AN OVERVIEW OF RADIATION EMERGENCIES: INTERNATIONAL PERSPECTIVE

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The catastrophe at the Chernobyl nuclear power plant at 01.23:47 on April 26, 1986 made it obvious that conventional emergency planning has serious shortcomings. An accident in the USSR caused radioactive contamination over most of Europe, triggering remedial actions for which the responsible authorities were utterly unprepared.

Although I have been asked to give an international perspective to emergency planning, I shall concentrate on the situation in Sweden, which is what I have been asked to do.

HISTORY

Earlier reactor accidents, such as the NRX accident at Chalk River in 1952 and the relatively minor accident at the Idaho Testing Station in 1956, did not cause any widespread environmental threat. Consequently, the early emergency planning was mainly to remedy the on-site plant situation. Therefore, at the first Atoms for Peace conference in Geneva in 1955, H.M. Parker and J.W. Healy received attention for reviewing the possible effects of a major reactor disaster when they mentioned lethal injuries up to distances of several tens of kilometers. Similar estimates were presented in the first major consequence assessment--the Brookhaven report "WASH-740" in 1957--where simple remedial actions, such as staying indoors, were mentioned and the importance of training local emergency teams was stressed.

It was the accident in the British plutonium-producing reactor, Nr. 1, at Windscale in 1957 that demonstrated the need for emergency planning to protect the public. Large areas of land were affected and it was necessary to discard milk contaminated with radioactive iodine for an area of approximately 500 km^2. Following this accident, the British Medical Research Council recommended action levels for evacuation and for the discarding of milk; these recommendations formed the basis for adoption of similar action levels in other countries.

In Sweden in 1962 a special law was passed requiring emergency plans in counties with nuclear power stations. Because it was considered impossible to base immediate actions on anything but checklists for preplanned actions, the early phase of an accident received the most attention. Most important were to establish a clear line of command for quick decisions, to train local emergency teams, to provide an

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organization for expert advice during the emergency, and to establish action levels for evacuation, distribution of iodine pills, and discarding contaminated milk.

This attitude was fairly similar in most European countries; however, the views on the need for medical preparedness differed somewhat. In some countries, this need was seen as a major element, while in other countries it was considered relatively unimportant.

International organizations interested in radiation protection also issued reports and recommendations on emergency planning: the World Health Organization (WHO) in 1965 and 1984, the International Commission on Radiological Protection (ICRP) in 1984, the International Atomic Energy Agency (IAEA) in 1979, 1981, and 1985, and the Commission of the European Communities in 1982. Some of the recommendations were influenced by the Three Mile Island accident in 1979, the first major emergency in a commercial nuclear power plant. This accident had severe consequences for nuclear power programs in many countries. In Sweden, for example, a public referendum caused the Swedish parliament to decide to stop all nuclear power production by the year 2010. It also led to the revision, updating, and expansion of emergency planning programs in many countries, including Sweden.

EXPOSURE PATHWAYS

After accidental release of radioactive substances, the public may be exposed through the following routes: (1) externally by gamma radiation from the passing radioactive cloud; (2) internally after inhalation of radioactive substances in the passing radioactive cloud; (3) externally mainly by gamma radiation from deposits of radioactive substances that remain on the ground; and (4) internally from radioactive substances ingested with contaminated food.

Early emergency plans were designed primarily to reduce exposure from the radioactive cloud, recognizing that there might not be time for evacuation within the distances where that exposure could cause acute harm. In addition, it was felt that evacuation to avoid exposure from the cloud may not be wise if the extent and movement of the cloud are not fully known. The main remedial actions envisaged, therefore, were for the public to stay indoors, to reduce ventilation, and, if practicable, to take stable iodine. Preparedness meant implementation of preconceived action plans once the conditions for alarm were met.

It became slowly recognized that, except for preplanned automatic evacuation of persons in the vicinity of the nuclear power plant, evacuation would only be justified if dangerous ground deposition of radioactive material was observed or expected. Thus, rapid monitoring and communication of measurement results were essential.

It was quite clear after the Windscale accident that contamination of agricultural land would pose a problem in later phases of a nuclear release and that radioactive iodine would be transferred to the milk of grazing cattle. However, this was generally seen as a temporary threat with one obvious course of action, namely, to discard the contaminated milk. Action levels for this eventuality were included in most emergency plans. Long-term food contamination with long-lived radionuclides, such as strontium-90 and cesium-137, was expected, but the likelihood of a major catastrophe that would make such contamination serious was believed too small to justify more detailed planning.

