Nuclear and radiation safety: Guidance for emergency response

Criteria have been established at the international level to guide decisions about protective actions after a nuclear or radiological emergency

by
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Accidents involving radioactive materials in recent years have had consequences for the health of the general public. These have ranged from the major accident at Chernobyl in 1986 to accidental dispersion of medical and industrial radioactive sources.

Responses to these accidents differed between countries. It later became apparent that some protective actions were taken that, in the most extreme cases, may have worsened, rather than improved, the well-being of the populations involved and their environmental surroundings. In other cases, the actions led to large but unproductive expenditures of national resources. Further, where the accident involved exposure of populations across national boundaries, many instances occurred of contradictory national responses either side of the national borders.

During the past decade considerable progress has been made in developing internationally recognized principles for decisions on protective measures following accidents involving radioactive materials, and in providing quantitative guidance for applying these principles. Efforts have involved the IAEA, the International Commission on Radiological Protection (ICRP), World Health Organization (WHO), Food and Agriculture Organization (FAO), Commission of the European Communities (CEC), and Nuclear Energy Agency of the Organization for Economic Co-operation and Development (OECD/NEA).

This article summarizes guidance on the radiation protection criteria that have been established with regard to responding to nuclear accidents or radiological emergencies, and the principles for establishing intervention levels. The guidance was developed to assist those at national and regional bodies and at nuclear facilities having responsibility for emergency response planning.

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Establishing international consensus

In 1985, the Agency published *Safety Series No. 72*, which set out guidance on the principles for establishing intervention levels for the protection of the public in the event of a nuclear accident or radiological emergency. That guidance was aimed at assisting national and regional authorities having responsibility for emergency response planning to specify levels of projected dose at which it may be necessary to introduce relevant protective measures. It recognized a need for practical quantities that could be readily compared with the results of measurements made in environmental materials and in foodstuffs, so-called Derived Intervention Levels (DILs). Shortly after the accident at the Chernobyl nuclear power plant in 1986, the Agency published *Safety Series No. 81*, which addressed the principles, procedures, and data needed to establish these DILS. Guidance was also given on the extent to which the supportive numerical data and the illustrative DILs might have more generic application.

Additionally over the past decade, new recommendations for radiation protection have been issued by the ICRP; the FAO/WHO Codex Alimentarius Commission published Guideline Levels of Radionuclides in Food Moving in International Trade; WHO issued recommendations on Derived Intervention Levels for Protecting the Public; and the International Chernobyl Project made a number of important recommendations.

In 1991, the IAEA revised its *Safety Series No. 72* to clarify the guidance with respect to intervention, and provided illustrative examples of how intervention levels are established in emergency plans. It stopped short of providing numerical intervention levels that might have some generic application.

The emergency response to the Chernobyl accident underscored the need for a simple set of consistent intervention levels at the international level. Such a set of values was considered desirable to increase public confidence in authorities charged with dealing with the aftermath of an accident. Additionally, since many countries do not have nuclear facilities and hence detailed emergency plans themselves, a simple internationally agreed set can assist them in the event of transboundary releases.

In the process of establishing international consensus on the values of these generic intervention levels, the IAEA convened a number of technical meetings. The work led to the preparation, in 1993, of *Safety Series No. 109, Intervention Criteria in a Nuclear or Radiation Emergency.* This Safety Guide, published in 1994, represents the international consensus reached on principles for intervention and numerical values for generic intervention levels. These principles and values subsequently became the basis of intervention guidance in the *Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources*, which have been issued jointly by the IAEA, FAO, ILO, NEA, PAHO, and WHO.

Summary of guidance

Prompt and Delayed Radiation Effects on Health. For most prompt (or deterministic) effects on health, the severity is related to the level of dose to the individual and there is a practical threshold radiation dose below which effects are not clinically observable. The most severe consequence is death, which may occur in sensitive individuals, due to bone marrow failure, at doses above one gray (Gy) delivered promptly to the whole body. Serious prompt effects may also occur in other organs. Most of the threshold doses for these are above that for bone marrow and will be avoided if the dose to the whole body is below one Gy. However, some individual organs, such as the thyroid and the lung, may receive high doses due to breathing or swallowing certain radionuclides and must be considered separately.

