1. Executive Summary

The purpose of this Report is to provide guidance to those who may be called to respond to radionuclide contamination incidents. Such incidents may range from situations in which one or a few persons have received minor contamination while working in research, medical facilities, or industry to those in which large numbers of people are contaminated as a result of accidental or deliberate releases of large quantities of radionuclides. The focus of this Report is on the medical management of individuals exposed to and potentially contaminated with radionuclides in such incidents. Thus, it is directed to persons who would provide medical care and those who would perform radiation-safety functions. This Report is intended as an update and expansion of the National Council on Radiation Protection and Measurements (NCRP) Report No. 65, *Management of Persons Accidentally Contaminated with Radionuclides* (NCRP, 1980).

The primary objective in the management of persons contaminated with radionuclides is to reduce the risk of health effects occurring either early after the contamination incident or later in life. Two types of effects are of concern. One type of effect is harmful tissue reactions, termed *deterministic* effects. Doses large enough (threshold doses) to damage a critical population of cells can result in serious tissue or organ malfunction and possibly death. These effects can occur early after the contamination incident or later in life. A second type is termed *stochastic* effects. Radiation damage to cellular deoxyribonucleic acid (DNA) can lead to the expression of cancer later in life and to heritable effects in offspring. Radiation-induced cancer has been observed to occur in humans as well as in experimental animals. Although they have not been observed in humans, the potential for radiation-induced heritable effects is a concern because they have occurred in experimental animals.

Heritable effects and cancer are not unique to radiation. According to the American Cancer Society (ACS, 2008), about one in three persons will be diagnosed with cancer in their lifetimes and one in four persons will die of cancer. The risk of radiation-induced lethal cancer is relatively low, ~5.5 % Sv^{-1} (100 rem) (ICRP, 2007). The total effective dose for persons in the United States in 2006 was estimated to be 6.2 mSv (620 mrem) (NCRP, 2009). In a population of >105,000 survivors of the atomic bombs in Japan, after 50 y, only

853 of nearly 17,000 cancers were attributable to radiation exposures which ranged from 0.005 to 4 Gy (0.5 to 400 rad) (Preston *et al*., 2007).

This Report is intended to provide guidance and recommendations to medical and radiation-safety personnel for reducing external and internal radionuclide contamination levels and thus the risks of radiation-induced health effects. The risk of deterministic effects can be reduced by controlling radiation doses to below their threshold doses. The risk of radiation-induced stochastic effects can be reduced, but not necessarily eliminated, by minimizing the dose. Radiation doses can be controlled or minimized by removing external radionuclide contamination and treating with blocking agents to decrease internal depositions and decorporation agents to increase the rate of elimination of radionuclides from the body.

This Report comprises two volumes, a Handbook and the Scientific and Technical Bases. The Handbook contains information for immediate "in-the-field" application to radiation contamination incidents. It is organized into four parts. Three sections in Part A provide Quick Reference Information for incident responders based on supporting information given elsewhere in the Report. Three sections in Part B contain essential information on medical and radiation-safety activities to be conducted at the site of a radionuclide contamination incident and prior to arrival at a hospital. This is followed by four sections in Part C that describe medical and radiation safety activities at the hospital. Part D comprises two sections providing guidance on medical follow-up of exposed persons and on handling contaminated decedents. Parts A, B, C and D are color coded for easy access by users. Concluding the Handbook is guidance on contamination control in medical facilities. Part E, the Scientific and Technical Bases volume is organized into seven sections and several appendices. It provides detailed scientific and technical information in support of the guidance in the Handbook.

While much of the information in the Scientific and Technical Bases can be found through diligent examinations of other publications, few organizations involved in responding to radionuclide contamination incidents will have access to all these publications or the staff to research them. Therefore, the Scientific and Technical Bases are presented as a resource, supporting and supplementing the material in the Handbook and for possible use in training emergency-response personnel.

