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Generic procedures for assessment and response during a radiological emergency

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GENERIC PROCEDURES FOR ASSESSMENT AND RESPONSE
DURING A RADIOLOGICAL EMERGENCY
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FOREWORD

One of the most important aspects of managing a radiological emergency is the ability to promptly and adequately determine and take actions to protect members of the public and emergency workers. Radiological accident assessment must take account of all critical information available at any time and must be an iterative and dynamic process aimed at reviewing the response as more detailed and complete information becomes available.

This manual provides the tools, generic procedures and data needed for an initial response to a non-reactor radiological accident. This manual is one out of a set of IAEA publications on emergency preparedness and response, including Method for the Development of Emergency Response Preparedness for Nuclear or Radiological Accidents (IAEA-TECDOC-953), Generic Assessment Procedures for Determining Protective Actions During a Reactor Accident (IAEA-TECDOC-955) and Intervention Criteria in a Nuclear or Radiation Emergency (Safety Series No. 109).

The procedures and data in this publication have been prepared with due attention to accuracy. However, as part of the ongoing revision process, they are undergoing detailed quality assurance checks; comments are welcomed, and following a period of time that will have allowed for a more extensive review, the IAEA will revise the publication as part of the process of continuous improvement. In the meantime, it remains the responsibility of the users to ensure that the information is correct and appropriate to their purposes. The manual uses a number of generic practices. Therefore, careful review and adaptation of its contents are strongly recommended prior to its use, so that the response is integrated into the response to all emergencies, and into national emergency response training schemes.

The IAEA is grateful for the contribution made by experts from various Member States who took part in the development and review of this publication, and in particular, to R. Martinčič (J. Stefan Institute, Slovenia). M. Crick, of the Division of Radiation and Waste Safety, was the IAEA officer responsible for this publication.

EDITORIAL NOTE

GENERIC PROCEDURES FOR

ASSESSMENT AND RESPONSE

DURING A RADIOLOGICAL EMERGENCY

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CORRIGENDUM

1. Page 99, Table E3. In the row “Cs-134” and column “50 Year”, the number “5.1E-03” should read “5.1E-02”.

2013-03-21

CONTENTS

INTRODUCTION

BACKGROUND

The use of sources of radiation in different fields of practice other than in reactors is growing daily. Despite safety precautions in design and operations, accidents involving radiation sources do occur more frequently than reactor accidents. Unlike reactor accidents, the impact of any such accidents generally affects only a small number of people. However, the impact on these few people may be serious.

OBJECTIVES

The aim of this publication is to provide practical guidance for emergency response that, if implemented, will provide a basic assessment and response capability needed to protect the public and the workers in the event of different types of radiological emergencies (excluding reactor accidents) consistent with international guidance [1, 2, 3].

This manual provides the tools, generic procedures and data needed for initial response to a *non-reactor radiological emergency*. It is intended for use by persons or groups who are responsible for responding to a radiological emergency. Tools, procedures and data required to evaluate protective actions during a *reactor accident* can be found in Ref. [4].

The practical guidance is provided in the form of generic procedures. These procedures are designed to be used primarily during the initial response to an accident and do not cover the recovery phase in detail, when more detailed assessments based on accident specific information can be carried out. In order to be effective, the procedures provided should be adapted as part of the preparedness process to integrate with the national and local system and infrastructure in the country where they are used, and only personnel who have been trained and drilled should use them. Furthermore, the exact application of each procedure will depend on the specific details of each accident. Although the steps in the procedures are listed in the general sequence in which they should be performed, it is possible that the sequence may need to be adapted at the time of the response.

This manual will also be reviewed and revised from time to time as part of the planning process to take into account actual radiation sources and radiological practices, potential accidents, local conditions, national criteria and other unique characteristics of an area or facility where it may be used.

SCOPE

This manual provides generic response procedures to protect the public and emergency workers for different types of radiological emergencies; including the accidents involving sealed and unsealed radioactive materials, radiation generators, and transport accidents. It does not cover reactor accidents or reprocessing plants or other large nuclear facilities.

This manual is also applicable to radiological emergencies that could result from deliberate acts, such as terrorist activities, although the security aspects of the response to such events are not within the scope of this publication.

The manual also relies on advanced planning by the country to provide the infrastructure, personnel and equipment needed to carry out the proposed procedures. However, it does not deal with the detailed development of emergency plans, nor does it deal specifically with detailed radiation monitoring procedures. Guidance for the development of plans, generic monitoring procedures and generic procedures for response to reactor accidents are provided in [4, 5, 6]. The procedures for dealing with radiological emergencies as provided in this manual assume the availability of the basic resources specified in Appendix 7 of Ref. [5]. Although responsibility for response always rests with the Member State, if not available in the country at the time of an accident, such resources and assistance can be requested through international organizations such as the IAEA.

STRUCTURE

The manual is organized in sections based on an assumed generic response organization (see Fig. O1). Each section contains stand-alone procedures. Each procedure is organized in the order that assessment and response actions will most likely be performed.

Section A deals with the first steps after notification of an accident. Section B contains the overall emergency management procedures. Section C provides generic procedures for emergency responders at the scene of an accident. Section D contains procedures for the managing of the radiological response at the scene of an accident. Section E contains procedures for performing basic dose projections and assessment in case appropriate computer software programmes are not available when needed.

In Appendix I guidance is provided on how to request IAEA assistance, Appendix II gives an overview of medical response to exposure/uptake and in Appendix III some guidance is given on the desirable level of instrumentation and equipment that should be available to provide the services required. Basic information on transport packages can be found in Appendix IV. In Appendices V and VI basic response steps in accidents with trans-boundary effects and in case of nuclear powered satellite re-entry are given, respectively. Appendix VII gives guidance on communication with the media and the public and finally in Appendix VIII a summary is given on how to prepare an accident report.

This manual also contains worksheets, which are provided as examples to assist in data recording and information transfer.

NOTE

There are three ways to find the appropriate item in the manual based on:

(a) generic response organization by using Fig. O1,
(b) the Contents, and
(c) key words using the Index.

OVERVIEW

OBJECTIVES OF EMERGENCY RESPONSE

The general objectives of emergency response are:

(a) To reduce the risk or mitigate the consequences of the accident at its source.
(b) To prevent deterministic health effects (e.g. early deaths and injuries) by taking actions before or shortly after exposure and by keeping the public and emergency worker individual doses below the thresholds for deterministic health effects.
(c) To reduce the risk of stochastic health effects (e.g. cancer and severe hereditary effects) as much as reasonably achievable by implementing protective actions in accordance with IAEA guidance [2] and by keeping emergency worker doses below the levels established in IAEA guidance [2].

PHILOSOPHY

The procedures contained in this manual are based on the following philosophy: keep the process simple, yet effective. The procedures provide action criteria that are:

(a) clear, concise and predetermined, allowing for immediate actions to be taken; and
(b) based on our current knowledge and experience with radiological emergencies.

It is very important to realize that in many non-reactor radiological emergencies, the hazard due to the radiation is often less than other conventional hazards present (e.g. fire, dangerous chemicals). Therefore the non-radiological aspect of a radiological emergency should almost always take precedence: saving lives, treating injuries, fire fighting hazards, protecting critical equipment and the safety of personnel are the priorities. Once the non-radiological situation has been stabilized, immediate steps must be taken to minimize the radiological risk to the public, the emergency workers and the environment.

RESPONSE ORGANIZATION

The manual designates responsible “persons”, or organizations, under five specific titles (see Fig. O1). These represent necessary functions to deal with emergencies. However, in small-scale accidents some of these functions may be combined and carried out by one person. Each one is discussed below.

Response Initiator

This is the person who, having been notified of an accident, initiates the formal response and has the authority to do so.

For example, at a facility where radioactive sources, radioactive material, or radiation generators are used, the response initiator may be the duty officer, the radiation safety officer or a responsible laboratory supervisor. If an accident occurs while no facility staff is present, the response initiator may be the fire department dispatcher or security personnel. For accidents in local municipalities, the response initiator might be the “on-call” emergency service, such as police or fire department or, in some cases, the duty officer of the national nuclear safety organization.

The response initiator is responsible for getting basic information on the emergency, providing initial advice to the caller, and notifying the emergency manager.

Emergency Manager

The emergency manager is in charge of the overall strategic management of the emergency response. He/she will manage the priorities and the protection of the public and emergency workers, will ensure that all appropriate resources have been activated and that communications with emergency personnel at the scene are established. He/she will also often be the primary spokesperson with the media but in a serious emergency he/she may need to appoint someone specifically to deal with the media. The emergency manager will work in close cooperation with the on-scene controller (see below), who is present at the scene. Depending on the nature and severity of the accident, the functions of emergency manager and on-scene controller may be performed by one person, at least at the initial stage of the response.

For example, at a facility where radioactive sources, radioactive material, or radiation generators are used, the emergency manager may be the facility manager or a designated senior staff member. For emergencies in municipalities, the emergency manager will normally be an appointed member of the local government (e.g. Chief Administrative Officer, Head of the municipal emergency response section or Head of the local civil defence organization). If the accident has large consequences beyond the municipality or needs resources outside of the municipality's capabilities, the emergency manager's duties could be assumed by a designated member of the regional, provincial or national government, depending on the standard emergency response strategy, plan and laws within the country.

First Responder (on-scene)

The first responder is the first person or team to arrive at the scene of an accident with an official role to play in the accident response.

For example, at a facility where radioactive sources, radioactive material, or radiation generators are used, the first responder might be the Radiation Protection Officer. For an accident in a public place, the first responder would likely be one of the emergency services, i.e. police, fire service, or emergency medical responders. first responders are responsible for dealing with all aspects of the emergency at the scene. Their work is supervised and coordinated by the on-scene controller (described below).

The first responders may or may not have available radiation detection equipment and dosimeters. Therefore, suitable generic precautions must be adopted by first responders to protect themselves and other people present at the scene from the radiological hazard, and a qualified radiological assessor should in almost all cases be called to assist with the radiological aspects of the response.

On-Scene Controller

The on-scene controller is responsible for the tactical management of response actions at the scene of an accident. He/she is responsible to the emergency manager for the implementation of mitigating measures, confinement, crowd management, coordination of all response units present at the scene, initial recovery and clean up operations, protection of emergency workers and protective actions. The on-scene controller relies on the expertise of the emergency response unit leaders to determine the best ways to implement response actions and to make recommendations to the emergency manager for the management of the emergency.

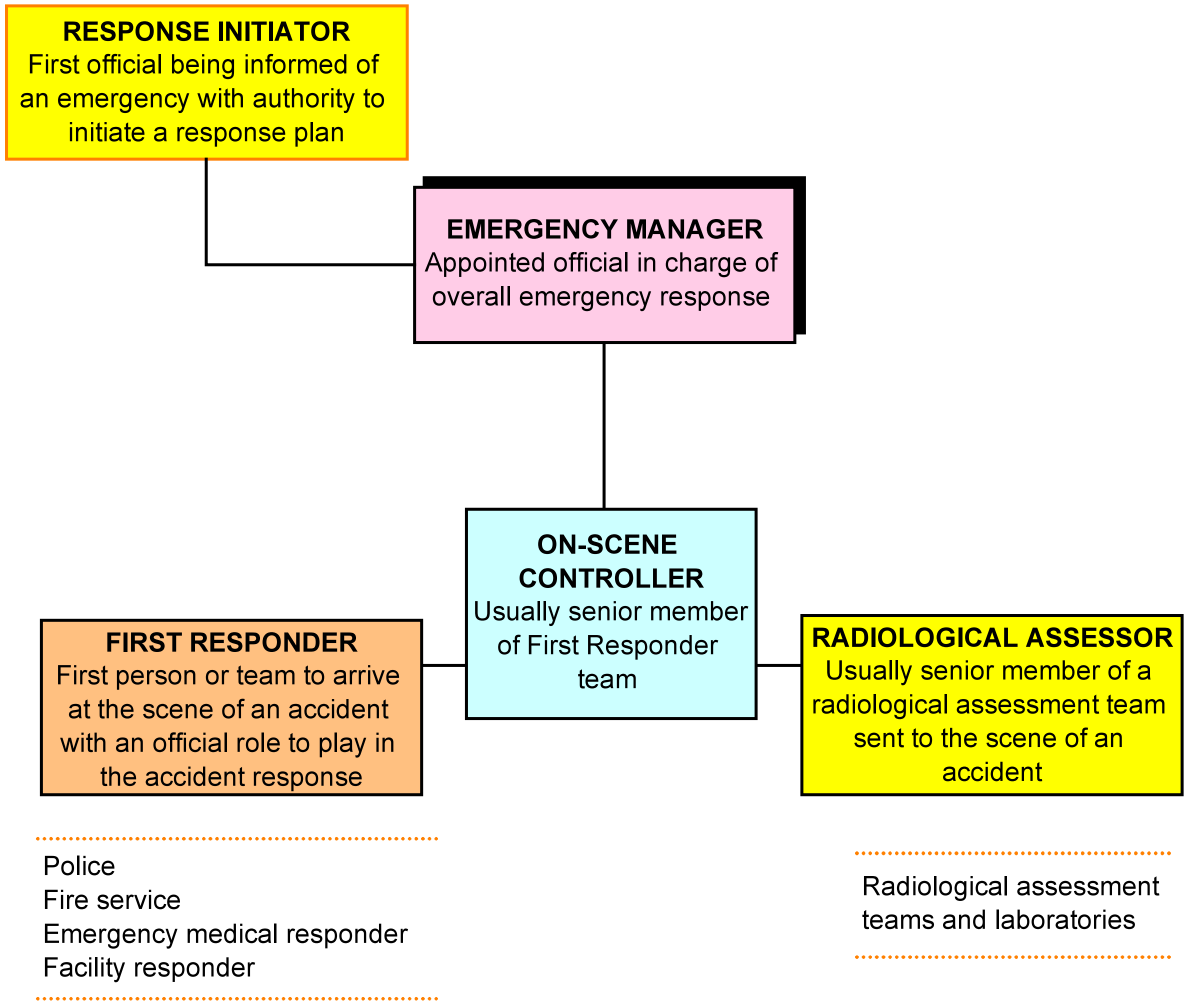


FIG. O1. Generic response organisation.

The on-scene controller is normally the senior member of the on-scene response teams. When several response units are present (e.g. fire fighters, police, radiological assessment team, etc.), the on-scene controller is designated by the emergency manager in accordance with local practices for hazardous material emergencies or based on the nature of the threat. For the response to an accident at a facility, a senior member of the facility staff may be designated as the on-scene controller.

Radiological Assessor

This position will normally be held by the most senior member of the team(s) of radiological professionals (qualified experts) sent to the scene of an accident to assess the radiological hazards, provide radiation protection for the first responders and make recommendations to the on-scene controller on protective actions. Radiological assessment resources should already be identified in plans. Contact point(s) and telephone number(s) for these resources should have been provided to potential response initiators.

The radiological assessor may be alone or part of a team. He/she is responsible at the scene for surveys, contamination control, radiation protection support to emergency workers and the formulation of protective action recommendations. The radiological assessor will also initiate and, in some cases, carry out source recovery, clean up and decontamination operations. The radiological assessor will also be responsible for setting turn back guidance for emergency workers, for estimating and recording the dose received by emergency workers and/or the public; for requesting additional radiological assessment resources, as required; and health physics expertise to carry out specialized hazard and dose assessment tasks.

INITIAL RESPONSE

An example of initial response to a notification of a radiological emergency is shown in Fig. O2.

On notification of an emergency the response initiator obtains initial information regarding the emergency and decides if it is a radiological one. If it is, he/she provides to the caller first advice and initiates the response by alerting/activating the emergency manager.

Based on available information the emergency manager assesses the level of the present or suspected hazard. If medium or high he/she activates through the response initiator local/national response organization(s): an appropriate first responder (if not yet at the scene), radiological assessor and any other needed services or authorities.

The senior official at the scene automatically assumes the role of the on-scene controller until relieved or confirmed by the emergency manager, who also determines whether the emergency is serious enough or has a sufficient public interest to warrant sending a national level on-scene controller to assume overall control.

If the actual or suspected level of hazard is low, the emergency manager activates only the radiological assessor and if necessary sends him/her to the scene to reassess the radiation hazard and/or to direct/perform recovery and clean up operations as appropriate.

The overall response must cater for providing information to the media and the public.

The functions of positions described are essential to an appropriate response and planning for an emergency should address each of these functions. Local terminology may be different and specific situations may require an amalgamation of these functions; however, it must be absolutely clear who should undertake the functions.

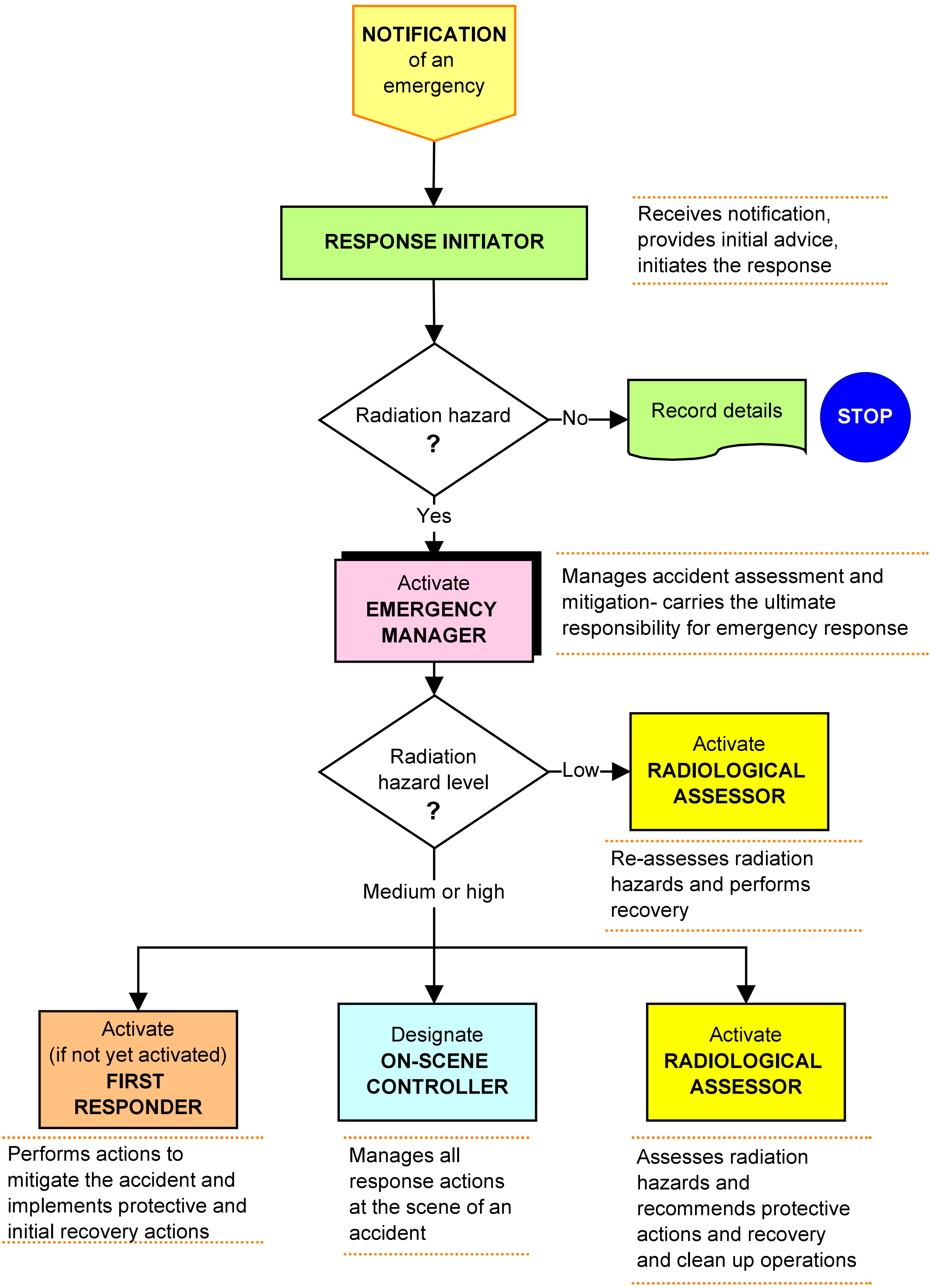


FIG. O2. An example of initial response to a notification of a radiological emergency.

ACCIDENT SCENARIOS

From an emergency management perspective, accident scenarios are classified in the following categories:

1. accidents with radiation sources or material;
2. accidents outside the country with trans-boundary effects; and
3. nuclear powered satellite re-entry.

A brief description of each is provided below.

Accidents with radiation sources or material

This is a broad category, which includes found radioactive material or contaminated areas or items, lost or missing sources, unshielded sources, accidents in a laboratory, industrial or research facility and transport accidents.

Radioactive materials in the form of sealed sources are used for a wide variety of purposes in industry, medicine, research and teaching as well as in a number of consumer products on sale to the general public. They are used for radiography, sterilisation units, radiotherapy and nuclear medicine, well logging, level-, thickness-, density-, and moisture gauges, anti-static devices and lightning rods and consumer products such as smoke detectors. These sources vary enormously in the magnitude of their activity.

Emergencies happen when there is a failure of the radiation safety controls in place (e.g. an industrial gamma radiography source left outside its shielded enclosure, or a radioactive package found in a public place). The greatest potential for serious injury arising from these sources comes principally from an unshielded high activity source. Consequences can be very serious, in some cases death, especially if the source is handled by persons who are not familiar with the hazard of radiation, or who do not know that the source is radioactive. Indeed, unshielded exposure at close quarters to the high activity sources and machines used for some industrial radiography, radiotherapy in medicine, and in sterilization units, could give rise to a lethal whole body dose in a matter of minutes. Accidents with such sources may also involve contamination if the source is damaged.

In addition to external irradiation hazard damaged sources of any nature and size can result in contamination of people and/or the environment. As a result of a fire or dispersion by wind or ventilation, contamination can also become airborne. The consequences could include serious skin burns from beta radiation and internal contamination, potentially leading to serious health consequences. The situation can be made worse if the accident is not discovered in time and dealt with properly.

Contamination with alpha emitters such as plutonium and americium is a special case in this category. Accidents may arise from examples such as transport of radioactive material, plutonium powered pacemakers and illicit trafficking. Plutonium presents a very high inhalation hazard, and it is difficult to detect it using commonly available instruments. Responding to accidents involving plutonium requires enhanced precautions.

A lost, stolen or misplaced source is a special case of emergencies involving radioactive material. The risk to the public will depend on the total activity involved. It must be assumed that the source may be in the possession of people who may not know its nature and hazard, who can handle it, break it and spread contamination. In some cases people can be exposed or contaminated to very high levels. In such an event, priorities must be given to finding the source through every reasonable means available. This may include police investigation, public advisories, monitoring of hospitals and clinics, and searches using radiation instruments.

Searching for a lost source with radiation monitoring equipment is effective for high-energy gamma sources, e.g. the types of sources used for industrial radiography and medical radiotherapy. The searching efficiency will depend upon sensitivity of monitoring equipment available, total activity and shielding. Instruments with large sodium iodide detectors are able to detect such source up to a few hundred metres away, unless the source remains in its shielded container.

Machines producing ionising radiation, principally X rays or particle accelerators, are also widely used in industry, medicine or research. The output, in terms of dose rate, from these machines, may be, and usually is, very much higher than that from all but the largest activity radioactive sources in use. The potential, therefore, for serious accidental exposures is normally much greater for these devices than for radioactive sources. On the other hand, the radiation output from these machines ceases when the devices are electrically fully switched off and discharged — though accidents have occurred through faulty switches and warning signals or through activated machine parts or target stations. However, attention is drawn to the fact that some units such as electron beam generators can still produce radiation, known as dark current radiation, for a short time after being switched off.

Throughout the world, many thousands of transport operations occur daily in connection with the use of radiation and radioactive materials. All forms of transport, e.g. road, rail, air and sea are involved to varying degrees. The spectrum of items transported is wide and includes nuclear industry products (including nuclear fuels and some radioactive waste materials), radiographic sources for industrial use, radiotherapy sources for medical use, equipment such as gauges, containing radioactive sources and some consumer products (e.g. smoke detectors) that are delivered in quantity and stored widely within the retail trade. By far the largest fraction of those operations is associated with the transport of radiopharmaceutical products for medical use, which are produced by a small number of manufacturers. There are also some exceptionally special transportations such as the movement by road, rail or air, of military-owned nuclear weapons normally incorporating plutonium; and similar movements of plutonium in specifically designed transport containers by the nuclear industry.

The main problem with planning for transport emergencies is that they can occur anywhere. Therefore appropriate emergency response arrangements need to operate on a mobile basis on a nationwide scale. The other common feature of transport accidents is that apart from the vehicle driver, it is primarily the general public who may be at risk from an accident.

The transport of radioactive materials is governed by strict regulations [7, 8] aimed at providing protection according to the hazard that the contents would present if a package were to be involved in an accident. The greater the potential hazard, the greater the built-in protection required by the regulations. Accidents involving correctly packaged radioactive material normally require no special protective actions for the protection of the public or the emergency workers if the package has not been damaged. Minor traffic accidents are unlikely to damage a package sufficiently to create a significant radiological hazard. Nevertheless, any such presumption should be checked by survey at the scene of the accident.

The regulations specify standards for packages containing radioactive material, and how they must be labelled. An ability to recognize and interpret the type of package and its label can provide considerable guidance to emergency responders. The types and labelling of transport packages are discussed in short in Appendix IV and in more detail in Ref. [7]. Specific planning and preparedness for emergency response to transport accidents involving radioactive material can be found in [9].

The response to an accident involving a nuclear weapon is complicated by other hazards such as possible spread of plutonium, enriched uranium or other special nuclear materials as well as high explosives, beryllium, and potentially other toxic materials. The response to a nuclear weapon accident will usually include a contingent (such as the military) whose mission will be to control the area to protect classified materials, and to secure the nuclear weapons and make them safe. Until all intact weapons or weapons components are declared "safe" by cognizant authorities, accident response efforts should be limited to areas not impacted by the weapons.

Accidents outside the country with trans-boundary effects

An accident that results in very serious consequences off-site at a nuclear power plant, large fuel storage facility or at fuel reprocessing facility is unlikely, but remains possible. An accident at a such facilities located 100 to 1000 km outside a given country is unlikely to have consequences significant enough to warrant urgent protective actions such as evacuation or sheltering in that country [5]. However, it can still have a significant direct impact on the food chain, in some cases requiring the control of national food and water supplies. It can also have an indirect impact through, for example food and supplies imported from affected countries, nationals living in affected countries or nationals wanting to visit affected countries and possibly contaminated transport vehicles entering the country. Trans-boundary effects also may result from an accident at a facility located on or near major bodies of water. Radioactive material released in such accident may be transported some distance from the accident site by water currents. Trans-boundary effects can also occur from such accidents as the fire involving radioactive material.

Planning for response to such trans-boundary impacts involves development of procedures and response organization at the national level. General guidance for response can be found in Appendix V and more specific procedures in sections B, C, D and F of Ref. [4].

Nuclear powered satellite re-entry

Nuclear power sources are used in space vehicles such as satellites and deep space probes. Plutonium, a component of radioisotopic thermoelectric generators and heating units is of special interest. Satellites may also contain radioactive materials in the form of a small nuclear reactor. Launch accidents do not usually present a significant hazard. Accidental re-entry as a result of loss of control of a space vehicle may lead to impact on the earth's surface and the spread of contamination. There will normally be sufficient advance notice to prepare for a response although the exact location of impact cannot be predicted.

National competent authorities will be informed of any pending nuclear powered satellite re-entry by the IAEA after it has received notification from the state responsible for the satellite. This is in accordance with the Convention on Early Notification of a Nuclear Accident [10].

Planning for response to such an accident involves development of procedures and response organization at the national level. General guidance for response can be found in Appendix VI and Ref. [11].

COMMUNICATION WITH THE MEDIA

A radiological accident will almost certainly attract the attention of the media. This will be particularly so if there are serious health hazards associated with the accident. Representatives of the press/television in many instances are likely to be at the scene and broadcasting live coverage before the full mobilisation of response. Therefore preparedness for communication with the media and the public is an essential part of emergency response plans.

It is important that personnel at the scene are aware of the potential for a rapid media response and should make arrangements for the reception, assembly and control of the media personnel as soon as practicable. The on-scene controller should establish a media reception point and appoint a press liaison officer, as appropriate. Further guidance on dealing with the media is provided in Appendix VII.

SECTION A

RESPONSE INITIATION

Caution: *The procedure in this section should be adapted to reflect national, local and/or facility conditions and capabilities for which it will be applied and integrate into emergency response arrangements for conventional accidents*

Purpose
To initiate formal response upon notification of a radiological emergency.

Discussion
This procedure should be known and followed by all members and staff of official organizations who may be the first ones to be notified of an emergency with potential radiological consequences.

Input
- Notification of a potential or real radiological emergency situation.

Output
- Emergency registry on Worksheet A1
- Alerted/activated emergency responders (Worksheet A2)
- Initial instructions to the caller

Step 1
Obtain emergency or accident description from the reporting person using *Accident Registry Form* (Worksheet A1). Verify the call.

Step 2
Advise the caller to take the following actions as applicable:

i. Do not handle any objects on the accident scene.
ii. Provide first aid if qualified.
iii. As a precaution, please move and ask others to move away from a hazard area a reasonable distance (say 50 m); this does not include first aid or/and casualty rescue personnel.
iv. Confine the area if possible.
v. Do not eat, drink or smoke near the accident area.
vi. Ask people present to remain on location, away from the hazard, until the arrival of emergency response services.
vii. Wait for emergency response services and brief the on-scene controller.

Step 3
Alert the emergency manager and provide him/her with the information from the *Accident Registry Form* (Worksheet A1).

Step 4
Obtain from the emergency manager a list of responders to be alerted/activated. Alert/activate them and complete *Alerted Emergency Responders Form* (Worksheet A2).

NOTE

In some arrangements it will be the emergency manager who contacts the responders, but it should be clear in a local plan who undertakes this task.

Step 5

Keep recording all events in a logbook. This includes all notifications, communications, emergency actions and any other information that may be useful in documenting the emergency.

SECTION B

MANAGING ACCIDENT RESPONSE

Caution: *The procedures in this section should be adapted to reflect local and facility conditions and capabilities for which they will be applied and integrate into emergency response arrangements for conventional accidents.*

Purpose

To provide an overview of basic actions the emergency manager should perform in the case of radiological emergency.

Discussion

The emergency manager should immediately assess the radiological and non-radiological situation based on information from the response initiator and the on-scene controller. Based on this assessment, initial response actions to mitigate the consequences should be implemented and appropriate protective actions taken.

The emergency manager should be aware that communication with the media and the public is an essential part of emergency response.

Input

- Notification of a potential or real emergency situation (Worksheet A1).

Output

- Assessment of the emergency
- Decisions on response actions
- Public information announcements

Emergency phase

Step 1

Obtain briefing from the response initiator (Worksheet A1) and any other person already involved in the management of the emergency (e.g. the on-scene controller, the radiological assessor or facility staff if already at the scene). Alert/activate any other needed responders.

Step 2

Initiate a personal log to record the critical actions and decisions made during the emergency, including:

i. time activated,
ii. persons called and time of call,
iii. emergency responder units at the scene, time contacted and time arrived,
iv. decisions on protective actions, including changes from previous decisions,
v. decisions on other response actions,
vi. major changes to the situation and time.

NOTE
Record keeping (data bank) about the accident is very important. The radiological and non-radiological response actions taken should be adequately registered and stored. This information may later be used for learning lessons or for legal arguments.

Step 3

Assess the initial information in accordance with Fig. B0 to get broad appreciation of the possible magnitude of the problem.

NOTE

Subject to the circumstances of each accident, it will be necessary to establish different command and staging facilities such as (see Fig. C1): command post, reception area for response personnel, vehicle marshalling area, media reception area, etc. Operational command of all field personnel will be co-ordinated from a command post, which will provide a facility for the on-scene controller to deploy resources at the scene. The command post will be the central point of contact for all responders (agencies) deployed.

Step 4

From the basic information identify the type of emergency and evaluate necessary main actions using appropriate figure listed below.

In case of:	See the summary actions in Figure:
Found source or contamination	B1
Missing source	B2
Unshielded source	B3
Laboratory accident	B4
Transport accident	B5
Dispersion of alpha emitters	B6
X ray machines and accelerators	B7

Step 5

For details go to the appropriate procedure.

In case of:	Follow Procedure:
Accident with radiation source(s) or material	B1
Missing source	B2

NOTE

General guidance for response in case of trans-boundary contamination or nuclear power satellite re-entry can be found in Appendix V or VI respectively.

Step 6

Make sure that all personal protection guides and actions are implemented in accordance with the recommendations of the radiological assessor.

Step 7

Ensure that personnel at the scene are aware of the potential for rapid media response and should make arrangements for the reception, assembly and control of media personnel as soon as practicable. Appoint a press liaison officer if necessary.

> **NOTE**
> The press must not be allowed unrestricted access to the scene, but where practicable should be permitted to photograph and film the scene. The provision for regular briefings or bulletins to media personnel keeps them updated on the facts as the accident progress. It should also ensure that media personnel do not hinder the work of the on-scene controller.

Post-emergency phase

Step 8

Once the emergency is over:

i. obtain dose assessment from the radiological assessor,
ii. ensure continued medical follow-up of persons sent to hospital(s),
iii. inform the media and the public,
iv. inform all organizations that have been activated that the emergency is under control.

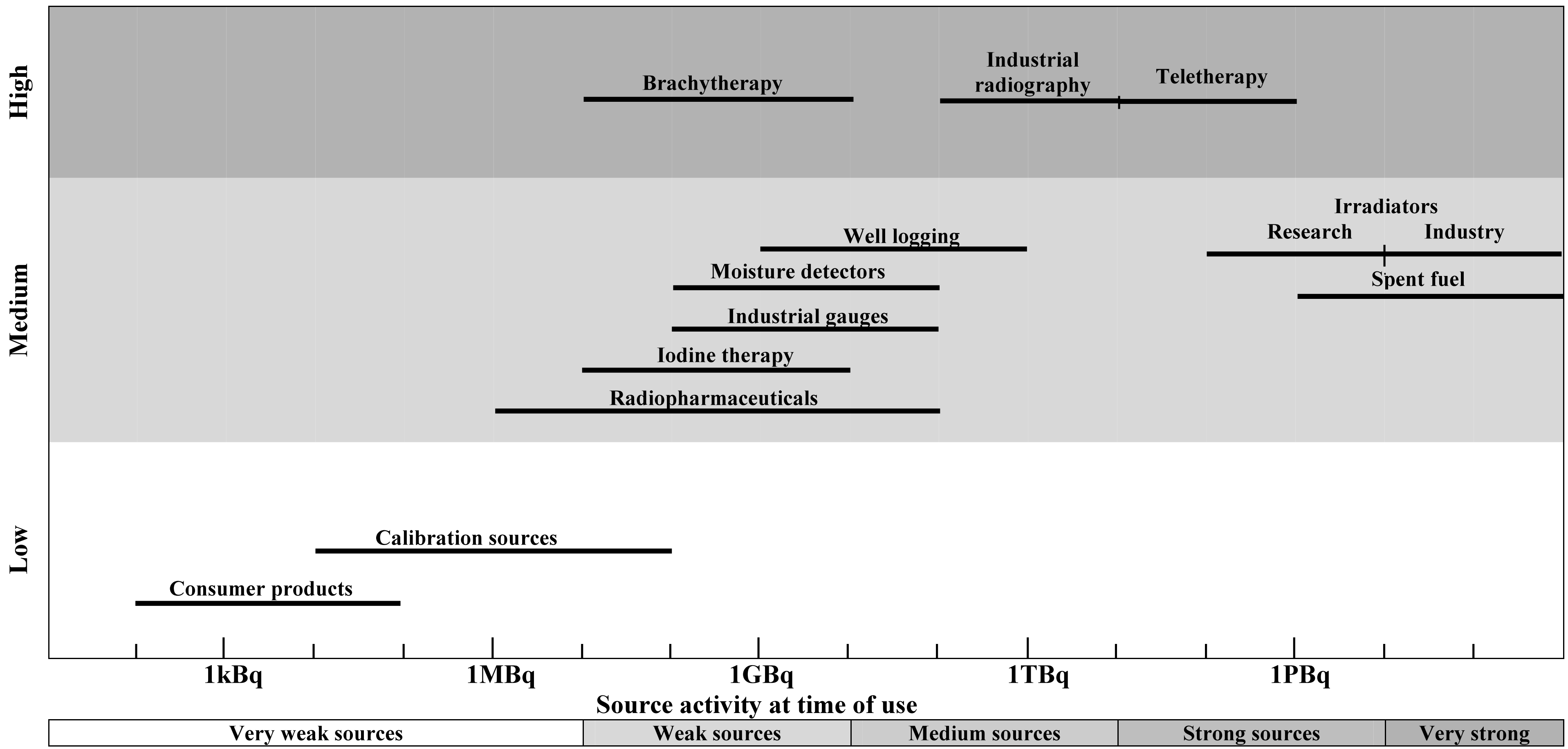
Step 9

Ensure that all actions, decisions and/or recommendations have been registered. Save all records, maps, status board, etc.

Step 10

Reconstruct the accident, evaluate the response and sum up lessons learned. If needed update the response plan accordingly. Prepare the final report (see Appendix VIII for guidance).

> **NOTE**
> The emergency will be terminated when there are no potential further abnormal exposures and the radiological consequences in terms of health effects for those exposed have been properly addressed.



REMARKS:
- Magnitudes of the problem within certain bands are more or less the same.
- Fixed nature of irradiators is such that whilst they can provide a potentially lethal dose to workers they are unlikely to provide significant risk to the public.
- Medium categorization is based on robustness of the transport containers, which would be expected in transport.

FIG. B0. Magnitude of the potential problem.

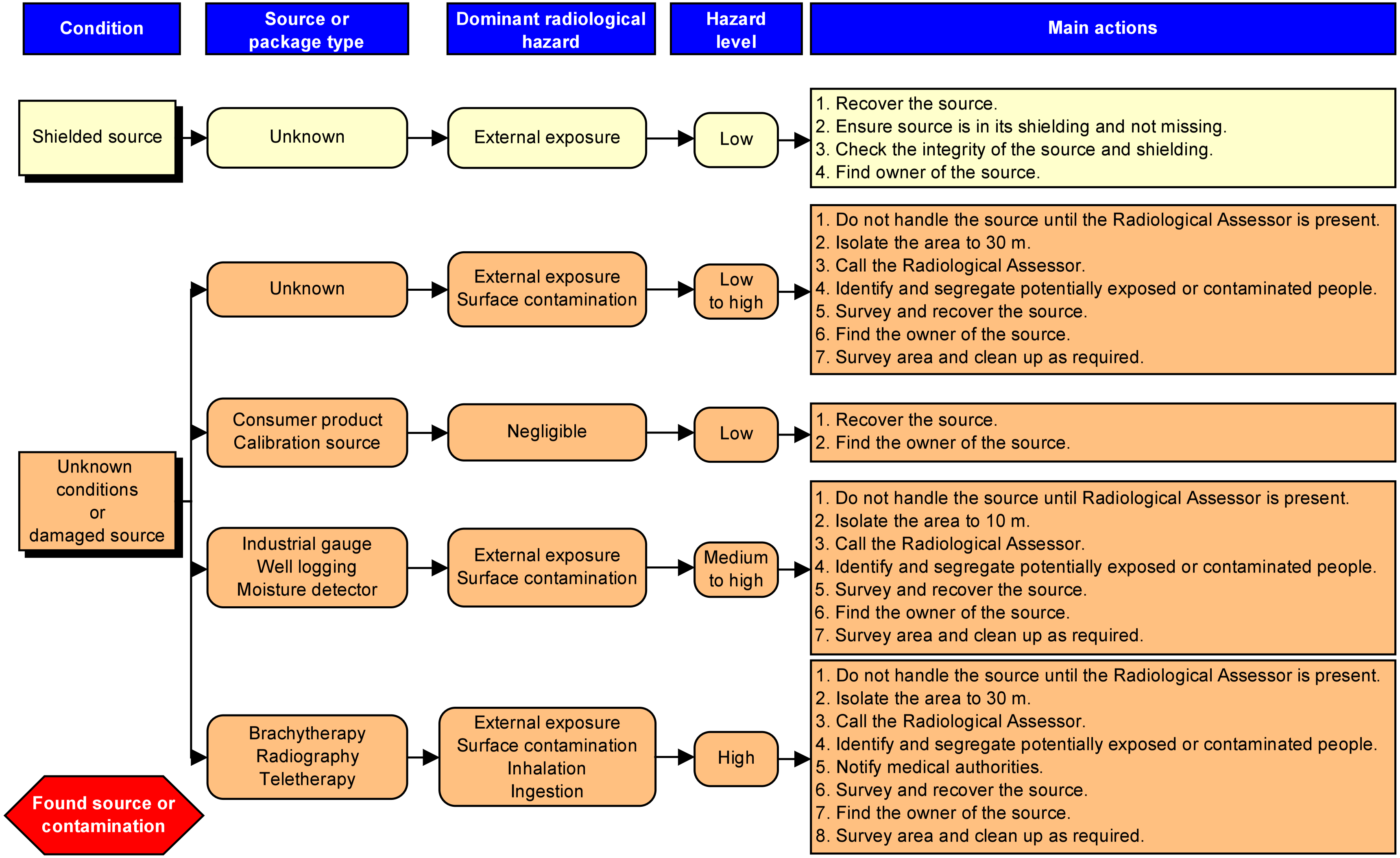


FIG. B1. Found source or contamination.