Delayed (or stochastic) effects include a wide range of cancers and hereditary effects, for which the probability of occurrence (not the severity) increases with dose. They usually appear many years after exposure, and, although they do not occur in every exposed individual, there is no threshold for their induction. Because of the assumed linear (proportional) relationship between dose and the probability of these effects, it is possible to estimate the number expected to occur in a large exposed population even if the chance of an effect is very small for most individuals. Since other causes (mostly unidentified) can give rise to the same effects, it will be usually impossible to identify those caused by radiation.

Typically, even a severe accident will cause high doses to relatively few and small doses to many people. Most cancers and hereditary effects will occur in large populations that receive small doses. These usually cannot all be avoided and the objective of intervention is to reduce their number as much as is reasonably possible.

Exposure Routes and Dose Projections. Although accidental releases may occur to air, water, or land, those most likely to require urgent protective action are major releases to air. Following such a release people may be exposed to radiation from the airborne radioactive cloud and through inhalation of radioactive dust from the cloud. As the cloud disperses, particles will slowly settle on the earth's surface or be deposited rapidly by rainfall. People then may be exposed to radiation from these deposits, from inhaling resuspended dust, or from contaminated food or water.

During an accident, potential doses to the population will usually be estimated by well-qualified professionals. However, early on, there are many uncertainties (e.g., in the amount and rate at which radioactive material is being released and in the meteorological situation). Because of this and the need to use simple mathematical models to obtain results soon enough to be useful, there will be large uncertainties in early dose estimates.

Decision-makers must be aware of this situation and ensure that their expert advisors provide an expression of uncertainties in early estimates of projected doses. They should not rely on "most likely" estimates alone (which could lead to wrong conclusions with severe repercussions for the population) and must consider the uncertainties in arriving at a suitable decision on urgent protective action. Later, as the situation becomes clearer, it will be possible to modify and initiate protective actions with a much firmer grasp of projected doses.

Normal and Emergency Situations. Under normal conditions, doses from man-made sources (e.g., from nuclear power or the practice of medicine) are kept within specified levels. These are much lower than would prompt a need for protective action; typically they are comparable to local variations in natural background radiation. They are achieved through the use of controls on the radiation source and do not require direct constraints on people.

In the event of an accident, radioactive material released into the environment is no longer under control; doses can only be reduced through protective actions — such as evacuation, sheltering, relocation, resettlement, prophylatic use of iodine, and restrictions on food and water — all of which impose constraints on people's activities. These actions may also incur additional risks. Therefore, in choosing the level at which a protective action should be initiated, it is necessary to consider the effects of constraints on people's activities and any additional risks from the action itself.

For the above reasons, the levels of dose for intervention following an accident and the levels for control of doses under normal conditions will be different and it is important to avoid confusion between the roles of these two different kinds of levels.

Protective Actions. There are limited major options available to protect the public after an accident. The most important are the following:

For early, or urgent, response: 1) sheltering, through advising people to remain indoors and close their doors and windows, usually for less than a day; 2) evacuation, the urgent removal of people from a specified area for periods on the order of days; and 3) prophylactic administration of iodine, if high intakes of radioactive iodine have occurred or are expected to occur.

For later phases of the response: 1) temporary relocation of people to a new habitat, usually for no longer than one to two years; 2) permanent resettlement of people in new or existing settlements for the foreseeable future; and 3) control of food and water contaminated in excess of specified levels.

Principles and levels of intervention

Three principles have been agreed upon by the international community as a general basis for intervention. They may be paraphrased as follows: 1) Intervention to avoid serious prompt health effects should be carried out as a first priority. 2) Protective actions to avoid delayed health effects should be initiated when they will produce more good than harm in the affected population; and 3) These actions should be introduced and withdrawn at levels that produce a maximum net benefit to the population.

The first principle is critical for response to an accident producing any high doses. It means that any immediate threat to individuals should be countered through evacuation (or, rarely, sheltering) (and, when appropriate, iodine prophylaxis) as a first priority, and carried out to the maximum extent of immediately available resources. There may be rare cases when evacuation to satisfy this first principle is not appropriate because it could cause greater harm (e.g. moving people on life support systems, or in the face of a competing disaster).

