2

Assessment of off-site radiation exposure

During the early and intermediate phases of an accident there is a need to predict the doses of radiation that members of the public are likely to receive. The main difference between the early and intermediate phases is that in the early phase decisions are made on the basis of predictions of potential doses yet to arise, whereas in the intermediate phase decisions can be based on the results of the confirmed environmental monitoring.

Activity Distribution in the Environment and Relevant Exposure Pathways

During the early phase of the accident estimates of the potential doses to members of the public in the immediate locality are estimated from the expected or already measured values of activity release. A comprehensive emission monitoring system is required to enable an estimate to be made of releases from all critical leakage points. Predictions of future release rates must be based on the available information on the conditions in the plant and possible future developments. In some installations data from static (fixed post) monitoring devices in the environment may be available.

Fig. 2 illustrates the pathways by which material released to the atmosphere is dispersed throughout the environment, leading to human exposure *(16)*.

In the case of releases into the atmosphere, the most important pathways during the early phase are:

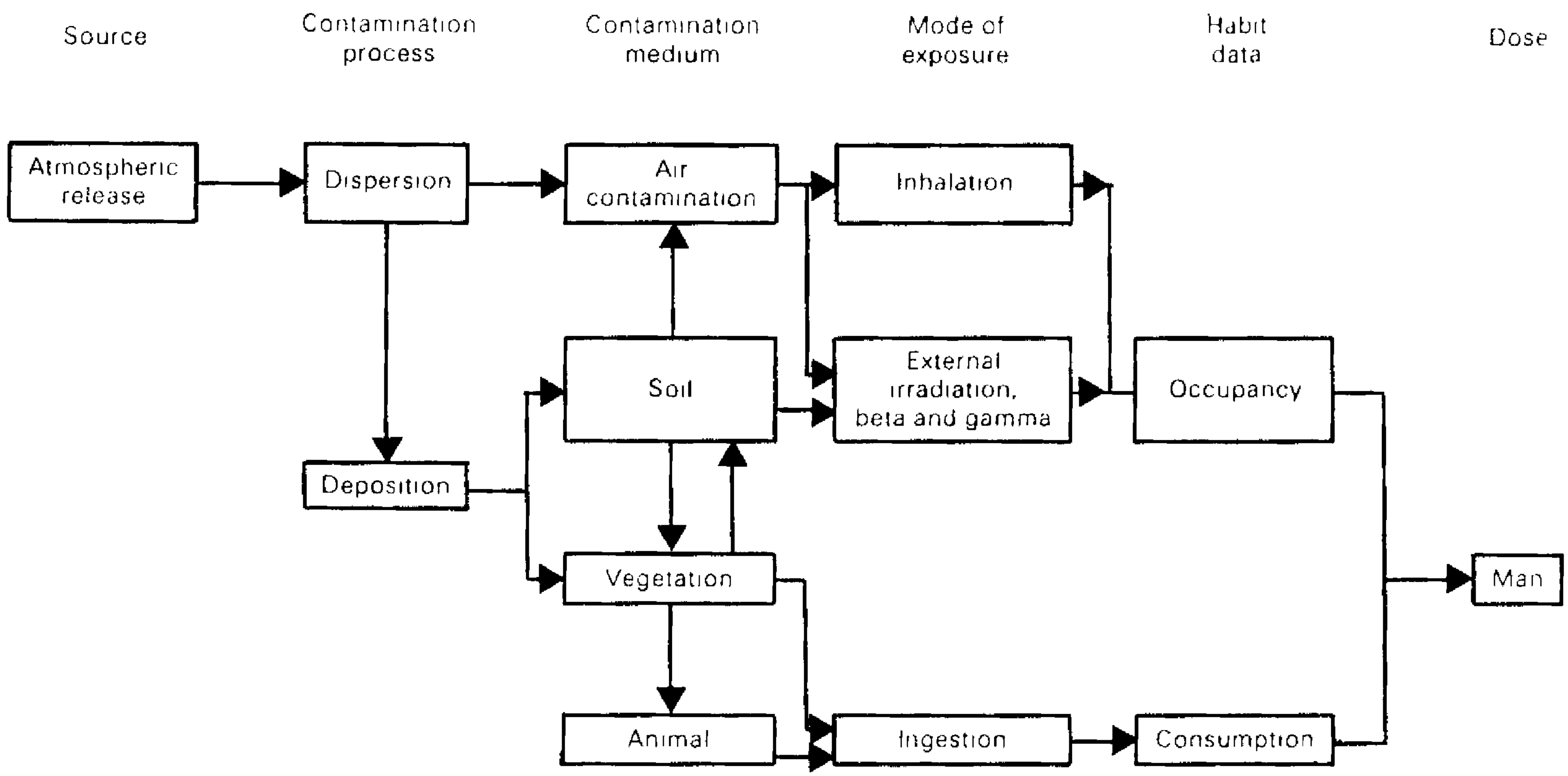
— external doses of beta- and gamma-radiation from airborne radioactive materials (external submersion dose);