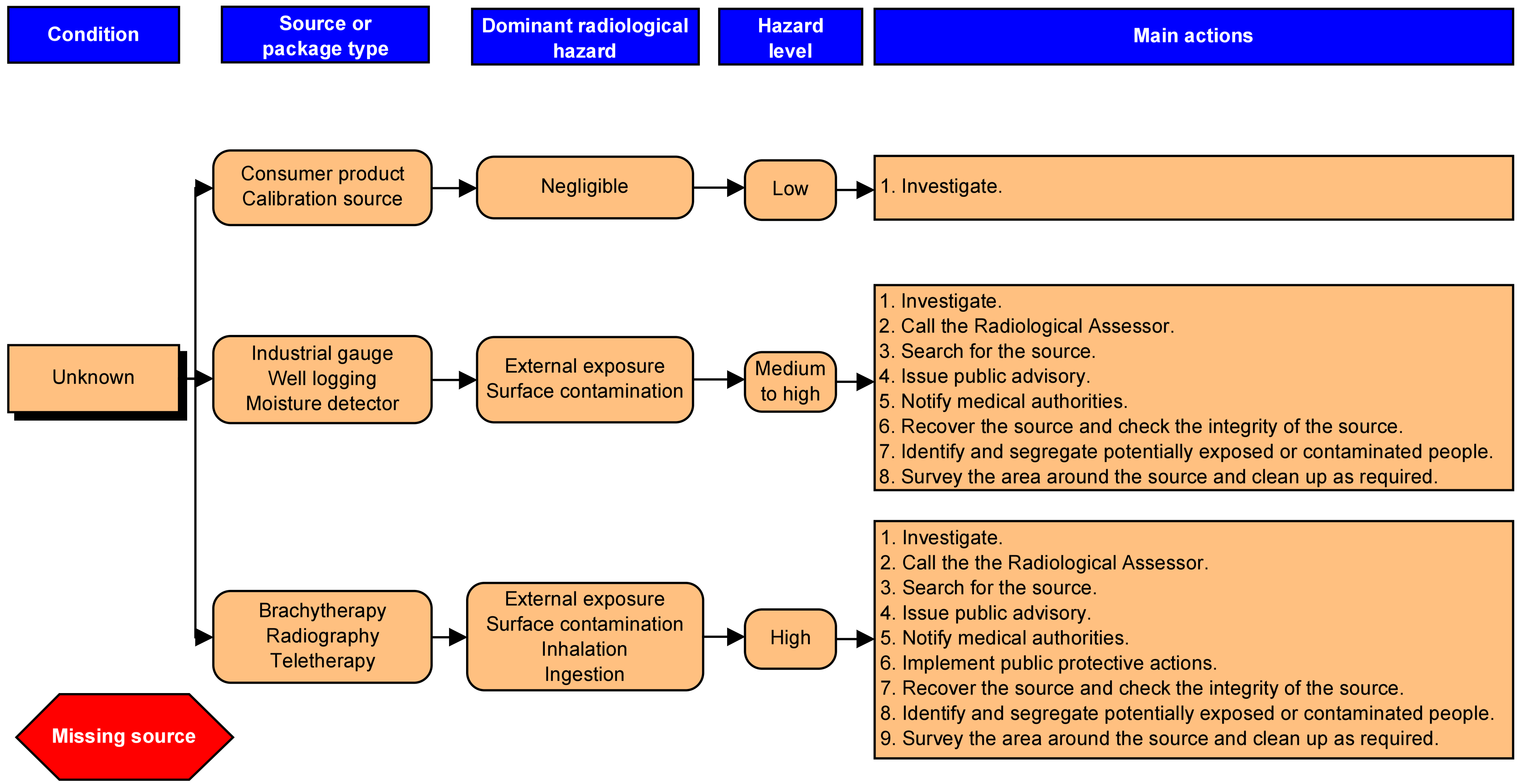


FIG. B2. Missing source.

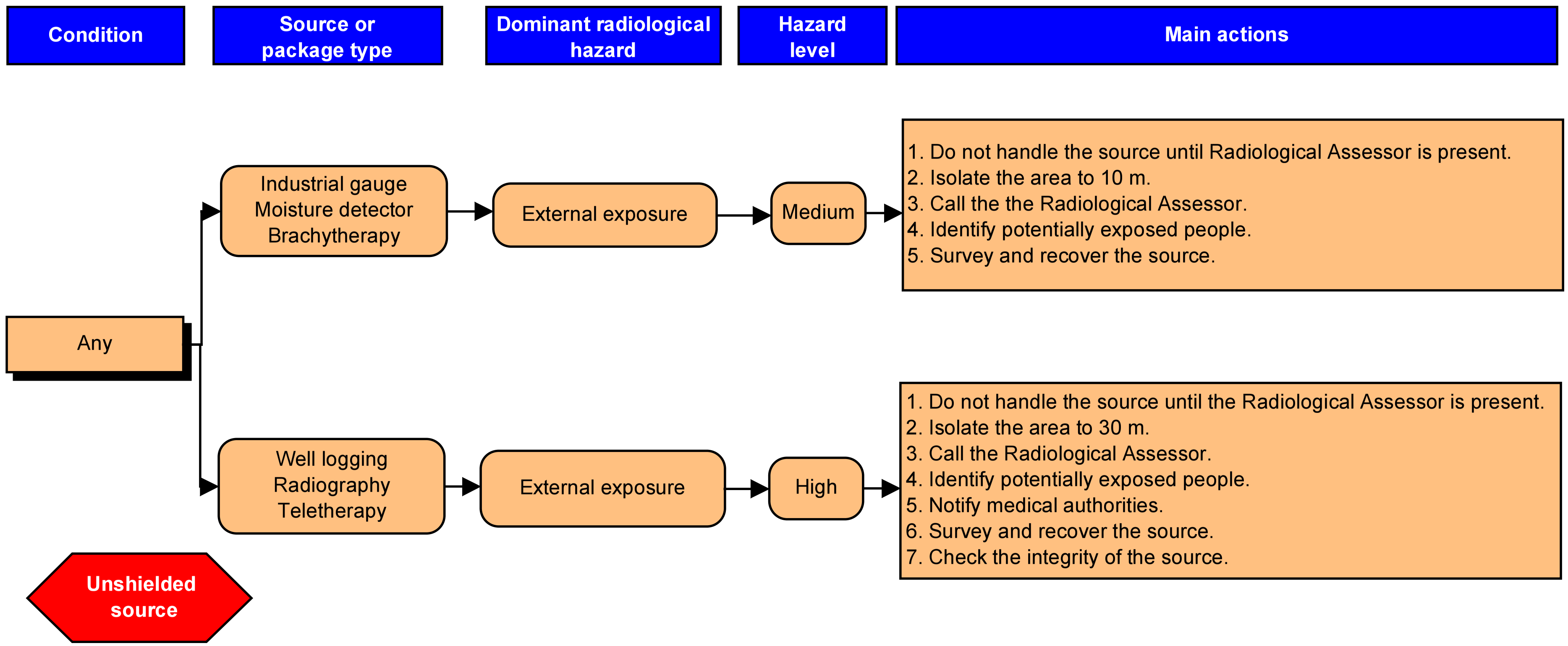
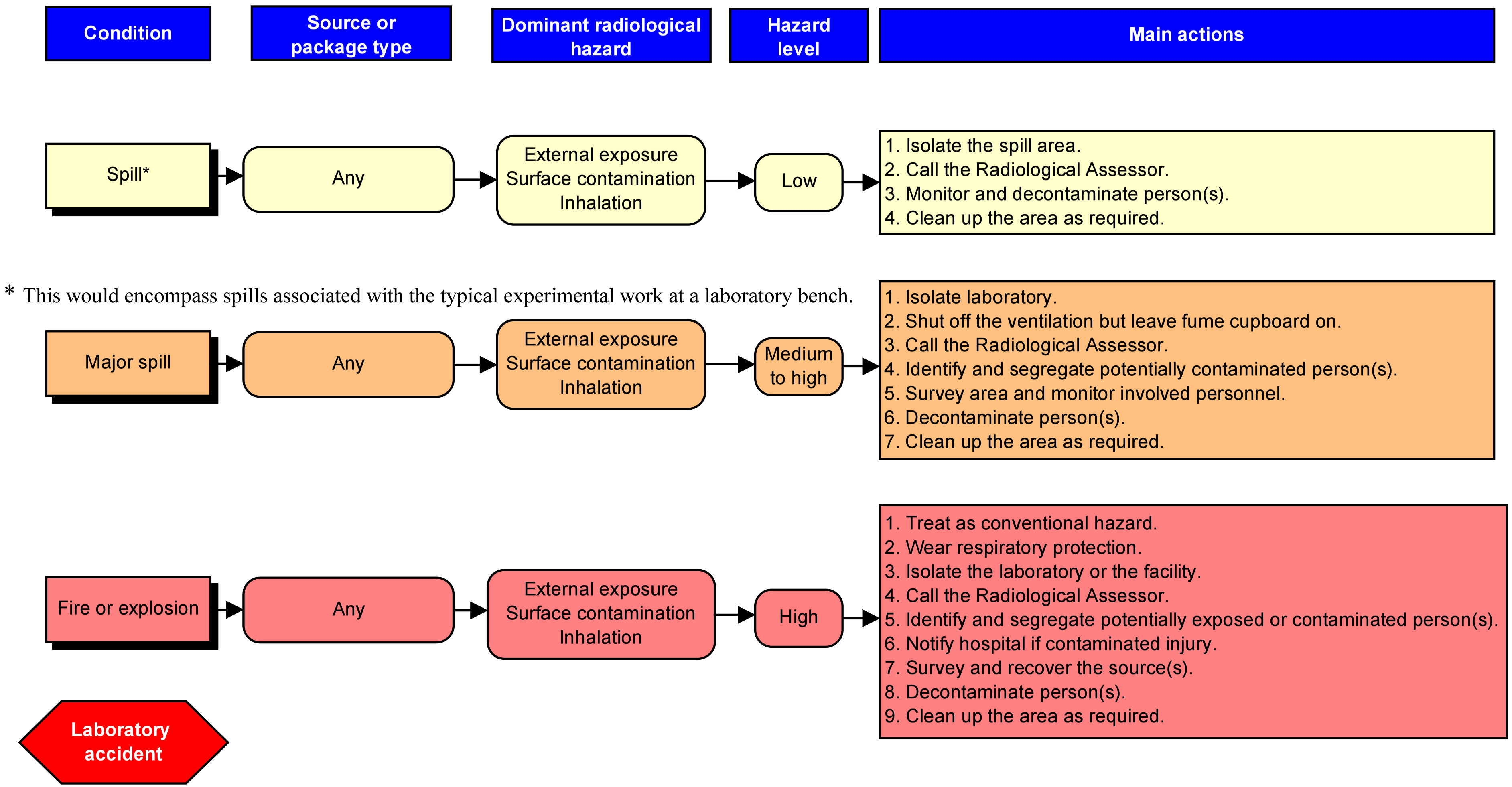


FIG B3. Unshielded source



* This would encompass spills associated with the typical experimental work at a laboratory bench.

FIG. B4. Laboratory accident.

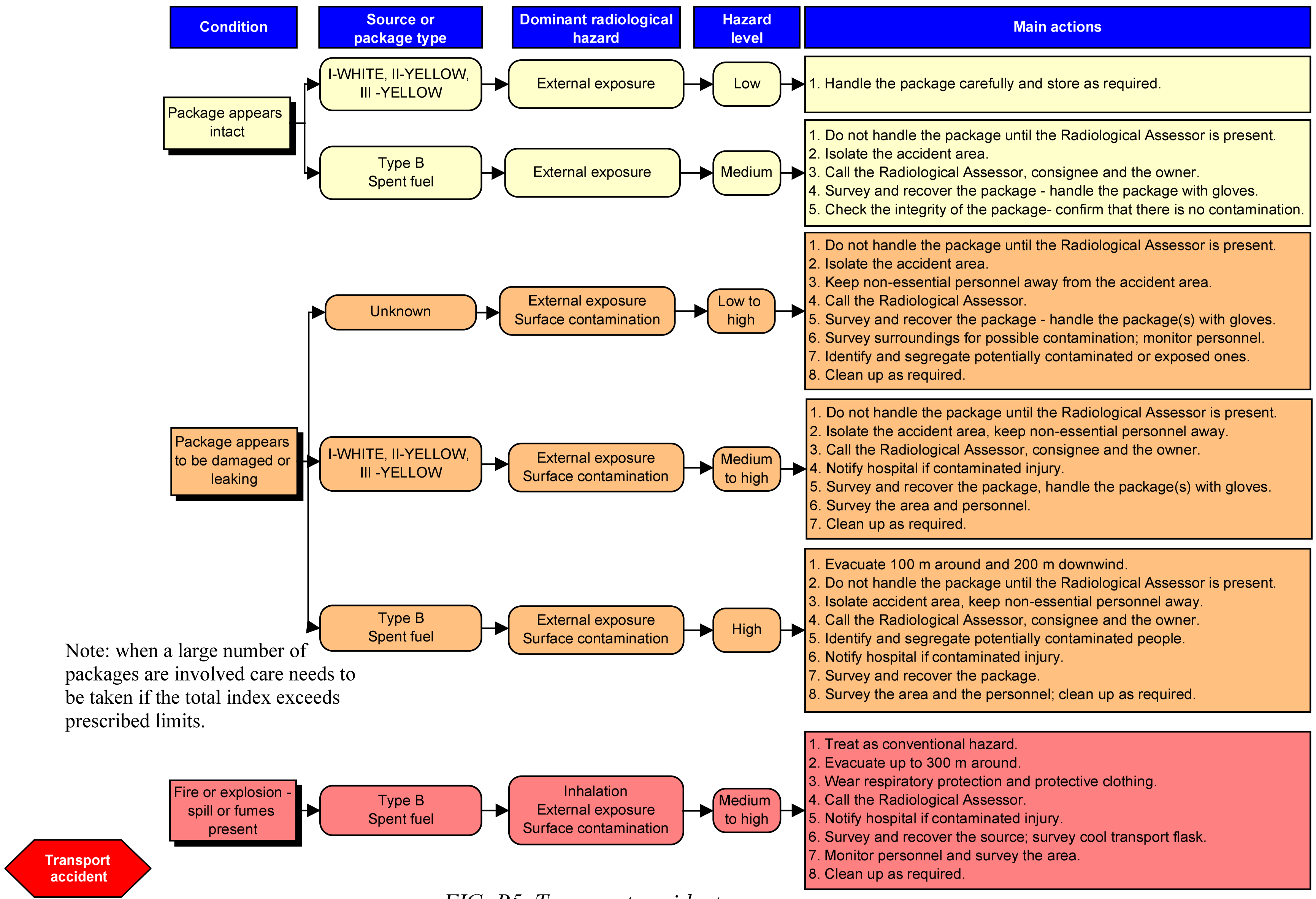
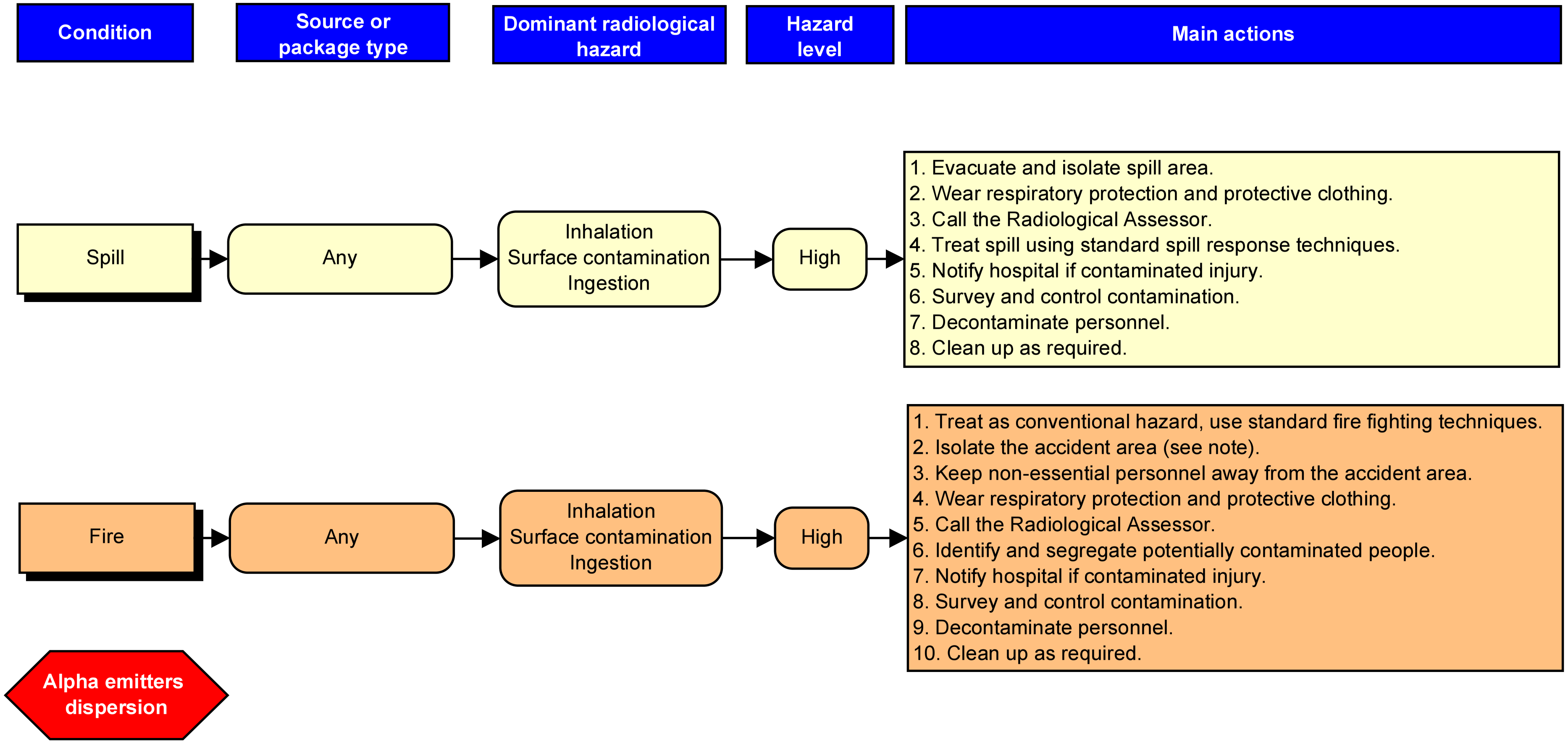


FIG. B5. Transport accident.



Note: Many of the sealed sources in use in industry are of special form designed to withstand high temperatures. Where unsealed alpha radioactive material is in use or very large sealed sources then it may be necessary to consider evacuation out to 300 m.

FIG. B6. Dispersion of alpha emitters.

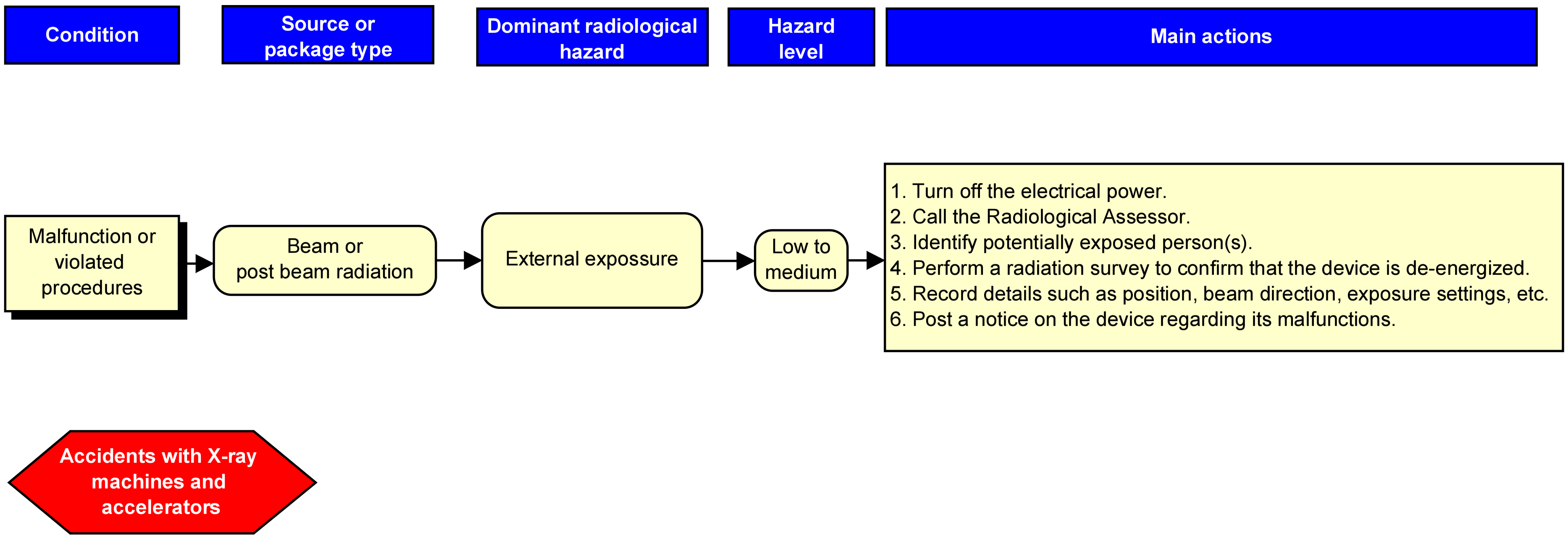


FIG. B7. X ray machines and accelerators

Purpose
To provide guidance on managing the actions to mitigate the consequences, limit exposure to the public and emergency workers, limit the spread of contamination, recover the source and/or clean up in emergency involving radiation source(s) or material.

Discussion
This is a broad category, which includes found source or contamination, missing source, unshielded source, accident in a laboratory or research facility, transport accident and dispersion of alpha emitters. However, initial precautions on approaching the source or contamination are the same. It may not be known *a priori* if there is contamination present (i.e. whether the source has been breached). Therefore, unless assurances are provided to the contrary, response to these types of accident should initially assume that contamination might be present. The extent of the hazard depends on the nature and activity of the source, which may not be known initially.

Input
- Notification of a potential or real emergency situation (Worksheet A1).

Output
- Assessment of the emergency
- Decisions on protective actions
- Public information announcements

Step 1
1.1 Designate the senior official on the scene as on-scene controller and establish communication with the scene. Provide initial instructions to the on-scene controller.

Initial instructions should address the following considerations, as applicable:

- rescue injured persons first;
- fight conventional hazard (e.g. fire) first;
- confine the source or contamination;
- set security perimeter at a safe distance (see Table C1);
- isolate people who may be contaminated;
- protect emergency workers;
- perform radiological survey;
- limit the spread of contamination.

1.2 Determine whether the event is serious enough or has a sufficient public interest to warrant sending a national level on-scene controller to assume overall control.

Step 2
If not already done, dispatch all necessary emergency responders to the scene. Inform them what radiological hazards may be present. Brief them on personal protective actions.

Determine in cooperation with on-scene controller if additional relevant and necessary resources may be required:

i. other emergency response services (firemen, police, civil defence, medical responders, etc.);
ii. regulatory authorities;
iii. members of your staff;
iv. other departments within your organization;
v. private companies (e.g. waste management, clean up teams, heavy equipment suppliers).

Step 3
Ensure that the on-scene controller is informed of contacted resources that could arrive at the scene.

Step 4
Get regular reports from the on-scene controller on:

i. status of the conventional hazards;
ii. status of the radiological hazards;
iii. public safety;
iv. recommended and implemented protective actions.

Regularly update the information in *Immediate Response Actions Record* (Worksheet B1).

Step 5
Based on monitoring results and recommendations from the radiological assessor reassess protective actions. Make decisions on additional protective actions for the public and instruct the on-scene controller if needed.

Step 6
Ensure that the radiological assessor monitors contaminated or potentially contaminated people and that, if required based on the advice from the radiological assessor, they are sent by appropriate means to a hospital. If so, notify the hospital that contaminated or potentially contaminated patients are being sent, and arrange for radiological support to the hospital.

Step 7
Inform the media and the public as needed in cooperation with the on-scene controller.

NOTE

The public has a right to know the facts, and the media has a legitimate interest in telling the public about these facts. The truth about a radiation emergency is almost certain to be less alarming than the exaggerated ideas that will circulate in the absence of public understanding based on factual public announcements.
Field teams SHOULD NOT provide data to the public but may provide the phone number for contacting the emergency manager. Field teams may explain WHAT they are doing and WHY.

Step 8

When the source and the contamination, if present, have been confined, coordinate source recovery and clean up activities. It may be necessary at that point to consult with the radiological assessor on the best options and on additional resources required. It may also be necessary to designate another on-scene controller (if the initial on-scene controller is a member of the emergency response team) to allow part of the emergency response services to return to their normal duties.

Step 9

Reassess the situation whenever there is any major change of status of the emergency.

Step 10

In consultation with the radiological assessor or any other professionals develop plans for source recovery and cleanup operations (if needed). Develop strategy for waste management (if any).

NOTE

In some cases the emergency workers may have been involved with the accident itself e.g. an industrial radiographer who finds a source stuck in an exposed position may also be involved with the source recovery because of his/her knowledge of the equipment. In such cases the personal dosimeter he/she wore during the accident should be replaced with a new one, this will permit the doses associated with the accident and the source recovery to be separately identified.

Step 11

Plan and rehearse the actions for recovery of the source.

Step 12

Supervise source recovery, clean up operations and waste management (if any).

Purpose

To provide guidance on identifying, locating and recovering a missing source while ensuring public and emergency workers safety.

Discussion

A lost source can be a significant hazard if members of the public who are not aware of the danger of radiation find it. The first priority in this type of accident will be to identify the location of the source as well as all the persons who may have unknowingly handled it. Information on the type of source, its activity and other physical and chemical characteristics will be essential in assessing its potential hazard for the public. Efforts to track the source would normally start at the last known location. Investigative work should be conducted to retrace the sequence of events. Reports from the medical community on possible contaminated or overexposed victims, surveys by radiological assessor and investigation by police are all possible sources of information on the source's whereabouts.

The emergency manager should be aware of the possibility that a missing source or radioactive material may be subject to illicit trafficking.

Input

- Notification of missing source (Worksheet A1)
- All available documentation and information on missing source

Output

- Assessment of hazards to the public
- Appropriate search plan
- Decisions on protective actions
- Public information and advisories if needed

Step 1

Assess all available documentation and information regarding missing source. Contact source owner.

NOTE
Information from different sources may be conflicting or confusing. Wherever possible, information obtained from different sources should be compared and checked to verify consistency and completeness.

Step 2

Contact the police to initiate the investigation of the source location. Reconstruct history and conditions of loss.

Step 3

Assess the level of the hazard, using Fig. B0 and B2. If the level of the hazard is high or medium, contact the radiological assessor. Provide the known information on the source type, activity and characteristics, and obtain from the radiological assessor an estimation of the potential hazard to the public.

Step 4

In conjunction with the radiological assessor, the source owner and the police, determine what public advisory, if any, should be issued. Consider the following possibilities:

i. Alert the hospitals and ask to be notified if persons with symptoms of radiation exposure or contamination arrive at the hospital.
ii. Alert the media to warn the population about the missing source, how it can be recognized, what it can do, what to do if discovered, and who to call for questions or for reporting that the source has been seen.

Step 5

Based on initial reports from the investigation, develop a search strategy. This will involve cooperation between the source owner, the police and radiological assessor. The search team(s) should include personnel trained in recognizing radiation sources and packages and in measuring radiation. Where possible all members of the search team should wear personal dose meters and at least one must. Search team members should use the monitoring procedures described in Ref. [6]. The search strategy should consider the following:

i. look for objects bearing the radiation symbol,
ii. look for objects with the name of the source owner or manufacturer,
iii. look for lead or other heavy shielding containers,
iv. for searches over wide areas, aerial or vehicular surveys with sodium-iodide or other suitable detectors, could be helpful in quickly determining the location of the source or the extent of contamination, if any; a search on foot will always complete the survey,
v. survey sanitary disposal sites and recycling facilities.

Step 6

Organize search team(s) and proper instrumentation and equipment. Brief them thoroughly in the operational aspects of the search task and what radiological hazards they could expect. All search activities shall be conducted so that exposure is maintained as low as reasonably achievable.

Provide information such as:

i. maps,
ii. building layouts,
iii. initial results of the investigation,
iv. people who may have been involved,
v. number of members of the public potentially affected.

NOTE

For searching in facilities or restricted areas administrative clearances may have to be obtained for the members of the survey team(s).

Step 7

Supervise search. Keep a record of all actions, decisions and findings. The planned routes of the survey and the results of visual observations and dose rate measurements should be entered on the survey maps, which become the basic document of the search.

Step 8

If the search was unsuccessful, document all facts and re-assess search strategy. Proceed with searching.

Step 9

When the source is located perform immediate actions to render source safe — the most immediate action to be taken once a source has been located is to ensure that members of the public in the vicinity are adequately protected (see Table C1). In addition:

i. inform the public that the source has been found (if prior notification has been given);
ii. ensure that all persons who may have been exposed are identified and, if required based on the advice from the radiological assessor, report to the hospital;
iii. provide radiological assistance to the hospitals, if required;
iv. initiate decontamination of persons (if needed) and make sure that medical follow up is provided.

Step 10

In consultation with the radiological assessor or any other professionals develop plans for source recovery and cleanup operations (if needed). Develop strategy for waste management (if any).

Step 11

Plan and rehearse the actions for recovery of the source.

Step 12

Supervise source recovery, cleanup operations and waste management (if any).

SECTION C

RESPONSE AT THE SCENE

Caution: *The procedures in this section should be adapted to reflect local and facility conditions and capabilities for which they will be applied and integrate into emergency response arrangements for conventional accidents*

Purpose
To provide guidance on mitigating the consequences of an accident and implementing response actions at the scene.

Discussion
If the accident occurs at a facility the most likely person to take charge will probably be the facility radiation protection officer, who is likely to have monitoring equipment and the knowledge to use it. In other situations the first professional person or team on the scene of an accident will usually be police, fire service or emergency medical responder. The senior person at the scene normally assumes the role of the on-scene controller until relieved by appropriate authorities. The procedure gives basic steps to mitigate the consequences of an accident and to implement response actions at the scene.

In almost every case, the hazard due to the radiation is less than other conventional hazards present, such as fire, explosion etc.

CAUTION
Facilities may have radioactive sources that can produce lethal doses to responders. Any response in these facilities must be directed by radiation safety personnel or authorized users of the source.

Input
- Notification of an accident
- Briefing by response initiator
- Situation at the scene

Output
- Response actions at the scene
- Liaison with the emergency manager

On notification

Step 1
Alert the radiological assessor (if not alerted yet). Establish contact with the emergency manager.

NOTE
The order in which some of the steps below are carried out might vary dependent on the capability of the on-scene controller and his/her location relative to the accident scene at the time of notification. In particular he/she may need to give initial advice over the telephone to the response initiator.

At the scene

Step 2
Approach the scene cautiously and resist the urge to rush in. Where there is the potential for release of radioactive material the approach to the scene should be from upwind. Assess the situation. Observe possible signs that radiation may be present (see Appendix IV) and may have spread, such as:

- placards with the radiation symbol,
- information from witnesses who may know something about the nature of the hazard,
- packages bearing the radiation symbol,
- spill, fire or explosion.

If you have survey meters, measure dose rates and check for contamination. Turn on the instrument while approaching the scene to provide the first indication of encountering radiation. DO NOT approach the suspected area of the source without the dose rate being measured.

CAUTION

Alpha particles and neutrons CANNOT be detected with gamma/beta survey meters.

Limit time spent in the immediate hazard area. Try to avoid direct contact with damaged or leaking containers.

Alpha emitters represent a significant inhalation hazard and require respiratory protection. The use of breathing apparatus requires specialised training, and the equipment should only be used by trained professionals.

Step 3
Remove non-essential personnel and members of the public from the accident area. If contamination is suspected, keep them in a separate area until the radiological assessor can monitor them for contamination.

Step 4
If persons involved in the accident appear to be injured use standard methods for medical first aid. DO NOT DELAY LIFE SAVING ACTIONS DUE TO THE PRESENCE OF RADIATION!

4.1 Remove the injured persons from the hazard area as soon as possible.
4.2 Notify Emergency Medical Responders and inform them that the victim may be contaminated with radioactive material.

Step 5
Supervise response actions by emergency responders according to the following priorities and procedures. If the designated first responders are not at the scene, designate members from other teams to carry out those tasks till the special teams arrive on the scene.

Action	First Responder:	Follow steps in Procedure:
Provide medical first aid	Emergency Medical	C4
Fight fire and control spills in accordance with standard procedures	Fire service	C3
Establish security and safety perimeters and control public and personnel access and egress at a initial safe distance (see Table C1 for safe distances and Fig. C1 for layout of the accident scene) i. If there is a fire, contamination may be spread beyond the accident scene. The radiological assessor must survey outside the immediate area. ii. Isolate objects with suspected contamination and delay clean up until instructed by the emergency manager or the radiological assessor.	Police	C2
Co-ordinate with facility response	Facility	C5

Step 6

Ensure that emergency responders are aware of emergency worker personal protection guides (Procedure C6) and that they are using appropriate precautions, as follows (see Table C1 for guidance on safe distances):

If a source is present

i. If the source or package is unknown, do not handle, wait for advice from the radiological assessor.
ii. If the source or package is damaged or appears to be leaking, assume that there is contamination. Do not handle. Limit the traffic of emergency responders in and out of the area and wait for the radiological assessor.
iii. If the package bears a category I-WHITE, II-YELLOW or III-YELLOW label AND appears to be intact, and it is urgent to remove the package for any reason, handle the package with care, put it in a bag, and hand over to the radiological assessor when arrives at the scene.

If contamination is suspected

i. Workers go in and out through the access control point, wear gloves and protective clothing (if available) and respiratory protection (if air contamination is suspected).
ii. If personnel with survey meters are present, emergency responders must be monitored prior to leaving the area.
iii. If no survey meters are present, limit the traffic of emergency responders outside the immediate area.
iv. Wait until the radiological assessor can monitor the emergency responders before letting them leave the scene. Animals, vehicles, equipment or other items suspected of being contaminated should not be permitted to be removed from the area unless released by radiological assessor.

NOTE

Under hazardous working conditions (heat, fire, fumes, etc.) there may be a need to medically check emergency responders for fitness (pulse, temperature, blood pressure, etc.) at pre and post-entry to the accident scene. Emergency Medical Responders can be asked to perform these checks.

Step 7

Once the radiological assessor is at the scene, ensure that proper contamination control procedures are implemented under his/her supervision.

Step 8

Get regular briefings from the radiological assessor on:

i. extent of contamination;
ii. required safety and security perimeters;
iii. protective actions required for emergency workers;
iv. time limits for emergency workers in the hazard area;
v. protective actions for the population;
vi. any difficulties encountered in implementing the actions.

Step 9

Adjust safety perimeter as required based on monitoring results or as recommended by the radiological assessor. Implement protective actions approved by the emergency manager as required. If the emergency manager cannot be reached, implement recommended protective actions (by the radiological assessor) if urgent.

Step 10

Provide regular updates to the emergency manager.

TABLE C1 EXAMPLES OF INITIAL SAFE DISTANCES IN RADIOLOGICAL ACCIDENTS

Situation	Initial safe distance
Intact package with a I-WHITE, II-YELLOW or III-YELLOW label	Immediate area around the package
Damaged package with a I-WHITE, II-YELLOW or III-YELLOW label	30 m radius or at readings of 100 μSv/h
Undamaged common source (consumer item) such as smoke detector	Immediate area around the source
Other unshielded or unknown source (damaged or undamaged)	30 m radius or at readings of 100 μSv/h
Spill	Spill area plus 30 m around
Major spill	Spill area plus 300 m around
Fire, explosion or fumes, spent fuel, plutonium spill	300 m radius or at readings of 100 μSv/h
Explosion/fire involving nuclear weapons (no nuclear yield)	1000 m radius

Initial safe distances recommended in Table C1 are for open air situations. Inside facilities smaller distances may be dictated by the ease of controlling access, and that structures provide shielding.

Post-emergency activities

Step 11

Evaluate the response and sum up lessons learned. Report to the emergency manager.

Purpose
To provide guidance for police response under radiological conditions.

Discussion
Police will likely be first on the scene if an accident occurred in a public place. The most likely accident scenario for which police have the role of first responder is a transport accident.

Input
- Notification of an accident
- Situation at the scene

Output
- Response actions at the scene

Step 1
If you are first at the scene assume the role of the on-scene controller until relieved. Follow Procedure C1. If not, get briefing by the on-scene controller.

Step 2
Secure the accident area (cordoned off area) and assure the safety of people. Use Table C1 to determine approximate safe distance from the source. See Fig. C1 for typical layout of security and safety perimeters.

If you have survey meters set safety perimeter at 100 μSv/h. Do not approach the area if the dose rate exceeds 10 mSv/h except for life saving and/or preventing the development of catastrophic conditions.

Set security perimeter outside the safety perimeter in order to keep the public from interfering with emergency responders.

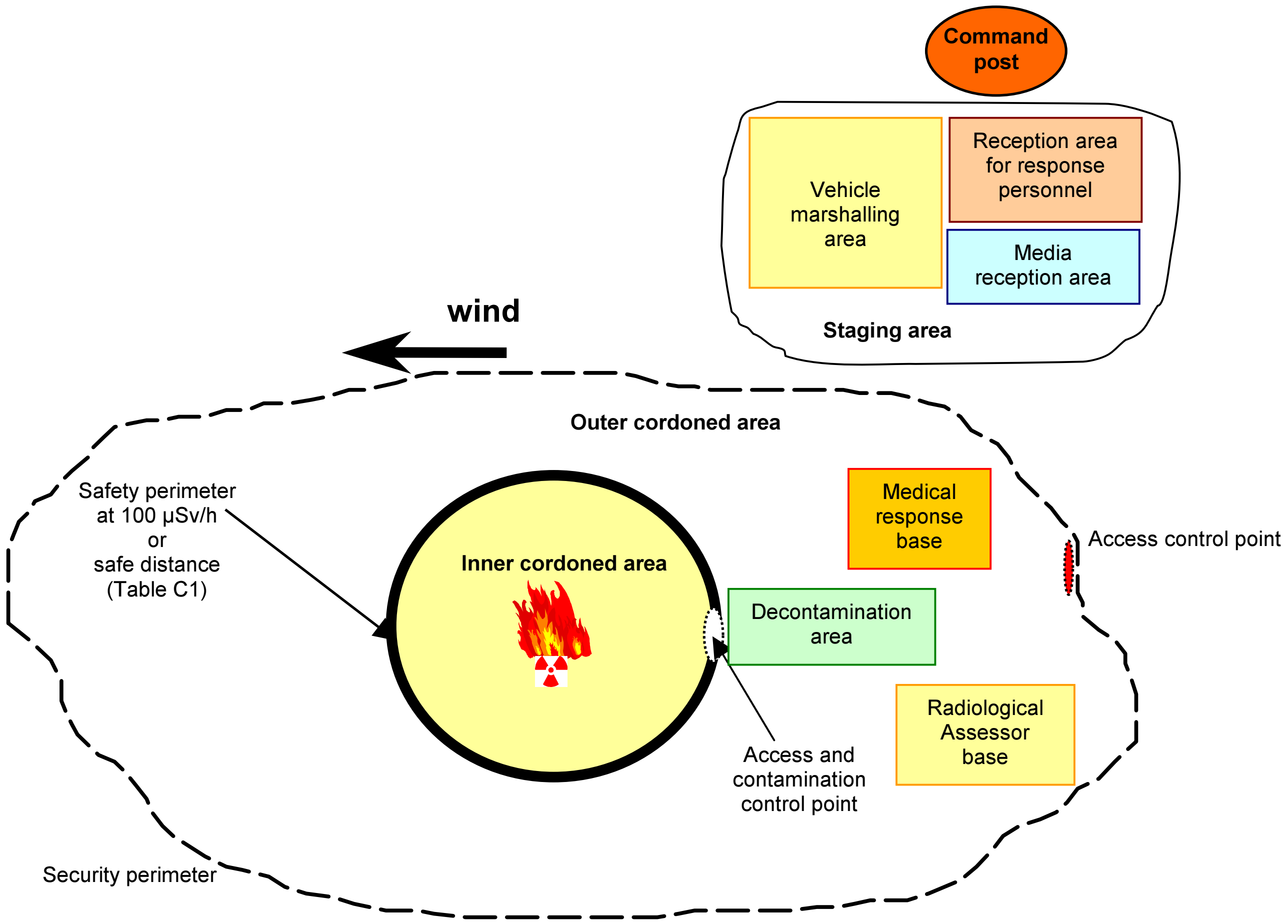
Step 3
Control access and egress from the cordoned off area using standard procedures.