ACTION LEVELS

The basic principles for remedial actions have been discussed by IAEA, ICRP, and WHO. The primary one is that the remedial action must improve the situation for those at risk. Therefore, the justifiable dose-avoidance by implementing a remedial action, the "primary action level," depends on the risks and other negative consequences of the action. It follows that one should never set an action level without referring to the type of action envisaged. It also follows that the internationally recommended dose limits for normal operations are irrelevant for accidental situations. Some measures to avoid severely harmful doses may themselves involve risks, while other measures are so free of negative consequences that they may be worth adopting even though the radiation dose is far below the normal dose limits. In Sweden and many other countries, primary action levels for various countermeasures have been chosen in accordance with recommendations of ICRP that appear in its publication 40.

Since even one and the same type of action may cause different outcomes under different circumstances, ICRP has recommended ranges of action levels; an action would rarely be considered if the potential dose were lower than the lowest value in each range but it would be taken always to avoid doses higher than the highest value. In the early phase, ICRP recommends the following:

5-50 mSv*: sheltering and administration of stable iodine

50-500 mSv: evacuation

ICRP has also warned about the recently recognized risk of mental retardation among children who are exposed in utero during the eighth to fifteenth weeks of pregnancy; the risk factor may be as high as 40% per Sv, making it advisable to be particularly cautious with regard to pregnant women.

For control of foodstuffs, ICRP recommends avoiding doses of 5 to 50 mSv during the first year after the exposure if there is "little penalty in not distributing fresh food, including milk." Obviously,

*All doses mentioned are effective dose equivalents, not organ doses.

if all food is contaminated and no other food is available, it is preferable to receive a dose higher than 50mSv rather than starve.

After a primary action level has been established, it is necessary to calculate a derived action level. For internal exposure to radionuclides ingested with food, dose factors (effective dose equivalent per unit of activity ingested in, eg, nSv/Bq) can be calculated. Thus, a derived action level for annual intake may be calculated for each significant radionuclide. If more than one radionuclide is expected to contribute significantly to the total dose, the action criterion is:

$$I_1/A_1 + I_2/A_2 + I_3/A_3 + \ldots \text{ greater than} \geqq 1$$

where I_i denotes the intake of nuclide i to avoid by remedial action and A_i denotes the action level for nuclide i in the absence of other radionuclides.

From a derived action level for annual intake, the corresponding derived action levels for activity concentration in various foodstuffs may be calculated based on estimations of consumed quantities. In practice, the annual intake may be controlled by limiting the activity concentration in the dominating base foods. High activity concentrations in foods consumed in small quantities are usually of little significance because these foods will not contribute significantly to the total annual activity intake.

THE SWEDISH EXPERIENCE

Pre-Chernobyl Emergency Plans: The Swedish emergency plans were revised after the TMI accident. Until TMI, the emphasis was on local preparedness and availability of centrally organized expert advice. The law on emergency planning in 1962 made the local county administration in the five counties where nuclear reactors existed fully responsible. The revision identified a number of weak points, the most important of which were that the alarm systems were not sufficiently effective; monitoring equipment and procedures needed to be improved; communication systems between power stations, local authorities, and central authorities were not acceptable; evacuation plans were too limited; and education and training were needed for local authorities, medical personnel, and persons involved in evacuation activities.

Communication and education were regarded as the weakest points. For instance, because the regular telephone network might not function effectively after a major accident, special communication links were established. In addition, a major education and training program was initiated.

The definition of command was still a major point of consideration, and the immediate responsibility remained within the local county administrations. Central authorities, such as the

Nuclear Power Inspectorate (SKI) and the Institute of Radiation Protection (SSI), were mainly advisory. It was also considered important that all official information to the mass media should come from one single source, ie, the local county administration.

Special zones were established around the nuclear power stations. Within a central alarm zone, a siren alarm was provided for the public. For an inner emergency zone to a radius of 12 to 15 km, evacuation plans were prepared and packages of iodine pills (20 pills of 0.2 g potassium iodide) were distributed to about 30,000 households. An extra supply of five million pills was available for distribution at longer distances after an accident. Procedures for measuring deposition activity were established for an outer zone of up to 50 km.

Little was said about agriculture and food, because priority was given to the early phase. Medical emergency planning was not considered important, because it was hard to imagine that the public could ever receive radiation doses calling for medical attention. However, it was considered important to inform and educate medical personnel at nearby hospitals (1) to handle correctly plant workers injured by radiation, and (2) to avoid rejecting patients because of personnel ignorance and exaggerated fear of radiation contamination.