— external doses of beta- and gamma-radiation from radionuclides deposited on the ground;

— external doses of beta- and gamma-radiation from contaminated clothes;

— the internal dose from inhaled radionuclides.

Fig 2. Pathways of radioactive contamination of the environment following atmospheric release



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

It should be emphasized that rain showers over residential areas may lead to greatly increased local external exposure from deposited activity. Normally the contribution from deposited radioactive material that is resuspended in the atmosphere will be small and may be neglected in the early phase.

Because of the delay in the distribution of foodstuffs and water, it is not usually necessary to ban their consumption in the early phase. Such decisions do have to be taken, however, in the intermediate phase. Ingestion can lead to exposure of people outside the contaminated area if no measures are taken to stop the distribution and consumption of foodstuffs produced in the contaminated area.

In the event of accidental releases into surface water the most important exposure pathways are:

— use of contaminated water for drinking and cooking;

— ingestion of contaminated fish;

— irrigation of plants with contaminated surface water.

In general, exposure from accidental releases into surface water can be reduced more efficiently than that from releases into the atmosphere.

Dose Estimation

Table 7 outlines the sequence of steps in evaluating the potential dose from accidental releases into the air.

The need in the early phase is to predict doses over short distances from the installation, typically of the order of a few kilometres. This is because decisions on the introduction of countermeasures are based on levels of dose to individuals. The first problem is that of the likely total quantities of radionuclides to be released. This can be estimated from knowledge of the condition of the installation, but a valuable source of information will be the stack monitoring information, if containment is not breached. Such monitoring equipment should be installed and should be capable of response in the event of a release several orders of magnitude greater than that anticipated in normal operation. In the early phase it is important that simple models for activity distribution in the environment and dose evaluation are applied. This is justified taking into account the uncertainties in the release predictions and the limited data available from environmental monitoring.

For evaluating the activity concentration in air as a function of distance, simple gaussian dispersion models will be sufficient in many cases, taking into account the meteorological conditions (wind direction and velocity; atmospheric stability) during the release period. For activity reaching the ground by wet and dry deposition, and for transfer through food chains, models have been developed that take into account the influence of seasonal variation. Detailed description of these radioecological models is outside the scope of this report; the reader is referred to special reports on the subject published by international bodies *(16–19)* and national authorities *(4,11,20–24)*.

Table 7 Evaluation of exposure from accidental releases of activity into the atmosphere

Period	Input data	Activity distribution in the environment (radioecological models)	Evaluation of potential doses (dosimetric models): pathway	Evaluation of potential doses (dosimetric models): dose
Early phase	Meteorological parameters (wind direction and velocity, atmospheric stability)	Activity concentration in air as function of distance (atmospheric dispersion model)	Inhaled activity during cloud passage	Committed inhalation dose
	Activity release rates (predicted values, results of emission monitoring)	Activity deposited onto ground and other surfaces by wet and dry fallout (fallout model)	External beta- and gamma irradiation — outdoor residence - indoor residence - from contaminated skin and clothes	External beta- and gamma-dose rate and dose
	Measured beta- and gamma-radiation levels in the environment — stationary devices (if available) — mobile stations	Evaluation of cumulative activity deposited, as function of place and time		
Intermediate phase	Activity of relevant radionuclides in environmental samples (soil, plants, foodstuffs, water)	Activity transfer through food chains, distribution in surface water	Ingested activity with food and drinking-water	Committed ingestion dose