NOTE

The best method to control access and egress is to use physical barriers. The placement of the barriers will need to take account of local conditions and the extent to which exposures can be reduced. Access to and egress from the cordoned-off area should be made through established checkpoint(s). This checkpoint(s) should serve as an assembly point for emergency personnel, as well as a radiological control station(s).

Step 4

Record names and addresses of all persons involved in the accident or who happened to be near the accident scene. If there is suspected contamination keep people in a segregated area until the radiological assessor can monitor them.



Notes:

i. The layout considers the need for a full-scale response to an accident that either poses a major health hazard or a security threat. In minor accidents this layout can be adapted for a more limited response.

ii. At the contamination access control point background reading on the contamination monitors should be sufficiently low to allow suitable detection limits.

FIG. C1. Example of a layout of safety and security perimeter.

Step 5

Perform personal and equipment contamination check using procedures in Ref. [6] or request assistance from the radiological assessor.

CAUTION

DO NOT leave the scene of an accident without being checked for possible personal contamination. DO NOT take any equipment out of the scene area prior to being checked for possible contamination.

Purpose
To provide guidance for fire service response under radiological conditions.

Discussion
In their traditional role, fire fighters are usually the ones responding to accidents involving fires and hazardous material. Radiation sources represent one of those hazardous substances. Techniques and procedures for responding to spills or fires involving radioactive material are therefore essentially the same as those for other hazardous substances. However, additional precautions and considerations must be taken into account when responding to an accident with radiation sources or radioactive materials.

If fire fighters are first on the scene responders they may need to perform also some tasks of police.

CAUTION
At many facilities radiation hazards will be just one of many hazards present e.g. chemical, biological etc., that Fire Services will need to be aware of and take into account in their emergency plans. In most cases the non-radiological hazards will dominate, but there are some radioactive sources that can give a lethal dose of radiation in a short period of time e.g. irradiation and teletherapy sources. Any response to such facilities must be directed by radiation safety personnel or authorized users.

Input
- Notification of an accident
- Situation at the scene

Output
- Response actions at the scene

Step 1
If you are first at the scene assume the role of the on-scene controller until relieved. Follow Procedure C1. If not, get briefing by the on-scene controller.

Step 2
If you have dosimeters wear them. Wear protective clothing as required.

NOTE
Protective clothing requirements will normally be determined by the conventional hazards. In case of vapour or fumes use protective masks or breathing apparatus.

Step 3
Use standard fire fighting and spill control techniques. Try to minimize spread of possible contamination.

NOTE

Plastic sheets or tarpaulins can be used to cover loose materials to help minimise their dispersion.

Runoff water from any fire fighting efforts or leakage from damaged containers or packages should be retained within the inner cordoned area by erecting temporary dikes using shovels or other available tools.

In case of:	Use:
Small fires	Dry chemical, CO_2, water spray or regular foam
Large fires	Water spray, fog (flooding amounts)
Small liquid spills	Sand, earth or other non-combustible absorbent material to cover and soak up spill
Large spills	Dike far downhill to collect runoff water

CAUTION

Do not walk into or touch spilled material. Avoid inhalation of fumes, smoke and vapours, even if no hazardous materials are known to be involved. Do not assume that gases or vapours are harmless because of lack of smell — odourless gases or vapours may be harmful.

In case of a spent fuel in a fire, spray cool with water fuel flask(s).

Step 4

Do not move damaged containers. Try to avoid direct contact with damaged containers. If feasible move undamaged containers present at the scene to a safe area (out of the range of fire).

Step 5

Perform personal and equipment contamination check using procedures in Ref. [6] or request assistance from the radiological assessor.

CAUTION

DO NOT leave the scene of an accident without being checked for possible personal contamination. DO NOT take any equipment or other items out of the scene area prior to being checked for possible contamination.

Purpose
To provide guidance on emergency medical response under radiological conditions or for the first responder on the scene who must perform first medical aid to injured person(s).

Discussion
Emergency Medical Responders will most likely arrive on the accident scene in a short time after the accident. Until then, police, fire service, or other personnel who have been adequately trained in techniques of basic first aid can provide emergency first aid for injured person(s). Radiation exposure or contamination with radioactive materials does not cause immediate signs or symptoms and therefore if accident victims are unconscious, disoriented, burned, or otherwise in distress look for causes other than radiation. See Appendix II for more detailed information on medical preparedness and response.

Input
- Notification of an accident
- Situation at the scene

Output
- Response actions at the scene

Step 1
If you are first at the scene assume the role of the on-scene controller until relieved. Follow Procedure C1. If not, get briefing by the on-scene controller.

Step 2
If you have personal dosimeters wear them. Wear protective clothing as required.

Step 3
Perform search and rescue for injured persons as soon as possible. Assess and treat life-threatening injuries immediately. Perform routine emergency care during extrication procedures. Remove injured persons from the hazard area as soon as possible. If necessary, request additional medical help.

Step 4
Perform radiological triage and isolate contaminated person(s). Remove all contaminated clothing unless medically contraindicated. Isolate (bag and secure) clothing, shoes, and personal belongings. Cover wounds with sterile dressings and prepare injured persons for transport to the hospital. Transport in a manner suitable to prevent further contamination of the patient, the ambulance, and attending personnel.

NOTE

A simple classification of the cases may be as follows (for details see Appendix II):

(a) Individuals with signs of radiation exposure and other injuries and/or burns; patients should be transported urgently to a specialised hospital after appropriate medical care.

(b) Individuals without signs of radiation exposure but with combined injuries and/or burns; patients should be taken to the specialised hospital where the medical treatment can be adapted to the type of pathology.
(c) Individuals with potential radiation symptoms; patients do not require immediate medical treatment but require urgent evaluation of the levels of dose.
(d) Uninjured and contaminated or possibly contaminated; these individuals need to be monitored to assess the degree of contamination if any.
(e) Individuals believed to be free of injury and radiation exposure; patients are normally sent home. Sometimes medical follow-up should be provided to ensure that the first assessment was correct and to evaluate the dose more accurately.

Take care not to spread contamination:

i. move the ambulance bed to the clean side of the contamination control line and unfold a clean sheet or blanket over the bed;
ii. place the patient on the covered bed and fold the sheet or blanket over the individual to “package“ the patient to aid in contamination control. Do not wrap injured persons in plastic as this may lead to hyperthermia;
iii. if injured persons are properly wrapped in a sheet or blanket it is not necessary to cover the inside of the ambulance although plastic covering for the floor may be desirable.

Step 5

Establish contact with the police to obtain names and addresses of the involved population for further interview(s).

Step 6

Inform the receiving hospital about the nature of the conventional injuries and any known or suspected exposure or contamination with radioactive materials. Identify the radioactive materials if known.

Step 7

Perform personal and equipment contamination check using procedures in Ref. [6] or request assistance from the radiological assessor.

CAUTION

When the medical conditions do not require urgent hospitalisation DO NOT leave the scene of an accident without being checked for possible personal contamination. DO NOT take any equipment out of the scene area prior to being checked for possible contamination.

If you have to leave the scene urgently then contamination control procedures should be done as soon as reasonable.

NOTE

Under hazardous working conditions (heat, fire, fumes, etc.) there may be a need to medically check emergency responders for fitness (pulse, temperature, blood pressure, etc.) at pre and post-entry to the accident scene.

Purpose

To provide guidance on initial response in case of an accident at a facility and on coordinating response with off-site emergency responders.

Discussion

An accident will often be discovered by the user and managed by the on-site emergency organization. The facility staff will need to support and work in collaboration with off-site emergency responders, if:

i. the consequences of the accident extend outside the facility; or
ii. the facility resources are insufficient to deal with the emergency; or
iii. the accident is reported by someone outside the facility staff and involves off-site emergency responders.

Input

- Situation at the scene

Output

- Initial response actions
- Request for assistance (if needed)
- Support to off-site emergency responders (if any)

General approach

Step 1

Alert the facility's radiological assessor (if any) and facility's management (the emergency manager).

Step 2

If personnel involved in the accident appear to be injured use standard methods for medical first aid (if qualified). DO NOT DELAY LIFE SAVING ACTIONS DUE TO THE PRESENCE OF RADIATION! Remove the injured persons from the hazard area as soon as possible.

Step 3

Confine and mitigate the hazard as much as possible.

3.1 Isolate and secure the accident area (cordoned off area) and assure the safety of people and the environment. Use Table C1 to determine approximate safe distance from the source. Shut off ventilation system if applicable.
3.2 If radiological assessment resources are available, start a survey of the affected area. Set safety perimeter at 100 μSv/h. Do not approach the area if the dose rate exceeds 10 mSv/h except for life saving and/or preventing the development of catastrophic conditions.
3.3 Evacuate non-essential personnel from the area.

3.4 Record names and addresses of all persons involved in the accident.
3.5 Do not leave controlled area unattended.

CAUTION
Avoid any contact with the radioactive source or material. Equipment or other items suspected of being contaminated should not be permitted to be removed from the area unless released by radiological assessor.

Step 4
If on-site and/or off-site emergency responders were alerted, remain at the scene until they arrive. Report to the on-scene controller on arrival. Brief him/her on the situation and actions taken. Warn him/her of possible hazards.

Step 5
If radiological expertise and resources are available at the facility, provide radiation protection assistance, advice and equipment to the emergency responders.

Step 6
Perform personal and equipment contamination check using procedures in Ref. [6] or request assistance from the radiological assessor.

CAUTION
DO NOT leave the scene of an accident without being checked for possible personal contamination. DO NOT take any equipment out of the scene area prior to being checked for possible contamination.

X ray machines and accelerators

Step 7
Turn off the electrical power. Alert the radiological assessor of the facility (if any) and facility management (the emergency manager) in accordance with the existing emergency plan.

Step 8
Perform a radiation survey to confirm that the device (tube) is de-energized. Be aware that the radiation output can be directed in small angle beams, which may be difficult to detect.

Step 9
Do not move the device until details such as position, beam direction and exposure settings are recorded.

Step 10
Do not use the device until it is examined and repaired as necessary by a qualified expert or manufacturer. Post a notice on the device regarding its malfunction.

Purpose
To give emergency workers basic instructions on personal protection.

Discussion
Emergency workers are taken to be any member of the response team including any regulatory personnel. Personal protection guidance is given in three areas: general instructions, thyroid protection and as emergency worker turn back guidance.

Input
- on-scene controller directives
- Situation at the scene

Output
- Safely performed tasks
- Report back to the on-scene controller

General instructions

Step 1
Always be aware of the following general instructions:

GENERAL INSTRUCTIONS

- ALWAYS be aware of the hazards that you may encounter in the field and take the necessary precautions.
- NEVER attempt any field activities without the appropriate safety equipment. Always know how to use it.
- All activities SHALL BE conducted so that exposures are maintained as low as reasonably achievable.
- BE AWARE of turn back levels. Emergency worker turn back doses are to serve as guidance and not limits. Judgement must be used in their application.
- DO NOT linger in areas where the dose rate is **1mSv/h** or greater.
- BE CAUTIOUS proceeding to areas where the dose rate is greater than **10mSv/h**.
- You SHALL NOT proceed to areas in which the dose rates exceed **100 mSv/h** unless otherwise directed by the radiological assessor.
- USE time, distance and shielding to protect yourself.
- PRE-PLAN entry into high dose rate areas in conjunction with your supervisor.
- DO NOT take unnecessary risks. DO NOT eat, drink, or smoke in any contaminated areas.
- WHEN in doubt seek advice from your team leader or coordinator.

Thyroid protection

> **NOTE**
> A small portion of accidents may involve the release of radioactive iodine. In such cases the thyroid is the organ most at risk and stable iodine tablets can be used to block the uptake of radioactive iodine.

Step 2
Take a stable iodine tablet when instructed to do so by your field controller/supervisor (here it is assumed such tablets are in your kit).

Step 3
Record the fact that you have taken a tablet in your personal dose record form (Worksheet D1).

Emergency worker turn back guidance

> **NOTE**
> Emergency worker turn back guidance (Table D4) is given as an integrated external dose on a self-reading dosimeter. The value has been calculated to account for inhalation dose. You should take all reasonable efforts not to exceed this value; however, emergency worker turn back doses are to serve as guidance and not limits.

Step 4
Make sure that you fully understand the tasks and radiation protection procedures to be followed.

Step 5
Make all reasonable efforts not to exceed the turn back dose guidance given by the on-scene controller.

Step 6
Report back to the on-scene controller when tasks are completed and give details of any difficulties encountered.

SECTION D
RADIOLOGICAL RESPONSE

Caution: *The procedures in this section should be adapted to reflect local and facility conditions and capabilities for which they will be applied and integrate into emergency response arrangements for conventional accidents*

Purpose
To provide guidance on assessment of the radiological situation, on appropriate protective action recommendations, on recovering the source and initial cleanup operations.

Discussion
When activated in response to an emergency, the radiological assessor will be expected to evaluate the radiological hazards or risks associated with the loss or discovery of a source or contaminated materials or the consequences of a facility or transportation accident involving radioactive materials. The radiological assessor may also be called upon to recommend appropriate protective actions as well as the steps necessary to mitigate the hazard, including recovery and disposal of the radioactive material.

The extent to which the radiological assessor is able to effectively advise the emergency manager on the radiological aspects of the situation will depend greatly on the availability of accurate and comprehensive information.

This procedure gives the basic steps that should be followed after a potential or real emergency has been reported, which enable the radiological assessor to assess the radiological situation, to recommend appropriate protective actions and to take steps to recover the source.

A record keeping (data bank) is very important. The radiological response actions taken should be adequately registered and stored. This information may later be used for learning lessons or for legal arguments.

NOTE

Use adapted procedures from *Generic procedures for monitoring in a nuclear or radiological emergency* [6] for source/environment, personnel and equipment monitoring.

Input
- Notification of an accident or emergency situation (Worksheet A1)
- Briefing by the response initiator, the emergency manager, or the on-scene controller
- Current circumstances/status of the scene
- Identification of the actual or potential radiation hazard

Output
- Hazard/risk analysis
- Protective action recommendations for public and emergency workers
- Advice for on-scene management
- Consideration of recovery and initial cleanup strategies

On notification

Step 1
Obtain briefing on radiological situation (current circumstances/status at the scene) by the response initiator, the emergency manager, or the on-scene controller.

Step 2
Using the *Accident Registry Form* (Worksheet A1) and risk data (Table D5) perform preliminary evaluation of radiological situation at the scene.

Step 3
Establish communication with the emergency manager and the on-scene controller. Recommend to the emergency manager or the on-scene controller (if the emergency manager can not be reached) initial protective actions and steps for precautions against possible spread of contamination.

Step 4
Prepare necessary measuring instruments and personal protective equipment according to the nature of the expected hazard (see Appendix III and Table III1).

Step 5
Based on the evaluation of the radiological situation decide on necessary personal protective actions using Tables D3 and D4.

Step 6
Instruct response teams on personal protection. Hold further briefings to give new instructions (if necessary). Inform emergency manager.

Step 7
Establish exposure control for the emergency workers. Use the *Exposure Control Record* (Worksheet D1) for each emergency worker (including yourself).

NOTE
In some cases the emergency workers may have been involved with the accident itself e.g. an industrial radiographer who finds a source stuck in an exposed position may also be involved with the source recovery because of his/her knowledge of the equipment. In such cases the personal dosimeter he/she wore during the accident should be replaced with a new one. This will permit the doses associated with the accident and the source recovery to be separately identified.

Step 8
If needed activate radiological assessment team(s). Brief the team(s) on the current radiological situation, emergency worker protective actions and turn back guidance. Carefully explain tasks using Table D2 as guidance. Dispatch the team(s) to the event site.

Hold periodic briefings to discuss assessment priorities.

At the scene

Step 9

On arrival, report to the on-scene controller. If you are the first on the scene, assume the duties of the on-scene controller until relieved. Follow procedure for the on-scene controller (Procedure C1).

Step 10

Approach the scene carefully with instruments turned on. Unless the source or package is confirmed to be intact, assume that there may be contamination and monitor ground contamination levels using an appropriate contamination meter.

Survey the entire perimeter. If contamination is detected, or if external dose rate are greater than 10 μSv/h outside the safety perimeter, recommend to the on-scene controller that the safety perimeter be adjusted accordingly.

Step 11

Assess the radiological hazards based on the measurements. Evaluate the need for immediate protective actions (e.g. evacuation) for the public using Table D1.

TABLE D1. OPERATIONAL INTERVENTION LEVELS (OILs) IN RADIOLOGICAL EMERGENCIES BASED ON AMBIENT DOSE RATE MEASUREMENTS FROM GAMMA-EMITTING RADIONUCLIDES

Major exposure conditions	OIL	Main actions
External radiation from a point source	100 μSv/h	Isolate the area Recommend evacuation of cordoned area Control access and egress
External radiation from ground contamination over a small area or in the case of not very disruptive evacuation	100 μSv/h	Isolate the area Recommend evacuation of cordoned area Control access and egress
External radiation from ground contamination over a wide area or in the case of very disruptive evacuation	1 mSv/h	Recommend evacuation or substantial shelter
External radiation from air contamination with an unknown radionuclide(s)	1 μSv/h	Isolate the area (if possible) Recommend evacuation of cordoned area or downwind in case of open area

Step 12

Establish and supervise an access and contamination control point as near as possible to the safety perimeter, up wind, inside the security perimeter (see Fig. C1) where ambient dose rate is close to background. If for any reason the radiation level at the contamination control point increases to above 10 μSv/h, move the contamination control point to another upwind location within the security perimeter where the level is close to background or at least sufficiently low to allow suitable detection limits.

Request the on-scene controller to increase the security perimeter if more room is needed.

Step 13

If needed establish an area inside the security perimeter for decontamination and disposal of contaminated objects and clothing.

NOTE

Contaminated items will need to be labelled and recorded (see Procedure D2).

Step 14

If airborne contamination is suspected take air samples and evaluate them using appropriate procedures in Ref. [6].

Step 15

Make sure that respiratory equipment is used, if appropriate. In case of airborne radioactive iodine make decisions regarding thyroid blocking drugs.

NOTE

To protect against inhaled radioactive iodine, one single dose of stable iodine would generally be sufficient, as it gives adequate protection for one day. The risks associated with the administration of stable iodine in a single dose (100 mg iodine) are very small. In case of a prolonged release, however, repeated doses might be indicated.

CAUTION

For iodine prophylaxis to be effective the dose should be administrated prior to exposure or within a few hours (around four) of exposure. Administration of stable iodine more than 8 hours after exposure is ineffective.

Use of stable iodine by emergency workers does not negate the need for use of respiratory protection (using a charcoal canister) when entering areas of elevated radioiodine concentrations in air.

Step 16

Supervise implementation of protective actions and control exposures. Use Table D2 as guidance to perform or manage radiological monitoring. Reassess protective actions and act accordingly.

Step 17

Continuously provide radiation protection assistance to emergency responders who must enter the safety perimeter, including:

i. provision of emergency worker turn-back guidance;
ii. advice on individual protective equipment required;
iii. support to the emergency medical response for transport of injuries, as required;
iv. contamination control and decontamination.

Step 18

When the primary cause of the emergency is under control AND the source is confined, AND all contamination is contained, consider the need for:

Tasks:	Follow Procedure:
Recovery of the scene/removal of the radioactive material	D1
Decontamination of people and equipment	D2
Initial cleanup of the site and disposal of radioactive wastes	D3

Post accident activities

Step 19

Make dose assessment for victims (if any), emergency workers and the public (if any) using procedures in Section E.

Step 20

Assess the need for longer-term protective actions.

Step 21

Prepare report for the emergency manager. Stress lessons learned and make recommendations for updating the emergency plan and other arrangements (if any).

TABLE D2. GUIDANCE ON MONITORING

Accident type	Monitoring	Objective
Misplaced, lost or stolen source	1. Source monitoring by foot, vehicle or aerial survey	i. To locate the source
Found source or contamination	1. Source monitoring 2. Contamination survey 3. In-situ gamma spectrometry 4. Sampling and laboratory analysis 5. Personal monitoring	i. To set security and safety perimeter ii. To implement immediate protective actions iii. To identify the source or contamination iv. To determine contaminated areas and/or objects v. To control personal exposure and contamination vi. To plan recovery and cleanup operations
Unshielded sealed source	1. Source monitoring 2. Contamination check 3. Personal monitoring	i. To set security and safety perimeter ii. To implement immediate protective actions iii. To check for possible contaminated surfaces and/or objects iv. To control personal exposure v. To plan source recovery
Damaged sealed source	1. Source monitoring 2. Contamination survey 3. Personal monitoring	i. To set security and safety perimeter ii. To implement immediate protective actions iii. To determine contaminated areas and/or objects iv. To control personal exposure and contamination v. To plan recovery and cleanup operations
Unsealed source accident	1. Air sampling 2. Gross alpha and beta in air 3. Source monitoring 4. Contamination survey 5. Ground deposition measurement 6. Sampling and laboratory analysis	i. To set security and safety perimeter ii. To implement immediate protective actions iii. To determine air contamination iv. To determine contaminated areas and/or objects

Accident type	Monitoring	Objective
	7. Personal monitoring	v. To control personal exposure and contamination vi. To plan recovery and cleanup operations
Dispersion of alpha emitters	1. Source monitoring 2. Contamination survey 3. Ground deposition measurement 4. Field sampling and radiochemical analysis 5. Personal monitoring	i. To implement immediate protective actions ii. To determine air contamination iii. To determine contaminated areas and/or objects iv. To control personal contamination v. To plan recovery and cleanup operations vi. To plan post accident activities (follow-up) and longer term protective actions
Nuclear powered satellite re-entry	1. Source monitoring by aerial survey 2. Contamination monitoring by aerial survey 3. Source monitoring 4. Contamination survey 5. Field sampling and laboratory analysis 6. Personal monitoring	i. To locate debris ii. To implement immediate protective actions iii. To determine contaminated areas and/or objects iv. To control personal contamination v. To plan recovery and cleanup operations vi. To plan post accident activities (follow-up) and longer term protective actions
Trans-boundary impact	1. Plume survey 2. Ground deposition measurement 3. In-situ gamma spectrometry 4. Field sampling and laboratory analysis 5. Environmental dosimetry 6. Contamination monitoring by aerial survey 7. Personal monitoring	i. To implement protective actions ii. To determine ground contamination iii. To identify isotopic mix iv. To determine food and drinking water contamination v. To assess doses to the public vi. To plan follow-up measures and longer term protective actions

NOTE: Use monitoring procedures in Ref. [6]

TABLE D3. IAEA TOTAL EFFECTIVE DOSE GUIDANCE FOR EMERGENCY WORKERS

Tasks	Total effective dose guidance [mSv]
Type 1: Life saving actions	<500[a]
Type 2: Prevent serious injury Avert a large collective dose Prevent the development of catastrophic conditions	<100
Type 3: Short term recovery operations Implement urgent protective actions Monitoring and sampling	<50
Type 4: Longer term recovery operations Work not directly connected with an accident	Occupational exposure guidance [2]

Reference: [2]

[a] This dose can be exceeded if justified BUT every effort shall be made to keep dose below this level and certainly below the thresholds for deterministic effects. The workers should be trained on radiation protection and understand the risk they face. They must be volunteers and be instructed on the potential consequences of exposure.

TABLE D4. DEFAULT EMERGENCY WORKER TURN BACK DOSE GUIDANCE (EWG) WHEN RADIOIODINE INHALATION HAZARD EXIST — EXPRESSED AS INTEGRATED EXTERNAL GAMMA DOSE

TASKS	**EWG**[a] [mSv]
Type 1: Life saving actions	250
Type 2: Prevent serious injury Avert a large collective dose Prevent the development of catastrophic conditions Off-site ambient dose rate monitoring (gamma dose rate)	50
Type 3: Short term recovery operations Implement urgent protective actions Environmental sampling	25
Type 4: Longer term recovery operations Work not directly connected with an accident	Occupational exposure guidance [2]

Reference: [4]

[a] It is supposed that thyroid blocking was taken before exposure. If no thyroid blocking is provided divide EWG by 5, if respiratory protection is provided multiply EWG by 2.

CAUTION

Emergency worker turn back guidance is given as an integrated external dose on a self-reading dosimeter. Values have been calculated to account for the inhalation dose from a core melt accident assuming that thyroid blocking has been taken. Emergency workers should take all reasonable efforts not to exceed this value. Note that skin contamination can also be a major source of dose and can lead to deterministic health effects for workers in highly contaminated areas if they are not provided with adequate protective clothing.

Emergency worker turn back doses are to serve as guidance and not limits. Judgment must be used in their application. If analysis of air samples or other conditions results in emergency worker turn back dose guidance that are significantly different from the Table D4, then revised guidance should be used.

Once the early phase of the accident is over, the total dose incurred (during the early phase) must be confirmed before an emergency worker is allowed to perform activities that may result in additional dose.

TABLE D5. RISK RELATED DATA FOR DIFFERENT PRACTICES

Practice or application	Radionuclide	Decay energy [keV] half-life	Typical activity	Dose rate at 1m[a,b,c] [mSv/h]	Time at 1m[a,b,c] to exceed 1mSv
Sealed sources used in medicine					
Bone densitometry	Am-241	γ (60) α (5486) $T_{1/2}$ = 433 a	1-10 GBq	3.E-02	30 h
	Gd-153	γ (97) $T_{1/2}$ = 242 d	1-40 GBq	4.E-01	2 h
	I-125	γ (35) e (34) $T_{1/2}$ = 59 d	1-10 GBq	6.E-02	20 h
Manual brachytherapy	Cs-137	γ (662) β (max.: 512) e (624) $T_{1/2}$ = 30 a	50-500 MBq	3.E-02	30 h
	Ra-226	γ (186) α (4784) $T_{1/2}$ = 1600 a	30-300 MBq	2.E-04	200 d
	Co-60	γ (1173; 1333) β (max.: 318) $T_{1/2}$ = 5.3 a	50-500 MBq	1.E-01	8 h
	Sr-90	β (max.: 196) $T_{1/2}$ = 29 a	50-1500 MBq	0	N/A
	Pd-103	X (20) $T_{1/2}$ = 17 d	50-1500 MBq	0	N/A
	I-125	γ (35) e (34) $T_{1/2}$ = 59 d	50-1500 MBq	9.E-03	5 d
	Ir-192	γ (317) β (max.: 675) e (303) $T_{1/2}$ = 74 d	200-1500 MBq	1.E-01	8 h
	Cf-252	α (6118) X (15) $T_{1/2}$ = 2.6 a	50-1500 kBq	3.E-07	400 a
Remote after loading brachytherapy	Co-60	γ (1173; 1333) β (max.: 318) $T_{1/2}$ = 5.3 a	≈ 10 GBq	3.E+00	20 min
	Cs-137	γ (662) β (max.: 512) e (624) $T_{1/2}$ = 30 a	0.03-10 MBq	6.E-04	70 d
	Ir-192	γ (317) β (max.: 675) e (303) $T_{1/2}$ = 74 d	≈ 400 GBq	3.E+01	2 min
Teletherapy	Co-60	γ (1173; 1333) β (max.: 318) $T_{1/2}$ = 5.3 a	50-1000 TBq	3.E+05	<1 s
	Cs-137	γ (662) β (max.: 512) e (624) $T_{1/2}$ = 30 a	500 TBq	3.E+04	<1 s
Whole blood	Cs-137	γ (662)	2-100 TBq	6.E+03	1 s

Practice or application	Radionuclide	Decay energy [keV] half-life	Typical activity	Dose rate at 1m[a,b,c] [mSv/h]	Time at 1m[a,b,c] to exceed 1mSv
irradiation		β (max.: 512) e (624) $T_{1/2}$ = 30 a			
Sealed sources used in industry					
Industrial Radiography	Ir-192	γ (317) β (max.: 675) e (303) $T_{1/2}$ = 74 d	0.1-5 TBq	4.E+02	9 s
	Co-60	γ (1173; 1333) β (max.: 318) $T_{1/2}$ = 5.3 a	0.1-5 TBq	1.E+03	3 s
	(Cs-137)	γ (662) β (max.: 512) e (624) $T_{1/2}$ = 30 a			
	(Tm-170)	γ (84) β (max.: 968) $T_{1/2}$ = 129 d			
Well logging	Cs-137	γ (662) β (max.: 512) e (624) $T_{1/2}$ = 30 a	1-100 GBq	6.E+00	10 s
	Am-241/Be	γ (60) α (5486) neutrons $T_{1/2}$ = 432.2 a	1-800 GBq	2.E+00	20 s
	(Cf-252)	α (6118) X (15) $T_{1/2}$ = 2.6 a			
Smoke detectors	Am-241	γ (60) α (5486) $T_{1/2}$ = 432.2 a	0.02-3 MBq	9.E-06	10 a
	Ra-226	γ (186) α (4784) $T_{1/2}$ = 1600 a			
	(Pu-239)	α (5157) γ (52) $T_{1/2}$ = 24000 a			
Lightning Rods	Am-241	γ (60) α (5486) $T_{1/2}$ = 432.2 a	50-500 MBq	2.E-03	30 d
	(Ra-226)	γ (186) α (4784) $T_{1/2}$ = 1600 a	<40 MBq	2.E-05	5 a
	Co-60	γ (1173; 1333) β (max.: 318) $T_{1/2}$ = 5.3 a	4-8 GBq	2.E+00	30 min
	Eu-152/154	γ (1408/1274) $T_{1/2}$ = 13.5/8.6 a	7–40 GBq	5.E+00	10 min
Moisture/density detector	Am-241/Be	γ (60) α (5486) neutrons $T_{1/2}$ = 432.2 a	0.1-2 GBq	6.E-03	7 d

Practice or application	Radionuclide	Decay energy [keV] half-life	Typical activity	Dose rate at 1m[a,b,c] [mSv/h]	Time at 1m[a,b,c] to exceed 1mSv
	Cs-137	γ (662) β (max.: 512) e (624) $T_{1/2}$ = 30 a	400 MBq	2.E-02	2 d
	(Cf-252)	α (6118) X (15) $T_{1/2}$ = 2.6 a	3GBq	6.E-04	70 d
	(Ra-226/Be)	γ (60) α (5486) neutrons $T_{1/2}$ = 432.2 a			
	Pu-239	α (5157) γ (52) $T_{1/2}$ = 24000 a			
Static electricity eliminator	Am-241	γ (60) α (5486) $T_{1/2}$ = 432.2 a	1-4 GBq	1.E-02	3 d
	Po-210	α (5304) $T_{1/2}$ = 138 d	1-4 GBq	4.E-06	30 a
	(Ra-226)	γ (186) α (4784) $T_{1/2}$ = 1600 a			
	Co-60	γ (1173; 1333) β (max.: 318) $T_{1/2}$ = 5.3 a			
Electron capture detector	Ni-63	β (max.: 67) $T_{1/2}$ = 100 a	200–500 MBq	0	
	H-3	$T_{1/2}$ = 12 a	1–10 GBq	0	
X ray fluorescence analyser	Fe-55	X (6) $T_{1/2}$ = 2.7	0.1–5 GBq	2.E-03	30 d
	Cd-109	γ (88) $T_{1/2}$ = 463 d	1–8 GBq	1.E+00	50 min
	(Pu-238)	α (5499) γ (84) $T_{1/2}$ = 88 a			
	(Am-241)	γ (60) α (5486) $T_{1/2}$ = 432.2 a			
	(Co-57)	γ (122) $T_{1/2}$ = 272 d			
Sterilization and food preservation	Co-60	γ (1173; 1333) β (max.: 318) $T_{1/2}$ = 5.3 a	0.1–400 PBq	1.E+08	< 1 s
	Cs-137	γ (662) β (max.: 512) e (624) $T_{1/2}$ = 30 a	0.1–400 PBq	2.E+07	< 1 s

Practice or application	Radionuclide	Decay energy [keV] half-life	Typical activity	Dose rate at 1m[a,b,c] [mSv/h]	Time at 1m[a,b,c] to exceed 1mSv
Calibration facility	Co-60	γ (1173; 1333) β (max.: 318) $T_{1/2}$ = 5.3 a	1–100 TBq	3.E+04	< 1 s
	Cs-137	γ (662) β (max.: 512) e (624) $T_{1/2}$ = 30 a	1–100 TBq	6.E+03	< 1 s
Level gauge	Cs-137	γ (662) β (max.: 512) e (624) $T_{1/2}$ = 30 a	0.1–20 GBq	1.E+00	50 min
	Co-60	γ (1173; 1333) β (max.: 318) $T_{1/2}$ = 5.3 a	0.1–10 GBq	3.E+00	20 min
	(Am-241)	γ (60) α (5486) $T_{1/2}$ = 432.2 a	4 GBq	1.E-02	3 d
Thickness gauge	Cs-137	γ (662) β (max.: 512) e (624) $T_{1/2}$ = 30 a	1 TBq	6.E+01	1 min
	Kr-85	β (max.: 687) $T_{1/2}$ = 10.8 a	0.1–50 GBq	1.E-02	4 d
	Sr-90	β (max.: 546) $T_{1/2}$ = 29 a	0.1–4 GBq	0	
	(Pm-147)	β (max.: 225) $T_{1/2}$ = 2.6 a	40 GBq	1.E-05	10 a
	Tl-204	γ (69) β (max.: 763) $T_{1/2}$ = 3.8 a	40 GBq	4.E-03	10 d
	(C-14)	β (max.: 156) $T_{1/2}$ = 5730 a			
	(Am-241)	γ (60) α (5486) $T_{1/2}$ = 432.2 a			
Density gauge	Cs-137	γ (662) β (max.: 512) e (624) $T_{1/2}$ = 30 a	1–20 GBq	1.E+00	50 min
	Am-241	γ (60) α (5486) $T_{1/2}$ = 432.2 a	1–10 GBq	3.E-02	1 d
Conveyor gauge	Cs-137	γ (662) β (max.: 512) e (624) $T_{1/2}$ = 30 a	0.1–40 GBq	2.E+00	20 min
Sealed sources used in research					
Calibration sources	Many different		< 0.1 GBq		
Electron capture detector	H-3	$T_{1/2}$ = 12 a	1–50 GBq		
	Ni-63	β (max.: 67) $T_{1/2}$ = 100 a	200–500 MBq		

Practice or application	Radionuclide	Decay energy [keV] half-life	Typical activity	Dose rate at 1m[a,b,c] [mSv/h]	Time at 1m[a,b,c] to exceed 1mSv
Irradiators	Co-60	γ (1173; 1333) β (max.: 318) $T_{1/2}$ = 5.3 a	1–1000 TBq	3.E+05	< 1 s
	(Cs-137)	γ (662) β (max.: 512) e (624) $T_{1/2}$ = 30 a			< 1 s
Calibration facilities	Cs-137	γ (662) β (max.: 512) e (624)	< 100 TBq	6.E+03	< 1 s
	Co-60	γ (1173; 1333) β (max.: 318) $T_{1/2}$ = 5.3 a	< 100 TBq	3.E+04	< 1 s
	Cf-252	α (6118) X (15) $T_{1/2}$ = 2.6 a	< 10 GBq	2.E-03	20 d
	(Am-241/Be)	γ (60) α (5486) neutrons $T_{1/2}$ = 432.2 a			
	(Pu-238/Be)	α (5499) γ (84) neutrons $T_{1/2}$ = 88 a			
	(Ra-226/Be)	γ (186) α (4784) neutrons $T_{1/2}$ = 1600 a			
Tritium targets	H-3	$T_{1/2}$ = 12 a	1–10 TBq		

Reference: compiled from different references.

[a] Gamma dose rates were calculated using upper value of the activity, conversion factor CF_6 from Table E1 and assuming total loss of shielding. The calculated values were rounded to 1 digit.
[b] Bremstrahlung radiation was not taken into account, however it may be very considerable in some cases.
[c] Times were calculated based on “dose rate” column (assuming total loss of shielding).

The physical and chemical form of the sources can be an important factor for a potential dispersion of radioactive material if the integrity of the source has been breached.

TABLE D6. PRINCIPAL RADIONUCLIDES USED IN NUCLEAR MEDICINE AND BIOLOGICAL RESEARCH

Radionuclide	Practice	Typical quantity per application	Waste characteristics
H-3	Clinical measurements Biological research Labelling on site	up to 5 MBq up to 50 GBq	Solid, liquid, organic Organics Solvents
C-14	Medical Biological research Labelling	less than 1 GBq up to 10 MBq	Solid, liquid Solvent Exhaled CO_2
F-18	Positron emission Tomography	up to 500 MBq	Solid, liquid
Na-22 Na-24	Clinical measurements Biological research	up to 50 kBq up to 5 GBq	Liquid effluent
P-32 P-33	Clinical therapy Biological research	up to 200 MBq up to 50 MBq	Solid, liquid effluent
S-35	Clinical measurements Medical and biological research	up to 5 GBq	Solid, liquid effluent
Cl-36	Biological research	up to 5 MBq	Gaseous, solid, liquid
Ca-45 Ca-47	Biological research Clinical measurements	up to 100 MBq up to 1 GBq	Mainly solid Some liquid
Sc-46	Medical and biological research	up to 500 MBq	Solid, liquid
Cr-51	Clinical measurements Biological research	up to 5 MBq up to 100 kBq	Solid Mainly liquid effluent
Co-57 Co-58	Clinical measurements Biological research	up to 50 kBq -	Solid, liquid effluent
Fe-59	Clinical measurements Biological research	up to 50 MBq	Solid Mainly liquid effluent
Ga-67	Clinical measurements	up to 200 MBq	Solid, liquid effluent
Kr-81m	Lung ventilation studies	up to 2 GBq	Gaseous
Sr-85	Clinical measurements Biological research	up to 50 MBq	Solid, liquid
Rb-86	Medical and biological research	up to 500 MBq	Solid, liquid
Sr-89	Clinical therapy	up to 300 MBq	Solid, liquid
Y-90	Clinical therapy and measurements Medical and biological research	up to 300 MBq	Solid, organic, liquid
Nb-95	Medical and biological research	up to 500 MBq	Solid, liquid
Tc-99m	Clinical measurements Biological research Nuclide generator	up to 1 GBq	Solid, liquid
In-111	Clinical measurements Biological research	up to 500 MBq	Solid, liquid
I-123 I-135 I-131	Medical and biological research Clinical measurements Clinical therapy	up to 500 MBq up to 500 MBq up to 10 GBq	Solid, liquid Occasionally vapour
Sn-113	Medical and biological research	up to 500 MBq	Solid, liquid
Xe-133	Clinical measurements	up to 400 MBq	Gaseous
Sm-153	Clinical therapy	up to 8 GBq	Solid, liquid
Au-198	Clinical measurements	up to 500 MBq	Solid, liquid
Tl-201	Clinical measurements	200 MBq	Solid, liquid
Hg-197 Hg-203	Clinical measurements Biological research	up to 50 MBq	Solid, liquid

Reference: compiled from different references.