Experience has shown that it would be extremely rare for trained radiation-safety and medical personnel to be first on the scene of any radionuclide contamination incident, whether it is an accidental spill in a laboratory or the deliberate release of a large

quantity of activity in a public place. It is more likely that the first on the scene will be a colleague in a work place and fire-protection and law-enforcement personnel in a public place. Also, contamination incidents can occur in locations where radiation-safety and medical personnel are not readily available. Therefore, this Report is intended for the broad spectrum of persons who may respond to radionuclide contamination incidents, those with limited knowledge of radiation-safety and medical response as well as the professionals with extensive knowledge.

Handbook, Part A, is intended to provide quick reference information that may be useful to anyone responding to a radionuclide contamination incident regardless of their radiation knowledge and experience. It begins with Section 3, a Compendium of Radiation Facts and Guidance. To help ensure that all responders are communicating with clarity and understanding, a number of terms are defined as they apply to this Report. Also, relevant properties of radiations emitted by radionuclides are reviewed. Since medical and radiation-safety personnel should be working as a team in all radiation incidents, their individual responsibilities are briefly summarized as well as guidance on working onsite and making preliminary health and radiation assessments. Section 3 also summarizes guidance on the management of injured and contaminated persons, identifying priorities and the actions to be taken in assessing exposure situations, and providing appropriate medical responses. A decision tree (Figure 3.1) for managing persons contaminated with radionuclides is included to guide radiation safety and medical personnel.

Section 4, Radiation-Safety Guidance for First Responders, is a quick review of the objectives for the first medical and radiation-safety personnel on the scene of a radionuclide contamination incident. These include providing medical aid to injured individuals, identifying irradiated and contaminated persons, detecting and identifying radioactive material, identifying sources of external radiation, controlling the contamination, and initiating decontamination of individuals and the site. All of this is to be achieved with attention to protection of exposed persons and the responders. If the incident is accompanied by serious hazardous situations like fire or explosive destruction of buildings and vehicles, evacuation of people may be the first priority. Guidance is provided in establishing radiation contamination control areas (*e.g.*, an inner area containing the radionuclide contamination incident site; an outer contaminated area; and outside of these, an uncontaminated secured area where onsite medical and radiation assessments and decontamination of people should be performed). Guidance is also

provided to ensure protection of responding personnel. This is further discussed in Appendix C, Emergency-Responders' Guidance on Radiation Risks.

Section 5, Performing Surveys and Controlling Personnel and Area Contamination, provides a review of how to survey individuals, equipment and other surfaces. This section is supported by Section 19, Instrumentation to Measure Radioactive Contamination, in the Scientific and Technical Bases, which provides more detailed information on radiation detecting instruments. Section 5 provides a quick review of the instrumentation to be used for a particular survey and how it is to be used (*e.g.*, the distance to hold the detector from the object or person being surveyed, calibrating the instrument, and correcting for background). Also important to first responders is guidance on personal protection and the equipment that should be used and how to use it (*e.g.*, inspection of equipment for damage such as tears in gloves, taping at the wrists and ankles, where to wear dosimeters, when respiratory protection is advised, and also how to remove the equipment to maintain control of the contamination).

The medical management activities described in Parts B, C and D are organized into nine stages as shown in Figure 3.1. The applicability of one or up to all nine stages depends upon the nature and consequences of the contamination incident. For example, a minor incident in a laboratory may be quickly assessed in Stage 1 as having no health consequences and the exposed individuals can be released to their home or workplace. On the other hand, a major incident involving a large release and intake of radionuclides, whether exposing one individual or many, could result in severe health consequences and even death. In such cases, all nine stages might be applicable. A description of the objectives and the recommended actions to be taken in each stage is the major focus of this two-volume Report.

Handbook, Part B, Onsite and Prehospital Actions, addresses actions to be taken *onsite* to assess and control both radiation and medical aspects of a radionuclide contamination incident, Stages 1 through 3 in Figure 3.1.