Although there are significant uncertainties involved in both the characterization and measurement of meteorological conditions, the uncertainties in source terms mean that simple models should be adequate in most cases. For some sites more sophisticated models may have been developed and these can be used if the detailed meteorological parameters are available at the site. This may require the linking of real-time site measurement data to national or regional meteorological forecasting services. In all of this prediction it is absolutely imperative that information on such factors as wind direction be unambiguous.

Although some monitoring results will become available in the early phase, there will be difficulty in using these results because of possible variations in release rate and meteorological conditions. In the intermediate phase, most of the release will have occurred and the primary requirement is to establish the extent and levels of the residual ground contamination. Initially, monitoring will be directed towards identifying higher levels of contamination in order to specify areas in which further countermeasures will need to be considered. However, it is important for monitoring to be undertaken well outside the areas where action might be anticipated. Such monitoring will ensure that competent authorities will be aware of all areas where there is measurable residual contamination.

For the evaluation of the dose to man from the different exposure pathways, the dosimetric models recommended by ICRP *(25)* can be applied. The derived dose coefficients, giving the dose per unit of inhaled or ingested activity, refer to adult members of the population. For dose estimation during the early phase and subsequent decisions on countermeasures, it may not be necessary to consider age-dependent dose coefficients, except in the case of estimating the dose to the thyroid, which is highly age-dependent *(26)*.

However, in the intermediate and recovery phases, appropriate age-dependent dose data should be used to obtain more realistic estimates of the cumulative dose over both short and prolonged periods (estimation of lifetime dose).

It is generally true that intake of activity by inhalation occurs only during the period when people are actually immersed in the radioactive plume. In contrast to the inhalation dose, the external beta- and gamma-dose rate from deposited activity is proportional to the cumulated activity per unit area, taking into account appropriate shielding factors for those indoors at the time. After the end of the period of deposition, the external dose rate decreases according to radioactive decay and the "run off" of the deposited activity.

The assessment principles and techniques that can be used range from simple measurement and calculation methods using inexpensive equipment ("rules of thumb", formulae, charts or graphs) to sophisticated and complex computer techniques with colour visual display units. Prominence is often given to computerized methods, but emphasis on sophisticated computer-based technology should be regarded as an indication of its rapidly developing capabilities rather than as implying that the latest systems are essential for the task of assessment. Even a small microcomputer can make a large difference in the speed and reliability of an assessment calculation, which may have to be performed repeatedly for many hours.

The disadvantages of a totally computer-based assessment plan must be pointed out. As a back-up against failure of computer-based assessment schemes, it is recommended that a catalogue of pre-calculated geographic dose distributions from sample scenarios be prepared to define the scope of the problem and to direct further calculation more effectively. Furthermore, it is prudent to cross-check some important computer numerical results against manual calculations for order-of-magnitude correctness. This will require data on population densities, dose–intake relationships, and the composition of the population. It must be recognized by public health authorities that computers can create an illusion of infallibility, while in reality there is potential for large errors caused by mistakes in programming or data entry.

This report is concerned with assessing off-site consequences that can be expressed as (or are directly related to) radiation doses to individuals, in order to make correct decisions about countermeasures. It is not concerned with the assessment of other kinds of off-site consequences such as economic, social or political consequences of the accident. These may, however, have to be taken into account as factors in decision-making when, in a serious emergency, important decisions have to be taken by those who are probably non-technical but are at or near the political level. The report makes no attempt to indicate the weighting that should be given to factors of this kind.

Environmental Monitoring: Objectives and Procedures

As soon as the release has begun, it is possible to begin to monitor the levels of environmental radioactivity. This monitoring is important to complement the modelling in the early phase and is the basis for decision-making in the intermediate phase. Indeed, although the models allow the prediction of levels of exposure in large areas within a short time, the results predicted are based on hypothesis and on dynamic (source-term, meteorological) parameters. Consequently, there are uncertainties that must be assessed from field measurements.

