offspring of exposed individuals. ICRP has classified health effects into two categories: stochastic and non-stochastic (*7*). Stochastic effects are those whose probability increases with increasing radiation doses, without threshold. The severity of stochastic effects is independent of the dose; only the probability of its occurrence is dependent on the dose. Non-stochastic effects are those whose severity increases with dose and for which therefore a threshold may exist.

After a severe reactor accident, doses large enough to produce non-stochastic effects could be absorbed from external exposure to the plume and to deposits, and from internal exposure to inhaled radioactive materials. Decisions on the implementation of countermeasures will be taken, at least during the early phase in the accident, with the object of avoiding the non-stochastic effects and limiting the stochastic effects of the irradiation.

Non-stochastic Effects

The relevant non-stochastic effects in the event of radiation accidents are short-term or medium-term. They may appear in any organ or tissue that has been irradiated. The type of biological response and the threshold level depend on the organ or tissue. The main organs or tissues that may be affected by non-stochastic risk are the bone marrow, the lung, the thyroid and the skin. As a first approximation, bone marrow exposure may be confounded with whole-body exposure. It has been shown that radiation damage to the bone marrow would probably be the most important effect given the inventory of radionuclides likely to be released after an accident in a light-water reactor. The effects on other organs or tissues, such as the gastrointestinal tract, may be considered less important. These effects include prenatal deaths and cases of early injury, as well as hypothyroidism, temporary sterility, cataracts and growth retardation.

As early non-stochastic effects are observed only after high doses delivered at high rates, they will occur only after severe accidents and only people who live in the immediate vicinity of the plant are liable to be affected. The duration of exposure depends on the particular accident sequence and the time needed for taking appropriate countermeasures. Biologically it has been established that the total dose necessary to produce a given effect is different when fractionated or protracted, the effect of the dose fractionation being tissue-dependent. Data used in radiotherapy on the influence of the fractionation of the exposure (*53–56*) could be used to assess the importance of the time factor.

The dosimetric quantities commonly used for radiation protection purposes are the dose equivalent and the committed dose equivalent. These quantities can be used to obtain an estimate of the stochastic risks incurred by individuals, when exposed to dose levels usually met in normal conditions. Another quantity used in radiation protection is the effective dose equivalent, in which use is made of weighting factors that represent the proportion of risk from irradiation of a given tissue to that for uniform irradiation of the whole body. Decisions in accident conditions have to be made on the basis of individual risk. For these reasons, any dosimetric quantity related to the detriment to the public, such as collective dose equivalent or collective dose equivalent commitment, is not suitable. The relevant dosimetric quantity for estimating the non-stochastic risk, however, is the absorbed dose and, therefore, the quality factor should not be used (*7,57*).

It is important to define the time periods over which doses should be integrated to assess the non-stochastic effects. A protracted dose is likely to lead to a lower incidence of non-stochastic effects and such information is needed to decide whether to take urgent countermeasures, especially evacuation.

Whole-body exposure

Following acute whole-body irradiation, the prognosis is directly related to the dose received by the haematopoietic system, i.e. the bone marrow, which is one of the most sensitive tissues in the body. Bone marrow is the source of most of the circulating cells, such as lymphocytes, granulocytes, erythrocytes and platelets. Lymphocytes are the most reactive to irradiation. The lymphocyte count decreases within a few hours of irradiation and the platelet and granulocyte count within a few days, while the erythrocyte count begins to decrease rather slowly only after a number of weeks (*58*). Repeated low doses to bone marrow may result in severe damage, but if the number of stem cells does not decrease below a critical level, peripheral cells will renew themselves and the irradiated individual will survive. The dose that would kill 50% of irradiated individuals in 60 days (LD_{50}/60d) without medical treatment has been estimated to be between 3 Gy and 5 Gy, when the dose is uniformly absorbed by the body (*9,51,52,59,60*).

For single whole-body exposure within a short time the risk of fatality starts at about 2 Gy; the LD_{90} lies around 5 Gy, assuming no treatment and no further complication. Around the LD_{50}, the clinical symptoms are always severe; the prognosis is based mainly on the time of appearance of the clinical symptoms and on the seriousness and rate of occurrence of blood disturbances (*61*). The most important syndrome to appear in the first days or weeks after the exposure is the haematological syndrome, with a decrease of lymphocytes, granulocytes and platelets. The number of lymphocytes quickly falls to a minimum; the sharper the slope of the fall and the lower the value of the minimum, the more severe is the exposure. Victims of irradiation accidents have survived after exposure above LD_{50}/60d, but only when subjected to intensive treatment (*62*).

Whole-body exposure may arise from both external and internal exposure. Consequently, the dose assessment must consider many parameters, each of them having a degree of uncertainty. Early mortality after acute exposure can be based on models, with all the difficulties involved with the control of parameters (*38,63,64*).

Lung exposure

The lung is the most sensitive organ of the thorax. In spite of its large functional reserves, its tissues have a very low probability of regeneration after a large loss of cells. It has been estimated that the threshold dose of non-fatal injury is above 5 Gy, and that the 50% probability is around 10 Gy. In all cases, the dose-effect curves show sharp slopes (*65–68*). Radiation pneumonitis appears some weeks or months after exposure. It is a complex phenomenon, including oedema, cell death, cell desquamation, fibrin exudate in the alveoli, fibrous thickening of alveolar septa, and proliferative changes in the blood vessels. The main non-fatal effect that appears is pulmonary fibrosis, resulting principally from the damage to and response of the fine vasculature (capillaries, arterioles and venules) and the connective tissues (*67*). The development of the lesions is highly influenced by the period of irradiation, the dose rate and the volume of organ irradiated. After a nuclear accident, lung exposure can be considered to be uniform through the whole organ. The functional state of the lung, i.e. the changes due to other diseases or aging, also contributes to the marked variability in the development of acute lesions.

The risk of death from lung exposure is assumed to start at levels around 15 Gy delivered to the whole organ; the 50% response is around 25 Gy (*66,67*).

Thyroid exposure

The thyroid is not considered an especially sensitive organ to the acute effects of radiation. When iodine isotopes are inhaled or ingested, they accumulate rapidly in the thyroid and are metabolized into organic iodine compounds that may reside in the organ long enough to cause local damage.

Considerable knowledge has been accumulated since the thyroid is commonly treated in nuclear medicine, either for benign or malignant diseases. The total ablation of the thyroid in a short period (two weeks) is achieved by a dose of about 300 Gy, which may be delivered with a single intake of ^{131}I, resulting in a few tens of MBq/g in the organ (*69*). It is believed that the damage is primarily related to the immune process and to capillary vessel reactions (*68, 70*), rather than to direct effects on the thyroid cells. The ablation of the thyroid seems not to involve any subsequent risk of either benign or malignant nodules (*71*). Patients treated therapeutically usually have the organ surgically removed and need to take substitute hormones.

After external irradiation of the thyroid, doses of about 10 Gy are needed to induce clinical hypothyroidism (*72, 73*). Myxoedema may appear at doses around 30 Gy (*73, 74*).