Reaction to the Chernobyl Emergency: Embarrasingly enough, none of the monitoring stations of either the SSI or the National Defence Research Institute was first to detect the radioactive contamination from the Chernobyl cloud. The contamination was registered by the automatic measuring devices, but the readings were not taken daily and particularly not over a weekend. In fact, the issue of whether the 24 stations of SSI were really needed in the future was being discussed just prior to the Chernobyl release. The contamination was first detected on Monday morning, April 28, at the Forsmark nuclear power station north of Stockholm during the routine control of personnel contamination.

After some initial confusion and before it could be ascertained that the contamination did not come from the Forsmark plant, it became obvious that the origin was from abroad. The relative proportions of various fission products indicated that the activity arose from a reactor release, and meteorologic plume assessments located the accident within the USSR.

It was early spring in Sweden and there was still snow in the north. Most cattle remained in cowsheds and, except in the south, there was little vegetation that could be directly contaminated. The immediate concern was the possible contamination of milk with radioactive iodine. Farmers were, therefore, told to keep milk-producing cattle indoors.

It was soon found that exposure rates above ground were surprisingly high in some regions north of Stockholm. In the region of Gävle, about 150 km north of Stockholm, some initial exposure rates approached one milliroentgen per hour. An area of approximately 400 km^2 had initial exposure rates exceeding 0.2 mR/h, while an area of about 50,000 km^2 had exposure rates from the ground that were more than five times the normal rates. The high activity deposition was caused by rainfall at the time when the radioactive cloud from Chernobyl arrived. Other areas of Sweden where the cloud had passed showed little activity deposition because of lack of rain. Other areas with relatively high deposits due to rainfall were near Munich and parts of Scotland. In some areas of Poland, however, exposure rates were as high as in Sweden, although there had been no rain.

Keeping cattle indoors for weeks is not an easy task and the authorities were faced with a problem of unexpected magnitude, which increased when the proportion of cesium-137 was found to be surprisingly high. The USSR report to the IAEA in August made it clear that the cloud that reached Sweden was from the emission on the first day of the accident; the violent explosion, but relatively low core temperature, produced mainly noble gases and volatile tellurium, iodine, and cesium of high activities. All other fission products, as well as the actinides, were thrown out as fragments of the core and were not easily transported over long distances. It is estimated that the strontium-90/cesium-137 activity ratio in the first day's emission was about 5%; by the time the cloud reached Sweden, the ratio was about 1%. Strontium-90, therefore, did not contribute significantly to the radiation exposure in Sweden, but larger proportions of strontium were released in the later phase of the accident at the beginning in May. At that time, however, the prevailing winds were east and south.

The situation in Sweden, as in other European countries outside the USSR, was not covered by emergency plans. There was no accident site within the country and, therefore, no local authority responsible for remedial action. Nevertheless, the central authorities, such as the SSI, SKI, the Food Administration, and the Medical Board, had to deal with the immediate situation. The SSI group that was trained for analyzing emergency situations established contacts with SKI and the Defence Research Institute. The company of Sveriges Geologiska AB, which was equipped for uranium prospecting by airplane, offered to map the activity deposition commencing on Friday, May 2.

The most urgent task was to find areas where milk-producing cattle could be released to the fields. Therefore, the measurements were first made in the south and proceeded northward. At the same time, action levels were established for the new situation. In Sweden, the lowest value in the ICRP range (5 mSv) was chosen as the action level for restricting the sale of contaminated food.

Both cesium-134 and cesium-137 were present at an activity ratio of 0.6:1.0; thus, a 5 mSv action level would correspond to an annual intake of 200,000 Bq cesium-137, or an average rate of about 500 Bq per day. The Swedish authorities decided that an appropriate level for rejecting food on the market would be 300 Bq/kg. This figure was slightly different from the one adopted by the Commission of the European communities (CEC), ie, 370 Bq/L for cesium-134 plus cesium-137 in milk, 600 Bq/kg for meat and vegetables. The CEC numbers, if expressed for cesium-137 alone, corresponded to about 250 Bq/L of milk and 400 Bq/kg of meat and vegetables.

In order to ascertain that dairy milk would not exceed 300 Bq/L, the Swedish authorities requested farmers in the most contaminated regions to keep milk-producing cattle indoors about six weeks. Fortunately, the vegetation was so late that contamination by direct deposit was not a severe problem. In the first year, the cesium uptake from soil through plant roots is usually negligible in comparison with the direct deposit on the vegetation. However, some berries and mushrooms showed relatively high concentrations.