The procedure used can take advantage of results of measurements made at fixed points; these results will confirm or modify the values theoretically predicted. Furthermore, it would be difficult to decide on important countermeasures implying serious socioeconomic consequences only on the basis of model predictions. For this reason, monitoring will aim at identifying the higher levels of contamination so as to specify areas in which countermeasures will need to be considered.

It must also be noted that the evaluation of the level of radioactive contamination recorded by the monitoring instruments can provide valuable information on the origin of the exposure (cloud and soil deposition).

Measurements that will need to be made in the intermediate phase will include external dose rates of beta- and gamma-radiation above the ground (these will need to be made according to a predetermined protocol specifying height above ground, etc.). Rapid assessment of the area affected will require either the use of airborne monitoring or hasty deployment of vehicles. For the resulting information to be comprehensible at the emergency centre, good communications must be established between the centre and each environmental monitoring team and the transmission of information must follow a fixed and predetermined pattern.

Samples of water, soil, plants and milk will be taken and passed to analytical laboratories where gamma-spectrometry and other methods of radiochemical analysis can be used to identify the nuclides that have been deposited. If various laboratories are involved, standard procedures of sampling and measurement must be defined. Since in most cases the analytical capacity of these radiochemical laboratories will be limited, priority in the order of analysis will have to be decided.

The last part of the monitoring will be undertaken later, during the recovery phase; residual levels in drinking-water and of ground contamination and activity in milk and other foodstuffs will be determined not only in the areas in which countermeasures were considered but also at distances well beyond those areas.

3

Guidance on planning for the medical and public health professions

It is the responsibility of the public health and medical professions to take an active part in the planning for response to a radiological emergency, with the aim of minimizing the health impact to the public. All actions to protect the public from consequences of a nuclear accident have this same objective and, therefore, the public health and medical professions should be represented on all planning and decision-making bodies.

It is recognized that the medical profession is accustomed to responding to a wide variety of emergency situations, with the obvious exception of those rare accidents that involve large releases of radioactive material. The purpose of this section is to provide information and guidance on special planning needs concerning the public health and medical professions for accidents involving such radioactive material.

Because of differences from country to country, this guidance cannot cover all the details required for developing radiological emergency response plans for the medical profession. Additional needs for planning in particular countries should be identified during exercises and/or drills, which are an important part of every radiological emergency response plan.

Two levels of planning are necessary: one for public health officials who must deal with general public health decisions, and one for medical personnel in the hospitals and field stations who must deal with the general public *(22)*. The planning elements discussed below are intended to provide only a listing of the major problems for which public health and medical officials should develop response plans. Some of the planning elements are discussed in more detail in other parts of this book.

Planning Elements for Public Health Officials

Protective measures and their risks

The protective measures of concern are shelter, evacuation, administration of stable iodine and restrictions on the intake of food and water. Public health officers must be aware that these measures, which are intended to reduce radiation exposure and associated risks, may result in risks of other kinds to the populations involved *(1,3,5)*.

In the early phase of an accident, decisions to provide shelter, to evacuate or to administer stable iodine are likely to be made rapidly (minutes to hours after recognition that an accident has occurred) and thus an evaluation of relative risks by public health officials will be impracticable. Therefore, these risks must be considered carefully during the planning phase, when intervention levels are selected to provide reasonable assurance of a net risk reduction. Special consideration should be given to those under medical care.

Potential radiation hazards

Because of the different types of nuclear installation that might be the source of an accidental release to the environment, public officials should be familiar with potential hazards associated with facilities in their area and should plan accordingly. Planning should include determining the information needs to support public health decisions, and should provide for channels for the timely dissemination of that information.

Training

As accidental irradiation of workers and the public is a rare event, it is not to be expected that doctors, nurses, paramedical staff and other health care professionals will have sufficient knowledge about the nature of radiation and its effects on the human body. For this reason, it is very important that all health workers receive education on the effects on health of exposure to ionizing radiation, and training in the proper and safe handling of patients contaminated with radioactive material in an emergency *(22)*. They must also learn to identify the signs of radiation sickness and their development with time, not least because this will enable them to identify those who have not been seriously irradiated, but who fear that they have.