Skin exposure

After a nuclear accident the skin may be exposed directly, or indirectly to deposits from the plume that land on the skin and clothing or to ground deposits of activity. In fact, the skin will only be partially exposed as it is protected by clothing. The first stage of skin reaction to radiation is erythema, with a threshold around 3–8 Gy in a single dose. When the dose is fractionated, the threshold is much higher and may reach 50 Gy if delivered over six weeks (*75*). Acute exudative radiodermatitis follows doses of around 12–20 Gy and often results in chronic radiodermatitis, with hyperkeratosis, and telangiectasia of the capillaries and superficial and deep blood vessels. The chronic phase may lead to ulceration, atrophy and necrosis.

Fetal exposure

Irradiation of the fetus and embryo can be an important factor in the pathogenesis of embryopathies. Exposure may occur either by the direct irradiation of both mother and fetus or by the internal contamination of the mother and subsequent transfer and fetal uptake. There is no evidence that for a given radionuclide the embryo and the fetus have the same critical organs or tissues as children and adults. The damaging effects in embryonic tissues are often different owing to the difference in radiosensitivity and to the different metabolic profile of the cells. This would apply, for example, to iodine before the biochemical activity of the thyroid and to bone before the calcification period. The main problems related to teratogenic effects concern decisions on the need for abortion after irradiation.

The classical effects of radiation on the developing mammal are gross congenital malformations, intrauterine growth retardation and embryonic death (*75–80*). These effects are non-stochastic and there is a threshold. There are estimates of the minimum dose for malformation, the minimum lethal dose, the minimum dose to produce growth retardation and the LD_{50}. The LD_{50} of embryos varies throughout gestation, being very low just after fertilization and gradually reaching adult levels near term (*77*); it is estimated to be less than 1 Gy on the first day, around 2 Gy after one month and around 3–4 Gy for a later fetus to term. There is no evidence of teratogenic effects from short-term exposure to less than 100 mGy during the first period of gestation. There is, therefore, no medical basis for pregnancy termination following that level of radiation exposure.

Stochastic Effects

Stochastic effects may be either somatic or genetic. The tissues at risk, as well as the risk factors for each tissue, have been reviewed by international and national organizations (*7, 46, 47*). Cancers and leukaemias are stochastic somatic effects for which the risk factor (i.e. the incidence of cancer arising in a given organ or tissue per unit of dose) is derived from human epidemiological studies. Human evidence is derived from population groups subjected to high doses including the survivors of the atomic bombs at Hiroshima and Nagasaki, rheumatoid spondilitics treated with radiation, and luminous-dial painters. An upper limit to the risk of inducing malignant disease at high doses, in the region of 1 Gy or more, can now be estimated from epidemiological surveys of particular groups of humans who have been exposed. ICRP has given the risk factors shown in Table 1 for fatal cancers and leukaemias, plus the risk of hereditary effects in the first two generations of the exposed individual (*7*).

Table 1. Risk factors recommended by ICRP

Tissue	Risk (per Gy)
Gonads	4×10^{-3}
Breast	2.5×10^{-3}
Red bone marrow	2×10^{-3}
Lung	2×10^{-3}
Thyroid	0.5×10^{-3}
Bone surfaces	0.5×10^{-3}
Remainder	5×10^{-3}
Total	16.5×10^{-3}

Source: **International Commission on Radiological Protection** (*7*).

These risk factors have been chosen for the exposure conditions usually encountered in normal operations. These factors are values averaged over all ages and for both sexes, because for protection purposes sufficient accuracy is obtained by using a single risk factor for each organ or tissue. Furthermore, these risk factors were specifically obtained for annual exposures ranging up to several tens of mSv of effective dose equivalent. It should be recognized that the risk factors for specific organs may be substantially higher in some age groups depending on the sex. For example, over all ages, women appear to have a risk of thyroid cancer up to 2–3 times higher than men and a higher risk of breast cancer, particularly when exposed at younger ages. Hereditary risks are obviously dependent on the age structure of the exposed population group. It is likely also that the risk of induction of fatal malignancies is about a factor of 2 higher than the average in the case of irradiation *in utero* and in early childhood.

It may not be necessary therefore to take account of the existence of population groups with radiosensitivity different from the average when planning an emergency response, since the risk is only a factor of 2 or 3 higher, even for the most sensitive group.

The main organs to be considered in the case of an accidental release are the lung and the thyroid, followed by red bone marrow and bone. Risk factors are established for fatal cancers but to express the total health detriment, the incidence of non-fatal cancers should also be assessed. Data are becoming available, especially for those organs or tissues presenting a good prognosis (*8,45–47*). For the lung, it can be assumed that cancer induction results in 100% mortality. The situation is quite different for the thyroid for two main reasons: thyroid nodules, which would typically appear between 10 and 40 years after exposure, may be either benign or malignant, and between 30% and 40% of all nodules due to radiation are malignant (*72,81,82*). In addition, mortality from thyroid cancer is relatively low, as the malignancy shows slow progress and therapy is often successful; the mortality rate for well managed thyroid cancer is estimated at between 2% and 9%[a]. Although it has been shown that internal irradiation is less potent than external irradiation as a cause of benign nodules or of cancers, especially in children, it would be prudent to be conservative and to use risk estimates from external irradiation in all cases. It has also been shown that females have a 2–3 times higher risk of thyroid cancer following irradiation (*47*). In addition, people with lower iodine intake have a higher incidence of thyroid cancer than those with a normal intake.

As stated in Chapter 1, decisions to take countermeasures will be made on the basis of individual risk. For stochastic effects, the quantity dose equivalent should be used for the expression of risk.

[a] **Rall, E.** Endocrine Society meeting, Washington, DC, June 1980.

5

The choice of countermeasures

When a release of radioactive material is or may become uncontrolled, then the exposure of the public can be limited only by the introduction of countermeasures that interfere with normal living conditions. The countermeasures must be appropriate to the nature of the risk and must be applied at the appropriate time.

Types of Countermeasure

Countermeasures that can be considered are many and varied (*14,61,83–85*). The selection of the most appropriate or practicable countermeasures depends on site-specific features and the circumstances of the accident, and therefore can only be decided on a case-by-case basis. The countermeasures must be sufficiently flexible to be adapted to the actual situation. Nevertheless, it is possible to identify specific situations in advance that may be the basis for planning possible countermeasures. The countermeasures should be selected on the basis of their effectiveness in reducing the individual dose, and the risks and difficulties in implementing them should be balanced against the risk from the level of projected individual dose. While these risks and associated social costs are very difficult to quantify, the methods for predicting the probabilities of health detriment following receipt of a given dose of radiation are already developed. It is clear, however, that the risks, difficulties, disruption and distress that follow the implementation of these various countermeasures will vary enormously and depend on the site, the installation, the analysis of potential accident sequences, and the meteorological conditions at the time of the accident.

