Post-Emergency Response: Health Physics Considerations

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INTRODUCTION

The health physics response to radiation accidents that involve only a few people are easily manageable; however, when many persons have been actually or potentially exposed, the majority of resources allocated to recovery operations may well be involved in one or another aspects of health physics. The goal of health physics operations will be to determine and control the radiation exposure of affected persons, and the decisions made will be based on determination of: 1) the geographical extent and magnitude of radioactive contamination of the environment, 2) the resulting external radiation dose rates to resident or responding persons, and 3) the external and internal contamination levels of exposed persons. Each of these tasks will require numerous measurements, whose sophistication and interpretation will be greatly affected by the particular radioactive materials involved. During the early post-emergency phase, the measurement results may be used to determine the need for evacuation, sheltering in place, importation of uncontaminated food and drinking water, treatment for internal or external exposure, and radiological safety constraints for responders. Later in the post-emergency phase, the measurements may be used to determine the need for decontamination, and to verify that decontamination goals have been achieved. Finally, the measurements may be used to reconstruct radiation doses to the exposed populations, thereby providing the "dose" component of the dose-response function for epidemiologic studies, and no doubt the basis for compensation for real or perceived harm to the exposed populations.

DISCUSSION

Well-established procedures exist for environmental monitoring of external (penetrating) radiation levels; the instrumentation is relatively simple, easy to operate, and provides instant read-out. Guidance on selecting instrumentation for post-emergency monitoring has been published, based on the experience gained in the Goiania accident (Becker et al., 1991.) The main problem lies in compiling the data into a usable form for decision-makers. Normally, dose rate or integrated dose contours are generated on standard regional maps. Measurements of radioactive contamination in or on environmental samples (air, water, soil, foliage, foodstuffs, exposed surfaces, etc.) are also reasonably straight forward, but may be more-or-less complex depending on the exact radionuclide involved. Gamma-ray emitters such as Cs-137 or Co-60 require minimal sample preparation; however, the detectors used may require extensive shielding, may need to be operated at liquid nitrogen temperature, and typically involve a computerized analysis of the data collected. Pure beta emitters, such as Sr-90, and especially low-energy beta emitters such as tritium (H-3), require careful sample preparation, usually including chemical separation, and more complicated detection procedures, such as liquid scintillation counting. Finally, alpha emitters such as Pu-239, are the most difficult to detect, normally involving extensive wet chemistry and sophisticated alpha spectrometers to determine their levels. In a reactor accident or weapon detonation, easily measured radionuclides such as Cs-137 normally serve as markers for the entire inventory of radioactive materials released; however, in dispersal of only one or a few radionuclides, such as a weapons accident with detonation of the conventional explosives, but no nuclear yield, only limited "marker" radionuclides are available (e.g., Am-241, which emits a low-energy (60 keV) gamma ray, may be used as a marker for Pu-239.)

Environmental measurements are still rather simple compared to measurements of radioactivity on or in exposed persons. External contamination monitoring requires about ten minutes to do a thorough survey, or "frisk" of a single person by an experienced technician; as the numbers of people to be surveyed mount, the time required quickly becomes unacceptably long. Every person will want to be measured as soon as possible, because of the extensive fear of radiation that permeates the general public. An initial triage of persons by likelihood of exposure is required, but very often, security personnel will be required to provide crowd control. As an example, after the Goiania accident in Brazil, persons who lived adjacent to the accident scene were told to report to the town's Olympic stadium for contamination monitoring, and 112,800 people presented. Of these, 129 were found to be contaminated on their clothes or shoes only, and another 129 were found to be contaminated on their skin or internally. Of the latter, 21 required hospitalization. (Rosenthal et. al., 1991.) Fortunately, the radionuclide involved, Cs-137, is easy to detect.