In the training programme it should be emphasized that the most probable accident to prepare for is unlikely to involve any seriously irradiated people needing highly specialized care. Individuals seeking medical help and advice will probably not have received a dose that could cause a non-stochastic effect or even a dose of any significance. However, a large number of people who have not been exposed to radiation at all will present themselves to medical staff. They will basically require reassurance. The proper handling of the psychological problems associated with a nuclear accident is therefore of great importance and must be included in the training programme.

Nevertheless, a certain number of people may be contaminated and they will have to be decontaminated, probably at the evacuation centres where the majority of those contaminated can shower and change clothes. These people will have been identified by the procedures in the emergency plan. A few may have been heavily contaminated and also injured, so that hospital care is necessary. In the training it should be stressed that it is very unlikely that any patient will be so contaminated that he will in any way constitute a risk to the hospital staff giving the treatment, given that proper precautions are taken. Life-saving measures such as treatment for shock and severe injuries should never be postponed for the sake of very ambitious decontamination procedures.

The need for facilities and equipment

Since the probability is slight that accidents will occur that are serious enough to cause acute radiation injury to the general population, emergency planners are advised against purchasing expensive special equipment or facilities to be set aside solely for use in caring for patients contaminated with or exposed to radioactive materials *(27)*.

Medical facilities in the vicinity of nuclear plants are usually equipped to care for any injured workers who have been contaminated or exposed to high doses of radiation. These facilities can also be used on those very rare occasions when a member of the general public who is similarly injured needs treatment. Lists of special supplies and equipment needed for caring for contaminated patients can be found elsewhere *(28,29)*.

Public information

The general public will require information on a wide variety of topics, some of which deal with public health considerations. Pamphlets should be prepared for handing out to the public, and training programmes or seminars on the emergency plan may be presented. Public health officials should ensure that the services to be provided by the medical profession are covered accurately and adequately.

After an accident has occurred the public may be concerned about many subjects. Thought should be given to anticipating questions of a medical or health nature, as well as the appropriate answers or sources of answers to these questions and methods of communication with the public. Convincing and prompt answers by an authority on health matters will generally go a long way towards reducing anxiety.

Public health needs for population dose estimates

Public health officials may be called on to estimate the health consequences (immediate effects, long-term carcinogenic effects, birth defects and psychological effects) of an accident. Once the accident is under control, and at the time of the withdrawal of countermeasures, the authorities will be expected to account for the consequences of their protective action and also to account to the public through the various committees and boards of inquiry about the total risk to the public from the accident. The public health authorities should be prepared to estimate the insult to the population based on the best available radiological data.

Years after the accident, it can be expected that the people around the facility — both exposed and non-exposed — may attribute the inevitable cancers and genetic effects that arise in any population to the accident. Since a significant fraction of the whole population will get cancers from causes other than the accident, there is a likelihood that many improper claims will be made unless there are adequate data to estimate the probability that the accident caused the cancers. Public health authorities should ensure that the data necessary to make these decisions are included in the planning.

Planning Elements for Medical Practitioners

Operators of medical facilities in the vicinity of nuclear plants generally have emergency response plans and associated training programmes for dealing with the more frequently encountered conventional emergencies. If the hospital is situated in the immediate vicinity of the plant, the planners should be aware that if the accident is severe another hospital may be required in the event that the first hospital needs evacuating. This points to a need to explain the possible consequences of a radiation accident involving members of the public to the local medical staff. The emergency plans for such hospitals should be amended as necessary to include the special requirements that may be associated with a radiological emergency. The following are some key items that should be considered in developing those plans. Important elements in the training programme that should accompany the emergency plan have already been discussed.

Evacuation and shelter

The medical profession has a special responsibility when it comes to planning the evacuation of hospitals and nursing homes, as well as evacuation of the infirm and handicapped living in their own homes. The risk of moving these people must be carefully weighed against the risk of any irradiation if they remain in the shelter of their house at the time of the accident. The final decision on evacuating these people is probably best taken by the doctors attending them.