Purpose
To provide general guidance on the basic steps necessary to initiate recovery of radioactive sources or removal of radioactive material when feasible.

Discussion
There are many variables to be considered in the recovery of a found source or mitigation of the consequences from a radiological accident.

A sealed source may require only appropriate handling to limit exposure and proper packaging to effect its recovery, while a solid, but loose or unshielded radioactive material may require extensive resources and a lengthy time-frame in order to ensure there is no unnecessary exposure.

Radioactive materials in chemical form, i.e. liquid or powder may not be easily or quickly recoverable without the possibility of spreading contamination. In such cases, where the material may become mixed with soil, water or debris as a result of an accident, it may be advisable to defer consideration of the recovery, decontamination and disposal until a thorough analysis of the situation can be developed.

The nature of the accident, physical size and activity level of the source, and the appropriateness of available resources are among the key factors that should determine the scope and feasibility of recovery activities. If there is also an element of illicit trafficking involved the radioactive materials may be regarded as an exhibit for any future court process and in such circumstances may be regarded as case property relative to the criminal activity associated with the accident. Final disposal of the radioactive materials may have to await the conclusion of any judicial process or criminal prosecution and may require a court order before eventual disposal can be implemented.

Input
- Characterization of the scene
- Identification and quantification of the radioactive material(s) involved

Output
- Definition of safety precautions
- Inventory of required resources
- Prescribed recovery steps

Step 1
Before determining what steps might be possible to recover a radioactive source or remove radioactively contaminated materials, confirm that that all necessary protective actions have been implemented and the location has been stabilized and secured.

Step 2

2.1 Review all available information on the identity, quantity, and physical properties of the radioactive materials involved.

2.2 Confirm the physical state of the radioactive material (sealed source, liquid or solids in confined container, materials in damaged or breached containers, or material spilled and possibly mixed with other hazards or environmental material).

2.3 For shielded (sealed) sources, determine whether available local resources are adequate to assure the safe recovery and packaging of the source for removal from the accident scene.

> **NOTE**
>
> For situations where the radioactive material is solid, but loose and unshielded, a determination must be made whether available resources and expertise are adequate to remove the material safely. The feasibility of doing so also depends on the quantity of radioactive or contaminated material involved, the type of equipment necessary to remove it, the means to package and transport it, and the prior designation of an appropriate temporary or interim storage location.
>
> Often in transportation accidents, dealing with the radiation hazard may be complicated by the presence of other hazardous materials such as chemicals or biohazards included in the shipment or hazards introduced into the area as a consequence of the accident, for example, spilled diesel or gasoline fuels.
>
> It is important to remember that efforts to remove loose or unshielded radioactive material may result in resuspension and increased risk of exposure or contamination of emergency workers.

Step 3

Determine whether immediate removal of the source or radioactive materials is necessary or advisable. Any determination to proceed with mitigation must be weighed on the basis of its effectiveness given the resources available.

3.1 For situations in which the radioactive source container remains intact, determine the size, shape and weight of the container to determine the most effective means for removal from the scene.

3.2 For situations where containment is damaged or breached, estimate the quantity of material that must be removed, including contaminated debris, to ensure that the radiation hazard is fully mitigated to the extent possible and the site no longer poses a radiation hazard.

> **NOTE**
>
> If the scene is densely populated, involves a busy roadway, or poses a serious impediment to commerce, efforts to quickly eliminate the hazard may be encouraged by local officials. In remote areas where access to the site can be easily controlled, there will generally be less pressure to mitigate the scene immediately.

Step 4

Identify an approved location or repository to which the source material is to be sent for interim or long-term storage once it is removed from the scene. Ensure that any such location is capable of providing secure storage for the material.

Step 5

If it is deemed advisable to attempt removal of the source of radiation, determine what type of equipment and other resources are required, e.g. shovels, bucket loader, dump truck, barrels, etc.

5.1 Determine allowable dose rates for emergency workers to be involved in the removal operations.
5.2 Ascertain whether personnel protective equipment appropriate to the hazard is available.
5.3 Assure the availability of proper containers, shielding, etc. to package and transport the radioactive materials.
5.4 Ensure that the material(s) removed from the scene will be taken to a properly prepared and secure storage area.

Step 6

Assess whether contained materials (sealed sources or waste in un-breached containers) can be safely recovered with existing resources. Ask on-scene authorities what types of equipment are readily available for recovery activities, i.e. hand tools, heavy equipment, shielding materials, overpacks for barrels, etc.

NOTE

For accidents involving mixed hazards (other toxic materials in addition to the radioactive source), or where radioactive materials are spilled on the ground and mixed with other debris or earth, removal and cleanup may require moving large amounts of potentially contaminated materials. Careful use and supervision of heavy equipment may be required to minimize resuspension or the spread of contamination.

The mitigation process selected will depend largely on the nature of the location of the source material and the surrounding area. Among the alternatives are:

i. Remove the source materials and attempt to decontaminate the area. This approach is feasible when the accident involves a small quantity of low-level radioactive material, and where the accident location is easily accessible to members of the general public. Example: a radiopharmceutical spill in a building or along a roadway in a built-up area;
ii. Remove the largest concentrations of contaminated material and seal the site, leaving the remainder in place to decay. This method works well when short to medium half-lives radionuclides are disbursed in an area not generally accessed by the public. Example: an airline crash or transportation accident in a remote area.
iii. Remove large amounts of contaminated material until activity levels in the area are at or near background. This should be required in any instance where radioactive material is disbursed to the environment in any populated area. Example: any accident involving the spillage of liquid or loose radioactive materials that could migrate in soils or ground water or be re-suspended as a result of subsequent weather conditions.

Step 7

Develop a step-by-step procedure for initiating the cleanup operations and instruct workers at the scene regarding the proper protocols for handling the radioactive elements, including the appropriate use of protective clothing, respirators, dosimetry, and length of time on-scene during each phase of the operation.

Step 8

Ensure that radiological monitoring capability is in place to survey the source container(s) or contaminated materials as they are removed from the site, packaged, and loaded for shipment before leaving the scene. Record all information as it is gathered.

Step 9

Ensure that all packages containing radioactive materials are properly labelled and identified as to contents and activity levels, and develop a shipping manifest that clearly identifies each package, including any surface radiation readings obtained after the containers are loaded and sealed.

Step 10

Once the source container(s) or loose contaminated material is removed, conduct another survey of the area to ensure that no portions of the site continue to exhibit readings above the prescribed clearance levels.

NOTE

As part of emergency response preparedness, national competent authorities should develop clearance levels [2]. Guidance on such levels is given in Refs [12, 13, 14] .

Purpose

To provide guidance on simple decontamination of personnel, essential equipment and vehicles.

Discussion

During a response to a situation in which radioactive material is released to the environment, response personnel and others at the scene as well as vehicles and equipment may become contaminated. In such instances, basic decontamination of personnel and equipment on-scene should be provided, particularly for fire service, police, medical services personnel, and other essential service providers who must immediately resume their normal duties following the radiological emergency. An accident in which the radiation source is sealed, solid, or remains shielded, generally poses no contamination hazard.

On-scene decontamination, when practical, serves several purposes: it reduces the potential for continuing individual exposure from contamination; limits the potential for the spread of contamination beyond the scene; and allows for the reuse of response equipment for other emergencies. The techniques applied are similar to those employed for other types of hazardous material (i.e. chemical or toxic substance) accidents.

While the decontamination approach suggested here is generic, it is important to note the differentiation between the appropriate techniques for people versus those for equipment and other items. It is important that all emergency workers and anyone who may have come in contact with loose radioactive material at the scene of an emergency be advised that they should be monitored for contamination. In addition, they should be advised that even if no detectable contamination is found, they should bathe, preferably shower, as soon as possible, and thoroughly launder all clothing.

Everyone who entered the area inside the established safety perimeter must be monitored for contamination. Likewise, any equipment, tools, or other material brought inside the safety perimeter area for use in the emergency response should be surveyed for contamination.

As a general rule, detectable contamination levels **greater than** twice background indicate decontamination should be attempted. "Simple decontamination" refers to the use of water to flush removable contamination from skin and non-porous materials. "Impounded" refers to the collection and isolation of items that exceed the prescribed operational intervention levels (contamination limit) and pose a potential exposure hazard, but cannot be easily or practically decontaminated at the scene with available resources.

Input

- Information regarding the type and activity level of the radioactive material involved
- Results of monitoring surveys of people, essential equipment and vehicles

Output

- Guidance on decontamination activities

General guidance

NOTE

It is difficult for one person alone to carry out all monitoring and recording. Reference [5] provides detailed guidance on the monitoring teams and suggests a minimum of 3 members per team: one to monitor, one to record results and one to deal with contaminated items or persons.

Step 1

Determine whether appropriate equipment and resources are available at or near the scene to accomplish simple decontamination, i.e. a supply of clean water, a shower arrangement, pumps, hoses, brushes, brooms, sponges, etc.

NOTE

Water used for decontamination will need to be considered as active liquid waste and the potential arrangements for disposal of such waste will need to be addressed in emergency planning. Arrangements will normally need to be agreed with the relevant regulatory authority for liquid waste. However, if there is an urgent need for flushing of contaminated surfaces, then keeping below the following levels will probably be acceptable.

- discharges to sewers : 20 MBq per 5000 litres
- discharges to watercourses: 2 MBq per 5000 litres

Most fire brigades can provide the necessary resources. An obvious consideration is weather. Wet decontamination is inappropriate in winter unless it can be conducted in a heated enclosure.

Step 2

Designate an area outside the safety perimeter in which to conduct the decontamination process (see Fig. C1).

NOTE

The area should have controlled entrance and exit points. It may also be advisable to isolate this area and provide the means to collect water runoff for analysis depending on the amount and type of loose radioactive material involved.

Step 3

People and items brought to the decontamination location should be surveyed using appropriate procedures from Ref. [6] and the activity levels for the contaminated areas recorded prior to any decontamination effort.

CAUTION

Individuals assisting in the decontamination of people and equipment should be monitored periodically to ensure they do not become contaminated.

Step 4
Re-survey the areas previously identified as contaminated to determine if the activity has been reduced below operational intervention levels. If the activity has been reduced, but still remains above the OIL, wipe the contaminated area with a clean strip of paper or cloth and survey it with the detector. Activity on the wipe indicates removable contamination remains. Repeat the decontamination process until no removable contamination remains.

Step 5
Before releasing any individual or item from the decontamination area or securely isolating a contaminated article, ensure that all documentation regarding the decontamination process, including the before-and-after survey readings, is complete and retained by the emergency manager or other authority.

PRECAUTIONS

- Soap, brushes, and other articles (equipment) used for decontamination may become contaminated during use and should be handled accordingly.
- Under all circumstances, unnecessary exposure to radiation should be avoided.
- Wear appropriate protective clothing when surveying and decontaminating equipment, at a minimum disposable gloves and booties.
- Care must be exercised to prevent contamination from spreading to other areas.
- Do not use decontamination methods that will spread localized materials or increase surface penetration.
- Appropriate personnel monitoring shall be utilized by emergency worker staff (Personal Monitoring and Decontamination Team [6]).
- Personnel must refrain from eating, drinking, or smoking in any areas where monitoring or decontamination activities are being conducted.

Decontamination of people

Step 6
People should remove contaminated articles of exterior clothing and be resurveyed before entering the decontamination area. Identify areas of exposed skin that are contaminated and instruct the individual to wash those areas with soap and tepid water, scrubbing gently so as not to abrade the skin surface, rinse thoroughly, and repeat the process again. See Table D7 for personal decontamination guide

NOTE

If after a second wash, the activity remains above the OIL, but is no longer removable, the contamination should be considered “fixed”. Individuals should be referred to medical authorities for further assessment.

Step 7
If contamination is confined to the clothing, determine whether it is feasible to decontaminate the clothing with available resources.

> **NOTE**
> For example, a fireman's rubber coat or boots may be contaminated, but easily washed. It may not be practical to immediately decontaminate some clothing items, vehicle interiors, leather shoes, etc.

Step 8

When contamination of these items exceeds the appropriate OIL and continued use might pose an exposure hazard, it is suggested the items be impounded and held until a determination can be made regarding further decontamination efforts or proper disposal.

Step 9

Contaminated items must be properly wrapped, labelled, and stored in such a manner as to constitute no hazard to personnel and to control spread of contamination. Use *Contaminated Item(s)* labels (Worksheet D2). Bag and label any contaminated items retained for proper shipment or storage.

Step 10

Measure fixed contamination levels on the skin and record them to assist in the estimate of skin dose.

> **NOTE**
> A monitor should be used that has range high enough to measure the actual level of contamination. "greater than" values are of only limited use.

Decontamination of vehicles and equipment

> **NOTE**
> Contaminated vehicles, tools, material, and equipment may be decontaminated using fire hoses, scrub brushes and detergent, if necessary. However, caution should be used to limit the strength and direction of water streams so as not to unnecessarily spread contamination.

Step 11

Decontaminate the vehicle exterior by washing the vehicle with soap and water.

> **NOTE**
> Fire hoses may be used to decontaminate vehicles if weather conditions permit. Exterior decontamination also may be carried out in commercial car wash establishments, if appropriate. Runoff water should be retained.

> **CAUTION**
> Do not attempt to wash vehicles when ambient temperatures are below freezing. Surface icing conditions could pose a hazard to personnel and equipment.

Step 12

If exterior decontamination is inadvisable due to weather or other circumstances, advise the vehicle operator that a vehicle found to be contaminated should be isolated in a secure area until an appropriate means for decontamination is determined. Provide the vehicle operator with a *Receipt for Contaminated Item(s)* (Worksheet D3). Record all information regarding the vehicle and the extent of contamination found (use appropriate Worksheet from Ref. [6]).

Step 13

After initial decontamination is attempted, re-survey the areas where contamination was detected. If the levels have been significantly reduced, but remain above the OIL, repeat the decontamination procedure and re-survey. If the readings still remain above the OIL, advise the vehicle operator that the vehicle should be isolated in a secure area pending further evaluation. Provide the vehicle operator with a *Receipt for Contaminated Item(s)* (Worksheet D3). Record all information regarding the vehicle and the extent of contamination found (use appropriate Worksheet from Ref. [6]).

Step 14

If a vehicle has interior contamination that cannot be removed by wiping with available cleaning materials, advise the operator that the vehicle should be isolated in a secure area until a determination is made regarding the appropriate means for removing or reducing the contamination to allowable levels. Provide the vehicle operator with a *Receipt for Contaminated Item(s)* (Worksheet D3). Record all information regarding the vehicle and the extent of contamination found (use appropriate Worksheet from Ref. [6]).

Step 15

If the initial exterior decontamination efforts fail to reduce the readings below the OIL, the contamination may be fixed. Confirm this with a wipe test (See Procedure A5 in [6]). For fixed contamination, readings at or below OIL will permit release of the vehicle, if no other removable contamination is found. Readings above OIL for fixed contamination dictate that the vehicle should be placed in secure isolation pending further evaluation. Advise the operator of the problem and provide him/her with a *Receipt for Contaminated Item(s)* (Worksheet D3). Record all information regarding the vehicle and the extent of contamination found (use appropriate Worksheet from Ref. [6]).

Step 16

All tools and equipment used by emergency workers should be monitored using procedures in Ref. [6] and efforts made as soon as possible to decontaminate those found to be contaminated. Decontamination, if required and feasible, can be accomplished using one of several methods, e.g. wiping with a dry cloth, soap and water, etc.

Step 17

If immediate decontamination is unsuccessful or impractical, and the worker relinquishes the items or equipment, provide the owner with a *Receipt for Contaminated Item(s)* (Worksheet D3). Contaminated items must be properly wrapped, labelled, and stored in such a manner as to constitute no hazard to personnel and to control spread of contamination. Use *Contaminated Item(s)* labels (Worksheet D2).

Step 18

Bag and label any contaminated items retained for proper shipment or storage.

NOTE

Where the accident may have resulted in ingestion or inhalation of radioactive material, consideration should be given to potential contamination from excretions. In the main this will be from urine or faeces, but there is also the potential for activity to be excreted in sweat. In addition to contamination control measures there will be a need to assess intake by either in vivo monitoring e.g. whole body monitoring, or by in vitro monitoring of excreta.

TABLE D7. PERSONAL DECONTAMINATION GUIDE

Contaminated areas	Method [a]	Technique	Remarks
Skin, hands and body	Soap and water	Wash 2–3 minutes and check activity levels. Repeat washing 2 times.	Wash hands, arms and face in sink, use showers for rest of body. [b]
	Soap, soft brush and water, dry abrasives such as cornflower	Use light pressure with heavy lather. Wash for 2 minutes, 3 times, rinse and monitor. Use care not to erode the skin.	After decontamination apply lanolin or hand cream to prevent chapping. [c]
	Soap powder or similar detergent, standard industrial skin cleaner	Make into a paste. Use with additional water and a mild scrubbing action. Use care not to erode the skin.	After decontamination apply lanolin or hand cream to prevent chapping. [c]
Eyes, ears, mouth	Flushing	Eyes: Roll back eyelids and gently flush with water. Ears: Clean the opening of the ear canal with cotton swabs. Mouth: Rinse with water-do not swallow.	Be cautious not to damage ear drum; rolling back the eyelids should be carried out by medical or suitably trained personnel.
Hair	Soap and water	Use light pressure with heavy lather. Wash for 2 minutes, 3 times, rinse, and monitor.	Hair should be back washed to minimize ingestion via mouth or nose.
	Soap, soft brush and water	Make into a paste. Use addition water and a mild scrubbing action. Do not erode the skin.	Hair should be back washed to minimize ingestion via mouth or nose.
	Haircut/shave head	Remove the hair to decontaminate scalp. Use skin decontamination methods.	Use only after other methods fail.

[a] Begin with the first listed method and then proceed step-by-step to the more severe method as necessary. In all personal decontamination procedures every effort should be made to prevent spread of contamination. All cleaning actions should be performed from periphery of contaminated area towards the centre.

[b] Simple irrigation of a wound, as for any cutter or abrasion should be carried out but further decontamination actions on wound should be done by a doctor or experienced medical personnel.

[c] For resistant contamination coat liberally with barrier cream and cover with rubber gloves; activity will frequently cross from the skin into the barrier cream over the next few hours.

Purpose
To provide guidance on preliminary considerations for the removal of radioactive wastes resulting from the consequences of a radiological emergency situation when possible. This procedure should be used during the emergency phase and if long-term cleanup measures are required these should be considered separately.

Discussion
Guidance is intended to suggest the issues that should be considered in dealing with radioactive wastes that might be generated as a result of an emergency situation. Such wastes may include sources whose ownership cannot be determined, unconfined radioactive material, and environmental material or material contaminated during the response to a radiation accident.

The removal methodology, required recovery equipment, and transport mechanisms must be determined in relationship to the quantity of radioactive material involved, its activity levels, and the availability of either interim or long-term storage facilities within the jurisdiction in which the waste is generated. In some instances, e.g. low-level spills, it may be possible to collect all or most contaminated waste relatively easily. In others, however, it may be impossible to quickly remove any material due to the volume of contaminated waste involved or high activity levels, or to dispose of the material because there is no readily available repository for the material.

When wastes cannot be removed from the scene and may pose a continuing exposure risk, temporary shielding and security should be provided at the scene.

Input
- Quantification and inventory of the wastes involved by category
- Information on the availability of safe transport means, proper packaging, and storage options

Output
- Recommendations for removal

Step 1
Once the emergency situation is stable, and survey activities have been completed, assess the need for removal of waste materials. Categorise wastes by type, level of activity, and volume.

NOTE
For example, a liquid radioactive material spill may produce significant quantities of contaminated waste that includes fluids, absorbent materials, clothing, and soil, each with different activity levels ranging from low-level to high-level depending on the radioisotope involved.

Step 2

In consultation with the emergency manager, determine the availability of appropriate disposal or storage facilities for each category of waste material.

Step 3

Identify the requirements for packaging each category or type of waste for transport from the emergency scene, and determine whether such packaging is readily available or can be reasonably obtained. Authorities may be willing to waive normal shipment requirements to expedite removal of the wastes from the emergency scene. In some instances, packaging may have to be improvised.

Step 4

Determine the appropriate means to transport the wastes from the emergency scene to the designated storage or disposal site. Volume and packaging will dictate the size and type of vehicle(s) required. The need for in-transit security should also be considered.

Step 5

Thoroughly document information about each packaged quantity of waste material prior to shipment, including activity levels of the material involved as well as survey readings for the exterior of the shipping container. A copy of the documentation must accompany each shipment from the scene to its disposal or storage destination.

Step 6

Once all contaminated waste materials are removed from the scene to the extent practical, the area should be resurveyed and catalogued with respect to any remaining areas where activity levels exceed normal background.

If further mitigation is necessary, the area should be secured to prevent unauthorised access.

NOTE

Activity concentrations of naturally occurring radionuclides in soil are as follows:

Radionuclide	Average concentration [Bq/kg]	Typical range [Bq/kg]
K-40	370	100–700
U-238 or Ra-226	25	10–50
Th-232	25	7–50

SECTION E
DOSE ASSESSMENT

Purpose

To estimate the dose to emergency workers and/or the public once the emergency situation is stabilized and recovery activities have been completed.

Discussion

In the event of an accident exposure of an individual may be external or internal and may be incurred by various pathways. External exposure may be due to direct irradiation from the source, airborne radionuclides in the air (immersion or exposure to an overhead plume), radionuclides deposited onto the ground and onto person's clothing and skin. Internal exposure follows from the inhalation of radioactive material either directly from a plume or re-suspended from contaminated surfaces, from the ingestion of contaminated food and water or through contaminated wounds.

Total effective dose can be calculated by taking into account all dominant routes by which individuals were exposed in an accident.

$$E_T = E_{ext} + E_{inh} + E_{ing}$$

Where
E_T = Total effective dose
E_{ext} = Effective dose from external radiation
E_{inh} = Committed effective dose from inhalation
E_{ing} = Committed effective dose from ingestion

Where direct means of assessing doses is available, principally the use of personal monitoring dosimeters for external exposure, this should be used. However in many cases such means may not be available or there may be a time delay in attaining the data.

This section provides various methodologies for calculating doses and dose rates based on the type of sources or radioactive materials involved and the circumstances of the emergency situation. While the radiological assessor may have access to computer programs to make the assessments, the procedures also provide written formulas so that calculations may be made by hand if necessary. The radiological assessor may also find the formulas and tables in this section useful in developing protective action recommendations for the emergency manager during the early stages of an emergency situation when information regarding the radiation source or material is readily available.

Input

- Type of exposure involved
- Radiation sources or material involved
- Results of survey
- Results from dosimeters
- Chronology of events

Output

- Accident-specific dose estimates

Step 1

Assemble and assess the dosimetric information directly available. This will include:

i. direct readings from Quartz Fibre Electrometers (QFE) or electronic personal dosimeters (EPDs);
ii. dose assessments from personal dosimeters such as film badges or thermoluminescent dosimeters (TLDs) — these should be sent for emergency assessment;

NOTE

The assessments may take up to 24 hours, but the data will be important to the investigation of the accident and as an input to any necessary medical response.

iii. where inhalation may have occurred, nose blows should be taken using material suitable for assessing the activity removed;
iv. where ingestion may have occurred, the need to collect urine and faecal samples should be considered;
v. for (iii) and (iv) the need for whole body or thyroid monitoring should be considered;
vi. if it is thought likely that the total effective dose limit may have been exceeded, a medical responder should be consulted about obtaining a blood sample for cytogenetic analysis.

NOTE

Actions (i) and (ii) should always be undertaken where dosimeters are available. The other measurements will depend on the circumstances of the accident.

CAUTION

The duration and extent of the accident may have been more extensive than apparent at the time of the initial response. It is therefore essential to check the direct reading dosimeters and personal dosimeters of ALL staff who may have been in the area concerned. In particular it is essential that dosimeters from persons not originally thought to be involved are not used for deliberate exposures as part of a dose reconstruction exercise. This could mask real exposures to the staff.

Step 2

Characterise the type of exposure involved and use the appropriate procedure(s):

In case of:	Use procedure:
Point source	E1
Line source and spill (small area)	E2
Ground contamination	E3
Skin contamination	E4
Inhalation	E5
Ingestion	E6
Air immersion	E7

Step 3

Estimate total effective dose by summing up contributions from all relevant exposure pathways by which an individual was exposed.

Purpose
To estimate the dose rate and the effective dose from a point source (known activity) or the activity and the distance to the point source from the dose rate measurements.

Discussion
This procedure uses effective doses and dose rates pre-calculated at 1 m from the point source, assuming no shielding. It can be used to estimate effective doses to the public or emergency workers or the expected instrument readings (e.g. when planning for search of a lost source). Shielding can be considered, but build up is not considered. Therefore, if shielding is included in the calculation, the result should be considered the **lower bound**. The calculated value may underestimate the dose.

Input
- Activity of the point source
- Distance from the point source
- Exposure duration

Output
- Dose rate and effective dose from a point source of known activity
- Activity and the distance to the point source from the dose rate measurements

Effective dose

Estimate the effective dose at a certain distance from a point source using the equation below. Set shielding thickness *d* equal to zero to disregard shielding.

$$E_{ext} = \frac{A \cdot CF_6 \cdot T_e \cdot (0.5)^{\frac{d}{d_{1/2}}}}{X^2}$$

Where

E_{ext} = Effective dose from a point source [mSv]
A = Source activity [kBq]
T_e = Exposure duration [h]
CF_6 = Conversion factor from Table E1 [(mSv/h)/(kBq)]
X = Distance from the point source [m]
$d_{1/2}$ = Half value layer from Table E2 [cm]
d = Shielding thickness [cm]

CAUTION
d is measured in [cm] and X in [m].

Dose rate

Calculate the dose rate at a certain distance from a point source using the equation below. To disregard shielding, set shielding thickness *d* equal to zero.

$$\dot{D} = \frac{A \cdot CF_7 \cdot (0.5)^{\frac{d}{d_{1/2}}}}{X^2}$$

Where

$\dot{D}$ = Dose rate [mGy/h]
CF_7 = Conversion factor from Table E1 [(mGa/h)/(kBq)]
A = Source activity [kBq]
X = Distance from the point source [m]
$d_{1/2}$ = Half value layer from Table E2 [cm]
d = Shielding thickness [cm]

CAUTION
d is measured in [cm] and X in [m].

Estimating the distance to the point source

A crude guess of a distance from the source can be obtained by measuring dose rates at two distances in the "line of sight" and using the inverse square law.

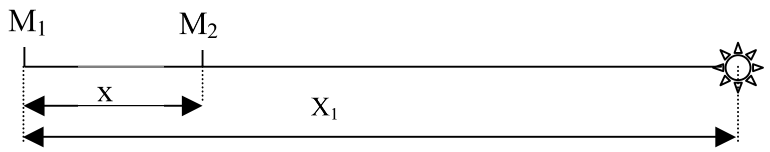
$$a = \frac{\dot{D}_1}{\dot{D}_2}$$

and

$$X_1 = \frac{x}{1 - \sqrt{a}}$$

Where

X_1 = Distance to the source (from measuring point M_1) [m]
x = Distance between two measuring points [m]
$\dot{D}_1$ = Measured dose rate at measuring point M_1 [mGy/h]
$\dot{D}_2$ = Measured dose rate at measuring point M_2 [mGy/h]



Estimating the activity

Knowing the distance from the source an estimate of the activity of the source can be made using the following equation:

$$A = \frac{\dot{D}_1 \cdot X_1^2}{CF_7 \cdot 0.5^{\frac{d}{d_{1/2}}}}$$

Where
A = Source activity [kBq]
X_1 = Distance to the source (from measuring point M_1) [m]
$\dot{D}_1$ = Measured dose rate at measuring point M_1 [mGy/h]
CF_7 = Conversion factor from Table E1 [(mGa/h)/(kBq)]
$d_{1/2}$ = Half value layer from Table E2 [cm]
d = Shielding thickness [cm]

CAUTION

d is measured in [cm] and X in [m].

TABLE E1. POINT SOURCE CONVERSION FACTORS AT 1 METRE FROM THE SOURCE

Radionuclide	CF_6 (mSv/h)/(kBq)	CF_7[a] (mGy/h)/(kBq)
H-3	0.0	0.0
C-14	0.0	0.0
Na-22	2.2E-07	3.4E-07
Na-24	3.8E-07	5.1E-07
P-32	0.0	0.0
P-33	0.0	0.0
S-35	0.0	0.0
Cl-36	3.1E-13	2.1E-11
K-40	1.6E-08	2.2E-08
K-42	2.8E-08	3.9E-08
Ca-45	8.9E-17	6.1E-15
Sc-46	2.1E-07	3.1E-07
Ti-44	1.1E-08	2.8E-08
V-48	2.9E-07	4.4E-07
Cr-51	3.4E-09	2.0E-08
Mn-54	8.6E-08	1.5E-07
Mn-56	1.7E-07	2.4E-07
Fe-55	3.2E-10	2.2E-08
Fe-59	1.2E-07	1.8E-07
Co-58	1.0E-07	1.6E-07
Co-60	2.5E-07	3.6E-07
Ni-63	0.0	0.0
Cu-64	2.0E-08	4.7E-08
Zn-65	6.0E-08	1.3E-07
Ga-68	9.8E-08	1.5E-07
Ge-68+ Ga-68	9.8E-08	2.1E-07
Se-75	3.9E-08	1.4E-07
Kr-85	2.3E-10	3.6E-10
Kr-85m	1.5E-08	3.0E-08
Kr-87	7.8E-08	1.1E-07
Kr-88+ Rb-88	2.5E-07	3.5E-07
Rb-86	9.6E-09	1.4E-08
Rb-87	0.0	0.0
Rb-88	5.7E-08	5.2E-08
Sr-89	1.4E-11	2.1E-11
Sr-90	0.0	0.0
Sr-91	7.1E-08	1.1E-07
Y-90	0.0	0.0
Y-91	3.7E-10	5.5E-10
Y-91m	5.5E-08	8.7E-08
Zr-93	0.0	0.0
Zr-95	7.6E-08	1.2E-07
Nb-94	1.6E-07	2.5E-07
Nb-95	7.9E-08	1.2E-07
Mo-99	1.6E-08	2.6E-08
Tc-99	4.1E-14	6.4E-14
Tc-99m	1.2E-08	2.1E-08
Rh-103	2.1E-08	3.0E-08

Radionuclide	CF_6 (mSv/h)/(kBq)	CF_7[a] (mGy/h)/(kBq)
Ru-103	5.0E-08	7.9E-08
Ru-105	8.1E-08	1.3E-07
Ru-106	1.4E-09	7.1E-09
Ru-106+ Rh-106	1.4E-09	7.1E-09
Ag-110m	2.8E-07	4.2E-07
Cd-109+ Ag-109m	1.6E-07	2.9E-07
Cd-113m	0.0	0.0
In-114m	1.0E-08	3.5E-08
Sn-113	3.4E-09	4.2E-08
Sn-123	7.0E-10	1.1E-09
Sn-126+ Sb-126m	5.7E-09	2.2E-08
Sb-124	1.9E-07	2.8E-07
Sb-126	2.8E-07	4.4E-07
Sb-126m	4.9E-10	7.8E-10
Sb-127	6.8E-08	1.1E-07
Sb-129	1.5E-07	2.2E-07
Te-127	6.0E-09	1.1E-08
Te-127m	1.6E-09	1.2E-08
Te-129	4.2E-08	6.5E-08
Te-129m+ Te-129	4.6E-08	7.8E-08
Te-131	4.5E-08	7.1E-08
Te-131m	1.5E-07	2.2E-07
Te-132	2.3E-08	4.9E-08
I-125	5.9E-09	3.8E-08
I-129	3.4E-09	2.1E-08
I-131	3.9E-08	6.2E-08
I-132	2.4E-07	3.6E-07
I–133	6.2E-08	9.8E-08
I–134	2.7E-07	4.1E-07
I-135+ Xe-135	3.8E-07	5.4E-07
Xe-131m	2.7E-09	1.7E-08
Xe-133	4.6E-09	1.9E-08
Xe-133m	4.8E-09	2.1E-08
Xe-135	2.4E-08	3.8E-08
Xe-138	1.1E-07	1.6E-07
Cs-134	1.6E-07	2.5E-07
Cs-136	2.2E-07	3.4E-07
Ba-137m	6.2E-08	9.5E-08
Cs-137+ Ba-137m	6.2E-08	9.5E-08
Ba-133	4.1E-08	9.3E-08
Cs-138	3.0E-09	4.2E-09
Ba-140	2.0E-08	4.3E-08
La-140	2.3E-07	3.4E-07
Ce-141	7.2E-09	1.4E-08
Ce-144+	3.1E-09	1.1E-08

Radionuclide	CF_6 (mSv/h)/(kBq)	CF_7[a] (mGy/h)/(kBq)
Pr-144		
Pr-144m	2.9E-09	2.8E-08
Pr-144	1.2E-09	5.8E-09
Pm-145	3.6E-09	2.0E-08
Pm-147	2.9E-13	4.4E-13
Sm-151	2.3E-12	9.8E-11
Eu-152	1.2E-07	1.9E-07
Eu-154	1.3E-07	2.0E-07
Eu-155	5.3E-09	1.6E-08
Gd-153	1.1E-08	4.3E-08
Tb-160	1.1E-07	1.8E-07
Ho-166m	1.6E-07	2.7E-07
Tm-170	5.0E-10	4.8E-09
Yb-169	2.9E-08	9.8E-08
Hf-172	2.2E-08	4.9E-08
Hf-181	5.5E-08	1.0E-07
Ta-182	1.3E-07	2.2E-07
W-187	4.9E-08	8.6E-08
Ir-192	8.3E-08	1.4E-07
Au-198	4.1E-08	6.7E-08
Hg-203	2.3E-08	4.5E-08
Ti-204	1.0E-10	1.1E-09
Pb-210	6.9E-10	3.5E-08
Bi-207	1.6E-07	2.9E-07
Bi-210	0.0	0.0
Po-210	8.8E-13	1.3E-12
Ra-226	6.2E-10	2.2E-09
Ac-227	3.9E-11	2.0E-09
Ac-228	9.5E-08	2.1E-07
Th-227	1.1E-08	8.4E-08
Th-228	3.9E-10	1.6E-08
Th-230	2.3E-10	1.4E-08
Th-231	2.5E-10	7.3E-09
Th-232	2.1E-10	1.4E-08
Pa-231	4.3E-09	7.9E-08
U-Dep & Nat[b]	2.3E-10	1.5E-08
U-Enric[b]	2.8E-10	1.8E-08
U-232	3.2E-10	2.1E-08
Pa-233	1.7E-08	4.6E-08
U-233	1.2E-10	6.8E-09
U-234	2.8E-10	1.8E-08
U-235	1.4E-08	7.4E-08
U-236	0.0	0.0
U-238	2.3E-10	1.5E-08

Radionuclide	CF_6 (mSv/h)/(kBq)	CF_7[a] (mGy/h)/(kBq)
Np-237	3.8E-09	5.0E-08
Pu-236	3.4E-10	9.9E-09
Pu-238	3.0E-10	8.8E-09
Np-239	0.0	0.0
Pu-239	1.2E-10	3.4E-09
Pu-240	2.8E-10	8.4E-09
Pu-241	0.0	0.0
Pu-242	2.3E-10	6.9E-09
Am-241	3.1E-09	3.7E-08
Am-242	8.5E-10	2.5E-08
Am-243	5.4E-09	3.8E-08
Cm-242	3.1E-10	9.2E-09
Cm-243	1.3E-08	6.6E-08
Cm-244	2.8E-10	8.2E-09
Cm-245	7.5E-09	6.0E-08
Cf-252	2.1E-10	6.1E-09

Reference: Calculations made by Oak Ridge National Laboratory (ORNL) using the CONDOS programme. Calculated at 1 metre with no shielding.

[a] Exposure rate is shown in its correspondent in mGy/h. For gamma exposure 1mGy/h □ 0.1 R/h.

[b] For natural and depleted uranium it is assumed all of the release is U-238 and for enriched uranium it is assumed all of the release is U-234. The activity of enriched Uranium is dominated by the concentration of U-234 (because of its high specific activity). While releases from natural and enriched Uranium will be composed of a mixture of U-234, 235 and 238, the dose factor of all these radionuclides are within 10%, so it is reasonable to use a single factor.

CF_6 Effective dose in one hour of exposure to 1kBq point source.

CF_7 Dose rate at 1 m from 1 kBq point source.

TABLE E2. HALF VALUE LAYER (HVL) $d_{1/2}$

The $d_{1/2}$ is the thickness of a substance that, when introduced in the path of a beam of radiation, reduces the exposure rate by one-half. Values are given for "good geometry" for which build-up of secondary radiation is not important.