The ten countermeasures available in the event of an accident are:

— sheltering

— radioprotective prophylaxis

— respiratory protection

— body protection

— evacuation

— personal decontamination
— relocation
— control of access
— food control
— decontamination of areas.

Each of these countermeasures is especially effective for a given route of exposure and is most applicable during a given time phase. Their possible application in relation to the phase of the accident is given in Table 2.

Table 2. Range of applicability of various countermeasures

Countermeasure	Phase		
	early	intermediate	late
Sheltering	+	±	—
Radioprotective prophylaxis	+	±	—
Respiratory protection	+	—	—
Body protection	±	±	—
Evacuation	+	+	—
Personal decontamination	±	±	±
Relocation	—	+	±
Control of access	±	+	±
Food control	—	+	+
Decontamination of areas	—	±	+

+ = Applicable and possibly essential.
± = Applicable.
— = Not applicable or of limited application.

Source: **International Atomic Energy Agency** (*14*).

Sheltering

Sheltering involves keeping people at home, with doors and windows closed and ventilation systems shut down. People should stay preferably in inner rooms or areas, applying improvised respiratory protection if necessary. They should be advised to listen to specific radio and/or television programmes, for further information. Sheltering is one of the simplest countermeasures from the point of view of its implementation and benefits. It also involves little risk if implemented for short periods.

Sheltering is appropriate for protection against external irradiation from plume and ground deposition, as well as against inhalation of iodine and aerosols (*86,87*). It will reduce the doses to various organs of particular importance such as the lung, the thyroid and the skin. Two main correlated parameters have to be considered in sheltering: shielding and ventilation control.

The shielding provided by a building against external radiation from airborne or deposited radionuclides can be expressed in terms of a shielding factor, which is the ratio of the dose received inside the building to the dose that would be received outside the building (*88*). The lower the shielding factor, the greater the protection. It is evident that the effectiveness of sheltering depends to a large extent on the type of building: for example, basements of any kind offer very effective shielding against external penetrating radiation. Average shielding factors have been estimated, taking into account regional differences such as the frequency of wood frame houses, brick houses, and houses with or without basements. Another important parameter for assessing the projected dose (without sheltering) is the fraction of time the exposed population spends outdoors.

When using the shielding factors, both for irradiation from the cloud and from the deposits, it is assumed that sheltering is complete prior to the arrival of the plume and that individuals remain indoors either until the plume has passed away or until they are relocated. In the latter case, exposure will be evaluated by combining two reduction factors: the shielding factor while individuals are sheltered and the shielding factor that may be applied while they are being relocated (see p. 33).

It must also be noted that the use of average shielding factors for assessing health consequences results in the assignment of average doses to all individuals within a given area, rather than a distribution of the doses that would actually occur due to the variation in shielding protection among individuals (*88*). Indicative reduction factors are given in Table 3.

With appropriate ventilation control, sheltering can be considered as respiratory protection. To be effective as a respiratory measure, sheltering must be synchronized with the passage of the plume. The benefit of limiting the ventilation rate can be estimated by comparing the fraction of dose avoided and the number of air changes per hour multiplied by the immersion time in the plume (*14*). Reduction factors around 0.1 do not seem unreasonable. Instructions should be given not only to close all outer doors and windows but also to shut off ventilation fans and ventilators, to put out all fires, and to close heater and chimney dampers. Where possible, the ventilation rate can be reduced still further by placing layers of moist paper or cloth in the chinks of doors and windows. This can produce a significant additional reduction factor for the inhalation dose. When the plume has passed away, individuals who have been sheltered should be advised to open windows and doors, to remove quickly the activity that has percolated into buildings.

The risk and harm associated with sheltering are low if it is imposed for relatively short periods of time, i.e. of the order of a few hours. Unplanned long-term sheltering, for 12 hours or longer, could cause social, medical and

Table 3. The average reduction factors against irradiation from plume and deposits for various types of building

	Reduction factor	
	plume	deposits
Outside (1 m above ground)	1	0.7
Wooden house	0.9	0.4
Wooden house, basement	0.6	0.05
Brick house	0.6	0.2
Brick house, basement	0.4	0.05
Large office	0.2	0.02
Large office, basement	—	0.01

Source: **International Atomic Energy Agency** (*14*); **Aldrich, D.C. et al.** (*88*).

other problems, as well as generating significant anxiety because of the inevitable uncertainties over the whereabouts of different members of families. There is probably little financial penalty unless industrial activity is disrupted. Having confined the population to buildings, there will be a need to decide in the short term either when the countermeasures can be withdrawn safely or whether another countermeasure, such as evacuation, is required.

Radioprotective prophylaxis

Radioprotective prophylaxis is the appropriate countermeasure to protect against internal irradiation from the intake of radionuclides. The only intervention that appears to be practically applicable to an entire population is the administration of stable iodine to block the uptake of radioactive iodine by the thyroid. This measure is effective in the case of both the inhalation and ingestion of radioiodine, but in practice it is to be considered as essentially a protection against inhalation (*71,89–93* and D.G. Crocker, unpublished data, 1982).

After an intake of ^{131}I, the activity in the thyroid reaches 50% of the maximum within about 6 hours and the maximum in 1 or 2 days. To obtain a maximum reduction of dose, stable iodine should consequently be administered preferably before, but in any case as soon as practicable after, the intake of radioactive iodine. If administered 6 hours or less before the intake, the protection afforded is nearly 100%; it is about 90% if it is administered at the time of inhalation, but decreases very quickly to 50% if administered about 6 hours after inhalation (*12,14,19,61,71*). It is therefore important to administer stable iodine as quickly as possible, despite all the difficulties inherent in this type of countermeasure.

Single doses of 100 mg of stable iodine are usually prescribed for adults although lower dosages have been proposed. The most widely used forms are KI and KIO_3; 100 mg of iodine corresponds to 130 mg of KI and to 170 mg of KIO_3. Both suppress thyroid uptake quickly and effectively. KIO_3 has an advantage over KI in that it is more stable and has a longer shelf life (about 10 years compared with 2 years). Immediate suppression is extremely important in the case of a release of radioactive iodine. A dose as large as 100 mg of stable iodine is necessary for rapid and complete blocking in the adult. Lower doses such as 65 mg of KI also suppress iodine uptake, but the time required for full effectiveness is much longer (*90,92,94*). Nevertheless, these lower doses of KI have been shown to be effective in children under the age of 1 year (*14,95*). Uptake returns to normal about one week after a single dose of 100 mg of iodine, although effective blocking is maintained with repeated doses of about 50 mg per day (*14*). The administration of stable iodine should not be continued unnecessarily. This measure is valid essentially on a short-term basis, as prolonged administration is impractical and should be unnecessary since prolonged high exposure to radioactive iodine should not occur.

Adverse reactions to iodine, and especially to KI, are well identified as this component is available in a large variety of pharmaceutical and non-pharmaceutical products. Reactions to KI may be divided into thyroid and non-thyroid effects. The adverse reaction rate has been estimated at between 1 in 10 million and 1 in 1 million doses (*71*).