Stage 1, Medical Assessment (Section 6) describes the initial assessment of a contamination incident and of the persons exposed to radiation and/or radioactive materials. This normally occurs onsite in a triage area within a secured area as shown in Figure 4.1. Ideally this will be conducted by both medical and radiation-safety personnel (Section 18.3.3). The highest priority is to provide immediate emergency care to individuals who have been seriously injured. The next priority is to identify those who have been exposed

and contaminated and those showing psychological distress. If there is evidence of radioiodine intakes, consideration should be given to administer potassium iodide (KI) and if intakes of transuranics such as plutonium are suspected, treatment with diethylenetriaminepentaacidic acid (DTPA) should be considered, since in both cases, prompt treatment can be most effective.

Stage 2, External Contamination Assessment (Section 7) provides a description of the steps to be performed onsite in the secured uncontaminated area by radiation-safety personnel, assisted by medical personnel as needed (Section 18.3.3). The objectives are to assess the contamination, examine for burns, wounds, shrapnel, and hot particles and make treatment and decontamination recommendations.

Stage 3, External Decontamination (Section 8) by radiation-safety and medical personnel should take place onsite in a location specifically identified for that purpose (Section 18.3.3). It could be a shower room if the incident occurred in a work location. If the incident occurred in a public area, it could be in a nearby gym, temporary tented facility, or hospital. The objective is to control external contamination to avoid inadvertent intakes through skin or by inhalation or ingestion. A second objective of removing contamination is to reduce radiation doses to skin and the risk of dermal injuries and to decrease amounts of radionuclides in wounds and their possible absorption into blood.

Handbook, Part C addresses activities that would normally occur away from the site of the contamination incident, in a clinic or hospital emergency department.

Stage 4, Patient Evaluation and Emergency Care (Section 9). In most cases, the patients will have been assessed for external contamination and decontaminated, but some of those severely injured may have arrived without having been decontaminated. Thus, proper radiation protection practices should be enforced to prevent contamination of the hospital. The emergency department physicians should have in hand all of the available documentation about the incident and any preliminary dose-assessment information for the patient, including the potential for whole-body external exposures. The objective is to evaluate and provide emergency treatment for injuries and examine for possible whole-body radiation exposures. Unless administered onsite, consideration should be given to administering KI if there is evidence of radioiodine intakes and DTPA if intakes of transuranics such as plutonium are suspected since in both cases, prompt treatment can be most effective.

Stage 5, Internal Contamination Assessment (Section 10) also occurs at an emergency facility or hospital. The objectives are to

verify the contamination and to evaluate the intake and radiation dose by determining the routes of intake, identifying the radionuclides and assessing their quantities with appropriate bioassay procedures. Information obtained during the previous stages will help ascertain how this is to be done. Specific information about the incident, air samples taken, location of the individual relative to a release of activity, and the length of time in a contaminated area can be very useful in establishing the routes of intake.

Stage 6, Clinical Decision Guidance (Section 11), would usually take place at hospitals and involves analysis of the internal dose assessments to determine whether consideration should be given to decorporation therapy. Information on radiation dose, excretion, and nasal swabs are compared to model predictions to assess whether intakes of radionuclides exceed the Clinical Decision Guide (CDG) for the particular radionuclide. The objective is to reduce the risk of stochastic effects, cancer, to a level consistent with current regulatory guidance for responding to emergency situations and to prevent the risks of deterministic effects. To guide physicians in considering the need for medical treatment to achieve this objective, a new operational quantity, CDG is introduced. The numerical values of dose used as a basis for computing the CDG intake values for different radionuclides, excluding isotopes of iodine, in adults are:

- 0.25 Sv (25 rem) (50 y effective dose) for consideration of stochastic effects [this represents about a 1.3 % lifetime risk of fatal cancer attributable to the radiation dose (ICRP, 2007)];
- 30 d RBE-weighted absorbed-dose value of 0.25 Gy-Eq (25 rad-Eq) for consideration of deterministic effects to bone marrow; and
- 30 d RBE-weighted absorbed-dose value of 1 Gy-Eq (100 rad-Eq) for consideration of deterministic effects to the lungs.