Radionuclide	$d_{1/2}$ [cm]					
	Lead[a]	Iron[a]	Al[a]	Water[a]	Air[b]	Concrete[a]
H-3	0	0	0	0	0.00E+00	0
C-14	0	0	0	0	0.00E+00	0
Na-22	0.67	1.38	3.85	9.4	7.94E+03	4.35
Na-24	1.32	2.14	6.22	14.75	1.27E+04	6.88
P-32	0	0	0	0	0.00E+00	0
P-33	0	0	0	0	0.00E+00	0
S-35	0	0	0	0	0.00E+00	0
Cl-36	0	0.01	0.02	0.04	3.90E+01	0.02
K-40	1.15	1.8	4.99	11.97	1.02E+04	5.63
K-42	1.18	1.84	5.1	12.21	1.04E+04	5.75
Ca-45	0.01	0.03	0.1	0.24	2.12E+02	0.11
Sc-46	0.82	1.48	4.2	9.84	8.47E+03	4.66
Ti-44	0.04	0.21	0.6	1.41	1.25E+03	0.67
V-48	0.8	1.48	4.18	9.95	8.50E+03	4.67
Cr-51	0.17	0.82	2.38	5.69	4.98E+03	2.68
Mn-54	0.68	1.33	3.8	9	7.70E+03	4.22
Mn-56	0.94	1.65	4.78	11.13	9.66E+03	5.27
Fe-55	0	0.02	0.05	0.12	1.02E+02	0.05
Fe-59	0.94	1.59	4.51	10.58	9.10E+03	5.02
Co-60	1	1.66	4.65	10.99	9.42E+03	5.2
Ni-63	0	0	0	0	0.00E+00	0
Cu-64	0.41	1.08	3.01	7.61	6.32E+03	3.43
Zn-65	0.87	1.53	4.34	10.15	8.74E+03	4.81
Ga-68	0.42	1.09	3.04	7.67	6.38E+03	3.47
Ge-68+Ga-68[c]	0.42	1.09	3.04	7.67	6.38E+03	3.47
Ge-68	0.01	0.03	0.08	0.18	1.60E+02	0.09
Se-75	0.12	0.62	1.79	4.26	3.74E+03	2.01
Kr-85	0.41	1.07	3	7.59	6.31E+03	3.43
Kr-85m	0.1	0.5	1.46	3.46	3.05E+03	1.64
Kr-87	0.83	1.67	4.84	11.46	9.92E+03	5.36
Kr-88+Rb-88[c]	1.17	1.89	5.51	12.74	1.11E+04	6.05
Kr-88	1.20	1.95	5.71	13.2	1.16E+04	6.25
Rb-86	0.87	1.53	4.35	10.13	8.74E+03	4.81
Rb-88	1.17	1.89	5.51	12.74	1.11E+04	6.05
Sr-89	0.74	1.4	4	9.35	8.05E+03	4.42
Sr-90	0	0	0	0	0.00E+00	0
Sr-91	0.71	1.38	3.94	9.31	7.98E+03	4.38
Y-91	0.96	1.62	4.57	10.74	9.23E+03	5.09
Zr-93	0	0	0	0	0.00E+00	0
Zr-95	0.6	1.26	3.58	8.61	7.31E+03	4
Nb-94	0.64	1.30	3.70	8.84	7.54E+03	4.13
Nb-95	0.62	1.28	3.63	8.72	7.42E+03	4.06
Mo-99+Tc-99m[c]	0.49	1.11	3.16	7.6	6.48E+03	3.54
Mo-99	0.49	1.11	3.16	7.6	6.48E+03	3.54
Tc-99	0.05	0.25	0.73	1.73	1.53E+03	0.82
Tc-99m	0.07	0.39	1.13	2.68	2.37E+03	1.27
Ru-103	0.4	1.06	2.97	7.53	6.25E+03	3.4
Ru-105	0.48	1.16	3.28	7.98	6.77E+03	3.69
Rh-106	0.49	1.17	3.29	8.16	6.84E+03	3.73

Radionuclide	$d_{1/2}$ [cm]					
	Lead[a]	Iron[a]	Al[a]	Water[a]	Air[b]	Concrete[a]
Ru-106+Rh-106[c]	0.49	1.17	3.29	8.16	6.84E+03	3.73
Ru-106	0	0	0	0	0.00E+00	0
Ag-110m	0.71	1.38	3.91	9.36	7.98E+03	4.38
Cd-109	0.01	0.06	0.18	0.43	3.80E+02	0.2
Cd-113m	0	0	0	0	0.00E+00	0
In-114m	0.23	0.75	2.14	5.18	4.45E+03	2.41
Sn-113	0.02	0.09	0.27	0.65	5.71E+02	0.31
Sn-123	0.88	1.53	4.36	10.16	8.77E+03	4.83
Sn-126+Sb-126m[c]	0.48	1.15	3.27	7.99	6.76E+03	3.68
Sn-126	0.04	0.19	0.55	1.3	1.15E+03	0.62
Sb-124	0.83	1.55	4.39	10.49	8.98E+03	4.9
Sb-126	0.52	1.19	3.37	8.21	6.95E+03	3.79
Sb-126m	0.48	1.15	3.27	7.99	6.76E+03	3.68
Sb-127	0.47	1.14	3.24	7.92	6.70E+03	3.65
Sb-129	0.72	1.4	3.98	9.45	8.09E+03	4.43
Te-127m	0.01	0.08	0.23	0.54	4.76E+02	0.26
Te-129	0.33	0.93	2.63	6.53	5.50E+03	2.99
Te-129m	0.38	0.82	2.33	5.65	4.79E+03	2.61
Te-131m	0.65	1.31	3.74	8.88	7.61E+03	4.17
Te-132	0.1	0.53	1.54	3.66	3.22E+03	1.73
I-125	0.01	0.08	0.23	0.54	4.77E+02	0.26
I-129	0.02	0.09	0.25	0.6	5.26E+02	0.28
I-131	0.25	0.93	2.67	6.5	5.59E+03	3.02
I-132	0.63	1.31	3.7	8.91	7.57E+03	4.14
I-133	0.47	1.15	3.23	8.05	6.74E+03	3.67
I-134	0.72	1.4	3.98	9.43	8.08E+03	4.43
I-135+Xe-135m[c]	0.98	1.66	4.7	11.06	9.53E+03	5.23
I-135	0.98	1.66	4.7	11.06	9.53E+03	5.23
Xe-131m	0.02	0.1	0.29	0.7	6.16E+02	0.33
Xe-133	0.03	0.16	0.47	1.11	9.80E+02	0.53
Xe-133m	0.05	0.25	0.73	1.72	1.52E+03	0.82
Xe-135	0.14	0.72	2.1	4.99	4.38E+03	2.36
Xe-135m	0.41	1.07	2.99	7.54	6.27E+03	3.41
Xe-138	0.9	1.64	4.79	11.09	9.72E+03	5.26
Cs-134	0.57	1.24	3.5	8.5	7.19E+03	3.93
Cs-136	0.65	1.32	3.76	8.86	7.62E+03	4.18
Cs-137+Ba-137m[c]	0.53	1.19	3.35	8.2	6.92E+03	3.77
Cs-137	0	0	0	0	0.00E+00	0
Ba-133	0.16	0.67	1.92	4.63	4.02E+03	2.17
Ba-137m	0.53	1.19	3.35	8.2	6.92E+03	3.77
Ba-140	0.33	0.96	2.69	6.72	5.65E+03	3.06
La-140	0.93	1.64	4.63	11.04	9.47E+03	5.19
Ce-141	0.07	0.37	1.07	2.52	2.23E+03	1.2
Ce-144+Pr-144m[c]	0.05	0.28	0.82	1.95	1.72E+03	0.93
Pr-144						
Pr-144m	0.02	0.1	0.28	0.67	5.88E+02	0.32
Pm-145	0.02	0.11	0.31	0.74	6.56E+02	0.35
Pm-147	0.06	0.34	0.99	2.35	2.08E+03	1.12
Sm-147						
Sm-151	0.01	0.03	0.09	0.21	1.82E+02	0.1
Eu-152	0.66	1.32	3.73	8.84	7.59E+03	4.17
Eu-154	0.74	1.38	3.91	9.24	7.92E+03	4.35
Eu-155	0.04	0.23	0.66	1.56	1.37E+03	0.74
Gd-153	0.03	0.18	0.51	1.21	1.07E+03	0.57
Tb-160	0.68	1.35	3.84	9.01	7.77E+03	4.26
Ho-166m	0.45	1.09	3.1	7.46	6.37E+03	3.48

Radionuclide	$d_{1/2}$ [cm]					
	Lead[a]	Iron[a]	Al[a]	Water[a]	Air[b]	Concrete[a]
Tm-170	0.03	0.18	0.51	1.21	1.06E+03	0.57
Yb-169	0.06	0.3	0.87	2.05	1.81E+03	0.97
Hf-181	0.27	0.86	2.41	6.02	5.07E+03	2.75
Ta-182	0.8	1.39	3.94	9.26	7.97E+03	4.39
W-187	0.43	1.03	2.91	7.17	6.04E+03	3.29
Ir-192	0.24	0.92	2.64	6.42	5.52E+03	2.98
Au-198	0.29	0.97	2.74	6.77	5.75E+03	3.11
Hg-203	0.14	0.73	2.13	5.04	4.44E+03	2.39
Tl-204	0.03	0.18	0.53	1.27	1.12E+03	0.6
Pb-210	0.01	0.05	0.15	0.35	3.11E+02	0.17
Bi-207	0.65	1.3	3.68	8.79	7.50E+03	4.11
Bi-210	0	0	0	0	0.00E+00	0
Po-210	0.65	1.31	3.73	8.88	7.58E+03	4.15
Ra-226	0.09	0.48	1.4	3.32	2.93E+03	1.58
Ac-227	0.01	0.08	0.22	0.52	4.57E+02	0.25
Ac-228	0.67	1.35	3.84	9.05	7.79E+03	4.27
Th-227	0.11	0.58	1.69	4.01	3.53E+03	1.9
Th-228	0.02	0.13	0.37	0.88	7.73E+02	0.42
Th-230	0.01	0.05	0.14	0.34	3.02E+02	0.16
Th-232	0.01	0.04	0.12	0.28	2.48E+02	0.13
Pa-231	0.09	0.46	1.35	3.2	2.82E+03	1.51
U-232	0.01	0.04	0.12	0.29	2.59E+02	0.14
U-233	0.01	0.06	0.16	0.39	3.44E+02	0.18
U-234	0.01	0.04	0.12	0.28	2.42E+02	0.13
U-235	0.09	0.46	1.35	3.19	2.81E+03	1.51
U-238	0.01	0.04	0.11	0.27	2.36E+02	0.13
Np-237	0.03	0.12	0.41	0.98	8.62E+02	0.46
Pu-236	0.01	0.04	0.11	0.27	2.39E+02	0.13
Pu-238	0.01	0.04	0.11	0.27	2.37E+02	0.13
Pu-239	0.01	0.04	0.12	0.29	2.58E+02	0.14
Pu-240	0.01	0.04	0.11	0.27	2.37E+02	0.13
Pu-241	0	0	0	0	0.00E+00	0
Pu-242	0.01	0.04	0.11	0.27	2.37E+02	0.13
Am-241	0.02	0.12	0.35	0.82	7.27E+02	0.39
Am-242m	0.01	0.04	0.13	0.3	2.67E+02	0.14
Am-243	0.03	0.18	0.52	1.24	1.09E+03	0.59
Cm-242	0.01	0.04	0.12	0.28	2.48E+02	0.13
Cm-243	0.08	0.43	1.26	2.98	2.63E+03	1.41
Cm-244	0.01	0.04	0.12	0.28	2.47E+02	0.13
Cm-245	0.05	0.27	0.79	1.86	1.64E+03	0.88
Cf-252	0.01	0.04	0.12	0.3	2.61E+02	0.14

Reference: Calculations made by Oak Ridge National Laboratory (ORNL) using the CONDOS programme. Build up was not taken into account.

[a] 0 = < .01.
[b] 0 = < .99.
[c] Used highest of the two.

Purpose

To assess effective dose or dose rates at a certain distance from the source or a spill or the activity of the line source or spill from the dose rate measurements.

Discussion

This procedure uses effective doses and dose rates pre-calculated at 1 m from the point source, assuming no shielding. It can be used to estimate effective doses to the public or emergency workers or the expected instrument readings.

Input

- Source activity
- Distance from the source
- Time of exposure

Output

- External effective dose
- Dose rates
- Source activity from dose rate measurements

Line source

Effective dose

Estimate the effective dose (external irradiation) from a line source (pipe) using the following expression:

$$E_{ext} = \frac{\pi \cdot CF_6 \cdot A_l \cdot T_e}{X}$$

Where

X = Distance from the line source (pipe) [m]

E_{ext} = Effective dose [mSv]

CF_6 = Conversion factor from Table E1 [(mSv/h)/(kBq)]

A_l = Activity per 1 m [Bq/m]

T_e = Time of exposure [h]

Dose rate

Calculate the dose rate at a distance X from a line source (pipe) from the following expression:

$$\dot{D} = \frac{\pi \cdot CF_6 \cdot A_l}{X}$$

Where
$\dot{D}$ = Dose rate [mGy/h]
CF_7 = Conversion factor from Table E1 [(mGa/h)/(kBq)]
X = Distance from the line source (pipe) [m]
A_l = Activity per 1 m [Bq/m]

Estimating the activity

Estimate the activity of a line source (pipe) from dose rate measurement using the following expression:

$$A_1 = \frac{\dot{D} \cdot X}{\pi \cdot CF_7}$$

Where
$\dot{D}$ = Dose rate [mGy/h]
CF_7 = Conversion factor from Table E1 [(mGa/h)/(kBq)]
X = Distance from the line source (pipe) [m]
A_l = Activity per 1 m [Bq/m]

Spill

Effective dose

Estimate the effective dose (external irradiation) from a spill using the following expression:

$$E_{ext} = 2\pi \cdot CF_6 \cdot A_s \cdot T_e \cdot \ln \frac{X^2 + R^2}{X^2}$$

Where
X = Distance from the centre of the spill [m]
R = Spill radius [m]
E_{ext} = Effective dose [mSv]
CF_6 = Conversion factor from Table E1 [(mSv/h)/(kBq)]
A_s = Activity of the spill [Bq/m^2]
T_e = Time of exposure [h]

Dose rate

Calculate the dose rate at a distance X from a spill using the following expression:

$$\dot{D} = 2\pi \cdot CF_7 \cdot A_s \cdot \ln \frac{X^2 + R^2}{X^2}$$

Where
$\dot{D}$ =Dose rate [mGy/h]
CF_7 =Conversion factor from Table E1 [(mGa/h)/(kBq)]
X =Distance from the line source (pipe) [m]
R =Spill radius [m]
A_s =Activity of the spill [Bq/m^2]

Estimating the activity

Estimate the activity of a spill from dose rate measurement using the following expression:

$$A_s = \frac{\dot{D}}{2\pi \cdot CF_7 \cdot \ln \frac{X^2 + R^2}{X^2}}$$

Where

$\dot{D}$ = Dose rate [mGy/h]
CF_7 = Conversion factor from Table E1 [(mGa/h)/(kBq)]
X = Distance from the centre of the spill [m]
R = Spill radius [m]
A_s = Activity of the spill [Bq/m^2]

Purpose
To assess effective dose from exposure to ground contamination.

Discussion
Effective dose includes external dose and committed dose from inhalation (resuspension) resulting from remaining on contaminated ground for the period of concern — 1^{st} month, 2^{nd} month or lifetime (50 years). Once comprehensive and representative radionuclide concentrations on the ground are known effective dose can be estimated based on ambient dose measurements or marker radionuclide concentration levels. Shielding and partial occupancies may also be taken into account.

Input
- Radionuclide concentrations on ground
- Ambient dose rate
- Time of exposure

Output
- Effective dose from deposition

Step 1
Obtain radionuclide concentrations on ground and ambient dose rate using monitoring procedures in Ref. [6].

Step 2
Estimate effective dose from deposition for the period of concern.

Based on comprehensive radionuclide concentrations on ground

Use the equation:

$$E_{ext} = \sum_{i=1}^{n} \overline{C}_{g,i} \cdot CF_{4,i}$$

Where

E_{ext} = Effective dose from deposition for the period of concern [mSv]

$\overline{C}_{g,i}$ = Average deposition (ground) concentration of radionuclide *i* [kBq/m^2]

$CF_{4,i}$ = Conversion factor from Table E3; effective dose per unit deposition for radionuclide *i*; includes external dose and committed effective dose from inhalation due to resuspension resulting from remaining on contaminated ground for the period of concern

n = Number of radionuclides

Based on ambient dose rate

Use the equation:

$$E_{ext} = \dot{H}^{*}_{g} \cdot \frac{\sum_{i=1}^{n} C^{rep}_{g,i} \cdot CF_{4,i}}{\sum_{i=1}^{n} C^{rep}_{g,i} \cdot CF_{3,i}}$$

Where

$\dot{H}^{*}_{g}$ = Ambient dose rate at 1 m above ground level from ground contamination [mSv/h]

$CF_{3,i}$ = Conversion factor from Table E3; ambient dose rate at 1 m above ground level per unit of deposition for radionuclide *i*

$C^{rep}_{g,i}$ = Representative deposition (ground) concentration of radionuclide *i* [kBq/m^2]

Based on marker radionuclide concentration levels

Use the equation:

$$E_{ext} = C^{sam}_{g,j} \cdot \frac{\sum_{i=1}^{n} C^{rep}_{g,i} \cdot CF_{4,i}}{C^{rep}_{g,j}}$$

Where

$C^{sam}_{g,j}$ = Concentration of marker radionuclide *j* in deposition samples [kBq/m^2]

$C^{rep}_{g,j}$ = Representative deposition (ground) concentration of marker radionuclide *j* [kBq/m^2]

Step 3

Adjust effective dose from deposition by taking into account shielding and partial occupancy. Use the following equation:

$$E^{po}_{ext} = E_{ext} \cdot [SF \cdot OF + (1 - OF)]$$

Where

E^{po}_{ext} = Effective dose from deposition for the period of concern assuming shielding and partial occupancy [mSv]

SF = Shielding factor from measurements during occupancy or from Table E4

OF = Occupancy fraction; fraction of time the shielding factor SF is applicable e.g. the fraction of time spent indoors; it is assumed that, for the rest of the time, there is no shielding; default — 0.6

TABLE E3. CONVERSION FACTORS FOR EXPOSURE TO GROUND CONTAMINATION

Radionuclide	Conversion factor CF_3[a] Ambient dose rate from deposition [(mSv/h)/(kBq/m^2)]	Conversion factor CF_4[b] Effective dose from deposition [(mSv/kBq/m^2)]		
		1st Month	2nd Month	50 Year
H-3	0.0E+00	NC	NC	NC
C-14	5.7E-11	5.2E-07	4.9E-07	1.0E-04
Na-22	7.4E-06	3.7E-03	3.4E-03	8.4E-02
Na-24	1.3E-05	2.0E-04	0.0E+00	2.0E-04
P-32	1.0E-08	5.3E-06	1.2E-06	6.8E-06
P-33	1.6E-10	1.1E-06	4.4E-07	1.8E-06
S-35	5.9E-11	1.2E-06	8.7E-07	4.7E-06
Cl-36	2.4E-09	8.1E-06	7.7E-06	1.6E-03
K-40	5.2E-07	2.6E-04	2.5E-04	5.3E-02
K-42	9.4E-07	1.2E-05	0.0E+00	1.2E-05
Ca-45	1.6E-10	2.9E-06	2.4E-06	1.8E-05
Sc-46	6.8E-06	3.0E-03	2.2E-03	1.2E-02
Ti-44+Sc-44	7.8E-06	4.0E-03	3.8E-03	5.9E-01
V-48	9.8E-06	2.8E-03	7.1E-04	3.7E-03
Cr-51	1.1E-07	3.8E-05	1.7E-05	6.9E-05
Mn-54	2.9E-06	1.4E-03	1.2E-03	1.4E-02
Mn-56	5.6E-06	1.5E-05	0.0E+00	1.5E-05
Fe-55	0.0E+00	9.1E-07	8.5E-07	2.2E-05
Co-58	3.4E-06	1.6E-03	9.4E-04	3.9E-03
Fe-59	4.0E-06	NC	NC	NC
Co-60	8.3E-06	4.2E-03	3.9E-03	1.7E-01
Ni-63	0.0E+00	5.3E-07	5.0E-07	9.1E-05
Cu-64	6.6E-07	8.6E-06	0.0E+00	8.6E-06
Zn-65	2.0E-06	9.4E-04	8.2E-04	8.0E-03
Ga-68	3.3E-06	NC	NC	NC
Ge-68+Ga-68	3.3E-06	1.6E-03	1.4E-03	1.5E-02
Se-75	1.3E-06	6.2E-04	4.9E-04	3.1E-03
Kr-85	9.3E-09	NC	NC	NC
Kr-85m	5.4E-07	NC	NC	NC
Kr-87	2.6E-06	NC	NC	NC
Kr-88+Rb-88	8.2E-06	NC	NC	NC
Rb-86	3.3E-07	1.0E-04	3.2E-05	1.5E-04
Rb-87	3.1E-10	NC	NC	NC
Rb-88	2.1E-06	NC	NC	NC
Sr-89	8.0E-09	1.1E-05	6.6E-06	2.8E-05
Sr-90	1.0E-09	1.7E-04	1.6E-04	2.1E-02
Sr-91	2.4E-06	3.4E-05	7.5E-08	3.4E-05
Y-90	1.9E-08	1.7E-06	6.7E-10	1.7E-06
Y-91	2.0E-08	1.7E-05	1.1E-05	4.9E-05
Y-91m	1.9E-06	1.6E-06	6.5E-09	1.6E-06
Zr-93	0.0E+00	2.2E-05	2.1E-05	4.8E-03
Zr-95	2.6E-06	1.4E-03	1.3E-03	6.8E-03
Nb-94	5.4E-06	2.7E-03	2.6E-03	5.5E-01
Nb-95	2.6E-06	1.0E-03	5.2E-04	2.1E-03
Mo-99+Tc-99m	9.5E-07	6.1E-05	3.1E-08	6.1E-05
Tc-99	2.8E-10	4.1E-06	3.9E-06	8.2E-04
Tc-99m	4.3E-07	2.7E-06	1.2E-14	2.7E-06
Ru-103	1.6E-06	6.4E-04	3.6E-04	1.5E-03
Ru-105	2.7E-06	1.4E-05	1.8E-12	1.4E-05
Rh-106	7.5E-07	NC	NC	NC
Ru-106+Rh-106	7.5E-07	4.2E-04	3.8E-04	4.8E-03

Radionuclide	Conversion factor CF_3[a] Ambient dose rate from deposition [(mSv/h)/(kBq/m^2)]	Conversion factor CF_4[b] Effective dose from deposition [(mSv/kBq/m^2)]		
		1st Month	2nd Month	50 Year
Ag-110m	9.4E-06	4.5E-03	3.9E-03	3.9E-02
Cd-109+Ag-109m	1.1E-07	6.4E-05	5.8E-05	8.6E-04
Cd-113m	9.3E-10	1.1E-04	1.1E-04	9.2E-03
In-114m	3.2E-07	4.5E-04	3.5E-04	2.2E-03
Sn-113+In-113m	9.9E-07	2.2E-05	1.7E-05	1.2E-04
Sn-123	3.0E-08	3.2E-03	3.2E-03	7.0E-01
Sn-126+Sb-126m	5.3E-06	2.6E-03	1.7E-03	7.8E-03
Sb-124	6.0E-06	2.4E-03	4.2E-04	2.9E-03
Sb-126	9.8E-06	NC	NC	NC
Sb-126m	5.4E-06	2.3E-04	1.1E-06	2.3E-04
Sb-127	2.4E-06	2.3E-05	4.9E-08	2.3E-05
Sb-129	4.9E-06	3.7E-06	3.6E-08	3.7E-06
Te-127	1.8E-08	1.8E-07	0.0E+00	1.8E-07
Te-127m	4.0E-08	3.4E-05	2.7E-05	1.6E-04
Te-129	2.1E-07	2.5E-07	9.7E-16	2.5E-07
Te-129m	1.3E-07	1.1E-04	5.4E-05	2.2E-04
Te-131	1.5E-06	1.2E-06	3.8E-08	1.2E-06
Te-131m	4.8E-06	2.0E-04	3.3E-06	2.0E-04
Te-132	8.0E-07	6.9E-04	1.1E-06	6.9E-04
I-125	1.5E-07	7.8E-05	5.2E-05	2.4E-04
I-129	9.1E-08	1.7E-04	1.6E-04	3.4E-02
I-131	1.3E-06	2.5E-04	1.8E-05	2.7E-04
I-132	7.8E-06	1.9E-05	0.0E+00	1.9E-05
I-133	2.1E-06	4.5E-05	0.0E+00	4.5E-05
I-134	8.9E-06	8.1E-06	0.0E+00	8.1E-06
I-135+Xe-135m	5.4E-06	3.7E-05	0.0E+00	3.7E-05
Xe-131m	7.3E-08	NC	NC	NC
Xe-133	1.6E-07	NC	NC	NC
Xe-133m	1.4E-07	NC	NC	NC
Xe-135	8.5E-07	NC	NC	NC
Xe-135m	1.5E-06	NC	NC	NC
Xe-138	3.6E-06	NC	NC	NC
Cs-134	5.4E-06	2.7E-03	2.5E-03	5.1E-02
Cs-135	1.2E-10	7.0E-07	3.9E-07	8.5E-06
Cs-136	7.4E-06	1.9E-03	3.6E-04	2.3E-03
Cs-137+Ba-137m	2.1E-06	9.9E-04	9.4E-04	1.3E-01
Cs-138	7.7E-06	NC	NC	NC
Ba-133	1.4E-06	7.0E-04	6.6E-04	4.8E-02
Ba-137m	2.1E-06	NC	NC	NC
Ba-140	6.4E-07	2.0E-03	4.4E-03	2.5E-03
La-140	7.6E-06	3.2E-04	1.2E-09	3.2E-04
Ce-141	2.6E-07	9.9E-05	4.9E-05	2.0E-04
Ce-144+Pr-144	2.0E-07	1.5E-04	1.3E-04	1.4E-03
Pr-144	1.3E-07	4.0E-08	0.0E+00	4.0E-08
Pr-144m	4.6E-08	2.2E-08	0.0E+00	2.2E-08
Pm-145	1.2E-07	6.0E-05	5.7E-05	5.8E-03
Pm-147	1.2E-10	4.4E-06	4.1E-06	1.0E-04
Sm-147	0.0E+00	NC	NC	NC
Sm-151	1.8E-11	3.5E-06	3.3E-06	5.9E-04
Eu-152	3.9E-06	2.0E-03	1.9E-03	1.6E-01
Eu-154	4.2E-06	2.1E-03	2.0E-03	1.3E-01
Eu-155	2.1E-07	1.1E-04	1.0E-04	4.2E-03
Gd-153	3.7E-07	1.8E-04	1.6E-04	1.5E-03
Tb-160	3.8E-06	1.7E-03	1.2E-03	5.8E-03

Radionuclide	Conversion factor CF_3[a] Ambient dose rate from deposition [(mSv/h)/(kBq/m^2)]	Conversion factor CF_4[b] Effective dose from deposition [(mSv/kBq/m^2)]		
		1st Month	2nd Month	50 Year
Ho-166m	6.0E-06	3.1E-03	2.9E-03	6.1E-01
Tm-170	2.1E-08	1.6E-05	1.3E-05	8.5E-05
Yb-169	1.1E-06	4.0E-04	2.0E-04	7.9E-04
Hf-172	4.0E-07	NC	NC	NC
Hf-181	1.9E-06	7.7E-04	4.5E-04	1.8E-03
Ta-182	4.3E-06	2.0E-03	1.6E-03	9.7E-03
W-187	1.7E-06	4.1E-05	0.0E+00	4.1E-05
Ir-192	2.8E-06	1.2E-03	8.9E-04	4.4E-03
Au-198	1.4E-06	9.4E-05	3.9E-08	9.4E-05
Hg-203	8.2E-07	3.3E-04	2.0E-04	8.5E-04
Tl-204	5.2E-09	4.0E-06	3.8E-06	1.2E-04
Pb-210	8.8E-09	1.9E-03	2.2E-03	5.9E-01
Bi-207	5.2E-06	2.6E-03	2.5E-03	3.4E-01
Bi-210	3.7E-09	1.2E-04	1.1E-04	7.3E-04
Po-210	2.9E-11	3.5E-03	2.9E+03	2.0E-02
Ra-226	2.3E-08	9.2E-03	9.2E-03	1.9E+00
Ac-227	5.5E-10	4.6E-01	4.4E-01	5.1E+01
Ac-228	3.3E-06	3.6E-05	1.4E-05	3.0E-04
Th-227	3.7E-07	7.7E-03	3.7E-03	1.3E-02
Th-228	8.3E-09	4.2E-02	3.9E-02	7.7E-01
Th-230	2.7E-09	3.7E-02	3.5E-02	7.5E+00
Th-231	6.5E-08	NC	NC	NC
Th-232	1.9E-09	1.9E-01	1.8E-01	4.6E+01
Pa-231	1.4E-07	1.2E-01	1.1E-01	6.7E+01
Pa-233	6.9E-07	NC	NC	NC
U-232	3.6E-09	3.2E-02	3.1E-02	1.2E+01
U-233	2.5E-09	8.0E-03	7.6E-03	1.7E+00
U-234	2.6E-09	7.9E-03	7.4E-03	1.6E+00
U-235	5.2E-07	7.4E-03	7.0E-03	1.5E+00
U-236	2.3E-09	7.3E-03	6.9E-03	1.5E+00
U-238	1.9E-09	6.8E-03	6.4E-03	1.4E+00
U Dep&Natf	1.9E-09	6.8E-03	6.4E-03	1.4E+00
U Enrichf	2.6E-09	7.9E-03	7.4E-03	1.6E+00
UF6g(sol 234)	2.6E-09	7.9E-03	7.4E-03	1.6E+00
Np-237	1.0E-07	2.6E-02	2.5E-02	5.3E+00
Np-239	5.8E-07	3.4E-05	6.4E-09	3.4E-05
Pu-236	3.5E-09	1.6E-02	1.5E-02	8.0E-01
Pu-238	3.0E-09	3.9E-02	3.7E-02	6.6E+00
Pu-239	1.3E-09	4.2E-02	4.0E-02	8.5E+00
Pu-240	2.8E-09	4.2E-02	4.0E-02	8.4E+00
Pu-241	6.8E-12	7.6E-04	7.2E-04	1.9E-01
Pu-242	2.4E-09	4.0E-02	3.8E-02	8.0E+00
Am-241	9.7E-08	3.5E-02	3.3E-02	6.7E+00
Am-242m	1.1E-08	3.2E-02	3.0E-02	6.3E+00
Am-243	1.9E-07	3.5E-02	3.3E-02	7.0E+00
Cm-242	3.4E-09	4.2E-03	3.5E-03	5.9E-02
Cm-243	4.4E-07	3.5E-02	3.3E-02	4.3E+00
Cm-244	3.1E-09	2.9E-02	2.7E-02	2.8E+00
Cm-245	3.1E-07	5.0E-02	4.7E-02	1.0E+01
Cf-252	2.6E-09	1.7E-02	1.5E-02	3.9E-01

Reference: [15, 16, 17]

[a] Based on "Dose Conversion for Exposure to Contaminated Ground Surface" factors from *External Exposure to Radionuclides in Air, Water and Soil* [15], Table III.3. The effective dose was multiplied by 1.4 to estimate ambient dose rate as recommended by EPA [16]. The external dose from daughters expected to be in equilibrium is included where noted.

[b] Initial resuspension rates for non-arid areas (1E-6) are from *Derived Intervention Levels in Controlling Radiation Doses to the Public in the Event of a Nuclear Accident or Radiological Emergency* [17].

[c] Principal radionuclides contributing to the dose from external exposure from deposition for a reactor accident.

NC Not calculated.

Table E3 contains dose conversion factors for the first, second month and 50 year periods of exposure to ground contamination. Decay, ingrowth and weathering have been considered. The conversion factors are based on International RASCAL (NRC95) runs. The ambient dose rate conversion factor (CF_3) is the exposure rate at 1 m above ground level from 1 kBq/m^2 deposition of isotope *i*, corrected for ground roughness. The CF_4 includes dose from external exposure and inhalation dose from resuspension. An initial resuspension factor of R_S = 1E–6 m^{-1} was used because it is considered to be the upper bound (conservative) assuming weathered (old) deposition. However, much lower resuspension factors have been seen in real accidents.

TABLE E4. SHIELDING FACTORS FOR SURFACE DEPOSITION

Structure or location	Representative SF (a)	Representative range
1 m above an infinite smooth surface	1.0	-
1 m above ordinary ground	0.7	0.47–0.85
One and two story wood-frame house (no basement)	0.4	0.2–0.5
One and two story block and brick house (no basement)	0.2	0.04–0.4
House basement, one or two walls fully exposed - one-story, less than 1 m of basement wall exposed - two story, less than 1 m of basement wall exposed	 0.1 0.05	 0.03–0.15 0.03–0.07
Three or four story structures (500 to 1000 m^2 per floor)[(b)] - first and second floor - basement	 0.05 0.01	 0.01–0.08 0.001–0.07
Multi-story structures (> 1000 m^2 per floor)[(b)] - upper floors - basement	 0.01 0.005	 0.001–0.02 0.001–0.15

Reference: [18]

[a] The ratio of the interior to the exterior doses; away from doors and windows.

[b] The SF values are appropriate if indoor deposition is negligible i.e. wet deposition outdoors; for dry deposition these numbers may be higher depending on air exchange rate [20]

Purpose

To assess skin beta dose from material deposited onto skin or clothing.

Discussion

Skin dose is very difficult to measure directly and is usually estimated. The beta dose to the skin, expressed in terms of the airborne concentration of a radionuclide, depends on the rate of deposition of material from the atmosphere onto skin and clothing and its subsequent retention. There are large uncertainties associated with these parameters owing to the lack of experimental data on deposition of the relevant materials to skin and in predicting the habits of individuals in the aftermath of an accident. The beta dose rate to the skin expressed in terms of average surface concentrations of a radionuclide on the skin gives usually more reliable estimates for this exposure pathway. However, the data in the literature may vary as much as an order of magnitude. Skin beta dose rate conversion factors, given in Table E5, were taken from Ref. [20].

Beta dose to the skin from airborne material is important only for the noble gas radionuclides. For other radionuclides it is insignificant in comparison with other pathways of exposure.

Input

- Average surface concentration of radionuclides on the skin or clothing

Output

- Equivalent dose (beta) to the skin

Step 1

Estimate skin beta dose from the following expression:

$$H_{s,i} = \overline{C}_{s,i} \cdot CF_{8,i} \cdot SF_b \cdot T_e$$

and

$$H_s = \sum_i H_{s,i}$$

Where

H_s = Equivalent dose to the skin [mSv]

$H_{s,i}$ = Equivalent dose to the skin from radionuclide *i* [mSv]

$\overline{C}_{s,i}$ = Average surface concentration of radionuclide *i* on the skin or clothing [Bq/cm^2]

$CF_{8,i}$ = Skin beta dose rate conversion factor for radionuclide *i* from Table E5 [(mSv/h)/(Bq/cm^2)]

SF_β = Shielding factor to take account of shielding afforded by clothing, etc.; taking into account only clothing (summer, spring/autumn and winter) representative values of shielding factor are approximately 0.2–0.3 and 0.001, respectively [21]

T_e = Time of exposure [h]

TABLE E5. SKIN BETA DOSE RATE CONVERSION FACTORS — SKIN BETA DOSE RATE FROM MATERIAL DEPOSITED ONTO SKIN OR CLOTHING

Radionuclide	$T_{1/2}$	Unit	CF_8 [(μSv/h)/(Bq/cm^2)]
H-3	12.3	a	0
C-14	5730	a	0.32
F-18	1.83	h	1.9
Na-22	2.6	a	1.7
Na-24	15	h	2.2
Al-26	7.20E+05	a	1.8
P-32	14.3	d	1.9
P-33	25.6	d	0.86
S-35	87.5	d	0.35
Cl-36	3.00E+05	a	1.8
K-40	1.30E+09	a	1.5
K-42	12.4	h	2.2
K-43	22.2	h	1.9
Ca-45	163	d	0.84
Ca-47/Sc-47	4.54	d	3.5
Sc-46	83.8	d	1.4
Sc-47	3.4	d	1.5
Cr-51	27.7	d	0.015
Mn-52	5.6	d	0.761
Mn-54	312	d	0.062
Mn-56	2.58	h	2.4
Fe-52	8.26	h	1.1
Fe-55	2.68	a	0.016
Fe-59	44.5	d	0.97
Co-56	77.1	d	0.55
Co-57	271.8	d	0.12
Co-58	70.8	d	0.3
Co-60	5.27	a	0.78
Ni-63	100	a	0
Ni-65	2.52	h	2.2
Cu-64	12.7	h	1
Cu-67	2.58	d	1.3
Zn-65	243.9	d	0.076
Ga-66	9.45	h	1.6
Ga-67	3.26	d	0.35
Ga-68	1.13	h	1.8
As-76	1.1	d	2.1
Se-75	119.8	d	0.14
Br-77	2.38	d	0.01
Br-82	1.47	d	1.5
Rb-87	18.64	d	1.9
Sr-85	64.8	d	0.06
Sr-89	50.5	d	1.8
Sr-90/Y-90	29.1	a	3.5
Y-90	2.7	d	2
Zr-95/Nb-95	64	d	1.6
Mo-99/Tc-99m	2.75	d	1.9
Tc-99m	6	h	0.25

Radionuclide	$T_{1/2}$	Unit	CF_8 [(μSv/h)/(Bq/cm^2)]
Tc-99	2.10E+05	a	1.2
Ru-103/ Rh-103m	39.3	d	0.78
Ru-106/ Rh-106	372.6	d	2.2
Ag-110m	249.8	d	0.68
Ag-111	7.5	d	1.8
Cd-109	462.6	d	0.54
In-111	2.8	d	0.38
In-113m	1.66	h	0.73
In-115m	4.49	h	1.3
Sn-125	9.64	d	2.3
Sb-122	2.7	d	2.2
Sb-124	60.2	d	2.2
Sb-126	12.4	d	1.8
Te-123m	119.7	d	1.1
Te-132	3.26	d	0.78
I-123	13.2	h	0.38
I-124	4.18	d	0.52
I-125	60.1	d	0.021
I-131	8	d	1.6
Cs-131	9.69	d	0.01
Cs-134	2.07	a	1.4
Cs-137	30.2	a	1.6
Ba-133	10.5	a	0.13
Ba-140/La-140	12.8	d	3.8
La-140	1.7	d	2.1
Ce-139	137.6	d	0.49
Ce-141	32.5	d	1.8
Ce-143	1.38	d	2
Pr-143	13.6	d	1.7
Pm-147	2.6	a	0.6
Sm-153	1.95	d	1.6
Eu-152	13.5	a	0.92
Eu-154	8.59	a	2.1
Eu-156	15.2	d	1.2
Er-169	9.4	d	1.1
Yb-169	32	d	1
Re-186	3.78	d	1.8
Re-188	17	h	2.3
Ir-192	73.8	d	1.9
Au-198	2.7	d	1.7
Hg-197	2.67	d	0.092
Hg-203	46.6	d	0.89
Tl-201	3.04	d	0.27
Tl-204	3.8	a	1.6
Pb-210	22.2	a	0.0084
Po-210	138.4	d	6.90E-07
U-235	7.04E+08	a	0.18

Radionuclide	$T_{1/2}$	Unit	CF_8 [(µSv/h)/(Bq/cm^2)]
U-238	4.47E+09	a	2.30E-03
Pu-238	87.7	a	3.70E-03
Pu-239	2.41E+04	a	1.40E-03
Am-241	432.7	a	0.019
Cm-244	18.1	a	2.20E-03
Cf-252	2.65	a	3.20E-03

Reference: [20]

CF_8 Skin beta dose rate conversion factor; skin beta dose rate per unit deposit of radionuclide on the skin.

NOTE

The dose rates are to the basal layer of the skin (70 µm in depth) due to beta rays and electrons. The gamma contribution to the dose rate is generally just a few per cent. Contamination is supposed to be uniformly spread over the skin (infinite thin deposit).

Purpose
To assess committed effective dose and equivalent dose to the thyroid from inhalation.

Discussion
Radionuclides released to atmosphere will give rise to exposure by external radiation and by inhalation of the passing plume. During dispersal radionuclides may be deposited on to the ground, depending on their physical form. Radionuclides may be transferred back into the atmosphere by the action of the wind or mechanical disturbance (resuspension). This procedure deals only with the inhalation.

Input
- Radionuclide concentrations in air
- Inhalation duration

Output
- Committed effective dose from inhalation
- Committed equivalent dose to the thyroid

Step 1
Obtain the concentration in air of major contributors to thyroid and effective dose either by measurements using the appropriate procedures in Ref. [6] or by crude estimation using procedure E5a.