The thyroid effects include:

- goitre with or without hypothyroidism, the most significant being neonatal goitre;
- hyperthyroidism as a complication of increased iodine intake in areas of endemic goitre; aggravation of thyrotoxicosis may arise with microgram amounts of KI given to patients with thyroid nodules, resulting in Jod-Basedow syndrome (*96*);
- hypothyroidism, which is rather unusual in patients treated with iodide, although a slight incidence of 2×10^{-3} has been reported; it must be noted that clinically significant myxoedema has never been reported after a single intake of iodide.

The non-thyroid side-effects include:

- dermatological reactions, with a large variety of skin eruptions, from mild rashes to acneiform lesions; individuals who suffer from skin diseases such as acne, eczema or psoriasis may show an exacerbation (*97,98*); all reported severe cases have involved high doses of KI, far higher than those recommended for thyroid blocking;
- hypersensitivity reactions, including fever, arthralgia and eosinophilia; particular individuals who might be at risk should be identified;
- various effects, such as iodide mumps (painful swelling), conjunctival irritation, nausea, vomiting and diarrhoea.

These side-effects occur in almost all cases of chronic daily administration of iodine, far in excess of those recommended in radiation emergencies. Its use as an appropriate short-term countermeasure is valid although some population groups require special attention.

— Pregnant women, because they are already at risk and because there is a special concern for the fetus. Pregnancy should not, however, be regarded as constraining the use of single doses of stable iodine.

— Fetuses, because it seems that the maternal intake of iodine may lead to high fetal thyroid concentrations. On the other hand, thyroid blocking is as effective for the fetus as for the mother.

— Neonates, because the iodine uptake of the neonatal thyroid is significantly higher than in the adult. In addition, as iodine concentrates in the mammary gland and is excreted in milk, the nursing neonate could be at risk of increased exposure. Based on current information, however, it does not seem reasonable to recommend any alteration of the treatment by stable iodine, especially when considering the high risk of the deleterious effects of radioactive iodine on the neonate.

— Young children, who may be at greater risk than adults as the uptake per gram in tissue is higher, and the immature tissue may be more susceptible to developing tumours.

— The elderly, because it has been reported that iodine treatment could induce hyperthyroidism.

It should be possible to identify those individuals likely to suffer severe morbidity from this kind of preventive treatment. On the other hand, it must also be possible to ensure that the population likely to receive excessive thyroid exposure has access to stable iodine treatment. To be effective, the distribution of stable iodine must be planned. This planning should include various parameters such as:

— plans for the rapid distribution of the drug to ensure that the exposed individuals get the iodine shortly before exposure begins;

— provisions for supplies;

— ways of informing the population of the need to take iodine and of the means of doing so;

— plans for renewing drug stocks.

Where stable iodine is distributed, it may be advisable to give medical advice on the possibility of side-effects, and to stress the need to maintain medical contact and to provide no more than one dose per person.

If evacuation is rapidly implemented, the use of stable iodine will not be necessary. Evacuation should be the most effective measure for avoiding thyroid exposure, and is of particular interest for those groups of people who are at higher risk (pregnant women, neonates, children, etc.) but it can only be used if there is sufficient warning time.

In the case of radioactive iodine releases, thyroid blocking provides protection against radioactive iodine only and is ineffective against external irradiation of the gland. It needs to be balanced against the effectiveness and costs of other countermeasures such as sheltering, respiratory protection and evacuation.

Respiratory protection

Respiratory protection may be provided by the use of simple items such as handkerchiefs, paper tissues or kitchen towels, clothing and other items to cover the mouth and nostrils. The protective efficiency of these materials may be enhanced by moistening them, as dry fabrics are less effective in filtering iodine than wet fabrics. It has been shown that readily available cotton fabrics, when tested for their ability to filter aerosols, gases and vapours (including I_2 and CH_3I) decrease the concentration by a factor of 10 or more when the particle size ranges from 0.4 μm to 5 μm (*14,99,100*). Personal respiratory protection should be used by people as they proceed to the shelters, possibly during sheltering when this countermeasure is not prolonged for a long time, and certainly during evacuation while there is still an airborne plume.

The use of more sophisticated systems, such as masks and respirators, is not practically feasible for the public and may only be applicable to special groups involved in emergency operations, such as rescue teams, police and firemen, who should be specially trained.

Body protection

Body protection is appropriate for skin and hair to avoid the deposition and absorption of radioactive materials. It may be provided by any articles of clothing, including hats, hoods, raincoats, anoraks, gloves and boots. They should be used while people proceed to shelters and during evacuation from a contaminated area. They should also be used if evacuation cannot be avoided while the plume still exists. The use of more sophisticated protective clothing should be confined to personnel involved in emergency operations (*15*). As this will involve only small specialized groups, its cost will be relatively small and its associated risks nil.

Evacuation

Evacuation is the urgent movement of people to avoid or reduce their exposure. Evacuation is appropriate for protection against external exposure to plume and ground deposition, as well as against internal exposure by inhalation of airborne radionuclides (*25,38,60*). This measure is the most disruptive and difficult to implement; it must therefore be applied only when absolutely necessary, for instance to avoid the short-term accumulation of doses leading to non-stochastic effects and, as far as possible, only to small groups of people in the immediate vicinity of the nuclear installation. When large populations live close by, evacuation becomes more difficult. In any case, early sheltering will be preferred, as it brings the population under control.

Evacuation is most practicable in the early phase for small groups close to the site and results in complete protection against the plume if there is sufficient warning time before release. If the evacuation is badly timed it could result in sending people through the plume, and exposing them to much higher doses than if they had been told to shelter. Evacuation may be effective during the intermediate phase, whether or not sheltering was introduced as a means of reducing the dose from deposits.

The main difficulty, when deciding whether some population groups should or should not be evacuated, is in weighing the risk of the potential exposure without evacuation against the risk involved in the evacuation itself. The former involves inevitable errors because of uncertainties about the evolution of the accident, the importance and nature of the sources and the possible variations in the meteorological conditions (such as wind gusts and the onset of rain or snow). The parameters that must be considered are varied and of unequal importance (*101–105*).

- — The characteristics of the accident itself.
- — The sociodemographic conditions: the number of persons to be evacuated, their age distribution, the presence and number of handicapped, sick or bedridden persons, and the existence and density of establishments presenting special difficulties, such as factories, hospitals, maternity clinics and retirement homes.
- — The meteorological conditions.
- — The time of day when the alert will be given.
- — The geographic conditions, such as the existence or not of a road or railway network suitable for evacuation.
- — The availability of relocation centres for the evacuated population which should be conveniently located geographically.