For radionuclides other than isotopes of iodine, the CDGs for children (0 to 18 y of age) and pregnant women are defined as one-fifth the adult value. CDG values for ^{131}I are based on the U.S. Food and Drug Administration (FDA) recommendations (FDA, 2001) that KI be administered to adults >40 y of age if the projected dose to thyroid is ≥5 Gy (500 rad), to adults 18 to 40 y of age if the projected dose is ≥0.1 Gy (10 rad), and to pregnant or lactating women or persons <18 y of age if the projected dose is ≥0.05 Gy (5 rad). CDGs are tabulated for 25 radionuclides.

Stage 7, Medical Management (Section 12), provides guidance on treatment that will most often occur in hospitals, at least initially.

The goal is to select a treatment modality that will enhance the excretion of the particular radionuclide from the body with minimal impact upon the health of the patient and thus reduce the lifetime risk of cancer and reduce the potential for both deterministic and stochastic effects. Treatment would include appropriate clinical follow-up.

Handbook Part D addresses actions that would occur after contaminated persons are discharged from hospital or in the event of death of contaminated persons.

Stage 8, Follow-Up Medical Care (Section 13), should involve a long-term plan for patients who experience radionuclide contamination sufficient to be considered for treatment as well as those who received treatment. They should be admitted to a registry for maintaining records of radiation dose, treatment, surveillance for subsequent malignancy, and other effects, including psychosocial.

Stage 9, Contaminated Decedents (Section 14) provides guidance to protect medical examiners and mortuary personnel from excessive radiation exposure and to ensure that burial or cremation of the body is conducted with care to control radionuclide contamination.

The Handbook concludes with Section 15, Contamination Control in Medical Facilities. Few emergency departments are staffed and equipped to handle radionuclide contaminated patients. Even in hospitals with radiation medicine departments there may not be sufficient expertise to assist emergency department personnel in controlling the spread of radionuclide contamination. While normal hospital sterility practices will in most cases be adequate, radionuclides do present special control problems with respect to the patients, the staff, and the facilities. However, treatment of contaminated patients is first priority. Guidance in this section is directed to those control issues.

The Scientific and Technical Bases volume, Part E, comprises seven sections and 10 appendices. Although much, but not all, of the information can be found in other publications, it is compiled here to help explain some of the recommendations in the Handbook and offer supplemental information.

Section 16, Overview of Radiobiology Concepts Pertinent to Radionuclides, is included in recognition of the fact that irradiation by radionuclides released in a contamination incident differs in major ways from irradiation by external sources. For example, radionuclides deposited upon the skin or in the body usually irradiate only part of the body, compared with external radiation that can irradiate the whole body (exceptions are when external beams are partially shielded or when radiation for therapeutic purposes is directed to specific tissues and organs). Also, except for

radionuclides with very short half-lives, radiation from radionuclides is delivered over a period of time that can range up to years. Radiation from external sources is delivered over a relatively short period of time, depending upon how long the individual is in the beam and how long a radiation generator is operating (exceptions are therapy doses protracted over weeks or months and natural background). These exposure differences can result in significantly different health consequences. When a person is in the vicinity of an uncontrolled radionuclide source, contamination of skin is more likely than an intake by ingestion or inhalation. Ingestion requires the source to be in food or water or moved to the mouth area by physical contact, and inhalation requires the source to be airborne in a person's breathing space.

Section 17, Settings in Which Individuals May be Contaminated with Radionuclides, describes numerous scenarios in which radionuclides can be released, inadvertently or deliberately. The radionuclides of concern are identified for each scenario. Also tabulated are deep-dose-rate and skin-dose-rate values from external sources. Contamination incidents can be small-scale such as an accidental release in a laboratory or large-scale, such as a rupture of a large radioactive source in a public place. Nearly all are accidental, but deliberate releases are becoming of greater concern with the increase of unaccounted-for (orphan) radionuclide sources.