Determination of internally deposited radioactivity in exposed persons is the most complex set of measurements to be performed in the post-emergency period. Although it can be argued that persons who are found not to be contaminated externally are unlikely to be contaminated internally, such a triage method may or may not be acceptable to the population involved. In addition, external contamination with tritium is very difficult to detect with survey instruments, and in such a case, there may be few ways to determine the likelihood of internal contamination other than by place of residence or work versus environmental monitoring results. Again, gamma-emitters are relatively easy to detect, and normally whole-body counters (mobile, unless a fixed facility is nearby) are used for the measurements. In Goiania, more than 300 persons, ranging in age from a few months to 72 years, received whole-body counts; some were so contaminated that special arrangements to reduce analyzer dead time were required (Oliveira et al., 1991.) After the accident at Three Mile Island, 760 persons, both plant workers and local residents, were counted with a single mobile whole-body counter over a period of eight days (ten minutes per count, 24 hours per day), and the measurement program was terminated when no radionuclides attributable to the accident were found in this population (Berger, 1981.) Following the Chernobyl accident, a total of 119,306 children were measured for Cs-137 content at five fixed facilities located in the Bryansk, Kiev, Zhitomir, Gomel, and Mogilev regions from May 1991 to April 1996; Cs-137 was used as a marker for the radioiodines released in the accident, and the resulting dosimetry information was used to determine the risk factor for thyroid cancer (Sharifov et al., 1997.) Another series of whole-body counts was performed on residents of the Rovno oblast of the Ukraine, not so much to determine individual intakes and doses, but to validate a mathematical model for environmental exposures and intakes through the food chain, that would be widely applied to the exposed population. (Likhtarev et al., 1996.) Other countries have prepared mobile whole-body counting facilities specifically for use in the post-emergency environment. For example, the French have prepared a railroad car with twenty whole-body counting stations, that can easily be deployed to the vicinity of an accident; no such capability exists in the United States.

In an accident involving primarily alpha (e.g., Pu-239) or beta (e.g., tritium) emitters, whole-body counting is either inappropriate or has inadequate sensitivity to be used, and measurements of radioactivity in excreta must be employed. Although the analytical methods used are essentially identical to those used for radioactivity in environmental media, the logistics of sample collection are much more complicated. Urine samples are relatively easy to collect, and most people have had the experience of providing a urine sample as part of a physical examination; however, for accurate dose assessment, a twenty-four sample is preferred, and for low-levels of intake, a sizable sample (one liter or more) may be required. Urinalysis is of course limited to soluble radionuclides that may be excreted in urine; in the case of inhalation or ingestion of insoluble compounds, such as the oxides of plutonium, fecal sample collection and analysis may be the only reliable means of detecting intakes. Most people are reluctant to provide fecal samples, although collection kits are readily available from medical supply firms. The logistical problems involved with urine samples, such as provision of containers, recovery of samples, and sample storage pending analysis are magnified in the case of fecal samples.

Once the data have been collected, the dose assessment can be performed, either for individuals from bioassay measurements, or for populations from environmental measurements. Standard biokinetic models have been published by the International Commission on Radiation Protection (ICRP Publications 30 and 54) and by the U.S. Nuclear Regulatory Commission (NUREG/CR-4884) that can be used to relate the results of a bioassay measurement to the intake of a radionuclide, if the time between the intake and the excreta collection or whole-body count is known. Similarly, standard models of environmental transport and pathway analysis are available to estimate population intakes based on the concentrations of radioactivity measured in environmental samples. Once the intakes have been determined, dose coefficients published by the U.S. Environmental Protection Agency for adults (Federal Guidance Report 11), and by the International Atomic Energy Agency for all ages (Basic Safety Standards, Safety Series No. 115) may be applied to calculate the resulting radiation doses. However, the estimation of the dose to a particular individual from environmental pathway analysis is particularly uncertain, and may be of little use for epidemiological studies attempting to determine dose-response functions.

CONCLUSION

The final health physics consideration in the post-emergency situation may well be the verification survey following decontamination efforts; that is, verifying that contamination levels have in fact been reduced to whatever level has been determined to be the goal of those efforts. Again, the logistical requirements for such efforts may be enormous; in Goiania, some fifty houses were decontaminated after the accident (some by complete removal), and the top 1.5 cm of soil were removed for distances of up to 100 m from the most contaminated sites (da Silva et al., 1991; Amaral et al., 1991), generating thousands of cubic meters of waste, all of which required monitoring.

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Session G, Track 2: Protective Actions

Friday, September 11, 1998
10:10 a.m. - 12:00 p.m.

Chair: Dorothy Meyerhof, Health Canada

The German Guide for Selecting Protection Measures

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INTRODUCTION

After the accident in the Chernobyl Nuclear Power Plant, many countries were first forced to perform ad-hoc countermeasures as well as to impose criteria and reference values with regard to the effects of the accident. Without detailed knowledge of the accident course, they had to estimate the radiological situation, to recommend protection measures and to inform and reassure the public. Different assessments of measured data resulted in considerable confusion, contradictory recommendations on how to behave put the public in a state of unnecessary uncertainty. Taking into account the experiences made and the recognized insufficiencies, the emergency plannings were checked worldwide, with the objective to be better prepared for the various types of radiological accidents - like accidents with contaminations over large areas, but also transport and satellite accidents.