Intervention levels for minimizing delayed health effects are based on the second and third principles. In applying these principles, the terms "good," "harm," and "benefit" include — in addition to health and safety and the tangible costs of protective actions — unquantifiable factors such as reassurance, stress, and attention to societal values. These are not within the primary professional competence of the radiation protection expert. They are more appropriately the responsibility of the decision-maker. He or she may choose to consider these factors, in addition to those addressed by this radiation protection advice, in arriving at decisions that will produce the maximum benefit in the affected population.

Furthermore, the second and third principles address only the risk of delayed effects in the population as a whole. This means that they do not explicitly limit individual risks. A significantly higher than normal risk of delayed effects to even a few individuals may be an important factor in national decision-making. For this reason authorities may choose an action level to avoid unacceptably high individual risks. Whether intervention at such a level is always possible will depend on the accident's severity and nature and the resources at the disposal of the country. Such action levels were not considered in deriving the generic intervention levels in *Safety Series No. 109* and may lead to lower values for intervention, particularly in the case of protective actions for later phases of a response.

Protective Actions for Early, or Urgent, Response. These actions must be applied promptly in order to be effective. Delays may lead to population doses that could have been avoided and in the worst cases could lead to prompt health effects. Rapid decisions are difficult because there is usually very limited early information about an accident and large uncertainty about its consequences. For this reason pre-planning should be carried out wherever possible so that decisions can be made rapidly based on facility conditions and pre-arranged patterns for response, rather than just on measurements carried out and actions hastily organized during the early course of an accident. In the case of fixed facilities with well-understood characteristics, response plans should prescribe action to implement urgent protective actions on the basis of facility conditions, rather than rely on confirmation of an actual release through measurements at the facility or offsite, whenever it is reasonably feasible to do so.

Sheltering means staying in buildings to reduce exposure to airborne contamination and surface deposits, and closing doors and windows and turning off ventilation systems to reduce inhalation of radioactive material from outside

Generic intervention levels in emergency response situations

Urgent protective actions

Action	Avertable dose (Generic intervention level)
Sheltering	10 mSv for a period of no more than 2 days
Iodine prophylaxis	100 mGy (committed absorbed dose to the thyroid)
Evacuation	50 mSv for a period of no more than 1 week

Generic action levels for foodstuffs
(From the CODEX Alimentarius Commission guideline levels for radionuclides in food moving in international trade following accidental contamination)

Radionuclides	Foods destined for general consumption (kBq/kg)	Milk, infant foods, and drinking water (kBq/kg)
Caesium-134, Caesium-137, Ruthenium-103, Ruthenium-106, Strontium-89	1	1
Iodine-131		0.1
Strontium-90	0.1	
Americium-241, Plutonium-238, Plutonium-239	0.01	0.001

Long-term actions

Action	Avertable dose (generic intervention level)
Initiating temporary relocation	30 mSv in a month
Terminating temporary relocation	10 mSv in a month
Considering permanent resettlement	1 Sv in a lifetime

air. Sheltering can also facilitate staging for evacuation and the prophylactic use of iodine. Because of the small penalties, sheltering may be justified at low dose levels. However, its effectiveness decreases rapidly with time for most structures (typically reducing doses to airborne particulates by a factor of two or three in a few hours) and is low for lightweight structures or those with high air exchange rates. Further, there is a limit to the time that populations can remain indoors without undesirable complications.

The generic intervention level for sheltering is 10 mSv. This value was selected based on the maximum anticipated period of sheltering (2 days). Sheltering may be advised at lower levels for shorter periods or to facilitate other protective actions.

Sheltering can be effective if the exposure is of short duration and buildings are of dense structure and well sealed, as in some northern countries. In many warm countries, however, most houses are made of light materials, and people cannot stay indoors in sealed houses for long periods. These factors must be considered when choosing between protective action through sheltering versus evacuation.

Evacuation is the urgent moving of people from their normal housing for a limited period of time. Its use should be based on the dose that can be avoided by evacuation and would not be avoided by sheltering. The generic intervention level for evacuation is 50 mSv. This value has been selected based on the maximum anticipated period of evacuation (7 days). Evacuation may be initiated at lower levels for shorter periods or when it can be carried out easily, e.g. for small groups of people. Under exceptional circumstances (such as hazardous weather, or the presence of a competing disaster) or where evacuation would be unusually difficult (for very large populations or in the absence of adequate transportation) initiation of prompt evacuation may be deferred to a higher intervention level.