In the event that a decision is taken by the appropriate authority to evacuate the general public from a certain area, the designated evacuation centres should be attended by some medical staff. The purpose of the medical presence at these centres should mainly be to reassure members of the public and, if necessary, to decide who needs further medical attention. Medical and nursing staff at the centres are probably the best people to reassure those who are worried about a possible dose of radiation, rather than officials from the nuclear plant or from responsible government agencies.

Care and treatment of injured people who may be contaminated

Contaminated people who may be injured and in need of medical aid will be taken to the designated medical facility *(27)*. The facility must be prepared to treat these patients without disruption of its normal services. Treatment of injuries should be a first priority over that of decontamination. The facility will need to consider the appropriate procedures and contamination limits for radiation monitoring of patients, and methods and/or supplies for decontaminating people. Levels of decontamination should be established as a part of the plan, so that priorities can be established for decontamination. It should be emphasized that the number of people likely to be contaminated to the extent that it will pose a health risk is quite small; however, the number of people who are very slightly contaminated, or not contaminated at all, may be very large. These people will need reassurance, and thus an effective monitoring programme is needed at the evacuation centres or at other places away from medical facilities. If this is not done, there is the risk that these "self-diagnosed" people may jam the medical services and prevent those who are injured from obtaining the help they need.

Advice to people who return to live in contaminated areas

After the early phase of the emergency and evacuation, it is to be expected that there will be measurable, albeit low, levels of contamination in the areas to which people are allowed to return. Public health agencies will need to be prepared to explain to people living or working in this contaminated area about the residual radiation risks, so that they can make an informed decision about returning. Guidelines should be established to minimize the uptake of any residual contamination, and attention should be paid to local food crops, water supplies, and resuspension of deposited contamination.

Communication

The single most important aspect of emergency response is the communication system. Experience has shown that when any major accident occurs — not just those involving radioactivity — the normal communication system breaks down, and therefore a reliable, competent alternative system of communication will be needed and must be available.

The planning authorities must identify the sources of information they may need to respond properly during the emergency, and the methods of communication needed to obtain such information so as to reduce confusion. They must communicate with the population of the area to assure them that there are enough properly trained medical personnel to take care of their medical needs. They will also need to communicate with the public on procedures for obtaining such medical services.

Another important line of communication is to an advisory group of technical experts competent in the radiation field. These experts should be identified along with communication methods. A list should be prepared in advance so that they may be rapidly mobilized to participate in the decisions that need to be taken in an emergency.

4

Administrative training and public information

Small, unplanned releases from nuclear facilities are not especially unusual events. However, increased public awareness and rapid dissemination of information about these events by the news media creates a need for accurate and credible responses by government authorities at all levels.

Responsibility for assessment, management, countermeasures and recovery may rest with different branches of government depending on the organizational arrangements in each country. These responsibilities may be further subdivided between the relevant authorities at the national level and those at the state or provincial level. Therefore, any generalizations made about how they might function must be modified for the specific arrangement within each country. This may complicate communications between countries when a nuclear emergency occurs near a national border, and such situations must be considered in the planning.

In general, the course of an accident will be influenced by the decisions of the operators of the facility within minutes or hours after the event occurs. However, once the event is detected and reported, the nuclear regulatory authority or its counterpart will be the most likely government department to assess the consequences and the action being taken to bring the situation under control. In some countries there are emergency management (disaster control) organizations that would receive the initial reports. It should be recognized that easy access to reports and announcements may lead to the news media disseminating information about the accident to the public before the appropriate authorities are informed of the facts. This press information may often be incomplete or inaccurate, and this complicates the role of the authorities when they attempt to present more accurate information. There is a danger that this will result in the undermining of public confidence in the authorities, since there is an apparent tendency to believe the views of the news media.

In spite of the number of different authorities involved in emergency planning and implementation, it is imperative that one authority be given the leading role, and that that authority should be responsible for promulgating advice and information on action taken. The concept of a leading authority or individual is also important in communicating with the press.