Finally, the basis was created for an improved co-operation in the case of an incident/accident and the scientific and technical basis for a more efficient emergency planning and preparation through the intensive efforts of the responsible organizations.

DISCUSSION

The experiences with the radiological effects of the Chernobyl accident triggered off a corresponding evaluation also in the Federal Republic of Germany. Among other things, this led to new legal regulations, in order to be able to act rapidly and appropriately in the case of an event with considerable radiological effects. According to the Radiation Protection Ordinance (Strahlenschutzverordnung, StrlSchV) [1], all necessary countermeasures have to be initiated in the case of incidents/accidents so that hazards to life, health and material goods are reduced to the minimum. According to the Precautionary Radiation Protection Act (Strahlenschutzvorsorgegesetz, StrVG) [2], in order to protect the population, radioactivity in the environment has to be monitored and, in the case of events with possible considerable radiological effects, has to be kept as low as possible, taking into account the state-of-the-art of science and technology and all circumstances.

Considering these objectives, a strategy of measures has been developed for the implementation of §§ 6, 7, 8, 9 StrVG which authorizes the Federal ministries - on the basis of the data compiled according to §§ 2, 3 StrVG and summarized by the Integrated Measuring and Information System (IMIS) for the monitoring of environmental radioactivity - to demand or, respectively, recommend together with the competent highest Federal State authorities certain modes of behaviour. As a guide for this strategy, the Catalogue of Countermeasures ("Survey of measures designed to reduce the radiation exposure after events of considerable radiological consequences") was elaborated.

In addition to the radiation protection precaution measures, the Catalogue of Countermeasures contains disaster measures like evacuation, for which the Federal states are competent. Intervention levels for precautionary measures are lower than those for disaster countermeasures.

The Catalogue should be a guide for experts from competent governmental and State authorities as well as persons belonging to the respective advisory and supporting panels, which have to make the assessment and evaluation in the case of a nuclear event with radiological consequences off-site.

The first version of the Catalogue was submitted in the summer of 1992 [3]. It is currently being revised. A new and more synoptical version is expected and will probably be published by the end of this year.

Content of the Catalogue of Countermeasures

The compilation of measures in the Catalogue is based on a literature analysis. The measures are arranged regarding the time phases of an accident (pre-release, release and late phase). For each measure, the effectiveness, the operational intervention level (OIL) and problems that may arise during the application of the measure are mentioned.

When using the Catalogue, it must in principle be presumed that not all measures will apply to all situations. Still, an attempt was made to provide a comprehensive overview as a basis for possible argumentation if, for example, a specific measure should not be initiated on account of its low effectiveness.

The main criterion for initiating and executing a protective measure is the radiation dose expected to be received from each of the considered pathways (external radiation, internal radiation after inhalation or ingestion). Since radiation dose is generally not measurable directly, directly measurable quantities (the OIL's) like the time-integrated concentration in air, soil contamination, etc. are used for decision-making.

To calculate OIL's, models must be used which include, (e. g., the circumstances of the release due to the condition of the nuclear installation) the dispersion of radioactive substances in the atmosphere, the radioecology as well as the incorporation-related metabolism of the radioactive substance.

The following OIL's are used:

- released activity in Bq,
- time-integrated air concentration in Bq•h/m^3,
- ground contamination in Bq/m^2,
- surface contamination in Bq/m^2,
- specific activity in Bq/kg or Bq/l,
- gamma dose rate in mSv/h.

Structure of the revised Catalogue

The revised Catalogue will consist of two parts. The first part, in form of diagrams and tables, will allow for short-term decisions on initiating precautionary measures on the basis of available data. It includes:

Introduction

This section represents information required for the understanding of the objective and directions of the Catalogue.

Chapter 1: Foundations and structure of the Catalogue

This chapter contains explanations for the used designations, the general conditions, the structure and use of the Catalogue.

Chapter 2: Orientation diagrams and tables

The orientation diagrams in this chapter serve as a guide for the use of orientation tables, including criteria for the selection of required measures. On the basis of actual available information, (e.g. measured or prognosticated data on the time-integrated air concentration of specific nuclides), the table of relevance for these data can be determined from this chapter and identified from a model. For each countermeasure, the table refers to relevant additional information and data contained in other chapters of the Catalogue.

Chapter 3: Nomograms

This chapter contains additional information about the radiological situation in the form of nomograms for dose estimation. With the help of nomograms a quick dose estimation based on the time-integrated concentration in air or the surface contamination is possible.

Chapters 4 to 6: Compilation of commentaries on all countermeasures

Based on each area where countermeasures apply, the compilation is divided into respective focal points:

- disaster measures (chapter 4),
- precautionary radiological protection measures (chapter 5),
- measures in the agricultural and feeding area (chapter 6).