Although experience in the evacuation of large groups of people is rather limited, it is possible to make a general statement as to the feasibility and rapidity of its implementation (*106–111*). Experience from North America suggests that the risks associated with evacuation are low, although this may not be applicable to the situation in many other countries (*108*). It has been shown that it is hazardous to use normal data from road traffic to evaluate the risks of evacuation, since driving conditions and drivers' behaviour are quite different (*110*). The health risk related to road traffic accidents may be low for an organized evacuation. Other health risks will have to be considered, especially those related to the evacuation of specific groups such as patients in hospitals and clinics (including patients with psychiatric diseases) and prisoners. Socioeconomic consequences would need to be quantified on the basis of the given regional conditions.

In addition, for the evaluation to be complete, the inherent risk in returning the population to the evacuated areas must be calculated. This risk is supposed to be much less than that involved in the evacuation, since the return home can be carried out under the best conditions, can be staggered and will in any case be well planned. Evacuation will be carried out by motorized means, preferably using public transportation. Self-evacuation should be discouraged where possible. Evacuation should be well planned, sector by sector, to avoid any traffic congestion. Many people will refuse to be evacuated, which will cause confusion. Special care needs to be taken not to separate families. It has sometimes been recommended that only some small groups among the exposed population be evacuated, such as pregnant women, schoolchildren and patients in hospitals, the discrimination being made using the criterion of the highest risk from radiation (*106,112,113*). This decision must be avoided where possible, because it will often result in confusion and sometimes in panic, and will always seem irrational to the public.

The social and economic considerations of evacuation weigh heavily in decision-making. The social cost is very different depending on whether the populations involved are in rural, agricultural, urban, industrial, commercial or residential areas. For agricultural populations, the most likely category in the immediate vicinity of a nuclear installation, the decision to evacuate even for a short time may cause concern because of the necessity of caring for their animals. A local industry affected by prolonged evacuation will find the financial cost high. In both cases, the socioeconomic detriment, although difficult to calculate, should carry weight in the decisional analysis.

In conclusion, the social cost of an evacuation may be high and, even though the risks involved are difficult to quantify, a decision on its introduction will not be taken lightly and must be based on a firm expectation of the doses likely to be received.

Another problem linked with the decision to evacuate is the difficulty of choosing criteria for re-entry into evacuated areas. Attention should be drawn to the need for public health authorities to identify as soon as possible the areas affected by residual low-level ground deposition. It should also be emphasized that re-entry into an evacuated area may create great psychological problems (see Chapter 6).

Personal decontamination

Personal decontamination is necessary only in the case of detected or suspected skin contamination. In general, ordinary shower facilities are adequate. If large numbers of people are involved and showering is not feasible, the careful removal of outer garments followed by the washing of hands, face and possibly hair could be sufficient. Personal decontamination can be of prime importance for some people who were outdoors under the plume, as contamination of the skin and especially of the hair may contribute a large dose. This countermeasure must not, however, be considered an alternative to any other countermeasure, such as evacuation.

Relocation

Relocation is defined as the progressive removal of groups of people under less urgent conditions than those required for evacuation. It is used when the exposure may lead to high accumulated doses after the release has finished and there is external irradiation from ground deposition. In the case of an accident that requires both evacuation and relocation to be carried out within two concentric areas, these countermeasures must be well coordinated to guarantee equity in the public health handling of the two groups of people during the phase of re-entry. This is especially important as, in most cases, it will take some time to determine affected areas and initiate relocation. The dose assessment for relocation will have to be combined with the one for sheltering, as populations will be relocated after they have been sheltered.

Control of access

Control of access will avoid an increase in the number of people affected by the accident, and minimize interference with the emergency operations within the affected areas in the early phase of the accident. In the long term, control of access may still be necessary in areas of significant ground contamination. Another advantage of this countermeasure is that it ensures that no unauthorized transfer of contaminated articles to clean areas takes place during the later phases of the accident. The difficulties of this control of access are related mainly to its enforcement. This emphasizes the need for coordination by the responsible authorities.

Food control

Food control may include banning or restricting the consumption of certain foodstuffs, such as milk, vegetables and water. After an atmospheric release it is unlikely that water would be contaminated to such a level that it would be necessary to ban its consumption. If open reservoirs exist, doses should be calculated to show whether the water is fit for consumption. Vegetables may be destroyed, or if they are used as animal feed, care should be taken that they do not indirectly affect human beings. Foodstuffs such as milk and dairy products may be diverted for delayed use. Contaminated food should not be diluted by mixing it with non-contaminated food; even if the radiological hazard associated with the resulting foodstuff is minimal, it is unlikely to be acceptable to the consumer.

In the case of cattle, the contamination of their meat and dairy products may be reduced by supplying them with stored feed and removing them as soon as possible from grazing.

Decontamination of areas

The decontamination of areas may consist of washing or vacuum-sweeping roads, the surfaces of buildings and equipment, ploughing agricultural land, removing surface layers of soil or fixing the contamination. This countermeasure is mainly applicable in the later phases of the accident to reduce external irradiation from deposited activity, as well as internal irradiation from the inhalation of resuspended activity.

There are problems associated with decontamination since it is expensive and produces large amounts of radioactive waste that have to be disposed of. The decontamination of buildings and roads may raise a variety of difficult problems and weather conditions may affect its effectiveness and feasibility.

Criteria for Choosing

The factors that affect the selection of countermeasures after a nuclear accident are:

— the time phase of the accident

— the magnitude of the release

— the composition of the release

— the conditions prevailing at the time

— the routes of exposure associated with each of the sources.

The most important scenarios and the appropriate countermeasures to take are identified in Table 4. These are not recommended countermeasures, but merely those that should be considered and appear physically feasible. A few comments can be made about the Table.

The scenarios presented are not all those that might be imagined, but only the most important and probable. The scenarios and countermeasures are classified chronologically according to the three phases into which the accident can be subdivided.

The categories of release to be considered come in two groups, immediate or delayed, and either may be of short or long duration. Therefore, four situations arise:

— immediate release of short duration

— immediate release of long duration

— delayed release of short duration

— delayed release of long duration.

Countermeasures will depend on the isotopic composition of the materials released. Three cases are chosen as typical: noble gases only, noble gases plus iodine, and long-lived fission products.

The source of exposure differs, but will probably be one of the following:

— direct radiation from the reactor

— the plume

— deposition on the body

— deposition on the ground

— the resuspension of activity from contaminated ground

— food chains.