Section 18, Roles and Responsibilities of Responders to Contamination Incidents, supplements the information given in Sections 3, 4, 5, 6, 7 and 8 for onsite and prehospital actions. It provides additional guidance on designating controlled areas and defining responsibilities for potential responders of various disciplines such as law-enforcement, fire-protection, medical, radiation-safety, and public-health personnel. Specific responsibilities are described for radiation-safety personnel ranging from determining the number of trained radiation-safety personnel required at the scene and conducting the necessary monitoring to documenting the actions for the incident commander.

Section 19, Instrumentation to Measure Radioactive Contamination, supports Sections 3, 5, 6, 7, 8, 9 and 10 with detailed descriptions of the instrumentation and the analytical procedures required to detect radionuclide contamination and assess external and internal contamination. This includes initial qualitative surveys to identify the presence of radioactive material and relatively precise quantitative measurements for the purpose of estimating radiation doses.

Section 20, Dosimetry and Case Studies for Selected Radionuclides, provides biokinetic and dosimetric information for the

radionuclides that are identified in Section 17 as being potentially involved in radionuclide-contamination incidents. This section is also the source of the dosimetric data tabulated in the Handbook. The information presented is intended primarily for assessment of radiation dose during the early hours or days after exposure. Forms of radionuclides and modes of intake were selected in an attempt to provide typical estimates of tissue dose from types of exposure that seem most likely based on case studies. Relevant case studies are included with each element covered in Section 20. It is assumed that consistent with past experience, while skin contamination is more likely, nearly all future inadvertent intakes of radionuclides will be by the inhalation route, although intakes by ingestion and through wounds or skin absorption are not excluded. Readers particularly interested in issues related to the behavior of radionuclides in wounds and their treatment should also consult NCRP Report No. 156, *Development of a Biokinetic Model for Radionuclide-Contaminated Wounds and Procedures for Their Assessment, Dosimetry and Treatment* (NCRP, 2006a).

Section 21, Dose-Assessment Methodologies, provides an overview of information and considerations for evaluating intakes and radiation doses needed to make treatment decisions. Although much information can be collected about an incident, the most important is the information collected from the contaminated individual. This section illustrates the use of data obtained using the instrumentation and procedures described in Section 19, to evaluate external and internal doses to exposed individuals.

Section 22, Research and Development, describes current and needed research and development to improve the effectiveness of responding to radionuclide contamination incidents. A concern is the paucity of facilities for decontaminating individuals, especially large numbers of people, and assessment of external and internal contamination including *in vivo* and *in vitro* bioassay capabilities. Cooperative agreements between local emergency planners and national laboratories and nuclear power plants around the country should be encouraged where they do not already exist. Research needs include improved instrumentation and modeling capabilities for internal dose assessment, development of biomarkers for biodosimetry, improved dosimetry software, and decorporation drugs. Current research on treating for internal contamination, described in this section, shows promise and should be continued.

Appendices, glossary, and references complete the Scientific and Technical Bases. Ten appendices provide specific information on several important topics relevant to both the Handbook and the Scientific and Technical Bases and are referenced in the appropriate

sections of both volumes. Topics covered in the appendices include record keeping, training, guidance on radiation risks for emergency responders, and communicating with the media, members of the public, and with patients and their families. Reference bioassay tables are included as an appendix for use in assessment of internal contamination (Sections 10 and 21) and another appendix contains several case studies as examples of radiation-safety and medical responses to major radionuclide exposure incidents. A list of useful resource documents is included as another appendix. This is followed by an appendix that provides details on validation and verification of the models, software, and associated parameters used for the biokinetic and dosimetric calculations in this Report and a final appendix that lists categories for drug use in pregnancy.