This will enable the other authorities to deal with the technical decisions at hand and eliminate the chance of the press receiving conflicting information.

In the event of a serious accident in which countermeasures are likely to be considered, the public health authorities must be involved in the decision-making. Public confidence can best be restored if decisions on such matters as evacuation, sheltering and thyroid blocking are based on the advice of the responsible public health authority, since all these decisions are in themselves risky, and must be balanced against the risk from the projected radiation exposure. Details of the radiation release will generally be made available to the nuclear agency or the emergency management agency either by the facility management or by the local environmental or health agency. The public health agency must participate as a member of the team with these other organizations in assessing the consequences and suggesting corrective action. But since the final decision on corrective action has implications for public health, it should be the responsibility of the public health agency to endorse it.

The public health role in such countermeasures or evacuation must be emphasized, since the disruption of the lives of evacuees — some of whom may be pregnant, disabled or in hospital — will require that clinical services are available at evacuation or relocation centres. Should these people become contaminated during the course of evacuation, the clinical personnel must be prepared to deal with decontamination in addition to other duties involved in health care. Food, water and sanitation services will also be needed along the route and at relocation sites, and this is also a public health responsibility.

In a serious reactor accident, the airborne release may extend tens of kilometres outwards from the facility, and the population within that area could become mildly contaminated under certain circumstances. Thus, there is a need for medical personnel within that area to understand how to deal with radiation emergencies including contamination.

Public health authorities must also be prepared to work with food and agriculture authorities to determine the impact of releases on the food, milk and water down wind of the accident. This means that radiation protection guides must be considered before the accident and included in the emergency plan. These guides should ideally be coordinated with similar guides developed by authorities in adjacent countries, so that action will be consistent. The basis for these guides should be a public health understanding of risk.

During the late phase of the accident, a decision must be made to terminate the countermeasures, and again the public health authority is in the best position to justify, on behalf of the government, the basis and effects of this decision. The information and assessment needed to make this decision will come from the measurements and calculations provided by the facility and the relevant government organizations.

Throughout the recovery phase of the accident, there is the potential for additional exposure of the population, depending on the severity and nature of the damage to the facility. Discharges to the atmosphere or hydrosphere may occur, either inadvertently or deliberately as part of the recovery phase.

Deliberate discharge may be necessary, for example to reduce high pressure inside the reactor building, and should take into account all the relevant factors that will influence the levels of dose delivered to the population (time of day, meteorological conditions, etc.). Such discharges may cause public concern and resistance. If the public health authority is involved in planning for any deliberate discharge, and is informed about the magnitude and consequences, then there is a greater chance that public fear will be minimized. If these events are explained by the nuclear energy authority without public health input, there is a greater potential for public anxiety.

The psychological impact of an accident on the population must not be underestimated. Again, the public health authorities are in the best position to keep these fears in perspective and to provide credible information to the public.

As stated previously, it must be recognized that many of the people who eventually develop cancer will attribute it to the accident, regardless of whether they were exposed or not. Determining the validity of any such claim will depend on comprehensive data being obtained at the time of the accident. That would include not only the best available dose information, but information on where these people were and for how long, so that in the future, the probability of any particular cancer being caused by the accident may be assessed. The public health authorities should consider this eventuality and should collect the information during the accident to make possible future epidemiological assessment.

In addition to the respective roles of the government authorities during the various stages of an accident, the role of planning and training must be emphasized. Only through proper planning and field exercises will the problems such as communications be identified and corrected. The consequences for mental and physical health should be included in the planning, scenario development and field exercises. The public health authority should participate with the other authorities in all these stages.

Involvement of medical and health care personnel in these exercises is important, and the public health authority is in the best position to coordinate the role that they will play in the accident. Since these clinical personnel are most unlikely to have been trained in radiation monitoring and protection, there is a need to keep them informed and advised.

Communicating with the local population (particularly officials, the medical community and the news media) prior to an accident is an effective way to keep them informed about the quality of the emergency plan. Involving these people in the exercises or in the review of the plans will go a long way towards building confidence in the facility.

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