Committed effective dose from inhalation

Step 2
Estimate the committed effective dose from inhalation using the following equation:

$$E_{inh} = \sum_{i=1}^{n} \overline{C}_{a,i} \cdot CF_{2,i} \cdot T_e$$

where

$\overline{C}_{a,i}$ = Average concentration of radionuclide *i* in air [kBq/m^3]

$CF_{2,i}$ = Conversion factor for radionuclide *i* from Table E6; a breathing rate of 1.5 m^3/h is assumed as recommended by ICRP for an adult performing light activities [22]

E_{inh} = Committed effective dose from inhalation [mSv]

T_e = Time of exposure to plume [h]

Committed equivalent dose to the thyroid

Step 3
Estimate committed equivalent dose to the thyroid by using the equation

$$H_{thy} = \sum_{i=1}^{n} \overline{C}_{a,i} \cdot CF_{1,i} \cdot T_e$$

Where

H_{thy} = Committed equivalent dose to the thyroid [mSv]

$CF_{1,i}$ = Thyroid conversion factor for radionuclide *i* (Tellurium or Iodine) from Table E7; a breathing rate of 1.5 m^3/h and 1.12 m^3/h is assumed as recommended by ICRP for an adult and a 10 years old child performing light activities [22]

TABLE E6. COMMITTED EFFECTIVE DOSE FROM ONE HOUR'S INHALATION OF CONTAMINATED AIR — FOR AN ADULT

Radionuclide	Conversion factor CF_2 [(mSv/h)/(kBq/m^3)]	Radionuclide	Conversion factor CF_2 [(mSv/h)/(kBq/m^3)]
H-3[a]	7.8E-04	Ru-105	2.7E-04
C-14	8.7E-03	Ru-106	1.0E-01
Na-22	2.0E-03	Rh-103m	4.1E-06
Na-24	4.1E-04	Rh-105	5.3E-04
P-32	5.1E-03	Rh-106	1.7E-04
P-33	2.3E-03	Ag-110m	2.0E-02
S-35 org.	2.9E-03	Cd-109	1.2E-02
S-35 inorg.	2.1E-03	Cd-113m	1.7E-01
Cl-36	1.1E-02	Cd-115	1.7E-03
K-40	3.2E-03	In-113m	3.0E-05
K-42	1.8E-04	In-114m	1.4E-02
Ca-45	5.6E-03	In-115	5.9E-01
Sc-44	2.7E-04	In-115m	8.9E-05
Sc-46	1.0E-02	Sn-113	4.1E-03
Ti-44	2.0E-01	Sn-123	1.2E-02
V-48	3.6E-03	Sn-126	4.2E-02
Cr-51	5.6E-05	Sb-124	1.3E-02
Mn-54	2.4E-03	Sb-126	4.8E-03
Mn-56	1.8E-04	Sb-126m	3.0E-05
Fe-55	1.2E-03	Sb-127	2.9E-03
Fe-59	6.0E-03	Sb-129	3.8E-04
Co-58	3.2E-03	Sb-131	6.6E-05
Co-60	4.7E-02	Te-127	2.1E-04
Ni-63	2.0E-03	Te-127m	1.5E-02
Cu-64	1.8E-04	Te-129	5.9E-05
Zn-65	3.3E-03	Te-129m	1.2E-02
Ga-68	7.4E-05	Te-131	4.2E-05
Ge-68	2.1E-02	Te-131m	1.4E-03
Se-75	2.0E-03	Te-132	3.0E-03
Kr-85	NC	I-125	7.7E-03
Kr-85m	NC	I-129	5.4E-02
Kr-87	NC	I-131	1.1E-02
Kr-88	NC	I-132	1.7E-04
Rb-86	1.4E-03	I-133	2.3E-03
Rb-87	7.5E-04	I-134	8.3E-05
Rb-88	2.4E-05	I-135	4.8E-04
Sr-89	1.2E-02	Xe-131m	NC
Sr-90	2.4E-01	Xe-133	NC
Sr-91	6.2E-04	Xe-133m	NC
Y-90	2.3E-03	Xe-135	NC
Y-91	1.3E-02	Xe-135m	NC
Y-91m	1.7E-05	Xe-138	NC
Zr-93	3.8E-02	Cs-134	3.0E-02
Zr-95	8.9E-03	Cs-134m	9.0E-05
Zr-97	1.4E-03	Cs-135	1.3E-02
Nb-93m	2.7E-03	Cs-136	4.2E-03
Nb-94	7.4E-02	Cs-137	5.9E-02
Nb-95	2.7E-03	Cs-138	6.5E-05
Nb-95m	1.3E-03	Ba-133	1.5E-02
Nb-97	6.8E-05	Ba-137m	NC
Mo-99	1.5E-03	Ba-140	8.7E-03
Tc-99	2.0E-02	La-140	1.7E-03
Tc-99m	2.9E-05	La-141	2.3E-04
Ru-103	4.5E-03	Ce-141	5.7E-03

Radionuclide	Conversion factor CF_2 [(mSv/h)/(kBq/m^3)]
Ce-143	1.2E-03
Ce-144	8.0E-02
Pr-143	3.6E-03
Pr-144	2.7E-05
Pr-144m	NC
Pm-145	5.4E-03
Pm-147	7.5E-03
Nd-147	3.6E-03
Sm-147	1.4E+01
Sm-151	6.0E-03
Eu-152	6.3E-02
Eu-154	8.0E-02
Eu-155	1.0E-02
Gd-152	2.9E+01
Gd-153	3.2E-03
Tb-160	1.1E-02
Ho-166m	1.8E-01
Tm-170	1.1E-02
Yb-169	4.5E-03
Hf-172	4.8E-02
Hf-181	7.5E-03
Ta-182	1.5E-02
Re-187	9.5E-06
W-187	2.9E-04
Ir-192	9.9E-03
Au-198	1.3E-03
Hg-203 org.	9.6E-04
Hg-203 inorg.	3.6E-03
Tl-204	5.9E-04
Pb-209	9.2E-05
Pb-210	8.4E+00
Pb-211	1.8E-02
Pb-212	2.9E-01
Pb-214	2.3E-02
Bi-207	8.4E-03
Bi-210	1.4E-01
Bi-212	4.7E-02
Bi-213	4.5E-02
Bi-214	2.1E-02
Po-210	6.5E+00
Fr-223	1.3E-03
Ra-223	1.3E+01
Ra-224	5.1E+00
Ra-225	1.2E+01
Ra-226	1.4E+01
Ra-228	2.4E+01
Ac-225	1.3E+01
Ac-227	8.1E+02
Ac-228	3.8E-02
Th-227	1.5E+01
Th-228	6.0E+01
Th-229	3.6E+02

Radionuclide	Conversion factor CF_2 [(mSv/h)/(kBq/m^3)]
Th-230	1.5E+02
Th-231	5.0E-04
Th-232	1.7E+02
Th-234	1.2E-02
Pa-231	2.1E+02
Pa-233	5.9E-03
Pa-234	6.0E-04
U-232	5.6E+01
U-233	1.4E+01
U-234	1.4E+01
U-235	1.3E+01
U-236	1.3E+01
U-238	1.2E+01
U Dep&Nat	1.2E+01
U Enrich	1.4E+01
UF_6	1.4E+01
Np-237	7.5E+01
Np-239	1.5E-03
Pu-236	6.0E+01
Pu-238	1.7E+02
Pu-239	1.8E+02
Pu-240	1.8E+02
Pu-241	3.5E+00
Pu-242	1.7E+02
Am-241	1.4E+02
Am-242	3.0E-02
Am-242m	1.4E+02
Am-243	1.4E+02
Cm-242	8.9E+00
Cm-243	1.0E+02
Cm-244	8.6E+01
Cm-245	1.5E+02
Cm-248	5.4E+02
Cf-252	3.0E+01

Reference: [2]

[a] Doubled to account for skin absorption.

NOTE

Committed effective dose per unit intake via inhalation for other age groups can be found in IAEA BSS [2]. In Table E6 the highest value from IAEA BSS is used (conservative approach) and breathing rate of 1.5 m^3/h is assumed (as recommended by the ICRP for an adult performing light activity [22]).

TABLE E7. COMMITTED EQUIVALENT DOSE TO THE THYROID FROM ONE-HOUR'S INHALATION OF CONTAMINATED AIR

Radionuclide	Conversion factor CF_1 $[(mSv/h)/(kBq/m^3)]$	
	Adult	**10 years**
Te-131m	2.0E-02	3.7E-02
Te-132	3.8E-02	6.8E-02
I-125	1.5E-01	2.5E-01
I-129	1.1E+00	1.5E+00
I-131	2.3E-01	4.1E-01
I-132	2.1E-03	3.8E-03
I-133	4.2E-02	8.3E-02
I-134	3.9E-04	7.3E-04
I-135	8.6E-03	1.7E-02

Reference: [23]

NOTE

For simplicity, the conversion factors are provided in terms of mSv acquired in one hour, breathing an air concentration of 1 kBq/m^3. In Table E7 the highest value for particulate aerosol from [22] is used (conservative approach). A breathing rate of 1.5 m^3/h and 1.12 m^3/h was assumed for adult and 10 years old child respectively (as recommended by the ICRP for performing light activity [22]).

Purpose
To assess radionuclide concentrations in air based on release rate of radionuclide.

Discussion
Radionuclides released to the atmosphere will be dispersed. The concentration at ground level at specific distances from the release point will depend on the quantity released, the height of the released point, local meteorological conditions, heat contained in the release, precipitation on the terrain, physical and chemical form of the released material, and other factors.

The best way to assess radionuclide concentrations in air is to measure them. However in the absence of measurements the method presented here gives a rough estimation. This method is valid ONLY if:

i. the release rate, wind direction, and wind speed are constant
ii. the meteorological and terrain conditions are simple
iii. the release height is ground level
iv. it is not raining and
v. there is a single release point

Input
- Release rate
- Average wind speed

Output
- Radionuclide concentrations in air

Step 1
Estimate concentration of radionuclide *i* in air by using the following equation:

$$C_{a,i} = \frac{Q_i \cdot DF_m}{\bar{u}}$$

where

$C_{a,i}$ = Concentration of radionuclide *i* in air [kBq/m^3]
Q_i = Release rate of radionuclide *i* [kBq/s]
$\bar{u}$ = Average wind speed [m/s]
DF_m = Dilution factor from Table E8 for certain distance from release point [m^{-2}]; for distances less than 0.5 km use Fig. E1, however, these calculations are very uncertain (building wake)

NOTE
Table E9 can be used to determine stability class and Table E10 for crude estimation of wind speed (in absence of measured data).

TABLE E8. DILUTION FACTORS [m^{-2}]

Distance [b] [km]	Class stability [a] A	B	C	D	E	F
≤ 0.5 [c]	5.7E-04	6.6E-04	7.2E-04	7.9E-04	8.4E-04	8.9E-04
1	3.3E-05	7.9E-05	1.3E-04	2.4E-04	3.4E-04	5.0E-04
2	9.2E-07	4.3E-06	1.3E-05	4.2E-05	8.6E-05	2.0E-04
3	7.3E-07	1.8E-06	5.9E-06	2.3E-05	4.6E-05	1.1E-04
4	5.6E-07	1.0E-06	3.4E-06	1.6E-05	3.2E-05	7.8E-05
5	4.4E-07	6.2E-07	2.1E-06	1.1E-05	2.4E-05	5.7E-05
10	2.6E-07	3.5E-07	7.2E-07	4.0E-06	9.1E-06	2.4E-05
15	1.8E-07	2.4E-07	3.5E-07	2.3E-06	5.6E-06	1.4E-05
20	1.4E-07	1.8E-07	2.5E-07	1.4E-06	3.6E-06	9.2E-06
25	1.2E-07	1.5E-07	2.0E-07	9.6E-07	2.5E-06	6.8E-06
30	1.0E-07	1.2E-07	1.8E-07	7.7E-07	2.1E-06	5.5E-06

Reference: Values for 0.5 km are based on interpolation of [23], Figs.5-7, pp. 25-27; others, [24], Figs. 3-5a-3-5f

[a] Pasquill turbulence types. Dilution factors are for centre line of ground-level release at a vertical dispersion of 1000m.

[b] Distance downwind of source on centre line of plume.

[c] These factors are dominated by building wake; in this table they are assumed to be constant and independent of stability class.

TABLE E9. RELATIONSHIP BETWEEN STABILITY CLASS AND WEATHER CONDITIONS

Surface wind speed [m/s]	Daytime insolation (solar radiation)			Night time conditions [a]		Day or night
	Strong	Moderate	Slight	Thin overcast or > 4/8 cloudiness	≤ 3/8 cloudiness	Heavy overcast
< 2	A	A-B	B	-	-	D
2	A-B	B	C	E	F	D
4	B	B-C	C	D	E	D
6	C	C-D	D	D	D	D
> 6	C	D	D	D	D	D

Reference: [24], p. 591.

[a] The degree of cloudiness is defined as that fraction of the sky above the local apparent horizon that is covered by clouds.

TABLE E10. RELATIONSHIP BETWEEN WEATHER CONDITIONS AND WIND SPEED

Observations	Wind speed [m/s]
Smoke rises vertically	0.3
Smoke drift gives direction but wind not felt on face	1
Wind felt on face, leaves rustle, vane moved by wind	2–3
Leaves and twigs in constant motion, wind extends flag	4–5
Moves dust, loose paper, and small branches	6–7
Small trees in leaf begin to sway	8–9
Large branches in motion, high wires whistle	10–12
Whole trees in motion	13–15
Twigs broken off trees; progress impeded	16–18
Slight structural damage occurs	19–21
Trees uprooted, considerable structural damage	22–25
Rare, widespread damage	> 25

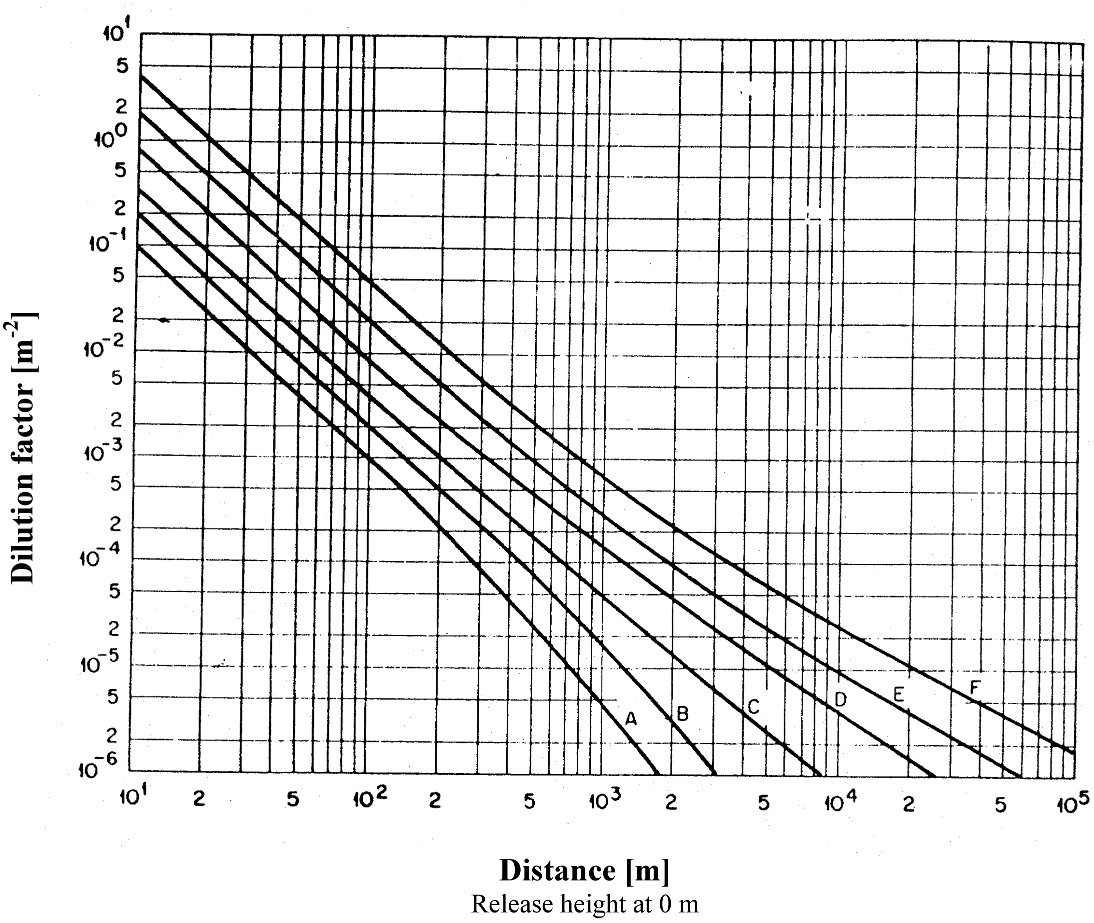


FIG. E1. Dilution factor as a function of downwind distance.

Reference: [26]

Release rates from a fire

This step uses the total activity involved in a fire to estimate the rate at which radioactive material is released. Filtering, plate-out, or other mechanisms that will reduce the release of non-nobles are not considered. This method should provide a reasonable upper bound for most accidents involving radioactive material.

Step 1

Estimate the release rate using the formula below:

$$Q_i = \frac{A_i \cdot FRF_i}{T_r}$$

Where

A_i = Activity of radionuclide *i* available in fire [kBq]

FRF_i = Fire Release Fraction for radionuclide *i* from Table E11 if form of compound is unknown or Table E12 if the compound form is known

T_r = Release duration [s]

TABLE E11. FIRE RELEASE FRACTION (FRF) BY RADIONUCLIDE

This table provides an estimate of the fraction of a radionuclide released if it is involved in a fire.

$$\text{FRF} = \frac{\text{Activity released [kBq]}}{\text{Activity involved in fire [kBq]}}$$

Radionuclide	FRF[a]	Radionuclide	FRF[a]
H-3(gas)	5.E-01	Se-75	1.E-02
C-14		Kr-85	
Na-22	1.E-02	Kr-85m	1.E+00
Na-24		Kr-87	
P-32		Kr-88	
P-33		Rb-86	
S-35	5.E-01	Rb-87	
Cl-36		Rb-88	
K-40		Sr-89	
K-42		Sr-90	
Ca-45		Sr-91	
Sc-46		Y-90	
Ti-44		Y-91	
V-48	1.E-02	Y-91m	
Cr-51		Zr-93	
Mn-54		Zr-95	1.E-02
Mn-56		Nb-94	
Fe-55		Nb-95	
Co-58	1.E-03	Mo-99	
Fe-59	1.E-02	Tc-99	
Co-60	1.E-03	Tc-99m	
Ni-63		Ru-103	
Cu-64	1.E-02	Ru-105	
Zn-65		Rh-106	
Ga-68	NC	Ru-106	
Ge-68		Ag-110m	
Cd-109		Xe-138	1.E+00
Cd-113m		Cs-134	
In-114m		Cs-135	
Sn-113		Cs-136	
Sn-123		Cs-137	
Sn-126		Cs-138	
Sb-124		Ba-133	
Sb-126		Ba-137m	
Sb-126m	1.E-02	Ba-140	
Sb-127		La-140	1.E-02
Sb-129		Ce-141	
Te-127		Ce-144	
Te-127m		Pr-144	
Te-129		Pr-144m	
*Te-129m		Pm-145	
Te-131		Pm-147	
Te-131m		Sm-147	
Te-132		Sm-151	
I-125	5.E-01	Eu-152	
I-129	5.E-01	Eu-154	1.E-02

<table>
<tr><th>Radionuclide</th><th>FRF[a]</th><th>Radionuclide</th><th>FRF[a]</th></tr>
<tr><td>I-131</td><td rowspan="5"></td><td>Eu-155</td><td rowspan="8"></td></tr>
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<tr><td>I-133</td><td>Tb-160</td></tr>
<tr><td>I-134</td><td>Ho-166m</td></tr>
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<tr><td>Xe-135</td><td>Ta-182</td><td>1.E-03</td></tr>
<tr><td>Xe-135m</td><td>W-187</td><td>1.E-02</td></tr>
<tr><td>Ir-192</td><td>1.E-03</td><td>U-232</td><td rowspan="17">1.E-03</td></tr>
<tr><td>Au-198</td><td rowspan="7">1.E-02</td><td>U-233</td></tr>
<tr><td>Hg-203</td><td>U-234</td></tr>
<tr><td>Tl-204</td><td>U-235</td></tr>
<tr><td>Pb-210</td><td>U-236</td></tr>
<tr><td>Bi-207</td><td>U-238</td></tr>
<tr><td>Bi-210</td><td>Np-237</td></tr>
<tr><td>Po-210</td><td>Np-239</td></tr>
<tr><td>Ra-226</td><td rowspan="10">1.E-03</td><td>Pu-236</td></tr>
<tr><td>Ac-227</td><td>Pu-238</td></tr>
<tr><td>Ac-228</td><td>Pu-239</td></tr>
<tr><td>Th-227</td><td>Pu-240</td></tr>
<tr><td>Th-228</td><td>Pu-241</td></tr>
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<tr><td>Pa-231</td><td>Am-243</td></tr>
<tr><td>Pa-233</td><td></td><td></td></tr>
</table>

Reference: [27]; FRFs for radionuclides not listed in [27] are from [28], Table 3.7 STCP Radionuclide Groups, page 12.

TABLE E12. FIRE RELEASE FRACTION (FRF) BY COMPOUND FORM

Compound Form	FRF[a]
Noble Gas	1.0
Very Mobile Form (i.e. particle attached to flammable trash in a fire)	1.0
Volatile and combustible compounds	0.5
Carbon	0.01
Semi-volatile compounds	0.01
Non-volatile powders	0.001
Uranium and plutonium metal	0.001
Non-volatile in flammable liquids	0.005
Non-volatile in non-flammable liquids	0.001
Non-volatile solids	0.0001

Reference: [27]

Purpose
To assess committed effective dose from ingestion of contaminated food or soil.

Discussion
Concentrations of radionuclides in food and milk can be altered by several natural and man-made mechanisms.

Input
- Radionuclide concentrations in food, water or milk
- Radionuclide concentrations in soil
- Time of intake

Output
- Committed effective dose from ingestion

Step 1
Obtain radionuclide concentrations in food or in soil samples using monitoring procedures in Ref. [6].

Step 2
Calculate committed effective dose from consumption of food or soil by using the equation:

$$E_{ing} = \sum_{i=1}^{n} C_{f,i} \cdot U_f \cdot DI_{f,i} \cdot CF_{5,i}$$

Where

E_{ing} = Committed effective dose from ingestion [mSv]

$C_{f,i}$ = Concentration of radionuclide *i* in food *f* after processing or in soil [kBq/kg]

U_f = The mass of food *f* consumed by the population of interest per day. For soil ingestion maximum adult ingestion is about 100 mg/d with an average of about 25 mg/d; the maximum consumption for a child is 500 mg/d with an average of 100 mg/d; [kg/d or L/d]

$CF_{5,i}$ = Conversion factor from Table E13 [mSv/kBq]; committed effective dose from ingestion per unit intake of radionuclide *i*

$DI_{f,i}$ = Days of intake[d]; the period food is assumed to be consumed; if $T_{1/2} > 21$ days use 30 days, if $T_{1/2} < 21$ days use the mean life (T_m) of the radionuclide

$$T_m = T_{1/2} \cdot 1.44$$

where $T_{1/2}$ is radiological half-life

NOTE
Age related dose conversion factors can be found in [2].

Step 3

Repeat step 2 for any food of interest or age group.

Step 4

Sum up the results to calculate total committed effective dose due to ingestion.

TABLE E13. COMMITTED EFFECTIVE DOSE FROM INGESTION PER UNIT INTAKE OF RADIONUCLIDE — INGESTION DOSE CONVERSION FACTORS FOR AN ADULT

Radionuclide	Conversion factor CF_5 [mSv/kBq]
H-3	1.8E-05
C-14	5.8E-04
Na-22	3.2E-03
Na-24	4.3E-04
P-32	2.4E-03
P-33	2.4E-04
S-35 org.	7.7E-04
S-35 inorg.	1.3E-04
Cl-36	9.3E-04
K-40	6.2E-03
K-42	4.3E-04
Ca-45	7.1E-04
Sc-44	3.5E-04
Sc-46	1.5E-03
Ti-44	5.8E-03
V-48	2.0E-03
Cr-51	3.8E-05
Mn-54	7.1E-04
Mn-56	2.6E-04
Fe-55	3.3E-04
Fe-59	1.8E-03
Co-58	7.4E-04
Co-60	3.4E-03
Ni-63	1.5E-04
Cu-64	1.2E-04
Zn-65	3.9E-03
Ga-68	1.0E-04
Ge-68	1.3E-03
Se-75	2.6E-03
Kr-85	0.0E+00
Kr-85m	0.0E+00
Kr-87	0.0E+00
Kr-88	0.0E+00
Rb-86	2.8E-03
Rb-87	1.5E-03
Rb-88	9.0E-05
Sr-89	2.6E-03
Sr-90	2.8E-02
Sr-91	6.5E-04
Y-90	2.7E-03
Y-91	2.4E-03
Y-91m	1.2E-05
Zr-93	1.1E-03
Zr-95	9.5E-04

Radionuclide	Conversion factor CF_5 [mSv/kBq]
Zr-97	2.1E-03
Nb-93m	1.2E-04
Nb-94	1.7E-03
Nb-95	5.9E-04
Nb-95m	5.7E-04
Nb-97	6.9E-05
Mo-99	6.0E-04
Tc-99	6.4E-04
Tc-99m	2.2E-05
Ru-103	7.3E-04
Ru-105	2.6E-04
Ru-106	7.0E-03
Rh-103m	3.8E-06
Rh-105	3.7E-04
Rh-106	1.6E-04
Ag-110m	2.8E-03
Cd-109	2.0E-03
Cd-113m	0.0E+00
Cd-115	1.4E-03
In-113m	2.8E-05
In-114m	4.1E-03
In-115	3.2E-02
In-115m	8.6E-05
Sn-113	7.4E-04
Sn-123	2.1E-03
Sn-126	4.8E-03
Sb-124	2.6E-03
Sb-126	2.5E-03
Sb-126m	3.6E-05
Sb-127	1.7E-03
Sb-129	4.2E-04
Sb-131	1.0E-04
Te-127	1.7E-04
Te-127m	2.3E-03
Te-129	6.3E-05
Te-129m	3.0E-03
Te-131	8.7E-05
Te-131m	1.9E-03
Te-132	3.8E-03
I-125	1.5E-02
I-129	1.1E-01
I-131	2.2E-02
I-132	2.9E-04
I-133	4.3E-03

Radionuclide	Conversion factor CF_5 [mSv/kBq]
I-134	1.1E-04
I-135	9.3E-04
Xe-131m	0.0E+00
Xe-133	0.0E+00
Xe-133m	0.0E+00
Xe-135	0.0E+00
Xe-135m	0.0E+00
Xe-138	0.0E+00
Cs-134	1.9E-02
Cs-134m	2.0E-05
Cs-135	2.0E-03
Cs-136	3.1E-03
Cs-137	1.3E-02
Cs-138	9.2E-05
Ba-133	1.5E-03
Ba-137m	0.0E+00
Ba-140	2.6E-03
La-140	2.0E-03
La-141	3.6E-04
Ce-141	7.1E-04
Ce-143	1.1E-03
Ce-144	5.2E-03
Pr-143	1.2E-03
Pr-144	5.1E-05
Pr-144m	0.0E+00
Pm-145	1.1E-04
Pm-147	2.6E-04
Nd-147	1.1E-03
Sm-147	4.9E-02
Sm-151	9.8E-05
Eu-152	1.4E-03
Eu-154	2.0E-03
Eu-155	3.2E-04
Gd-152	4.1E-02
Gd-153	2.7E-04
Tb-160	1.6E-03
Ho-166m	2.0E-03
Tm-170	1.3E-03
Yb-169	7.1E-04
Hf-172	1.0E-03
Hf-181	1.1E-03
Ta-182	1.5E-03
Re-187	5.1E-06
W-187	6.3E-04
Ir-192	1.4E-03
Au-198	1.0E-03
Hg-203 org.	1.9E-03
Hg-203 inorg.	5.4E-04
Tl-204	1.3E-03
Pb-209	5.7E-05
Pb-210	6.9E-01
Pb-211	1.8E-04
Pb-212	6.0E-03
Pb-214	1.5E-04
Bi-207	1.3E-03
Bi-210	1.3E-03
Bi-212	2.6E-04

Radionuclide	Conversion factor CF_5 [mSv/kBq]
Bi-213	2.0E-04
Bi-214	1.1E-04
Po-210	1.2E+00
Fr-223	2.3E-03
Ra-223	1.0E-01
Ra-224	6.5E-02
Ra-225	9.9E-02
Ra-226	2.8E-01
Ra-228	6.9E-01
Ac-225	2.4E-02
Ac-227	1.1E+00
Ac-228	4.3E-04
Th-227	8.8E-03
Th-228	7.2E-02
Th-229	4.9E-01
Th-230	2.2E-01
Th-231	3.4E-04
Th-232	2.3E-01
Th-234	3.4E-03
Pa-231	7.1E-01
Pa-233	8.8E-04
Pa-234	5.1E-04
U-232	3.3E-01
U-233	5.0E-02
U-234	4.9E-02
U-235	4.6E-02
U-236	4.6E-02
U-238	4.4E-02
U Dep&Nat	4.4E-02
U Enrich	4.9E-02
UF6	4.9E-02
Np-237	1.1E-01
Np-239	8.0E-04
Pu-236	8.6E-02
Pu-238	2.3E-01
Pu-239	2.5E-01
Pu-240	2.5E-01
Pu-241	4.7E-03
Pu-242	2.4E-01
Am-241	2.0E-01
Am-242	3.0E-04
Am-242m	1.9E-01
Am-243	2.0E-01
Cm-242	1.3E-02
Cm-243	1.5E-01
Cm-244	1.2E-01
Cm-245	3.0E-01
Cm-248	1.1E+00
Cf-252	9.0E-02

Reference: [2]

NOTE

Ingestion dose conversion factors for other age groups can be found in IAEA BSS [2].

Purpose
To assess effective dose from external exposure to γ- emitting radionuclides in a radioactive plume.

Discussion
The direct exposure pathway for γ-emitting radionuclides released in to the atmosphere will be external γ-dose to the whole body from the radioactive material in the plume.

Estimates for external exposure to γ radiation due to immersion in contaminated air provide conservative estimates for exposure to an overhead plume.

Input
- Average concentration of radionuclides in air
- Duration of exposure

Output
- Effective dose from external exposure to γ radiation from the plume

Step 1
Estimate the air immersion dose using the following expression:

$$E_{ext} = T_e \cdot \sum_i \overline{C}_{a,i} \cdot CF_{9,i}$$

Where

E_{ext} = Effective dose from external exposure due to immersion in contaminated air [mSv]

$\overline{C}_{a,i}$ = Average concentration of radionuclide i in air [kBq/m^3]

$CF_{9,i}$ = Conversion factor for radionuclide i from Table E14

T_e = Exposure duration [h]

TABLE E14. CONVERSION FACTORS FOR EXTERNAL γ EXPOSURE DUE TO IMMERSION IN CONTAMINATED AIR

Radionuclide	CF_9 [(mSv/h)/(kBq/m^3)]
H-3	0.0E+00
C-14	0.0E+00
Na-22	4.8E-04
Na-24	1.0E-03
P-32	0.0E+00
P-33	0.0E+00
S-35	0.0E+00
Cl-36	1.8E-12
K-40	3.4E-05
K-42	6.3E-05
Ca-45	3.4E-15
Sc-46	4.4E-04
Ti-44	2.8E-05
V-48	6.3E-04
Cr-51	6.7E-06
Mn-54	1.9E-04
Mn-56	4.1E-04
Fe-55	4.8E-09
Fe-59	2.6E-04
Co-58	2.1E-04
Co-60	5.6E-04
Ni-63	0.0E+00
Cu-64	4.1E-05
Zn-65	1.3E-04
Ge-68	1.9E-08
Se-75	8.5E-05
Kr-85	4.8E-07
Kr-85m	3.4E-05
Kr-87	1.9E-04
Kr-88	4.8E-04
Kr-89	4.4E-04
Rb-86	2.1E-05
Rb-88	1.5E-04
Rb-89	4.8E-04
Sr-89	3.0E-08
Sr-90	0.0E+00
Sr-91	1.5E-04
Y-90	0.0E+00
Y-91	7.8E-07
Zr-93	0.0E+00
Zr-95	1.6E-04
Zr-97	4.1E-05
Nb-94	3.4E-04
Nb-95	1.7E-04
Mo-99	3.4E-05
Tc-99	1.1E-10
Tc-99m	2.8E-05
Ru-103	1.0E-04
Ru-105	1.7E-04
Ru/Rh-106[a]	4.4E-05
Pd-109	1.4E-07
Ag-ll0m	5.9E-04
Cd-109	4.8E-07
Cd-113m	0.0E+00
In-114m	1.9E-05
Sn-113	1.8E-06
Sn-123	1.5E-06
Sn-125	6.7E-05
Sn-126	1.0E-05
Sb-124	4.1E-04
Sb-126	5.9E-04
Sb-127	1.4E-04
Sb-129	3.2E-04
Te-127m	6.7E-07
Te-129	1.1E-05
Te-129m	7.4E-06
Te-131m	3.1E-04
Te-132	4.4E-05
Te-134	1.9E-04
I-125	2.3E-06
I-129	1.8E-06
I-131	8.1E-05
I-132	5.2E-04
I-133	1.3E-04
I-134	5.9E-04
I-135	3.5E-04
Xe-131m	1.8E-06
Xe-133	7.4E-06
Xe-133m	6.3E-06
Xe-135	5.2E-05
Xe-135m	9.3E-05
Xe-137	4.1E-05
Xe-138	2.6E-04
Cs-134	3.4E-04
Cs-136	4.8E-04
Cs/Ba-137[a]	1.3E-04
Cs-138	5.2E-04
Ba-133	7.8E-05
Ba-139	7.8E-06
Ba-140	4.1E-05
La-140	5.2E-04
La-141	9.3E-06

Radionuclide	CF_9 [(mSv/h)/(kBq/m^3)]
La-142	6.7E-04
Ce-141	1.6E-05
Ce-143	5.6E-05
Ce-144	3.7E-06
Ce/Pr-144[a]	1.1E-05
Nd-147	2.8E-05
Pm-145	3.5E-06
Pm-147	7.8E-10
Pm-149	2.5E-06
Pm-151	7.0E-05
Sm-151	1.9E-10
Eu-152	2.5E-04
Eu-154	2.7E-04
Eu-155	1.2E-05
Gd-153	1.9E-05
Tb-160	2.4E-04
Ho-166m	3.5E-04
Tm-170	1.0E-06
Yb-169	5.9E-05
Hf-181	1.1E-04
Ta-182	2.8E-04
W-187	1.0E-04
Ir-192	1.7E-04
Au-198	8.5E-05
Hg-203	4.8E-05
T1-204	2.1E-07
Pb-210	2.8E-07
Bi-207	3.4E-04
Bi-210	0.0E+00
Po-210	1.9E-09
Ra-226	1.4E-06
Ac-227	2.7E-08
Ac-228	2.0E-04
Th-227	2.2E-05
Th-228	4.1E-07
Th-230	8.1E-08
Th-232	4.1E-08
Pa-231	6.3E-06
U-232	5.6E-08
U-233	5.2E-08
U-234	3.2E-08
U-235	3.3E-05
U-236	2.6E-08
U-238	2.2E-08
U-240	1.5E-07
Np-237	4.8E-06
Np-239	3.6E-05
Pu-236	2.5E-08
Pu-238	1.9E-08
Pu-239	1.7E-08
Pu-240	1.8E-08
Pu-241	0.0E+00
Pu-242	1.6E-08
Am-241	4.1E-06
Am-242m	1.0E-07
Am-243	1.1E-05
Cm-242	2.1E-08
Cm-243	2.7E-05
Cm-244	1.8E-08
Cm-245	1.5E-05
Cm-246	1.5E-08
Cf-252	1.6E-08

Reference: [16]

[a] The contribution from the short-lived daughters is included in the factors for the parent radionuclide.

NOTE

The values are derived under the assumption that the plume is correctly approximated by a semi-infinite cloud.

Purpose
To calculate activity of a radionuclide at a specific time or of a radioactive material if weight of material is known.

Discussion
By the use of the half-life data and activity at certain time the radionuclide activity at some later time can be calculated. By the use of the specific activity of a radionuclide the weight of a radioactive material can be converted to activity.

Input
- Half-live of a radionuclide
- Activity at a certain time
- Weight of radioactive material
- Atomic mass number of a radionuclide

Output
- Activity of a radionuclide at a specific later time
- Activity of a radioactive material

Activity at a specific time

Calculate the activity at specific time using the following equation:

$$A_t = A_o \cdot 0.5^{\left(\frac{\Delta t}{T_{1/2}}\right)}$$

Where

A_o = Activity at the time t_o [kBq]

A_t = Activity at the time t [kBq]

Δt = $t-t_o$; elapsed time [same unit as half-life]

$T_{½}$ = Half-life of the radionuclide

Activity of a radioactive material

The specific activity is defined as the activity per gram of material and can be calculated by one of the following equations depending on the radiological half life ($T_{½}$) units used:

$$A_{sp} = \frac{1.16 \cdot 10^{17}}{T_{1/2}(h) \cdot AMN}$$

$$A_{sp} = \frac{4.83 \cdot 10^{15}}{T_{1/2}(d) \cdot AMN}$$

$$A_{sp} = \frac{1.32 \cdot 10^{13}}{T_{1/2}(y) \cdot AMN}$$

Where
A_{sp} = Specific activity [kBq/g]
AMN= Atomic mass number; the number that identifies the radionuclide
T = Half life in hours (h), days (d) or years (a)

Calculate the activity of a material using the following equation:

$$A = W \cdot A_{sp}$$

Where
A = Activity [kBq]
W = Weight [g]

WORKSHEETS

Caution: *The worksheets in this section should be adapted to reflect conditions for which they will be applied*

Completed by: *Response Initiator*	**WORKSHEET A1** **ACCIDENT REGISTRY FORM PART 1**	*No.* ______ *1 of 2*

Full Name: ________________________________ Date: ___________
(response initiator)

Provide copy to: ☐ Emergency Manager Time: ___________

Name of caller: ____
(Full name)

Member of: ☐ Public ☐ Facility staff ☐ Emergency Services

Organization or address of caller: ____

Telephone no. of caller: ___________________ Time of call: ______________________

Accident location: ____
(Facility address or site location)

Accident description: ____

____

____

____

____

Public involved: ☐ YES ☐ NO

Does the situation require urgent attention? ☐ YES ☐ NO
What assistance is required?

____

____

What advice was given (by phone):

____

____

____

Call verified: ☐ YES ☐ NO

Source details Radionuclide(s)/Activity: *Sealed:* ☐ capsule ☐ foil ☐ pencil ☐ other *Unsealed:* ☐ liquid ☐ gas ☐ solid ☐ powder *Generators:* kV mA	**Type of location** Factory: making Laboratory: type Office: function Public place:
Type of equipment ☐ Diagnostic X ray ☐ X ray optics ☐ Veterinary X ray ☐ Unsealed source ☐ Teletherapy ☐ Smoke detectors ☐ Brachytherapy ☐ Static eliminators ☐ Nuclear medicine ☐ Lab sealed sources ☐ Baggage inspection ☐ Yield monitors ☐ Gamma radiography ☐ Radioactive waste ☐ X-radiography ☐ Tracers ☐ Irradiator ☐ Processing of ore ☐ Thickness gauge ☐ Scrap metal recycling ☐ Level gauge ☐ Other (specify) ☐ Density/moisture gauge ☐ Unknown	**Nature of emergency** ☐ Found source ☐ Found contamination ☐ Unshielded source ☐ Damaged source ☐ Missing source ☐ Laboratory spill ☐ Transport ☐ Dispersion of activity ☐ Illicit trafficking ☐ Other (specify) ☐ Unknown
How discovered	**Current status** Is access being controlled? ☐ YES ☐ NO Actions to prevent exposure:
Backtrack Last time source known to be safe: Where did it come from: Source owner:	**Radiological hazards** (**M**aybe) ☐ Significant radiation dose **M** ☐ Inhalation hazards **M** ☐ Contaminated restricted areas **M** ☐ Release to the environment **M** ☐ Potential for dispersion **M**
Conventional hazards (**M**aybe) ☐ Fire **M** ☐ Explosives **M** ☐ Chemicals **M** ☐ Vapour, fumes **M** ☐ Other (specify)	**Medical effects** (**N**umber, **M**aybe) ☐ Injured persons **N**:_____ **M** ☐ Death **N**:_____ **M** ☐ Exposed individuals **N**:_____ **M** ☐ Contaminated individuals **N**:_____ **M**
Challenges to monitoring (**M**aybe) ☐ Explosive atmosphere **M** ☐ Static **M** ☐ RF **M** ☐ Water **M** ☐ Other (specify)	**Other data** (e.g. transport label details, dose rate measurement, contamination levels, weather details)

Signature: ___________________

Completed by: *Response Initiator*	**WORKSHEET A2** **ALERTED EMERGENCY RESPONDERS FORM**	*No.*________

Alerting by: ______________________________________ Date: ___________

(Full name)

Provide copy to: ☐ Emergency Manager

Emergency responder	Name of the person alerted	Telephone or fax No.	Time of first call	Time person alerted
Emergency Manager				
Radiological Assessor				
First Responder				
Police				
Emergency Medical Service				
Fire Service				
Civil Protection				
Facility personnel				
Other Responders				
Local Authorities				
Regulatory Authorities				
Health Authorities, hospital(s)				

REMARK:

Signature: ___________________

Completed by: Emergency Manager	WORKSHEET B1 **IMMEDIATE RESPONSE ACTIONS RECORD**	No.________

Completed by: ________________________________ Date: ___________
(Full name)

Immediate response action	Time initiated	Time arrived /completed	Remark
Initial instructions provided			
Emergency Responder arrived at the scene ❑ Police ❑ Fire service ❑ Emergency Medical Responder			
First on-scene controller: Relieved by:			
Security perimeter established Average distance:			
Safety perimeter established Average distance:			
Access and egress control established			
Contamination control established: ❑ Emergency workers ❑ Public			
Emergency worker protection: ❑ Respiratory protection ❑ Stable iodine ❑ Protective clothing ❑ Dose control			
Evacuation Sectors/areas:			
Sheltering Sectors/areas:			
Food control Sectors/areas:			
Fire fighting			
Spill control ❑ Confined ❑ Cleaning up			
Source survey			
Area survey			
Decontamination: ❑ People ❑ Equipment ❑ Area			

Signature: __________________

Completed by: Radiological Assessor	WORKSHEET D1 **EXPOSURE CONTROL RECORD**	No.________

Prepared by: ________________________________ Date: ___________
(Full name)

Provide to: ☐ Emergency Manager Time: ___________

Emergency Worker: ______________________________ Response Team: ____________
(Full name)
Personal ID No.: ____________

Using direct reading personal dosimeter

Dosimeter type: ___________________ Model: ___________ Ser No.: _______

Date of reading	Time of reading	READINGS [mSv]	Location at time of reading

Using gamma dose rate meter

Instrument type: ___________________ Model: ___________ Ser No.: _______

Location	Dose rate [mSv/h]	Time spent [min]	Estimated accumulated dose [mSv]

Stable iodine use record

Date	Time	Dosage	Remarks	Initials

Using TLD or film badge

TLD or film badge No.: _____________
(NOT to be read in the field)

Received		Collected		Reading [mSv]
Date/Time	Signature	Date/Time	Signature	
/		/		
/		/		
/		/		

NOTE: Film badge or TLDs should be assessed as soon as possible after the exposure and recorded above. To ensure a quick response the dosimetry service should be informed the dosimeter was worn during an emergency/recovery operation.