In cases before an actual release has started, and where projected doses exceeding this level have a relatively high probability of occurrence, preventive evacuation normally will be advisable. Evacuation as a protective action is commonly used when people are threatened by other man-made hazards (e.g., fire or chemical spills) or by forces of nature (e.g., hurricanes, tornados, earthquakes, or floods). In most cases people return in a short period, typically one to two days, if their homes do not require prolonged clean-up. Because of the short time involved, primitive accommodation in schools or other public buildings is typical.

Prophylactic use of iodine is the administration of stable (non-radioactive) iodine in order to block the uptake of radioiodine by the thyroid. It must be carried out promptly to be effective (ideally several hours before and no later than a few hours following exposure). For this reason this protective measure is most commonly practical only when emergency planning has included predistribution of stable iodine to the population at risk. It will usually be coupled with evacuation or sheltering. The generic intervention level for prophylactic use of iodine is 100 mGy. This level applies to the dose to the thyroid that would be received from intake of radioiodine. Since there may be complications depending on local diet and other factors, public health authorities should be involved in implementing this measure.

Protective Actions for Later Phases of a Response. Sheltering and evacuation are short-term protective measures. If measurements confirm that doses warrant further action, temporary relocation or permanent resettlement, and control of food and water may be necessary.

For early protective actions, the greatest benefit is likely to accrue if action is taken with minimal delay, based on rough predictions of how the accident will develop. For long-term protective actions, there will usually be a rather small radiological health penalty for delaying to obtain accurate measurements for projecting doses. Moreover, the social and economic penalties for imprudent decisions can be high, owing to the long period protective actions may be in effect. It is important that a decision to implement these protective actions is carried out in as informed a manner as possible, using best estimates for the consequences of different options.

Temporary relocation means the organized removal of people for an extended but limited period of time (e.g., several months) to avoid doses from radioactive material deposited on the ground, including resuspended materials, and in some cases from local food or water. People typically would be housed in temporary accommodation of a reasonable minimum standard of comfort and privacy. The generic intervention levels for initiating and terminating temporary relocation are 30 mSv in a month and 10 mSv in a month, respectively; i.e., people should be temporarily relocated if the dose avertable over the next month is expected to be greater than 30 mSv. They may return when the avertable dose falls below 10 mSv in a month. However, if the dose accumulated in a month is not expected to fall below this level within a period of a year or two, the population should be permanently resettled. Two levels are specified because there are relatively high penalties for initiating relocation compared to maintaining it. It is also necessary to specify the period of time it is reasonable to live in temporary housing.

Permanent resettlement means complete removal of people from the area with no expectation of return for at least several years. People typically would be resettled in accommodations comparable to those vacated. This may involve construction of new housing and infrastructure. The generic intervention levels for permanent resettlement are 1 Sv in a lifetime or a dose exceeding 10 mSv per month that persists beyond one or two years (i.e., that does not permit return from temporary relocation within one or two years). It should be recognized that projected doses below the intervention levels for evacuation or for terminating temporary relocation could also, over a lifetime, become high enough (i..e., exceed 1 Sv) to warrant permanent resettlement.

Control of food and water may have to be considered under three different circumstances: where alternative supplies are available; where alternative supplies are scarce; and for distribution in international trade. Generic action levels have been established for use by national authorities when alternative supplies of food are available. *(See table.)* The values depend upon the type of foodstuff and the type of contaminating radionuclide. The radionuclides in question are those most likely to be of concern in foods following an accident.

In situations where extensive restrictions on food supplies could result in nutritional deficiencies or, in the extreme, starvation, case-by-case evaluations will be required. In most such situations relocation will be indicated, and alternative food made available. However, when this is not possible, the radiation hazard must be considered realistically in comparison to competing health hazards, and higher action levels should invariably be adopted.

Following any event that may contaminate foodstuffs, a variety of countermeasures may be instituted at various stages in production and marketing. These should be implemented to ensure that, to the maximum extent practicable, foodstuffs are maintained below the action levels. The generic action levels for foodstuffs will also satisfy the requirements for distribution of foodstuffs in international trade for consumption in countries unaffected by an accident. ❐