The exposure routes considered are:

— external irradiation of the whole body;

— internal irradiation of the thyroid after the inhalation of radionuclides;

Table 4. The most probable scenarios and the most appropriate countermeasures

Phase of accident	Category of release	Component of release	Source of exposure	Relevant exposure route	Hazard to be controlled	Relevant countermeasure
Early	Variable	Variable	Reactor containment	External (whole body) irradiation	Individual stochastic and non-stochastic	Evacuation[a]
Early	Immediate and short	Noble gases	Plume	External (whole body) irradiation	Individual stochastic and non-stochastic	Shelter (1st priority)
Early	Immediate and short	Iodine	Plume, body deposition	Internal irradiation by inhalation, external irradiation, internal irradiation by adsorption	Individual stochastic and non-stochastic	Respiratory protection, body protection, shelter, KI, personal decontamination
Early	Immediate and long	Noble gases	Plume	External irradiation	Individual stochastic and non-stochastic	Shelter, access control

Table 4 (contd)

Early	Immediate and long	Iodine	Plume, body deposition	Internal irradiation by inhalation, external irradiation, internal irradiation by adsorption	Individual stochastic and non-stochastic	Respiratory protection, body protection, shelter, KI, evacuation,[a] personal decontamination
Early	Delayed and short	Noble gases	Potentially plume	External irradiation	Individual stochastic and non-stochastic	Shelter, access control
Early	Delayed and short	Iodine	Potentially plume	Internal irradiation via inhalation	Individual stochastic and non-stochastic	Shelter, access control, KI, evacuation[a]
Early	Delayed and long	Noble gases	Potentially plume	External irradiation	Individual stochastic and non-stochastic	Shelter, access control
Early	Delayed and long	Iodine	Potentially plume	Internal irradiation via inhalation	Individual stochastic and non-stochastic	Shelter, access control, KI, evacuation[a]
Intermediate	Variable	Variable	Reactor containment	External irradiation	Individual stochastic	Evacuation, relocation[a]

Table 4 (contd)

Intermediate	Short	Iodine	Ground deposition	External irradiation	Individual non-stochastic	Evacuation,[a] relocation
			Food chain	Internal irradiation via ingestion	Individual stochastic	Food control
Intermediate	Short	Long-lived fission products	Ground deposition	External irradiation	Individual non-stochastic	Evacuation[a]
					Individual stochastic	Relocation
Intermediate	Long	Noble gases	Plume	External irradiation	Individual stochastic and non-stochastic	Evacuation,[a] relocation
Intermediate	Long	Iodine	Plume	Internal irradiation via inhalation	Individual stochastic and non-stochastic	KI → relocation
			Ground deposition	External irradiation	Individual stochastic and non-stochastic	Relocation
			Food chain	Internal irradiation via ingestion	Individual stochastic	Food control

Table 4 (contd)

Intermediate	Long	Long-lived fission products	Plume	Internal irradiation via inhalation	Individual stochastic and non-stochastic	Relocation
			Ground deposition	External irradiation	Individual stochastic and non-stochastic	Relocation
			Food chain	Internal irradiation via ingestion and resuspension	Individual stochastic	Food control, relocation
Late	Short or long	Iodine	Food chain	Internal irradiation via ingestion	Stochastic	Food control
Late	Short or long	Long-lived fission products	Ground deposition	External irradiation	Stochastic	Decontamination of areas
			Food chain	Internal irradiation via ingestion and resuspension	Stochastic	Food control, decontamination of areas

[a] Only for short distances and small groups.

— internal irradiation of the lung after the inhalation of radionuclides;

— internal irradiation of bone and bone marrow after the inhalation of radionuclides;

— internal irradiation of the whole body after the inhalation of radionuclides;

— internal irradiation of the thyroid after the ingestion of radionuclides;

— internal irradiation of various other internal organs after the ingestion of long-lived fission products.

The selection of countermeasures is based on:

— the avoidance of individual non-stochastic risk;

— the minimization of individual stochastic risk.

The identification and selection of appropriate countermeasures for any given situation may be facilitated by the use of pre-established computer programmes aimed at assessing the likely features of the accident and its evolution. Planning the introduction of the consequent countermeasures can be based on descriptions of the parameters relevant to the real situation under examination (*23, 26, 84, 103, 104, 114, 115*).

6

Psychosocial effects

Past experience of civil nuclear emergencies suggests that all people who may be affected by such situations should be informed about measures to protect themselves. Awareness of the successful application of countermeasures will diminish anxiety and psychological stress. Medical doctors, ancillary medical staff, emergency and rescue personnel, as well as the population, especially those living in the vicinity of nuclear power facilities, should also be informed about potential nuclear incidents that may cause radiological hazards affecting their health and safety. The Dauphin County Emergency Management Agency, for example, has produced a leaflet entitled *Three Mile Island. Emergency information for Dauphin County.* It must be stressed that these situations are absolutely different from those connected with the Hiroshima and Nagasaki experiences, as well as the Marshall Island accident.

Nature of the Problem

The individual's psychological reactions towards radiation are similar to his reactions to major illness or injury. They are linked with:

- the undetectability of radiation by human senses;
- the equating of A-bomb effects (including blast and fire) with nuclear power plant accident potential;
- conflicting information in radiation accidents, as at Three Mile Island (*116–118*);
- inadequate information leading to seemingly irrational public action and causing undue individual anxiety.

Management of the Problem

It must be recognized that anxiety in the off-site population is a real health consequence of a radiation accident, although it will not necessarily be related to the magnitude of any release or exposure. As such, it must be dealt with as part of the public health aspects of nuclear emergency planning. Such planning should be based on similar planning and experience with other potential environmental hazards. The existence of such a plan itself would be a preventive measure in controlling undue public anxiety.

Pre-event preparations

There should be public information and input concerning the location and operation of nuclear plants.

Education and training should be provided both within the emergency planning zone and outside it. The population groups addressed should include health professionals (*119*), emergency personnel (*120*), the public and public officials (*121*). Although the level of presentation will vary with the particular group, the topics to be discussed should include methods of radiation measurements (*41–43*), the late and early effects of radiation (*49, 50, 59, 62*), and the nature and efficacy of countermeasures; training materials, booklets, self-instruction audiovisual materials, training exercises and drills (*122, 123*) should also be provided.

Plans should be made for the communication of information to the public.

Implementation

Flexibility of response should be maintained to cope with varying situations.

Special psychological support should be available in case of need, especially among emergency personnel, populations in evacuation centres, and patients with pre-existing psychological problems.

Post-event considerations

There should be intensive education about specific recovery operations and about the potential for related health effects to manifest themselves after the event.

The management of psychological problems should return to normal channels.

A follow-up analysis should be made of the performance of the emergency plan to improve the future psychological management of radiation accidents.

Public Acceptability

Detailed emergency planning, the elements of which have been outlined in this report, is not unique to nuclear emergencies. Its acceptance by the public, however, poses a psychological problem. This may be reduced if it is emphasized that such a plan should be integrated with other emergency schemes available to meet natural as well as industrial accidents, such as in the chemical or petrochemical industry.

It should also be emphasized that the nuclear emergency plan includes a variety of measures ranging from simple actions, such as staying indoors and closing windows, to more drastic measures such as evacuation, and that the likelihood of the latter is small.

7

Choice of reference levels

General Guidelines

There is no essential difference between the philosophy of decision-making in nuclear emergencies and that for decision-making in any other kind of emergency. In all cases, the individuals required to make decisions have at their disposal hard information, assumptions, knowledge of certain or potential consequences, and two or more options to choose from.