The text and tables summarize important information on countermeasures, particularly emphasizing on preconditions, feasibility, effectiveness, advantages, and disadvantages.

Chapter 7: Combination of data , information and documents

This chapter contains additional information which may be helpful for the work with the Catalogue. Among others, it includes data on nuclear power plants in Europe, tables referring to the nuclear inventory and the International Nuclear Event Scale.

Chapter 8: Example of use

The example serves to explain the work with the Catalogue in several time phases of an accident.

Appendix: Theoretical foundation

The appendix, the second part of the Catalogue, contains a summary of the theoretical principles and the most important equations used for the calculation of OIL's in the Catalogue. It provides the background for a more detailed familiarization with the Catalogue.

Limits of the Catalogue

In consequence of the manual-like character of the Catalogue, its universality is considerably limited compared to computer programs:

- For pre-calculation, it is necessary to establish specific model parameters. Under certain circumstances, such model parameters must be changed, if this should result in a better estimation of the actual accident situation.

- By a computer program essential quantities like contamination and radiation exposure can be determined by one process for all involved sites and points of time. With a manual, however, these quantities can be determined for only one site at a time and one point of time. Therefore, it is essential to gain first an overview of the sites and points of time for which estimations are to be prepared from measurement results.

- A particularly important restriction applies to the intervention level (IL). In the Catalogue, the dose corresponding with the IL is assumed to be fully exhausted by one exposure pathway. In practice, however, it must be assumed that next to one pathway there may also be others that play a more or less important role. Accordingly, the OIL which corresponds with the respective IL is generally too high. Nevertheless, this approach seems to be justified by the fact that the OIL is calculated based on the lower IL of the ICRP bandwidth concept. In addition, the proportions of the various exposure pathways contributing to the total exposure by one single nuclide may be determined by prepared nomograms.

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Protective Action Guidance For Nuclear Emergencies In Canada

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INTRODUCTION

In Canada, approximately 15% of the electricity generated is produced using nuclear reactors. The process for dealing with nuclear emergencies is essentially similar to that in the United States. The operators of nuclear generating stations, research reactors or other nuclear facilities are responsible for *on-site* emergency planning, preparedness and response. The provincial governments, like the states in the United States, have the primary responsibility for protecting public health and safety, property and the environment within their borders. The role of the Federal government is to develop, control and regulate the peaceful uses of nuclear energy, manage nuclear liability, and coordinate support to the provinces in their response to a nuclear emergency. The Federal government is also responsible for liaison with the international community.

Health Canada is the lead Federal department for planning and execution of the Federal Nuclear Emergency Plan[1]. This plan, recently revised, is intended to establish and organize a coordinated response by the Federal departments and agencies during a nuclear emergency in Canada or abroad. This Department also participates in a Joint Canada-United States Radiological Emergency Response Plan.

The Protective Action Guides (PAGs), or Protective Action Levels (PALs), are pre-specified levels of radiation dose that would justify the introduction of countermeasures to protect health and safety, property and the environment. These include sheltering, iodine prophylaxis and evacuation in the early phases of an accident, and relocation and food controls in later phases. All three Canadian provinces with operating nuclear power plants have their own protective action guides with specified radiation dose levels. However, there remains a need for a set of PAGs at the Federal level in order to coordinate the response to radioactivity that may cross provincial or national boundaries. Furthermore, it is recognized that countermeasures could also be introduced in response to the status of a damaged nuclear facility, without reference to explicit dose criteria.

DISCUSSION

In order to establish Federal PAGs, it was decided to review the international guidance on the subject. The ICRP-40 (1984)[2] recommended three basic tenets of radiation protection for planning purposes, viz., dose limitation, justification and optimization. This document also proposed projected upper and lower dose levels for different countermeasures as summarized in Table 1 which also contains doses from other agencies. The IAEA Safety Series No. 72 (1985)[3] introduced the concept of Derived Intervention Levels (DILs) (i.e., a dose rate or Becquerel concentration of activity that would correspond to a prescribed dose level for intervention). No numerical values for DILs were cited.

The ICRP-63 (1993)[4] supersedes the ICRP-40, and introduces the concept of dose averted (i.e., a dose that would be avoided by the introduction of countermeasures (Table 1)). At the time of an emergency, the actual intervention levels will be based on accident-specific parameters. The IAEA Safety Series No. 109 (1994)[5] was prepared as a revision of Safety Series No. 72. It incorporates the latest recommendations from ICRP-60 and ICRP-63. Safety Series No. 109 abandons the concept of a range of doses between upper and lower limits, and instead recommends single numerical values, called *generic* intervention levels, for the various countermeasures. Each generic intervention level is based on an optimization procedure for a generic accident scenario. When details of a specific accident become available, it will then be possible to carry out a further optimization to obtain *specific* intervention levels. The generic intervention dose levels are summarized in Table 1.