REMARKS:

Signature: _________________
(Radiological Assessor)

Completed by: *Radiological Assessor*	**WORKSHEET D2** **CONTAMINATED ITEM(S) LABEL**	*No.*________

CAUTION
CONTAMINATED ITEM(S)

Date: ______________________________ Time: __________________

Name: ____
(Emergency worker or owner)

Address: ____

____

Telephone No.: _____________________________

Item Description	**Max. Radiation Levels on the Surface***	
	Radiation type	**[cps]**
1.		
2.		
3.		

Responsible Person's Name: ______________________________________
(Radiological Assessor)

Signature: ________________________
(Radiological Assessor)

* **Note:** For details see original measurement records kept by Radiological Assessor.

Completed by: *Radiological Assessor*	**WORKSHEET D3** **RECEIPT FOR CONTAMINATED ITEM(S)**	*No.*_______

RECEIPT FOR CONTAMINATED ITEM(S)

Date: ________________________________ Time: ___________________

Location: ____

Name: ____
(Emergency worker or owner name)

Address: ____

____

Telephone No.: ______________________________

Item Description/Approximate Value

Item Description	Value
1.	
2.	
3.	

The item(s) described will be returned if decontamination is possible.

Signatures:

_____________________________ _____________________________
(Radiological Assessor) (Owner/Emergency worker)

ALL CLAIMS FOR REIMBURSEMENT SHOULD BE MADE TO:

____

APPENDICES

Appendix I

HOW TO REQUEST IAEA's ASSISTANCE

The responsibilities entrusted to the IAEA for the purpose of implementing the *Convention on Early Notification of a Nuclear Accident* and the *Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency* have necessitated among others, the establishment of a focal point within the Secretariat to which the IAEA's Member States, Parties to the two Conventions and relevant International Organizations can promptly and effectively direct its notification (in the case of an accident) or event reports, request for emergency assistance, request for information, etc. For this purpose and to facilitate the co-ordination of actions within the Secretariat, in 1986, the IAEA's **Emergency Response Centre** (ERC) was established and designated by the Director General to serve as a centre for management and control of the IAEA's response to nuclear accident or radiological emergency anywhere in the world. This Centre is located at the IAEA Headquarters in Vienna — Austria, on building B, 7th floor, rooms B0720 to B0725. During normal operation, this Centre is under the supervision of the Emergency Preparedness and Response Unit, Radiation Safety Section, Division of Radiation and Waste Safety of the Department of Nuclear Safety.

Step 1

The request for IAEA's assistance under the terms of the *Assistance Convention* shall be in a form of **written communication**.

NOTE

Under the terms of *Assistance Convention* the ERC expects to receive a request for assistance from the IAEA's Member States. However, the ERC, if the situation requires, is ready and expects to receive in the same format or by any other means of communication, request for emergency assistance from a Non Member State.

Step 2

In the request provide the following information:

A *Radiological emergency:*

- i. nature of the event
- ii. location
- iii. time of its occurrence
- iv. name and full address of the organization in charge of the response actions
- v. name and contact numbers of the person assigned as counterpart to the IAEA's requested emergency assistance

B *Type(s) of assistance required:*

- i. aerial survey
- ii. radiation monitoring
- iii. radionuclide identification
- iv. source recovery
- v. radiation safety assessment and advisory
- vi. medical support and/or advisory
- vii. bioassay support and/or advisory
- viii. radiopathology support and/or advisory
- ix. biodosimety support and/or advisory
- x. waste safety support and/or advisory
- xi. other(s), should be specified

It is essential for every message to contain the name of the sender and of the contact telephone and/or facsimile numbers.

> **NOTE**
> Messages arriving at the ERC in languages other than English may be delayed until a proper translation could be performed. If the language of the message is in any other language than in one of the IAEA's official languages, an additional delay between the receipt of the message and any subsequent action may occur. Therefore, as far as practicable, the use of English is strongly recommended in order to avoid delays in dealing properly and promptly with any notification or request for assistance.

Step 3

The request to the IAEA shall come from the **official Contact Point/Competent Authority** in your country.

> **NOTE**
> Direct your request for assistance only to the IAEA's **Emergency Response Centre** and not to any other office in the IAEA. In particular, refrain from sending any request for assistance to any personal contacts you may have in the IAEA.

Step 4

Inform **your Mission to the IAEA** of submitting a request for assistance to the IAEA. This will facilitate smooth co-ordination between the IAEA and your country.

Step 5

To be sure that you know the official contact point in your country for the *Assistance Convention* write the details here:

Organization:……………………….…………………………………….

Telephone number(s):………………………..………………………..

Facsimile number(s):……………………….…………………………

Keep this information updated at all times!

Appendix II

MEDICAL PREPAREDNESS AND RESPONSE

Effective medical response is a necessary component of an overall response to radiological emergencies. In general, the medical response to radiological accidents may represent a difficult challenge to the authorities due to the complexity of the situation, often requiring highly qualified specialists and organisational and material resources. Therefore an adequate planning is needed.

In radiological accident workers will be much more likely affected than members of the public. However, depending on the scale of the accident, both workers and members of the public may be exposed to ionising radiation from:

i. unshielded source(s);
ii. radionuclides deposited on the ground or other surfaces;
iii. radionuclides contaminating the body, clothing or possessions, and
iv. inhalation or ingestion of radioactive substances as a result of direct atmospheric or environmental contamination or, subsequently, by radioactive material in water or food.

Medical preparedness begins with awareness of where and what type of ionising radiation and radioactive materials are used in a country. This information data base should include at least:

i. locations where radiation or radioactive materials are used;
ii. types and activities of radioactive sources;
iii. types of radiation generating devices;
iv. information regarding the transportation of radioactive materials through any respective area;
v. spectrum of possible accidents, and
vi. estimation of the number of persons potentially affected in a severe radiological accident.

This information is necessary for adequate planning of medical capabilities. General and specialised medical centres may be needed, depending on the degree and nature of radiation induced injuries. Specialised advice may not be routinely available at the scene of the accident, except at medical facilities that use sources, such as medical irradiation therapy hospitals, where there are medical professionals who are experienced in dealing with radiation injuries or who have some knowledge in this respect. National Emergency Plan needs to identify organizations, plans and procedures for providing such assistance.

In the planning stage the following lists should be prepared:

i. a list of medical facilities at the local, regional, and national levels;
ii. a list of specialized medical facilities in other countries;
iii. a list of medical and support staff with telephone numbers and addresses in each respective location;
iv. a list of specialised medical centres for treating patients with radiation induced skin lesions or immunosuppression;
v. list of equipment and supplies needed for emergency response, and
vi. agreements with ambulance transport services.

The basic principles of the medical handling of exposed persons are based, to a large degree, on the methods used for handling other types of accidents, taking into account the specificity of the possible health effects of radiation and problems with contamination.

Exposed persons with high levels of external dose will be rare and usually among employees or other professionals. In the case of a lost or stolen source limited groups of the general public may receive doses that can lead to deterministic health effects. Such situation requires special medical care and supportive treatment for the early effects of acute radiation. In the event of internal exposure, especially by long-lived radionuclides, decorporation might be considered, even if the dose is below the threshold for deterministic health effects. The decision about decorporation levels should be based on committed equivalent dose to the organs and the effective committed dose.

Medical handling in an emergency situation is normally divided into medical care on-site (more often for workers) and medical care off-site (for workers and for affected population). To organise the medical response it is recommended that some kind of System for Medical Assistance for Radiation Emergencies under supervision of health authorities i.e. Ministry for Public Health is set up. General structure of the system is shown in Figure II1.

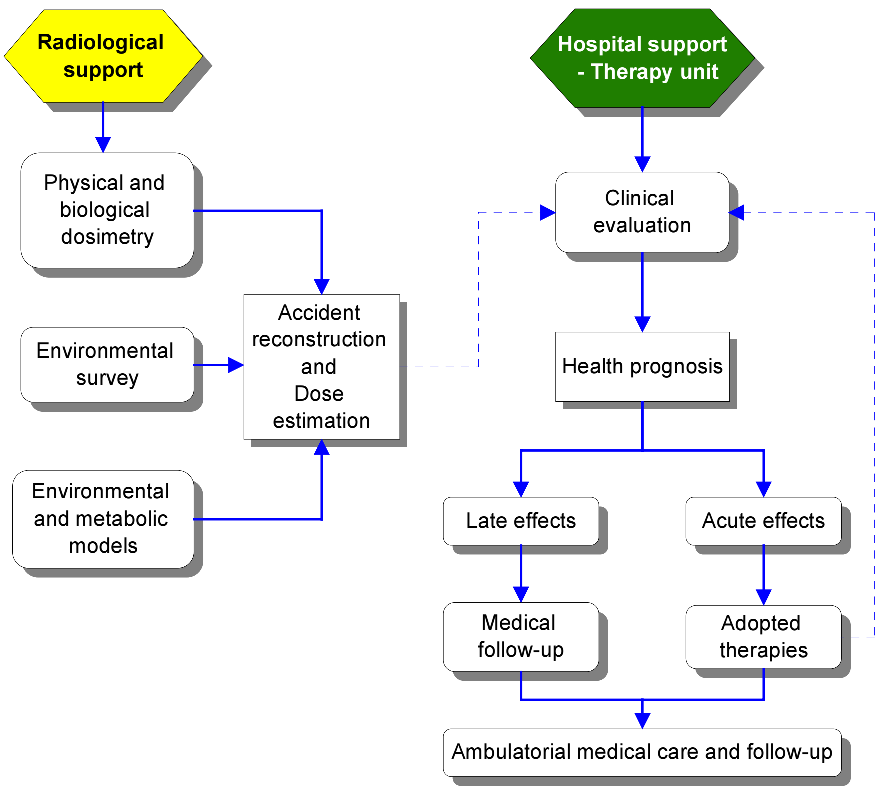

FIG. II1. Medical assistance in radiological emergencies interfaces and activities.

The Ministry for Public Health is usually responsible for providing advice to other Government departments on the health implications of any exposure to radiation. It is also responsible for ensuring that plans exist to provide treatment, monitoring and health advice to the public and to persons who may have, or fear they may have been contaminated or exposed to radiation.

In general, there are three levels of response, according to the degree of complexity, with respect to the necessary resources for assistance and the severity of consequences:

1. first aid provided at the scene of the accident;
2. initial medical examination, detailed investigation and medical treatment in a general hospital; and
3. complete examination and treatment in a specialised medical centre for treatment of radiation injuries.

At facilities with radioactive sources trained personnel on every shift should normally provide any first aid required. In the case of serious injury medical personnel from suitable off-site medical centres should be available. The purposes of medical handling on-site are to prevent traumatic injuries from threatening life, as well as possible assessment of contamination and performance of limited decontamination. If persons received high doses exceeding threshold for deterministic effects usually it is recommended to transport them directly to a highly specialised medical hospital for complete medical examination, treatment and assessment of the dose.

All persons involved in a radiological accident should be carefully interviewed to provide a detailed description of the emergency situation, positions of persons at the scene of an accident and time spent there. This is necessary for the purpose of dose reconstruction.

For situations involving large number of exposed persons one of the usual procedure is triage of persons — action to identify persons with different levels and kinds of damage. For example, after the Goiânia radiation accident 112800 persons were triaged based on the level of damage [31]. To perform the triage the existing medical facilities may be used effectively.

Any person who is externally contaminated or who is suspected to be contaminated should be confined in a comfortable area to prevent the spread of contamination. He/she should be decontaminated as soon as practicable. Priority should go to persons who are heavily contaminated and to those who have open wounds or contamination near the mouth and face, in order to reduce the risk of internal contamination.

The task of medical staff at the first off-site stage should be to identify the type, origin, severity and urgency of the cases. The basic principle is that treatment of serious or life-threatening injuries must take priority over other actions. A simple classification of the cases may be as follows:

1. Persons with symptoms of radiation exposure

Patients should be transported urgently to a specialised hospital after appropriate medical care. Experience has shown localised external exposure often without radioactive contamination is the most common consequence of radiological accident. In most cases the treatment can be offered in hospital units specifically identified for this purpose as part of a medical emergency plan.

2. Persons with combined injures (radiation plus conventional trauma)

Treatment of such patients has to be individualized in accordance with the nature and grade of the combined injury. Usually combination of radiation exposure with mechanical, thermal or chemical injuries may worsen prognosis.

3. Persons with external and/or internal contamination

These individuals need to be monitored to assess the degree of contamination if any. Decontamination facilities will be required. It is possible that contamination alone, without physical injury or a significant dose from external radiation, would be sufficient to cause an acute effect to the patient but not to attendants. Decontamination is required to prevent or reduce further exposure, to reduce the risk of inhalation or ingestion of contaminating material, and to reduce spreading of contamination.

4. Persons with potential radiation symptoms

Patients do not require immediate medical treatment but require urgent evaluation of the levels of dose. Because of this, medical staff should have sufficient knowledge, developed procedures, equipment and supplies to perform the first biological, medical examinations and analysis, which are necessary immediately after the accident.

5. Unexposed persons with conventional trauma

Patients should be taken to the specialised hospital where the medical treatment can be adapted to the type of pathology.

6. Persons believed to be uninjured and unexposed

Patients are normally sent home. Sometimes medical follow-up should be provided to ensure that the first assessment was correct and to evaluate the dose more accurately.

At all stages of medical care the treatment of highly contaminated individuals will require special facilities or isolated facilities with the special procedures that limit the spread of contamination and disposal of contaminated waste. For the detection of radioactive contamination necessary equipment should be available, such as, specialised radiation monitoring instruments, whole body counter and iodine thyroid counter. Usually the Radiation Protection Officer or health physicist performs measurements. For the purpose of dose reconstruction different instruments and methods can be used such as EPR spectrometry and cytogenetic dosimetry. Because of this, collection of various tissues (blood, hair, and teeth) and clothes of exposed but non-contaminated persons should be organised. Provisions (plastic bags, labels, etc.) should be made in advance.

Medical staff dealing with contaminated persons should use protective clothing (overalls, masks, plastic gloves, overshoes as required), personal dosimeters and should be monitored for possible contamination. Provisions for changing clothes, necessary stocks of clothes, places for washing for staff should be made in advance. Contaminated clothing should be carefully removed and discarded in well marked plastic bags. Dry decontamination using a towel may be a practical way to decontaminate a person if access to showers is not possible. Otherwise, contaminated individuals should shower, using mild soap as required to wash off the contamination. Harsh scrubbing is not recommended as it may injure the skin and lead to internal contamination. If the hair is heavily contaminated, cutting it off may be the simplest and most effective solution. Decontamination should be generally repeated until measurements indicate background levels. Collecting contaminated cleaning fluids would be desirable, but is often not practical.

At the national level it is necessary to provide specialised assistance to victims with acute radiation syndrome or serious radiological injuries of the skin. For this purpose it is necessary to indicate beforehand highly specialised hospitals with various departments (haemotology, haemotherapy, intensive care, plastic surgery) and develop agreements to treat highly exposed persons at such hospitals. The capability to treat high exposures in the country is not essential and can be obtained through the IAEA or WHO collaborating centres (Argentina, Australia, Brazil, France, Germany, Japan, the Russian Federation, USA).

Medical staff and support personnel should be trained in the purposes and principles of radiation protection, health consequences of the exposure and methods for dealing with exposed and/or contaminated persons. The training should include drills and exercises in medical response and in performing contamination monitoring, decontamination, interviews, etc.

Management of every designated medical facility is responsible for the following aspects:

(a) designation and, if necessary, additional training of appropriate staff;
(b) development of detailed emergency plan and procedures;
(c) indication of space where reception and treatment can take place, and
(d) provision and properly maintenance of special equipment and all necessary materials.

For detailed medical aspects of the medical response during emergency refer to [30, 31] and for the case histories to [29, 32, 33, 34, 35].

Appendix III

GUIDE TO SUITABLE INSTRUMENTATION*

The purpose of radiation survey instrumentation in a first-response call-out is to determine whether any radiological hazard does in fact exist, and to make a reasonable, but not especially, accurate estimate of its magnitude.

Identifying and locating sources of radiation

Upon arrival at the accident scene the first responder may not know if an exposure or contamination hazard exists. Many incidents involve suspected sources of radiation. It is important to establish quickly whether radiation levels above previously determined background are present. Other incidents may involve searching for lost sources of radiation, which could be either unshielded or still in their containers.

The best instruments for either purpose are those with sodium-iodide detectors, which may give (some newer instruments) also information about radionuclide involved. Sensitive Geiger-Mueller (GM) and proportional counter instruments are useful substitutes, although they are about an order of magnitude less sensitive than sodium-iodide scintillators to gamma emitters in the 1 MeV energy range. To help in searching through outdoor wreckage, or in other difficult conditions, the instrument should preferably have an audio output and headphones.

Measuring gamma dose rate

Instruments of the type mentioned above are difficult to use for quantitative measurements because they are energy dependent over a wide range of gamma energies and therefore the first responder who is not trained in the techniques of instrument calibration should use instruments for detection and not measurements. Measurements are best made with an energy compensated instrument which has a uniform response from about 50 keV upwards. Such instruments typically use energy compensated GM tubes, ionisation chambers, plastic scintillators or proportional counters. The instrument should be capable of measuring dose rates from $1 \mu Svh^{-1}$ or more.

GM-tube instruments are generally smaller and lighter than the other types, and normally have an audio output. However, energy compensated GM instruments will not measure gamma and X ray energies below about 50 keV, and are incapable of detecting particles.

Ionisation chamber instruments less easy to use at low dose rates than GM tubes: they suffer more from changes in temperature and humidity and are less robust. However, they will operate at gamma energies down to 10 keV, which is useful for radionuclides such as I-125, and can normally be used for measuring beta dose rate as well. Scintillation instruments are very sensitive and can cover a wide range of gamma dose rates, at energies down to about 30 keV, but they tend to be heavy and are not useful for beta radiation.

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*The text in this appendix has been extracted from the NAIR Handbook, 1995 Edition, published by NRPB [36].

Measuring beta dose rate

Pure beta-emitting sources are less common than gamma emitters, but can be encountered in beta backscatter and thickness gauges. Ionisation chamber instruments can be used, as well as thin end window GM tubes.

Measuring beta contamination

Beta contamination could be encountered in accidents involving radiopharmaceuticals, and leaking sealed gamma sources (many are beta/gamma emitters) or radiochemical used in industry and agriculture. Suitable instruments are those using thin end window GM tubes, beta scintillation detectors or proportional counters with aluminised plastic or titanium windows.

The most serious problem in using these instruments is likely to be damage to the window, leading to total failure of GM and proportional types, or serious light sensitivity leading to lowered sensitivity in scintillation detectors. When checking for beta contamination it will often be necessary to take a wipe sample (using filter or other paper) and monitor it away from any other source of gamma or X rays.

Tritium is particularly difficult to detect because of its very soft (low energy) beta emission. The most suitable instruments are windowless gas flow proportional counters, but in practice it is probably satisfactory to rely upon liquid scintillation counting of wipes after the event.

Measuring X ray dose rates and contamination

X ray emitters are very common in radiopharmaceuticals. Suitable instruments include thin sodium-iodide detectors and xenon-filled proportioned counters. Suspected contamination by X ray emitters will almost always require taking a wipe sample and monitoring it away from other sources of radiation, including the suspect package itself.

Measuring X rays from X ray generators needs special equipment and experience.

Measuring alpha contamination

Since alpha particles travel only short distances in air they are difficult to detect. Alpha particles cannot be detected through even a thin layer of water, blood, dirt, paper, or other material. A variety of instruments have been designed to measure alpha radiation. Special training in the use of these instruments is essential for making accurate measurements. Suitable instruments include thin-windowed zinc-sulphide scintillation counters and thin-windowed refillable proportional counters. Thin end window GM tubes are also satisfactory for levels down to about 5 Bq cm^{-2}.

Supplies

Other useful equipment that should form part of a permanent “equipment kit” includes notebooks, waterproof pens, a hand torch, a pocket calculator, a steel tape measure, plastic bags, PVC tape for sealing bags, and filter papers for taking wipes. A lead pot and tongs are useful for recovering small gamma sources; a pot with 25 mm walls is reasonably portable and offers a useful degree of shielding.

In addition to the normal personal dosimeter it is desirable to carry a direct reading dosimeter, such as a QFE or, even better, active alarm dosimeter.

The kit should include protective clothing that is waterproof, visible and easily decontaminated if necessary, along with gloves, wellington boots and the safety helmet. A camera should also be included as an aid to recording the incident.

The equipment listed here is suggested as the minimum that can be specified for an early response team. More detail lists of equipment for special tasks are given in Ref. [6].

TABLE III1. RADIONUCLIDE DATA AND GUIDE TO SUITABLE DETECTORS

The wide variety of uses for radioactive material is reflected in the large number of radionuclides that could become involved in radiological accidents. The table in this appendix give the half-lives of virtually all these nuclides, and their most prominent emissions. Taking into account the nature of this emissions and the capabilities of various types of instruments, the table also indicates which instruments would be suitable for making measurements of dose rate and of contamination.

			Suitability for dose rate measurements				**Suitability for contamination measurements**						
Radionuclide	**Half-life**	**Prominent radiations and maximum energies [MeV]**	**Energy compensated GM**	**End window GM**	**Ionisation chamber**	**Plastic scintillator**	**End window GM**	**Full energy β scintillator**	**High energy β scintillator**	**Xe-filled proportional**	**Refillable proportional**	**α scintillator**	**NaI scintillator**
H-3	12.3 a	β^-0.019	no external hazard				–	–	–	–	–	–	–
Be-7	53.3 d	γ 0.48	R	U	R	R	–	–	–	R	–	–	R
C-14	$5.7\ 10^3$ a	β^- 0.156	–	R	R	–	R	R	–	R	R	–	–
Na-22	2.6 a	β^+ 0.55 γ 1.28	S	U	R	S	R	R	–	R	R	–	–
Na-24	15.0 h	β^- 1.4 γ 1.4, 2.8	S	U	R	S	R	R	R	R	R	–	U
P-32	14.3 d	β^- 1.7	–	R	R	–	R	R	R	R	R	–	U
S-35	87.5 d	β^- 0.17	–	R	R	–	R	R	–	R	R	–	–
Cl-36	$3.0\ 10^5$ a	β^- 0.71	–	R	R	–	R	R	–	R	R	–	–
K-42	12.4	β^- 3.6 γ 1.5	S	U	R	S	R	R	R	R	R	–	U
Ca-45	163.0 h	β^- 0.26	–	R	R	–	R	R	–	R	R	–	–
Ca-47	4.5 d	β^- 0.69 (82%) γ 1.3, 2.0 (18%)	S	U	R	S	R	R	–	R	R	–	–
Sc-46	83.8 d	β^- 0.36 γ 1.0	S	U	R	S	R	R	–	R	R	–	–
Cr-51	27.7 d	x 0.005 γ 0.3	S	U	R	S	–	–	–	P	–	–	P
Ma-54	312.5 d	γ 0.8	R	U	R	R	–	–	–	P	–	–	P
Fe-55	2.7 a	x 0.006	–	U	R	–	–	–	–	P	–	–	P
Fe-59	45.1 d	β^- 0.4 γ 1.2	S	U	R	S	R	R	–	R	R	–	–
Co-56	78.8 d	β^+ 1.5 γ 1-3	S	U	R	S	–	–	–	–	–	–	R
Co-57	271.4 d	γ 0.13	R	U	R	R	–	–	–	P	–	–	P
Co-58	70.8 d	β^+ 0.5 γ 0.8	S	U	R	S	U	U	–	P	U	–	P
Co-60	5.3 a	β^- 0.3 γ 1.3	S	U	R	S	R	R	–	R	R	–	–
Ni-63	100.0 a	β^- 0.066	–	U	R	–	–	P	–	–	P	–	–
Zn-65	243.8 d	γ 1.1	R	U	R	R	–	–	–	R	U	–	P
Se-75	119.8 d	γ 0.1-0.4	R	U	R	R	–	–	–	R	–	–	R
Br-82	1.5 d	β^- 0.4 γ 0.5-1.5	S	U	R	S	R	R	–	R	R	–	–

			Suitability for dose rate measurements				Suitability for contamination measurements						
Radionuclide	**Half-life**	**Prominent radiations and maximum energies [MeV]**	**Energy compensated GM**	**End window GM**	**Ionisation chamber**	**Plastic scintillator**	**End window GM**	**Full energy β scintillator**	**High energy β scintillator**	**Xe-filled proportional**	**Refillable proportional**	**α scintillator**	**NaI scintillator**
Kr-85	10.7 a	β^- 0.7	–	U	R	–	–	–	–	–	–	–	–
Ru-86	18.7 d	β^- 1.8 γ 1.1	S	U	R	S	R	R	R	R	R	–	–
Sr-85	64.8 d	γ 0.5	R	U	R	R	–	–	–	R	–	–	R
Sr-89	50.5 d	β^- 1.5	–	R	R	–	R	R	R	R	R	–	U
Sr-90	29.1 a	β^- 0.5	–	R	R	–	R	R	–	R	R	–	–
Y-88	106.6 d	γ 1.8	R	U	R	R	–	–	–	R	–	–	R
Y-90	2.7 d	β^- 2.3	–	R	R	–	R	R	R	R	R	–	U
Y-91	58.5 d	β^- 1.5	–	R	R	–	R	R	R	R	R	–	U
Zr-95	64.0 d	β^- 0.4 γ 0.7	S	U	R	S	R	R	–	R	R	–	–
Nb-95	35.2 d	β^- 0.16 γ 0.76	S	U	R	S	R	R	–	R	R	–	–
Mo-99	2.8 d	β^- 1.2 γ 0.7	S	U	R	S	R	R	R	R	R	–	U
Te-99	2.1 10^5 a	β^- 0.3	–	R	R	–	R	R	–	R	R	–	–
Te-99m	6.0 h	γ 0.14	R	U	R	R	–	–	–	–	–	–	R
Ru-103	39.4 d	β^- 0.2 γ 0.5	S	U	R	S	R	R	–	R	R	–	–
Ru-106	1.0 a	β^- 1.5-3.6 γ 0.5-2.9	S	U	R	S	R	R	R	R	R	–	U
Ag-110m	249.9 d	β^- 0.5 γ 0.6-1.5	S	U	R	S	R	R	R	R	R	–	U
Cd-109	1.3 a	x 0.02 γ 0.09	S	U	R	S	–	–	–	–	–	–	R
In-111	2.8 d	x 0.02 γ 0.2	S	U	R	S	–	–	–	R	–	–	R
Sn-113	115.1 d	x 0.02 γ 0.4	S	U	R	S	–	–	–	R	–	–	R
Sn-119m	293.0 d	x 0.02	–	U	R	U	–	–	–	R	–	–	R
Sb-124	60.2 d	β^- 0.1-2.3 γ 0.6	S	U	R	S	R	R	U	R	R	–	R
Sb-125	2.7 a	β^- 0.6 γ 0.6	S	U	R	S	R	–	–	–	–	–	–
I-125	60.1 d	x γ 0.03	–	U	R	U	–	–	–	R	–	–	R
I-129	1.6 10^7 a	β^- 0.15 x 0.03	–	U	R	S	R	R	–	R	R	–	R
I-131	8.0 d	β^- 0.6 γ 0.4	S	U	R	S	R	R	–	R	R	–	–
Xe-133	5.3 d	β^- 0.3 γ 0.08	S	U	R	S	–	–	–	–	–	–	–
Cs-134	2.1 a	β^- 0.6 γ 0.7	S	U	R	S	R	R	–	R	R	–	–
Cs-137	30.0 a	β^- 0.5 γ 0.7	S	U	R	S	R	R	–	R	R	–	–

Radionuclide	Half-life	Prominent radiations and maximum energies [MeV]	Suitability for dose rate measurements				Suitability for contamination measurements						
			Energy compensated GM	End window GM	Ionisation chamber	Plastic scintillator	End window GM	Full energy β scintillator	High energy β scintillator	Xe-filled proportional	Refillable proportional	α scintillator	NaI scintillator
Ba-133	10.7 a	γ 0.3	R	U	R	R	–	–	–	R	–	–	R
Ba-140	12.7 d	β^- 1.0 γ 0.5	S	U	R	S	R	R	U	R	R	–	U
La-140	1.7 d	β^- 1–2 γ 0.3-2.5	S	U	R	S	R	R	R	R	R	–	U
Ce-139	137.7 d	γ 0.2	R	U	R	R	–	–	–	R	–	–	R
Ce-141	32.5 d	β^- 0.5 γ 0.15	S	U	R	S	R	R	–	R	R	–	–
Ce-144	284.9 d	β^- 3 γ 1-2	S	U	R	S	R	R	–	R	R	–	–
Pm-147	2.6 a	β^- 0.2	–	R	R	–	R	R	–	R	R	–	–
Sm-151	89.9 a	β^- 0.6	–	U	R	–	R	R	U	R	R	–	–
Eu-152	13.3 a	β^- 0.7 γ 0.3-1.3	S	U	R	S	U	U	–	R	U	–	R
Gd-153	242.0 d	x γ 0.04-0.1	R	U	R	R	–	–	–	R	–	–	R
Tb-160	72.3 d	β^- 0.5–1 γ 0.1-1.3	S	U	R	S	R	R	U	R	R	-	-
Tm-170	128.6 d	β^- 1, x γ 0.01-0.08	S	U	R	S	R	R	U	R	R	–	–
Yb-169	32.0 d	x γ 0.01-0.3	R	U	R	R	R	R	–	R	R	–	R
W-185	75.1 d	β^- 0.4	–	R	R	–	R	R	–	R	R	–	–
Ir-192	74.0 d	β^- 0.7 γ 0.5	S	U	R	S	R	R	–	R	R	–	–
Au-198	2.7 d	β^- 1 γ 0.4	S	U	R	S	R	R	U	R	R	–	U
Au-199	3.1 d	β^- 0.4 γ 0.2	S	U	R	S	R	R	–	R	R	–	–
Hg-103	46.6 d	β^- 0.2 γ 0.3	S	U	R	S	R	R	–	R	R	–	–
Tl-204	3.8 a	β^- 0.8	–	R	R	–	R	R	U	R	R	–	U
Pb-210	22.3 a	β^- 0.06 γ 0.05	S	U	R	S	–	–	–	U	–	–	U
Po-210	138.4 d	α	no external hazard				–	–	–	–	R	R	–
Ra-226	1.6 10^3 a	α β^- 3 γ 0.2-2	S	U	R	S	R	R	R	R	U	U	–
Th-228	1.9 a	α β^- 2 γ 0.1-3	S	U	R	S	U	U	–	–	R	R	–
Th-232	1.41 10^{10} a	α β^- 2 γ 0.5–2	–	–	–	–	U	U	–	–	R	R	–

Radionuclide	Half-life	Prominent radiations and maximum energies [MeV]	Suitability for dose rate measurements				Suitability for contamination measurements						
			Energy compensated GM	End window GM	Ionisation chamber	Plastic scintillator	End window GM	Full energy β scintillator	High energy β scintillator	Xe-filled proportional	Refillable proportional	α scintillator	NaI scintillator
U-238	4.5 10^9 a	α β^- 2 γ 0.1-2	S	U	R	S	U	U	–	–	R	R	–
Ne-237	2.1 10^6 a	α γ 0.03-0.4	S	U	R	S	U	U	–	–	R	R	–
Pu-238	87.7 a	α	no external hazard				U	U	–	–	R	R	–
Pu-239	2.4 10^4 a	α x	S	U	S	S	U	–	–	–	R	R	U
Am-241	432.0 a	α γ 0.06	R	U	R	R	–	–	–	–	R	R	U
Cm-244	18.1 a	α	no external hazard				U	U	–	–	R	R	–
Cf-252	2.6 a	α n 2 γ	R	U	R	R	U	U	–	–	R	R	–

NOTES:
Nuclide data includes emissions from decay products that are likely to be present and are not shown in the table separately.

R Recommended
S Recommended when the low energy X rays or the beta emissions from the source are shielded either by packaging or because the material is in the form of an encapsulated source.
U Usable in the absence of recommended equipment.
P Precautions required: results depend critically on instrument adjustment.
– Not suitable.

Appendix IV

TRANSPORT PACKAGES AND SOURCE IDENTIFICATION

Container labelling and shipping list requirements generally apply to all hazardous substances moved in general commerce, and provide emergency responders with essential information about the types of hazards being encountered. Most shipments of radioactive material and sources are in prescribed packaging or containers, accompanied by shipping papers or "bills of lading" which identify the contents, quantity, and activity levels. Such packaging labels and shipping papers are of great value in assessing the potential radiation hazards in a transportation accident.

The categories of radioactive materials packaging related to the quantity or activity level of the radioactive source involved include:

"Excepted" packages

- No special protection other than containment for the radioactive contents.
- Used for very small quantities of radionuclides, which would present a negligible hazard if the package were destroyed.
- Dose rate at any point on the external surface shall not exceed 5 μSv/h.
- No external "Radioactive" label. Vehicles carrying "Excepted" packages are not required to be placarded.

"Industrial" packages

- Used for physically large items of low specific activity material or surface contaminated objects; may be a drum or bulk tank.
- Intended only to prevent the loss of contents under normal transport conditions.
- Should be labelled either "Low Specific Activity" or "Surface Contaminated Object".
- Includes bulk consignments of low-level radioactive waste, or thorium or uranium compounds.

"Type A" packages

- Intended to provide adequate containment and shielding for limited quantities of radioactive materials, in a normal transport environment.
- Each package carries a "Radioactive" label, and a category designation ("I, II or III, in red numerals") that is related to the dose rates at or close to the surface. See Table IV1)

TABLE IV1. LABELLING OF TRANSPORT PACKAGES

Label category	Maximum radiation level at surface [mSv/h]	Maximum radiation level at 1 m [mSv/h]
I–WHITE	0.005	-
II–YELLOW	0.5	0.01
III–YELLOW	2	0.1

- If a package that has been involved in an accident appears intact, or has suffered only superficial damage, and also the measured dose rates correspond with the category on the label, there is no need to invoke protective action for the public and emergency services.
- The category I label has an all-white background; category II and III labels are half yellow and half white (see Fig. IV1).
- Size of the package has no relationship to the category on the label.

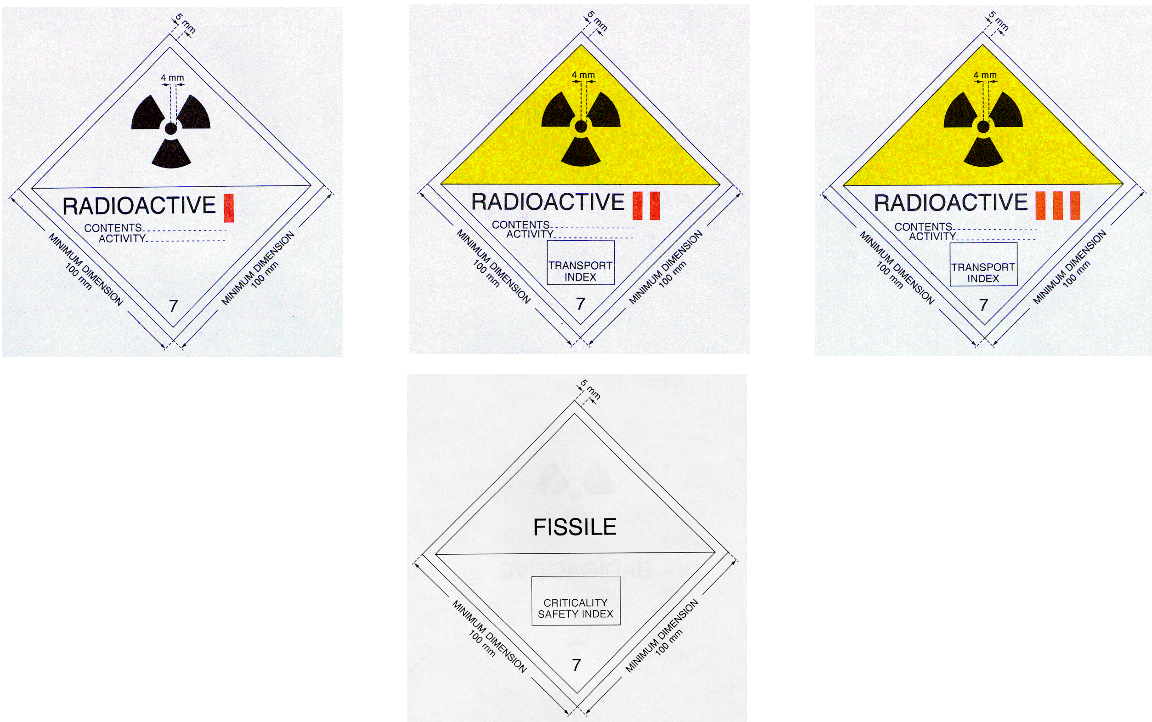


FIG. IV1. Transport category labels

"Type B" packages

- Usually cask shaped, intended to withstand severe accident conditions.
- Large transport flasks used by the nuclear power industry; those likely to be encountered in transport accidents are much smaller.
- Labelled as Type B and category I, II or III, and fireproof/waterproof designations.

"Type C" packages

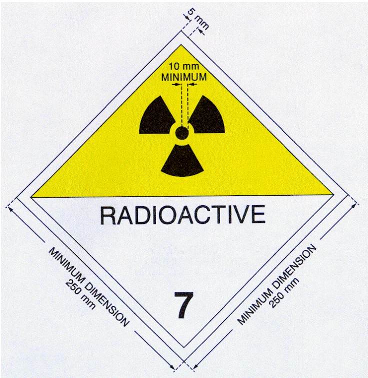
- Designed to transport large activities of radioactive material by air.
- They are analogous to Type B but designed to withstand more severe tests.

Placarding of vehicles, freight containers, and tanks

- Transport regulations require placarding of vehicles and containers in most situations.
- Freight containers or tanks should be placarded with the United Nations Commodity Number describing the contents, which the police and fire services can interpret.
- Road vehicles should carry a warning placard on each side and the rear, and a fire-resistant notice in the driver's compartment. Packages transported by road require a

consignor's certificate giving details of the material being carried; in most cases the driver will carry a copy.

- Railway vehicles carrying radioactive materials together with parcels or other goods are not required to be placarded.
- Certain professional users may carry radioactive materials in road vehicles without placarding and without consignor's certificates. These users are site radiographers and certain hospital staff. However, appropriate packages must be used and correctly labelled, and a fire resistant notice should be carried in the driver's compartment.



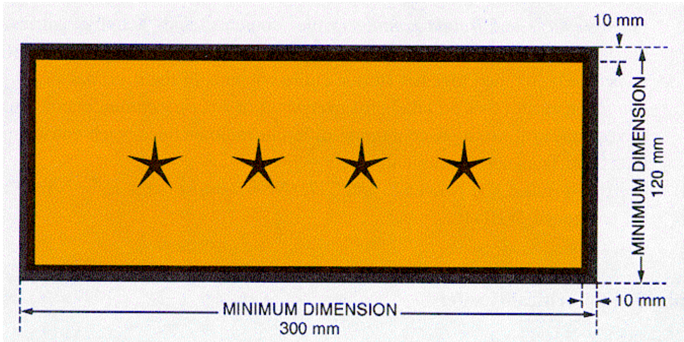


FIG IV2. Placarding signs

Unpackaged and lost sources

Emergency responders may be called to incidents involving lost sources, or gamma radiography sources that cannot be returned to their shielding containers (although site radiographers should be trained to deal with this). Instruments containing radioactive sources can also be damaged while in use, e.g. moisture and density gauges have been run over by road rollers.

Radioactive sources come in all manner of physical form, and if separated from their packaging will probably not be marked in any way. Without the aid of an appropriate survey instrument, purely visual search for a lost source of unknown appearance is unlikely to be successful.

Empty packaging

Many incidents are found to involve empty containers previously used to package radioactive material. These containers should have had warning notices removed and replaced by a label saying "Empty — Having Contained Radioactive Material". There are regulatory requirements concerning the obscuring, removal and misuse of "Radioactive" labels.

For additional information on transport packaging and regulations, see [7, 8, 36, 37].