Decisions on the application of countermeasures are the result of an analysis that compares the value of the dose avoided (that is to say the effectiveness of the countermeasures) and the total cost of the countermeasures. The general problem that is immediately raised is that the results of the analysis will be different in each case, depending on such parameters as demography, ecology, meteorology and the timing of the accident. In addition, as each different countermeasure has its own positive and negative aspects, decisions must be specific for each measure.

It has been shown that decisions will be based, from the radiological point of view, on projected doses to individuals. The level of projected dose at which any particular countermeasure will be introduced will depend on the site, the installation and an analysis of the potential accident sequence. It has also been shown that the countermeasures should be sufficiently flexible in application to be adapted for the particular population groups exposed and for all conditions prevailing in the region at the time of the accident. In addition, the projected doses that would be used as a basis for decision-making should also take into account the dose reductions achieved by previous countermeasures. This general philosophy has already been developed by IAEA (*10, 14*), the European Communities (*124*) and ICRP (*7*).

One of the main parameters, which is by definition out of anyone's control, is the time factor. Consequently, decisions on the introduction of countermeasures will differ in each phase of the accident sequence.

In the early phase, the main characteristic is that decisions about actions involving the public are made mainly on the basis of the conditions at the plant. The objective is to set intervention levels on the basis of levels of projected individual risk. There are likely to be three dose ranges of interest, including an upper range where non-stochastic effects may occur and a lower range where the potential radiological risks are so low that countermeasures are not worthwhile. Intervention levels are expected to be set for limit countermeasures in the middle range and will depend on the site characteristics. These levels must be applicable in a flexible manner to allow for whatever conditions may apply at the time of the accident.

In the intermediate phase, if there has been severe ground deposition, decisions are to be made on the same basis as in the early phase for those subjected to the highest potential doses. It will also be necessary to consider introducing controls on foodstuffs and the controlled relocation of population groups. These decisions will probably be influenced by the extent of the ground contamination and the nature of the activities that take place in those areas.

In the recovery phase, the problem is to select criteria for the re-entry of populations and for the resumption of the unrestricted distribution of foodstuffs.

In many cases the total cost of the countermeasures taken will be difficult to assess. Many data must be considered and they will contain significant uncertainties. Evaluations have been made of different countermeasures (*23,101*), comparing mainly the costs of evacuation and relocation (the cost per person evacuated or relocated). Some other costs must also be considered, related to property, crop loss, decontamination, etc. Cost, however, will only be one factor in deciding on action in the early phase, whether the action is to be taken by the operator of the nuclear facility, by the public authority handling the emergency, or by the appropriate national authorities (*14*).

Reference Levels

Within a broad range of projected doses, a number of specific dose levels can be set as reference levels. These reference levels can be fixed to set off emergency interventions in the event of an accident. The lower reference level corresponds to dose levels below which it would not be appropriate to take a given action (*7,12,14*). This level would thus be generally applicable and only when its value is exceeded should an assessment be initiated with a view to decision-making.

The upper reference level corresponds to the expected dose value above which remedial measures would be virtually certain to be applied in all cases (*7,12,14*). This value is much more difficult to define precisely than the previous one, since the effectiveness of a countermeasure is variable and depends on various parameters.

There are variations from country to country in socioeconomic and demographic conditions, the environmental characteristics of nuclear installations and the types of plant concerned in accidents. Since values for reference levels should take into account all these main parameters, it is not possible to recommend values that will be universally applicable. In fact, the reference levels recommended in different countries all have a large range of values, according to different situations, conditions and parameters (*12, 14, 15, 19, 25–30, 125–133* and T. Nagaoka, unpublished data, 1981).

In practice, for use with environmental measurements, derived reference levels will need to be established corresponding to radionuclide concentrations in the air, in drinking-water, in foodstuffs and on surfaces. These can be concentrations of the individual radionuclides or of mixtures whose release can be predicted (*7, 10, 14*). In order to facilitate decision-making, it is recommended that the responsible authorities should have tables or diagrams ready containing suitable data on pathways, radionuclides, population groups and the various derived intervention levels that should be used for each type of countermeasure.

Reference levels should be established on a national basis to take into account the particular character of the release and the likely exposure. The most likely release situations have been summarized in Table 4. By considering the various possible types of exposure and the main countermeasures to be taken, it is possible to distinguish seven reference levels from A to G as shown in Table 5. The main countermeasures to be taken at these reference levels are as follows.

Sheltering and stable iodine distribution (A, B, C, D)

In all the situations likely to occur in the early phase the decisions will be similar. The introduction of countermeasures probably begins to be considered at levels around the authorized dose limits for individual members of the public. Decisions will probably be based on non-quantitative data. As a simple indication, sheltering would not generally be necessary for whole-body doses below the annual dose limit for members of the public. Action should probably be taken once doses exceed 10 times this dose limit. Both lower and upper levels, however, are only indicative and should be considered as a general range for guidance only.

Evacuation in the early phase (D)

This relates to possible evacuation to avoid exposure to the plume. This is only realistic either for releases with sufficient warning or for very prolonged releases where the time taken to move populations will be much less than the release duration. The reference levels should be high, both for inhalation and whole-body dose. Thus evacuation should start to be considered at doses of the order of 10 times the annual dose limit; the level of dose at which it would definitely be implemented should be set so as to avoid non-stochastic effects.

Evacuation in the intermediate phase (E)

This relates to a projected dose in a short time requiring urgent decisions on evacuation. The time over which the dose is calculated should be of the order of a week, and the limiting consideration may be its teratogenic effects. Evacuation should be considered to avoid an equivalent instantaneous dose of around 20 times the annual dose limit for members of the public. This

Table 5. Reference levels for countermeasures to be taken in different exposure situations

<table>
<tr><th rowspan="2">Exposure situation</th><th colspan="7">Reference level and corresponding countermeasure</th></tr>
<tr><th>A
Respiratory protection</th><th>B
Iodine administration</th><th>C
Shelter</th><th>D
Shelter and/or evacuation</th><th>E
Evacuation</th><th>F
Relocation</th><th>G
Decontamination and agricultural restrictions (milk restriction)</th></tr>
<tr><td rowspan="2">Time phase</td><td colspan="4" rowspan="2">Early</td><td colspan="3">Intermediate</td></tr>
<tr><td></td><td colspan="2">Late</td></tr>
<tr><td>Source</td><td colspan="4">Cloud</td><td colspan="2">Ground deposition</td><td>Food</td></tr>
<tr><td>Exposure route</td><td colspan="3">Inhalation</td><td>Cloud</td><td colspan="2">External irradiation</td><td>Ingestion</td></tr>
<tr><td>Relevant dosimetric quantity</td><td colspan="3">Committed doses from inhalation</td><td>External cloud dose</td><td>Projected dose over short time</td><td>Projected annual external dose</td><td>Projected annual dose</td></tr>
<tr><td>Risk of acute effect</td><td>+</td><td>+</td><td>+</td><td>+</td><td>+</td><td></td><td></td></tr>
<tr><td>Applicability of countermeasure</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>— noble gases</td><td></td><td></td><td></td><td>+</td><td></td><td></td><td></td></tr>
<tr><td>— noble gases + iodine</td><td>+</td><td>+</td><td>+</td><td>+</td><td>+</td><td></td><td>+</td></tr>
<tr><td>— noble gases + iodine + cesium, etc.</td><td>+</td><td>+</td><td>+</td><td>+</td><td>+</td><td>+</td><td>+</td></tr>
</table>

could be translated in practice into a dose rate of a few mGy/d in the first few days after the accident. Definite action should be taken when doses are 10 times higher.