The highest activity concentrations in food had other explanations. Moose and reindeer in the most contaminated areas had very high cesium concentrations, because they graze on very meager vegetation; reindeer in particular feed on lichens, which effectively trap any material deposited on them. Also, predatory freshwater fish showed very high cesium concentrations. The radioactive contamination was tragic for the reindeer-breeding Laplanders and threatened their whole livelihood and hence culture and traditions.

The collective dose from Chernobyl outside the USSR is being assessed by UNSCEAR and, as yet, there are no reliable estimates. In Sweden alone, it may be approximately 10,000 man Sv. The highest annual dose from external radiation the first year may be a few mSv and over a lifetime perhaps 50 mSv. Food restrictions will limit the annual dose from contaminated food to much less than 5 mSv except for Laplanders or moose hunters who may eat considerable quantities of meat with cesium-137 concentrations of 1,000 to 10,000 Bq/kg.

Sweden's costs for emergency actions, measurements, public information measures, compensation for rejected food, compensation for increased fodder costs for stalled cattle, and potassium added to soil etc. is approximately $100,000,000 (U.S.). There may be a few hundred extra cases of cancer in Sweden alone, which, however, will be hidden by the random fluctuations in the normal cancer rate.

LESSONS LEARNED

Nuclear catastrophes clearly respect no borders. Conventional emergency planning for an accident within a country is not sufficient when widespread contamination arrives from outside the country. The lines of decision and control are different and many authorities become involved who usually are not informed and trained to meet the situation.

Communications are, therefore, vastly more complex than in the conventional situation; in Sweden, many county authorities obtained their information from the mass media before they heard from those in command. One consequence of this experience is that education and training of public health personnel at both county and local levels is now recognized as important.

It is difficult to say whether an early warning from the USSR would have prompted the Swedish authorities to advise people in the areas most affected to stay indoors, but the authorities would have been better prepared and would have had more time to react. The IAEA "Convention on Early Notification of a Nuclear Accident" is, therefore, an important initiative.

The information problem has been dangerously underestimated; direct contacts with mass media and the public were a heavy burden to those directly engaged in the emergency operations. These contacts could not be delegated without loss of information and apparent contradictions. Somewhat surprisingly, the situation was less difficult the first week, when all information from the authorities was newsworthy and was propagated quickly and word-for-word by all mass media. Later, however, the message from the authorities had lost much of its news value; reporters looked elsewhere and favored other sources of news, looking for critical or contrasting statements by persons not directly involved in the operations. This is when the authorities had severe difficulties in getting their information to the public.

The credibility aspect of the information problem was particularly difficult. Here was a situation where, according to normal standards, the risk to all involved was very small. In line with the usual high ambitions of radiation safety, however, remedial actions and food restrictions were initiated. These actions caused concern, as many persons were frightened beyond reason. Statements from the authorities, intended to reassure, often had the opposite effect and caused suspicion, although one study indicated that the majority of the public had more confidence in the protection authorities than in the mass media.

Several mistakes were made in the way in which the action levels for food rejection were presented. The first mistake was to call them "limits" rather than action levels. The second mistake was to put the emphasis on the activity concentration rather than on the total activity intake. A concentration "limit" was perceived as a borderline between absolute safety and impending danger, and the action level of 300 Bq/kg was seen as the objective rather than as a means of keeping radiation doses low.

A further mistake was to apply the action level indiscriminately to all foods, regardless of the quantities consumed. This had severe and unjustified consequences for moose and reindeer meat. In Sweden, more than 100,000 moose are shot during the hunting season each year. After the Chernobyl accident, many animals with cesium-137 concentrations only marginally higher than 300 Bq/kg were buried in the ground or blown up with dynamite when the ground was frozen. In order to maintain a stable population, reindeer must be slaughtered in similar numbers each year; because of the radioactive contamination, the meat had to be sent to mink farms as animal food.

Although international recommendations on action levels existed before the Chernobyl accident, derived action levels were not established. Basic information on dose factors for different age groups had to be collected in a rush and the risk of mistakes was great. The principles for applying action levels had not been much discussed in advance. There were unnecessary differences in approach and numbers in different countries.

A special investigator was appointed to look into the actions of the various authorities after the accident and to advise on improvements. He concluded that only the competence and the experience of the people involved in decision-making made it possible to handle the situation reasonably in spite of the lack of planning for this type of emergency.

Sweden, like many other countries, was lucky that the accident did not happen later in the grazing season and that the rain-out of radioactive material from the cloud did not occur over the main agricultural areas; otherwise, the consequences would have been much worse.