The protective action guidelines operative in the United States are most relevant to Canadian conditions because of the Canada-United States Joint Radiological Emergency Response Plan (1996).[6] At the U.S. Federal level, the Nuclear Regulatory Commission is responsible for technical advice and coordination among different levels of responsibility centres. The Environmental Protection Agency establishes Protective Action Guides at varied projected dose levels as enunciated in the Manual of Protective Action Guides and Protective Actions for Nuclear Incidents (1992).[7] As in ICRP-40 (1984), this Manual distinguishes between different phases of accidents as follows:

> *Early Phase:* This period refers to the beginning of a nuclear accident when immediate decisions for effective protective actions are required. This phase may last from hours to days.
>
> *Intermediate Phase:* The intermediate phase is the period beginning after the source and releases have been brought under control, and reliable environmental measurements are available for use as a basis for decisions on additional protective actions. This phase may overlap the early and late phases, and may last from weeks to many months.
>
> *Late (Recovery) Phase:* This is the period beginning when recovery action designed to reduce radiation levels in the environment to acceptable levels for unrestricted use are commenced, and ending when all recovery actions have been completed. This period may extend from months to years.

The protective actions recommended in the EPA manual are based on projected doses as shown in Table 1. Based on optimization, dose rates may vary significantly depending upon weather and personal conditions.

The food restrictions were developed by the U.S. Department of Health and Human Services, and Food and Drug Administration in the event of a nuclear incident. The Protective Action Guides for the consumption of contaminated foodstuff are set at an equivalent dose of 5 mSv (500 millirem) for the whole body and at 15 mSv (1.5 rems) to the thyroid; these guidelines are being reviewed at the present time.

All three Canadian provinces with operating nuclear power plants - Ontario, Quebec and New Brunswick - have their own protective action guides with specified radiation dose rates and/or levels. They are essentially based on international guidance and consensus as developed by the ICRP and IAEA.

Health Canada has drafted guidelines for the restriction of radioactivity in food in the event of a nuclear emergency. Presently, these guidelines are being discussed with other Federal agencies and the provinces for adoption. For drinking water, it has been decided that the existing Guidelines for Canadian Drinking Water Quality (1996)[8], meant for non-emergency conditions, be adopted in order to sustain public confidence. These guidelines are based on a lifetime exposure of 0.1 mSv/year; however, this exposure may be raised up to a level of 1 mSv/year during a nuclear emergency, if the conditions warrant. Thus, it appears that the Federal guidelines will be based on 1 mSv/year for each of the three food groups, viz. fresh milk, other foods and water. All the Federal guidelines and PAGs, existent or when developed, will become an integral part of our Federal Nuclear Emergency Plan.

A simplified summary of the Protective Action Guides from all jurisdictions discussed above is presented in Table 1. Some details (e.g., dose rates) have been omitted in order to simplify the comparison. With these considerations, it is remarkable to see the degree of consistency between the PAGs of different agencies. For nearly every countermeasure, the dose levels overlap.

In developing Federal protective action guidance, review of the international literature, including that of the United States, is essentially complete. We have also reviewed our provincial protective action guides. In the near future, we hope to specify projected radiation dose levels for different countermeasures. When completed, the PAGs will be discussed with our regulatory agency, the Atomic Energy Control Board, the provinces and the U.S. Federal agencies before adoption. Nonetheless, it is very likely that our protective action levels are likely to be in the range of those accepted internationally and by our provinces.

Table 1. Summary of Protective Action Guides by various agencies. All entries are expressed in mSv to the whole body except for KI administration, which is expressed as mSv to the thyroid.

Organization	Sheltering	KI Amins.	Evacuation	Relocation	Food Control
ICRP-40	5 - 50	50 - 500	50 - 500	50 - 500	5 - 50
ICRP-63	5 - 50	50 - 500	50 - 500	1000 lifetime	10
IAEA, SS109	10	100	50	1000 lifetime	~5
WHO, Codex					~5
EPA & FDA	5 - 50	250	10 - 50		~5
Health Canada					~3
Ontario	1 - 10	100-1000	10 - 100		~5
New Bruns.		500	50		~5
Quebec	3 per 12 hr	100	50 per 7 days	100-1000 life	2 in 1st year

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