Relocation (F)

Relocation decisions depend on the size of area affected and the nature of the activities that take place there. Decisions should not be made where annual doses are of the order of natural background doses. In general, at a level of external dose equal to the annual dose limit for occupationally exposed workers, it would be necessary to relocate. The values must be flexible, however, depending on the actual circumstances.

Decontamination of areas and diversion of food supplies (G)

Cost-benefit considerations will be involved by this stage in deciding the levels of individual dose from ground contamination at which normal living can be resumed. In general, there will be no need to exceed the annual dose limits for individual members of the public from the consumption of foodstuffs, unless there is a serious possibility of dietary deficiency. In the case of fresh milk, it may be cost-effective to withhold supplies at significantly lower levels of dose.

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MEMBERSHIP OF SUBGROUPS

Subgroup 1 on general principles

Dr E. Kunz
Dr D.W. Moeller (*leader*)
Dr A.A. Moiseev
Dr V.R. Shah

Subgroup 2 on reference levels

Dr D. Beninson
Dr R.H. Clarke
Dr B. Lindell (*leader*)
Dr W. Seelentag

Subgroup 3 on countermeasures

Dr F. Breuer
Dr K.F. Hübner
Dr O. Ilari (*leader*)

Subgroup 4 on risk estimates

Dr D. Beninson
Dr L.B. Sztanyik
Dr S.S. Yaniv (*leader*)

Subgroup 5 on psychosocial aspects

Dr H. Daw
Dr T. Kumatori
Dr A. Lafontaine
Dr F.E. Stieve
Dr N. Wald (*leader*)

Annex 2

PARTICIPANTS

Temporary advisers

Dr D. Beninson, Director, Nuclear Installations Licensing, National Commission of Atomic Energy, Buenos Aires, Argentina

Dr F. Breuer, Nuclear Safety and Radiation Protection Directorate, Nuclear Energy Commission (CNEN), Rome, Italy

Dr R.H. Clarke, Secretary, National Radiological Protection Board, Chilton, Didcot, United Kingdom (*Rapporteur*)

Mrs H. De Clercq, Radioactivity Section, Department of Environment, Institute of Hygiene and Epidemiology, Brussels, Belgium

Mr G. Fieuw, Head, Department of Measurement and Radiation Control, Nuclear Energy Research Centre (CEN/SCK), Mol, Belgium

Dr K.F. Hübner, Assistant Chairman, Medical and Health Sciences Division, Oak Ridge Associated Universities, TN, USA

Dr H.P. Jammet, Director of Protection, Institute of Nuclear Safety and Protection, Atomic Energy Commission (CEA), Fontenay-aux-Roses, France (*Chairman*)

Mr R. Kirchmann, Head of Section, Department of Radiobiology, Nuclear Energy Commission (CEN/SCK), Mol, Belgium

Dr T. Kumatori, Director-General, National Institute of Radiological Sciences, Chiba-Shi, Japan

Dr E. Kunz, Deputy Head, Radiation Hygiene Department, Institute of Hygiene and Epidemiology, Prague, Czechoslovakia

Dr A. Lafontaine, Professor and Director, Institute of Hygiene and Epidemiology, Brussels, Belgium

Dr B. Lindell, Professor and Director, Swedish National Institute of Radiation Protection, Stockholm, Sweden

Dr D.W. Moeller, Professor of Engineering in Environmental Health, School of Public Health, Harvard University, Boston, MA, USA

Dr A.A. Moiseev, Head, Laboratory of Whole Body Counters, Institute of Biophysics, Moscow, USSR

Dr J.-C. Nénot, Chief, Radiation Health Services, Department of Health Protection, Institute of Protection and Nuclear Safety, Atomic Energy Commission (CEA), Fontenay-aux-Roses, France (*Rapporteur*)

Dr W. Seelentag, Head, Medical and Biological Problems of Radiation Protection, Federal Ministry of the Interior, Bonn, Federal Republic of Germany

Dr V.R. Shah, Head, Medical Group, Bhabha Atomic Research Centre, Tromby, Bombay, India

Dr F.E. Stieve, Professor, Society of Radiation and Environmental Research, Neuherberg, Federal Republic of Germany

Dr E. Strambi, Medical Adviser, Nuclear Energy Commission (CNEN), Rome, Italy

Dr L.B. Sztanyik, Director, National Research Institute of Radiobiology and Radiohygiene, Budapest, Hungary

Dr N. Wald, Professor and Head, Department of Radiation Health, Graduate School of Public Health, University of Pittsburgh, PA, USA

Dr S.S. Yaniv, Radiological and Health Effects Specialist, Health Effects Branch, Office of Nuclear Regulatory Research, US Nuclear Regulatory Commission, Washington, DC, USA

Representatives of other organizations

International Atomic Energy Agency (IAEA)

Dr H. Daw, Senior Officer, Division of Nuclear Safety, Vienna, Austria

Organisation for Economic Co-operation and Development (OECD)

Dr O. Ilari, Deputy Head, Radiation Protection and Waste Management Division, Nuclear Energy Agency, Paris, France

International Radiation Protection Association (IRPA)

Dr. J.-C. Nénot

World Health Organization

Regional Office for Europe

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The widespread use of radiation makes it imperative to know how to protect the public from accidents which, though unlikely, have been known to happen. This book gives guidance on how to deal with unexpected events or situations in nuclear plants that have the potential to release radioactive materials into the environment in excess of the authorized limits.

The book shows national authorities how to develop the capacity to take action in a nuclear emergency. From the experience gained at Three Mile Island, it is clear that two of the most important factors in emergency planning are coordinating the activities of the various authorities involved, and avoiding the psychosocial problems caused by keeping people in the dark both before an accident and during it. The guiding principles presented are based on the philosophy developed by bodies such as the International Commission on Radiological Protection. The emergency countermeasures to be taken are described and their effects, both good and bad, discussed. The advisability of taking these countermeasures must be weighed against these effects and will also depend on the source and timing of the radioactive releases. The report also deals with the main parameters involved in decision-making and how to define and fix the reference levels that will prompt the introduction of emergency measures.

This is an important book for all those involved in safety issues in nuclear plants, both in the plants themselves and in the local authorities responsible for public health. The response to a given accident, and particularly the selection of specific countermeasures and the timing of their implementation, will depend heavily on the specific situation, including the nature of the accident, the geography of the area and the weather conditions at the time. This book has deliberately maintained flexibility in the recommendations it makes, so that it will be of maximum use under the widest possible circumstances.