Appendix V

ACCIDENTS WITH TRANS-BOUNDARY EFFECTS

Severe accidents in nuclear installations may have consequences that might affect countries far from accident country. In accordance with the Convention on Early Notification of a Nuclear Accident [10] national competent authorities will be informed of any such accident by the IAEA, after it has received notification from the accident country. The main aim of the response to such an accident is to reduce the likely stochastic health effects (e.g. cancer) as much as reasonably achievable. Decisions on protective actions in the affected country should be based on environmental monitoring and food measurements and comparisons first to operational intervention levels (OILs) and later in time to generic or national action levels.

The most significant threat from such accidents is due to contamination of the environment (deposition). Deposition is highest if rain is present at the time of plume passage. Regardless of the actual threat, the perception of the threat conveyed by the media is in itself a significant consequence.

However, depending on the distance from the accident site, there is usually time, measured in hours to days, to initiate appropriate protective actions. If the plume is expected to affect a given country, enhanced national radiological monitoring of air and ground and large-scale food sampling may be required. Precautionary measures such as the protection of drinking water supplies from rain systems may be helpful in limiting the consequences and reassuring the public. Banning of some food, including game and wild produce may be required. To counter the indirect threat, radiological control at the borders may be needed. In all cases, providing prompt and accurate information to the population on the real risk will be an essential component of crisis management.

Basic emergency managers' response steps in such accidents are as follows:

(i.) Inform relevant national governmental organizations, including at least Ministries of Foreign Affairs, Health, Environment, Agriculture, Food, Trade, Tourism and Nuclear Regulatory Authorities.
(ii.) Alert appropriate personnel (including the radiological assessor) or committees in accordance with the national response organization structure.
(iii.) Ensure that relevant organization(s) will provide meteorological data on continuous basis (special attention for the possible changes in wind direction, rain).
(iv.) Obtain information what countries were affected and may be affected.
(v.) Assess the possible radiological impact from the accident (direct and indirect) on your country.
(vi.) Consult the national organization(s) on the need to carry out the appropriate precautionary measures based on the possible impact, using Fig. VI1.
(vii.) Reassess the possible indirect impact based on information from affected countries or other sources and updated meteorological information.
(viii.) In case of direct impact implement appropriate protective actions (see Fig. VI1) based on the actual radiological data.
(ix.) Keep relevant governmental organizations informed about the progress of the situation and your decisions.
(x.) Keep media and public well informed at all time about actions taken and recommended measures.

(xi.) Ensure that all actions, decisions and/or recommendations have been registered. Save all records, maps, status boards, etc.

(xii.) Once the acute stage is over develop plan for long-term follow up (if needed) in consultation with the radiological assessor and relevant national organizations.

(xiii.) Initiate and supervise dose assessment for the public.

(xiv.) Evaluate the response and sum up lessons learned. If needed update the response plan accordingly. Prepare the report.

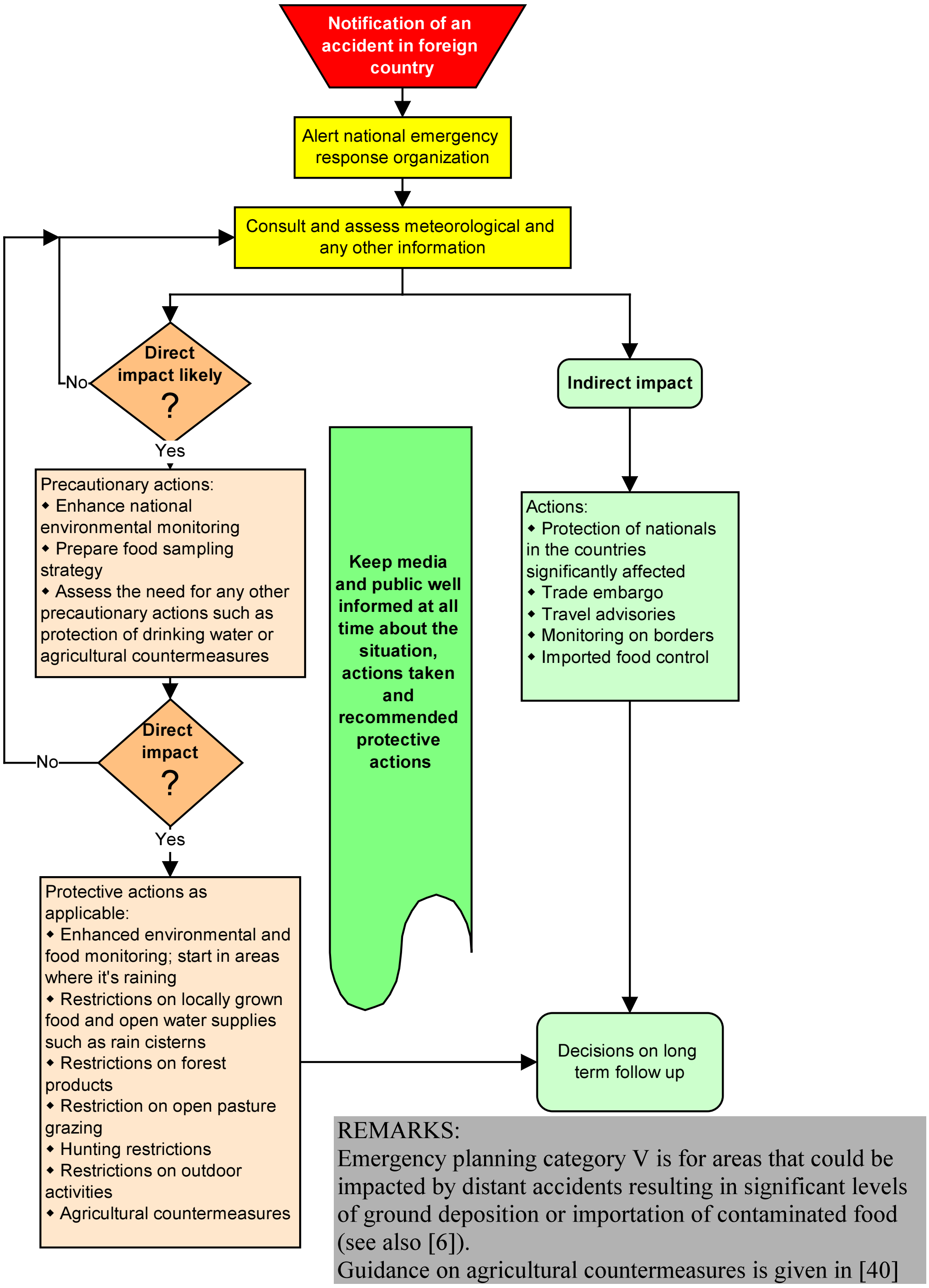


FIG. V1. Response scheme for country in emergency planning category v in case of severe nuclear accident.

Appendix VI

NUCLEAR POWERED SATELLITE RE-ENTRY

Nuclear power sources used in space can suffer several types of accident. Accidental re-entry, as one of them, would occur as a result of the loss of control of the space vehicle leading to the interaction of its trajectory with the earth's atmosphere in such a way that the satellite suffers an unplanned and premature re-entry and impact on earth's surface. A nuclear powered satellite re-entry is an accident that may be foreseeable several weeks or month in advance, although some accident sequences could occur within hours. Although the exact location of impact cannot be determined, a general broad band of the earth's surface where the impact is expected can be determined. Typically the impact area covers 100,000 km^2. A satellite may contain radioactive materials in the form of a nuclear reactor or a thermal generator. The radiation risks from these materials will vary from very small to great. Surface radiation levels of up to 5000 mSv/h have been recorded from satellite debris.

In accordance with the Convention on Early Notification of a Nuclear Accident [10] national competent authorities will be informed of any pending nuclear powered satellite re-entry by the IAEA, after it has received notification from the state responsible for the satellite. There will normally be sufficient advance notice to prepare for a response. When the notification is received, national emergency response personnel should be alerted of the possibility of the satellite impact.

Basic emergency managers' response steps in such accidents are as follows.

(i.) Establish contacts and communication lines with the appropriate authorities and organizations.
(ii.) Assess information about the satellite re-entry. Alert the radiological assessor.
(iii.) In conjunction with the radiological assessor determine what public advisory should be issued. Consider the following possibilities:

- alert the hospitals and ask to be notified if people with symptoms of radiation exposure or contamination arrive at the hospital;
- alert the media to warn the population about the possible satellite debris, how it can be recognized, what it can do, what to do if discovered, and who to call for questions or for reporting that the debris have been found.

(iv.) Provide at least the following instructions:

- do not approach or touch any debris from the satellite;
- keep away from the impact site.

(v.) Based on assumed location of impact develop a search strategy. Monitoring by airplane, helicopter or car can be considered. A search on foot will always complete the survey.
(vi.) Organize search team(s) and proper instrumentation and equipment. Brief them thoroughly in the operational aspects of the search task and what radiological hazards could they expect.
(vii.) Search team(s) should use monitoring procedures from Ref. [6].

(viii.) When locating satellite debris perform immediate actions to render debris safe — the most immediate action to be taken once debris have been located is to ensure that members of the public in the vicinity are adequately protected. In addition:

- inform the public that the debris have been found;
- ensure that all people who may have been exposed are identified and, if required based on the advice from the radiological assessor, report to the hospital;
- provide radiological assistance to the hospitals, if required;
- initiate decontamination of people and make sure that medical follow up is provided.

(ix.) In consultation with the radiological assessor or any other professionals develop plan for cleanup operations (if needed). Develop strategy for waste management (if any).

(x.) Supervise cleanup operations and waste management.

(xi.) Initiate and supervise dose assessment for search team(s) and members of the public (if any). Insure that all actions, decisions and/or recommendations have been registered. Save all records, maps, status boards, etc.

(xii.) Evaluate the response and sum up lessons learned. If needed update the response plan accordingly. Prepare final report.

Additional useful information can be found in Ref. [11].

Appendix VII

COMMUNICATION WITH THE MEDIA AND THE PUBLIC

WHY

Communication with the media and the public is an essential part of emergency response preparedness plans. Experience has shown that failure to have adequate arrangements in place and the commitment of resources at the time of the emergency, can seriously hinder actions to bring the emergency under control, the implementation of longer term restorative measures and the credibility of the Authorities. The key objectives are:

(i.) To make the public aware of the situation; what has happened, the consequences for them and the actions being planned.
(ii.) To prevent rumour and conflicting information; in the absence of authoritative coherent information rumour will fill the vacuum and counteracting this will take considerably more effort than effective communication in the first place.
(iii.) To maintain the credibility of the Authorities and other organizations involved in the emergency.
(iv.) To allow those who are operationally dealing with the emergency to concentrate on that function.
(v.) To reduce the psychological impact.

WHEN and WHAT FORM

If you leave everything until an accident actually happens, you will not be able to provide effective communication, the response will be reactive rather than proactive and positive; and as a consequence credibility will be dented.

(a) General information leaflets should be prepared as part of emergency preparedness; these should cover general terms and units used, emergency arrangements and putting risks in perspective.
(b) Background information on radiation uses and emergency plans should be produced as Media briefing material; this can be used in the first few hours when facts on the accident may be limited.

In preparing these and other communications one should be clear what the target audience is. For small scale accidents it may be restricted to the workforce and possibly their families, whilst for large scale accidents it will be the public in general, although there will be groups who are particularly affected and may need to be addressed separately.

Communication will obviously need to be maintained throughout the emergency and may be necessary for some time after: this will be particularly so in the restorative phase after an accident with widespread consequences. There will also be a need to communicate what is being done to prevent re-occurrence of such incidents.

For large scale accidents it may be necessary to produce leaflets and other documents targeted at the public and specifically on the circumstances and consequences of the accident. The media have production deadlines to meet for newspapers, radio and television:

i. Be aware of these and try to gear Media briefings to meet these needs.

ii. Be predictable and reliable in when information is going to be provided.

For large scale accidents the public will get much of their information from the media, however, there is likely to be a significant number of people who want information specific to their circumstances and may well require reassurance. Experience from previous accidents such as the one in Goiânia, Brazil (1987) [29], indicate that significant resources may have to be committed to meeting this need, and may need to include:

(a) "hot lines" for people to telephone;
(b) meetings with interested groups;
(c) with the increasing access to the Internet, placing material on a dedicated Web site may help.

HOW

Where possible communication with the media and at public meetings should be through a Spokesperson authorised by the organizations concerned. For a small accident this may be limited to a Spokesperson for the site where the accident occurred. As the scale of the accident increases other organizations and government agencies will become involved. It is essential for communications to the media and the public to be coherent and consistent and not send conflicting facts or information. To achieve this the various organizations need to co-operate: the mechanism for this should be part of the emergency preparedness arrangements. The manner in which communications are delivered at interviews and public meeting is crucial to the confidence people will have in the messages given. Some key points about this are given below.

FUNDAMENTAL PRINCIPLES OF COMMUNICATIONS

Organizations that communicate well are more effective over the long-term than those who remain silent and obscure information.

Less can be more: people look for depth, not breadth.

Communication is a job for ***trained communications experts*** who work in direct consultation with technical nuclear professionals. The communication function should be placed at the ***executive level*** within the organization to facilitate information exchange and co-ordination.

Communication must be on-going and predictable. It is not possible to establish trust with silence or with communication only when there are problems.

The foundation of trust is openness, even when the information is an embarrassment. A Regulatory Authority must develop and protect its credibility just as it protects public health and safety.

Use terms that are simple and easy to understand and avoid "insider jargon."

Build ***evaluation methods*** into the programme and ***annual budget*** and use the audience's need for information to guide the programme.

THE TEN RULES OF COMMUNICATION DURING AN INTERVIEW

Be yourself
Avoid fancy, pretentious language. It does not impress anyone. In fact, it confuses people and cuts you off from the audience.

Be Comfortable and Confident
Relax and remember that you probably know more about your subject than anyone in the audience. Stay calm no matter what has happened.

Be Honest
If you do not know the answer to a question, admit it. Your credibility is crucial. Do not jeopardize it. If you have bad news to say, do it. But inform what is being done to solve the situation.

Be Brief
Keep it short and simple try to make your point in 30 second sound bites. You will look and sound better if you get right to the point, avoiding technical language.

Be Human
Do not be afraid to use humour in the right place. It promotes a friendly and confident image.

Be Personal
Personal stories and anecdotes help get across an idea or concept. The audience remembers the key points because of your personal insights.

Be Prepared, Positive and Consistent
Keep your goals in mind and stick to them. Control and focus all of your material. Decide what (maximum) three points you wish to make in the interview and stick with those three points **no matter what the question is**. Play your aces! Do not waste time with scientific background, etc.

Be attentive
Concentrate — do not be concerned with any distractions. Listen carefully to any questions asked. Say what you mean and mean what you say.

Be Energetic
Use gestures, facial expressions and body language to add vitality to your words. Keep your voce conversational but imagine that it has a “face” which can show different emotions and expressions.

Be Committed and Sincere
Speak convincingly. Do not be afraid to pause. Every time you open your mouth, look and sound as if you really care.

Appendix VIII

HOW TO PREPARE THE ACCIDENT REPORT

A formal report should be prepared for all radiological emergencies. These reports are helpful for documentation of important accident information including the general description, location, date, persons involved, estimates of exposure/contamination, medical actions, environmental aspects, and initial aspects for accident mitigation. These reports may also serve as a basis for accident investigation to determine causes and consequences, as well as, provide useful information to aid in the prevention of future accidents. Reports also provide information to assist experts in assisting the host country with accident mitigation. At a minimum each report should contain the following:

SUMMARY

Brief description of the accident, its causes and consequences, response actions, lessons learned; main conclusions and recommendations (if any)

DESCRIPTION OF THE ACCIDENT

- Initiating events
- Location of the accident

Use as many descriptors as needed: country, republic, state, administrative district, city, facility, laboratory, etc.

- Accident date and time
- Event contact

Name, telephone number, fax, e-mail

- Accident environment

Irradiation facility, isotope production, industrial radiography, research, medical diagnosis/therapy, transportation, public domain, military, non-military, nuclear R&D, other (specify)

- Source or radiation devices

Critical assemblies, reactors, or chemical assemblies; indicate known or estimated activity, specify transuranics, tritium, fission products, radionuclides eg. Co-60, Cs -137, Ir –192; sealed sources, X ray devices, accelerators, radar generators etc.)

- Radiation type

Gamma, beta, gamma-neutron, X ray, alpha

RESPONSE TO THE ACCIDENT

Initial action upon discovery, protective actions for emergency workers, public; remedial actions

HUMAN CONSEQUENCES

- Nature of exposure

External exposure, external contamination, internal contamination

- Number of persons involved

Number of injured, exposed, contaminated

- Medical assistance and medical follow-up (if any)

ENVIRONMENTAL CONSEQUENCES

- Type of contamination

Airborne contamination, contamination of water, land, foodstuffs, objects

- Summary of radiological survey and environmental monitoring
- Criteria for actions
- Waste disposal

DOSE ASSESSMENT

Dose estimates for emergency workers and persons involved

CONCLUSIONS AND RECOMMENDATIONS

Lessons learned, follow-up activities, recommendations for accident prevention, upgrading emergency response

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GLOSSARY

A

accident

Any unintended event, including operating error, equipment failure or other mishap, the consequences or potential consequences of which are not negligible from the point of view of *protection and safety.*

action level

See *level*

activity

The rate at which atomic disintegrations occur in a radioactive material. Mathematically:

$$A(t) = \frac{dN}{dt}$$

where dN is the expectation value of the number of spontaneous nuclear transformations from the given energy state in the time interval dt. The SI unit is the reciprocal second (s^{-1}), termed becquerel (Bq)[1] 1Bq = 1 disintegration/s.

activity concentration

The *activity* of a radionuclide per unit mass (or per unit volume) of a material or per unit surface area.

ambient dose rate

See *dose rate*.

annual dose

See *dose*.

area

controlled area: A defined area in which specific protection measures and safety provisions are or could be required for controlling normal exposures or preventing the spread of *contamination* during normal working conditions, and preventing or limiting the extent of potential exposures.

assessment

The process, and the result, of analysing systematically the hazards associated with *sources* and practices, and associated *protection and safety* measures, aimed at quantifying performance measures for comparison with criteria.

atomic mass number (A)

The sum of the number of protons and neutrons in the atom.

avertable dose

See *dose*.

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1 The curie (Ci), equal to 3.7×10^{10} Bq is the former unit of *activity*.

averted dose

See *dose*.

B

background (radiation)

Ionising radiation normally present in the region of interest and coming from sources other than that of primary concern.

becquerel

The specific name for the unit of *activity* of a *radionuclide*. See also *activity.*

boundary

site boundary: The boundary of the site area.

C

calibration

A measurement of, or adjustment to, an instrument, component or system to ensure its accuracy or response is acceptable. *Calibration* of a model is the process whereby model predictions are compared with field observations and/or experimental measurements from the system being modelled, and the model adjusted if necessary.

cloud shine

Gamma radiation from radioactive materials in an airborne plume.

collective dose

See *dose*.

committed dose

See *dose*.

competent authority

A national *regulatory body* or international regulatory organization.

contamination

The presence of radioactive substances or materials on surfaces, or within solids, liquids or gases (including the human body), where they are unintended or undesirable.

fixed contamination: *Contamination* other than *non-fixed contamination*.

non-fixed contamination: *Contamination* that can easily be removed.

countermeasure

An *intervention* aimed at alleviating the radiological consequences of an *accident*. These may be *protective actions* or *remedial actions*, and these more specific terms should be used where possible.

D

decontamination

The complete or partial removal of *contamination.*

deposition

The *contamination* found on or within a few cm of the surface of the ground or on the surface of other material.

deterministic effect

A radiation induced health effect that is certain to occur — with a severity that increases with increasing *dose* — in an individual exposed to a radiation *dose* greater than some threshold *dose*. The level of the threshold *dose* is characteristic of the particular health effect but may also depend, to a limited extent, on the exposed individual. Examples of *deterministic effects* include erythema and radiation sickness. See also *stochastic effect*.

disposal

See *waste disposal*.

dose

A measure of the energy transferred from radiation to a target. Commonly used without qualification when the context makes the qualifier obvious, or as a general term where different qualifiers could equally validly be used. See also *absorbed dose*, *collective dose*, *effective dose*, *equivalent dose* and *organ dose*.

absorbed dose: The energy transferred from radiation to unit mass of the exposed matter, unit J/kg, given the special name gray (Gy)[2]. Mathematically defined as:

$$D = \frac{d\bar{\varepsilon}}{dm}$$

i.e. the mean energy imparted to the matter in a volume element divided by the mass of the volume element. This term is therefore defined at a point; for the average in a tissue or organ, see *organ dose*. See ICRP Publication 60 [40].

annual dose: The *dose* received from *external exposure* in a year plus the *committed dose* from intakes of radionuclides in that year. Therefore this is not, in general, the *dose* actually received in that year.

avertable dose: A prospective estimate of the *averted dose* expected to result if a specified *countermeasure* or set of *countermeasures* were to be applied.

averted dose: A retrospective estimate of the *dose* prevented by the *countermeasure* or set of *countermeasures* applied, i.e. the difference between the *projected dose* if the *countermeasure(s)* had not been applied and the actual *projected dose*.

collective dose: The total *dose* to a defined population. Unless otherwise specified, the time over which the *dose* is integrated is infinite; if a finite upper limit is applied to the time integration, the *collective dose* is described as 'truncated' at that time. The relevant *dose* is normally *effective dose*, and the unit is the man sievert (man·Sv).

committed dose: The *dose* resulting from an intake of radioactive material, integrated over the 50 years after intake, (or integrated to age 70 years for intake as an infant or child). The relevant *dose* may be *absorbed dose*, *effective dose*, *equivalent dose* or *organ dose*, with units Gy or Sv as appropriate.

effective dose: A measure of *dose* designed to reflect the amount of *radiation detriment* likely to result from the *dose*, calculated as the weighted sum (using *tissue weighting factors* w_T) of the *equivalent doses* H_T in the different tissues of the body, i.e.:

$$E = \sum_T w_T H_T$$

Values of *effective dose* from any type(s) of radiation and mode(s) of *exposure* can therefore be compared directly. Unit J/kg, given the special name sievert (Sv)[3]. See ICRP Publication 60.

equivalent dose: A measure of the *dose* to a tissue or organ designed to reflect the amount of harm caused, calculated as the product of the average *absorbed dose* in the tissue or organ and the appropriate *radiation weighting factor*. Values of *equivalent*

2 The rad, equal to 0.01 gray, is the former unit of *absorbed dose*.

3 The rem, equal to 0.01 sievert, is the former unit of *equivalent dose* and *effective dose*.

dose to a specified tissue from any type(s) of radiation can therefore be compared directly. Symbol H_T, unit J/kg, given the special name sievert (Sv). See ICRP Publication 60 [39].

organ dose: The average *absorbed dose* in a tissue or organ, i.e. the total energy imparted in a tissue or organ divided by the mass of the tissue or organ.

projected dose: The *dose* that would be expected to be received if a specified *countermeasure* or set of *countermeasures* — especially no *countermeasures* — were to be taken.

dose coefficient

The *committed effective dose* from intake, by a specified means (usually ingestion or inhalation), of unit *activity* of a specified radionuclide in a specified chemical form. Values are specified in the BSS [2]. Formerly termed *dose per unit intake*.

dose equivalent

A measure of the *dose* to a tissue or organ designed to reflect the amount of harm caused, calculated as the product of the average *absorbed dose* in the tissue or organ and the appropriate *quality factor*. Superseded by *equivalent dose* (see *dose*) as a primary quantity recommended by ICRP, and in the calculation of *effective dose*. However, the definitions of a number of operational *dose* quantities still refer to this term.

ambient dose equivalent: A directly measurable proxy for *effective dose* for use in *environmental monitoring* of *external exposure*. Defined by ICRU [40] as the *dose equivalent* that would be produced by the corresponding aligned and expanded field in the ICRU sphere at a depth d on the radius opposing the direction of the aligned field, symbol $H^*(d)$ [40]. The recommended value of d for *strongly penetrating radiation* is 10 mm.

dose rate

A measure of the rate at which energy is transferred from radiation to a target. Commonly used without qualification when the context makes the qualifier obvious, or as a general term where different qualifiers could equally validly be used, e.g. *absorbed dose rate*, *equivalent dose rate*.[4]

E

effective dose

See *dose*.

effective dose equivalent

See *dose equivalent*.

emergency

Any natural or man-caused situation that results in or may result in substantial injured or harm to people, property or the environment, and for which prompt action is needed to protect people, property or the environment.

emergency exposure

See *exposure*.

4 Although *dose rate* could, in principle, be defined over any unit of time (e.g. an *annual dose* is, technically a *dose rate*), in IAEA publications the term *dose rate* is used only in the context of short periods of time, e.g. *dose* per second or *dose* per hour.

emergency plan

A document describing the organizational structure, roles and responsibilities, concept of operation, means and principles for intervention during an emergency.

emergency procedure

A set of documents describing the detailed actions to be taken by response personnel during an emergency.

emergency response function

An identified task or set of tasks with a common specific goal that may be required to be carried out in the event of an emergency.

emergency worker

Person performing emergency services.

emergency worker guidance

Total *dose emergency worker* should make every attempt not to exceed while performing emergency services.

environmental monitoring

See *monitoring*.

equivalent dose

See *dose*.

evacuation

The rapid, temporary removal of people from the area to avoid or reduce short term radiation exposure in the event of an *emergency*.

exposure

The act or condition of being subject to irradiation.[5]

acute exposure: A descriptive term for *exposure* occurring within a defined (short) period of time.

emergency exposure: *Exposure* received during an emergency situation. This may include unplanned *exposures* resulting directly from the emergency and planned *exposures* to persons undertaking actions to mitigate the emergency.

external exposure: *Exposure* from a *source* outside the body.

internal exposure: *Exposure* from a *source* inside the body.

occupational exposure: All *exposures* of workers incurred in the course of their work, with the exception of excluded exposures and exposures from exempt practices or exempt *sources*.

potential exposure: *Exposure* that is not certain to occur but that may result from an event or sequence of events of a probabilistic nature, including *accidents* and events influencing the integrity of a waste repository.

public exposure: *Exposure* incurred by members of the public from radiation sources, excluding any occupational or medical exposure and the normal local natural background radiation but including exposure from authorized sources and practices and from *intervention* situations.

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5 The term *exposure* is also used in radiodosimetry to express the amount of ionisation produced in air by ionising radiation.

exposure pathway

A route by which radiation or radioactive material can reach or irradiate humans.

external exposure

See *exposure*.

F

first responder

First responders are the first professionally competent members of a response organization to respond to the scene of an accident, spill or fire involving radiation sources. They include members of the police, fire fighters, medical or on-site response teams.

fixed contamination

See *contamination*.

G

generic intervention level (GIL)

See *level*.

generic action level (GAL)

See *level*.

gray

The name for the unit of absorbed *dose*; see also *dose*.

ground shine

Gamma radiation from radioactive materials deposited on the ground.

H

half-life

The time taken for the *activity* of a radionuclide to halve as a result of radioactive decay. Also used with qualifiers to indicate the time taken for the quantity of a specified material (e.g. a radionuclide) in a specified place to halve as a result of any specified process or processes that follow similar exponential patterns to radioactive decay.

biological half-life: The time taken for the quantity of a material in a specified tissue, organ or region of the body (or any other specified biota) to halve as a result of biological processes.

effective half-life: The time taken for the *activity* of a radionuclide in a specified place to halve as a result of all relevant processes.

hot spot

Localized areas where *dose rates* or *contamination* as a result of *deposition* are much higher than in the surroundings.

I

illicit trafficking

The unauthorised receipt, possession, use, transfer or disposal or radioactive materials, whether intentional or unintentional and with or without crossing international borders.

immersion
To be surrounded or engulfed by the radioactive cloud.

individual monitoring
See *monitoring*.

inhalation dose
Committed dose resulting from inhalation of radioactive materials and subsequent deposition of these *radionuclides* in body tissues.

internal exposure
See *exposure*.

intervention
Any action intended to reduce or avert *exposure* or the likelihood of *exposure* to *sources* which are not part of an authorized practice (or an exempt practice), or which are out of control as a consequence of an *accident*.

intervention level
See *level*.

iodine prophylaxis
The ingestion of a compound of stable iodine (usually potassium iodine) to prevent or reduce the uptake of radioactive *isotopes* of iodine by the thyroid in the event of an accident involving radioactive iodine. The term *thyroid blocking* is used in the literature as a synonym.

isotope
Nuclide of a particular element that contain the same number of protons but different number of neutrons.
marker isotope: An isotope contained in deposition or sample that is easily identified in the field or laboratory. It is used to determine areas of concern before performing a comprehensive isotopic analysis.

L

level
action level: In general, the value of a specified measurable quantity above which a specified action will be taken. Most commonly used to mean a level of *dose rate* or *activity concentration* above which *remedial actions* or *protective actions* should be carried out in *chronic exposure* or *emergency exposure* situations.
generic action level: The generic level of *activity concentration* above which remedial actions or protective actions should be carried out in chronic exposure or emergency exposure situations.
intervention level: The specific level of *avertable dose* at or above which a specific *protective action* or *remedial action* is taken in an *emergency exposure* or *chronic exposure* situation.
generic intervention level: The generic level of *avertable dose* at which specific *protective action* or remedial action is taken in an *emergency exposure* situation or a *chronic exposure* situation. Values are specified in the BSS [2].
operational intervention level: A calculated value (e.g. *ambient dose rate* or *activity concentration*) measured by instruments or determined by laboratory analysis that correspond to intervention or action levels.

limit

The value of a quantity that must not be exceeded.

dose limit: A *limit* on the total *annual effective dose* to an individual (or the average *annual effective dose* over a specified number of years) or the *annual equivalent dose* to a tissue or organ from specified *sources*. The BSS [2] specify dose limits for *workers* and *members of the public*.

prescribed limit: A *limit* on a measurable quantity, established or formally accepted by a *regulatory body*. Equivalent in meaning to authorized limit, this term has been more commonly used in nuclear safety. Wherever possible, authorized limit should be used.

M

member of the public

In a general sense, any individual in the population except when subject to *occupational exposure* or *medical exposure*.

monitoring

The measurement of radiological or other parameters for reasons related to the *assessment* or control of *exposure*, and the interpretation of such measurements. Also used in nuclear safety for the periodic or continuous determination of the status of a system.

environmental monitoring: *Monitoring* in which the parameters measured relate to characterizing an environment allowing the possible *exposure* in that environment to be estimated.

individual monitoring: *Monitoring* in which the parameters measured relate to the *exposure* that a specific individual (most commonly a *worker*) is receiving.

source monitoring: The measurement of external dose rates due to *sources* or of *activity* in radioactive materials being released into the environment.

N

natural exposure

See *exposure*.

non-fixed contamination

See *contamination*.

O

occupational exposure

See *exposure*.

off-site

The area outside the *site boundary*.

on-site

The area within the *site boundary*.

operational intervention level (OIL)

See *level*.

organ dose

See *dose*.

P

plume (atmospheric)

The airborne "cloud" of material released to the environment, which may contain radioactive materials and may or may not be invisible.

projected dose

See *dose*.

protection

Radiation protection or ***radiological protection:*** Used in two slightly different ways. For the more general usage — protection against radiological hazards — see *protection and safety*. The term *radiation protection* is also often used in the context of operating *nuclear installations* to refer specifically to those measures related to the control of *occupational exposure*, as distinct from prevention and mitigation of *accidents*, the control of discharges or waste management.

protection and safety

The protection of people against *exposure* to ionising radiation or radioactive materials and the safety of radiation *sources*, including the means for achieving this, and the means for preventing *accidents* and for mitigating the consequences of *accidents* should they occur.

protective action

An *intervention* intended to avoid or reduce *doses* to *members of the public* in *chronic exposure* or *emergency exposure* situations. See also *remedial action*. Also used in nuclear safety, for a protection system action calling for the operation of a particular safety actuation device.

Q

quality assurance

Planned an systematic actions necessary to provide adequate confidence that an item or service will satisfy given requirements for quality.

quality factor

A number by which the *absorbed dose* in a tissue or organ was multiplied to reflect the *relative biological effectiveness* of the radiation, the result being the *dose equivalent*. Superseded by *radiation weighting factor* in the definition of *equivalent dose* by ICRP, but still defined, as a function of *linear energy transfer*, for use in calculating the *dose equivalent* quantities used in *monitoring*.

R

radiation weighting factor

A number by which the *absorbed dose* in a tissue or organ is multiplied to reflect the *relative biological effectiveness* of the radiation in inducing *stochastic effects* at low *doses*, the result being the *equivalent dose*. Values are specified by ICRP as a function of unrestricted *linear energy transfer*. See also *quality factor*.

radiation protection; radiological protection

See *protection*.

radioactive half-life
See *half-life*.

radioactive decay
Transformation of unstable isotopes into a more stable form, accompanied by the emission of particles and/or gamma rays.

radioactive waste
Material, whatever its physical form, remaining from practices or interventions and for which no further use is foreseen that contains or is contaminated with radioactive substances and has an activity or activity concentration higher than the level from regulatory requirements.

radioiodine
One or more of the radioactive isotopes of iodine.

radionuclide
A nucleus (of an atom) that possesses properties of spontaneous disintegration (radioactivity). Nuclei are distinguished by both their mass and atomic number.

regulatory body
An authority or authorities designated or otherwise recognized by a government for regulatory purposes in connection with *protection and safety*. (Sometime the term regulatory authority is used.)

relocation
The removal of *members of the public* from their homes for an extended period of time, as a *protective action* in a *chronic exposure* situation.

remedial action
Action taken to reduce *exposures* that might otherwise be received, in an *intervention* situation involving *chronic exposure*. Actions applied to people in any type of situation would normally be considered *protective actions* rather than *remedial actions*. See also *protective action*.

S

sealed source
See *source*.

sheltering
A *protective action* whereby *members of the public* are advised to stay indoors with windows and doors closed, intended to reduce their *exposure* in an *emergency exposure* situation.

site boundary
See *boundary*.

sievert
The name for the unit of *equivalent dose*. See also *dose*.

source

Anything that may cause radiation *exposure* — such as by emitting ionising radiation or by releasing radioactive substances or materials — and can be treated as a single entity for *protection and safety* purposes. For example, materials emitting *radon* are *sources* in the environment, a sterilization gamma irradiation unit is a *source* for the *practice* of radiation preservation of food, an X ray unit may be a *source* for the *practice* of radiodiagnosis; a *nuclear power plant* is part of the *practice* of generating electricity by nuclear fission, and may be regarded as a *source* (e.g. with respect to *discharges* to the environment) or as a collection of *sources* (e.g. for occupational *radiation protection* purposes). In common usage, the term *source* (and particularly *sealed source*) tends to carry the connotation of a fairly small intense radiation source, such as might be used for medical applications or in industrial instruments.

natural source: A naturally occurring *source* of radiation, such as the sun and stars (*sources* of cosmic radiation) and rocks and soil (terrestrial *sources* of radiation).

sealed source: Radioactive material that is (a) permanently sealed in a capsule, or (b) closely bounded and in a solid form. The term *special form radioactive material*, used in the context of *transport* of radioactive materials, has a very similar meaning.

unsealed source: Any *source* that does not meet the definition of a *sealed source*.

stable iodine

Iodine which is comprised of only non-radioactive isotopes of iodine. See also *thyroid blocking agent*.

stochastic effect

A health effect, the probability of occurrence of which is greater for a higher radiation *dose* and the severity of which (if it occurs) is independent of *dose*. *Stochastic effects* may be somatic effects or hereditary effects, and generally occur without a threshold level of *dose*. Examples include cancer and leukaemia. See also *deterministic effect*.

survey

radiological survey: An evaluation of the radiological conditions and potential hazards associated with the production, use, transfer, release, disposal, or presence of radioactive material or other *sources* of radiation.

T

thyroid blocking agent

A substance which prevents or reduces the uptake of radioactive iodine by the thyroid. Usually stable potassium iodide (KI) is taken orally for this purpose.

tissue weighting factor

Numbers by which the *equivalent dose* to tissues or organs are multiplied to account for their different sensitivities to the induction of *stochastic effects* of radiation. Values for use in the calculation of *effective dose* are specified by ICRP [39].

triage

Rapid method utilizing simple procedures to sort persons into groups based on their injury and/or disease for the purpose of expediting clinical care and maximising the use of the available clinical services and facilities.

turn back guidance

An integrated dose reading on a self reading dosimeter indicating that an emergency worker dose guidance has been exceeded and that the emergency worker should leave the areas where further significant dose is possible.

W

waste disposal

The emplacement of *radioactive waste* in an appropriate facility with no intention of retrieving it.

SYMBOLS

Symbol	Unit	Description
A	Bq kBq MBq	activity; activity of the source, radionuclide activity; subscripts i specify the radionuclides; A_t is activity at time t, A_o activity at time t_o
A_l	Bq/m	line activity concentration
AMN		atomic mass number; the number that identifies the radionuclide
A_s	Bq/m^2	surface activity concentration
A_{sp}	kBq/g	specific activity
$C_{j,i}$	Bq/m^3 Bq/L Bq/kg Bq/m^2	activity concentration; concentration of radionuclide(s) in air, samples or on surfaces; first subscript specifies: a-air, g-ground, s-surface (or skin), f-food; second specifies radionuclide; bar over C means average concentration or best estimate; for surface activity concentration A_s is used sometimes
$CF_{1,i}$	$(mSv/h)/(kBq/m^3)$	thyroid conversion factor for radionuclide *i*; committed equivalent dose to the thyroid from one hour inhalation of contaminated air; a breathing rate of 1.2 m^3/h is assumed
$CF_{2,i}$	$(mSv/h)/(kBq/m^3)$	conversion factor for radionuclide *i*; committed effective dose from one hour inhalation of contaminated air; a breathing rate of 1.2 m^3/h is assumed
$CF_{3,i}$	$(mSv/h)/(kBq/m^2)$	conversion factor; ambient dose rate at 1 m above ground level per unit of deposition for radionuclide *i*
$CF_{4,i}$	$(mSv/h)/(kBq/m^2)$	conversion factor; effective dose per unit deposition for radionuclide *i*; includes external dose and committed effective dose from inhalation due to resuspension resulting from remaining on contaminated ground for the period of concern
$CF_{5,i}$	mSv/kBq	ingestion dose conversion factor; committed effective dose from ingestion per unit intake of radionuclide i
$CF_{6,i}$	(mSv/h)/(kBq)	point source conversion factor at 1 m from the source; effective dose in 1 h of exposure to 1 kBq point source
$CF_{7,i}$	(mGy/h)/(kBq)	point source conversion factor; dose rate at 1 m from 1 kBq point source
$CF_{8,i}$	$mSv/(Bq/cm^{-2})$	skin beta dose conversion factor; equivalent dose to the skin per unit deposit of radionuclide *i* onto skin or clothing
$CF_{9,i}$	$(mSv/h)/(kBq/m^3)$	conversion factor for external γ exposure due to immersion in contaminated air
$\dot{D}$	μGy/h mGy/h	γ dose rate
$DI_{f,i}$	D	days of intake; the period food is assumed to be consumed
$d_{1/2}$	Cm	half value layer
DF_m	-	dilution factor
E_T	Sv MSv	total effective dose
E_{ext}	Sv MSv	effective dose from external radiation

Symbol	Unit	Description
E_{inh}	Sv MSv	committed effective dose from inhalation
E_{ing}	Sv mSv	committed effective dose from ingestion
FRF	-	fire release fraction
$\dot{H}_g^*$	mSv/h	ambient dose rate at 1 m above ground level from ground contamination
H_s $H_{s,i}$	Sv mSv	equivalent dose (beta) to the skin; subscript *i* stands for the radionuclide *i*
H_{thy}	Sv mSv	committed equivalent dose to the thyroid
OF	-	occupancy fraction; fraction of time the shielding factor SF is applicable e.g. the fraction of time spent indoors; it is assumed that, for the rest of the time, there is no shielding; default — 0.6
Q_i	kBq/s	release rate of radionuclide *i*
SF	-	shielding factor for surface deposition
SF_{β}	-	shielding factor for β to take account of shielding affording by clothing, etc.
t	s h	time
$T_{1/2}$	h, days, years	radionuclide half-life
T_e	h	exposure duration
T_m	h, days, years	mean life of the radionuclide: $T_m = T_{1/2} \cdot 1.44$
T_r	s	release duration
$\overline{u}$	m/s	average wind speed
U_f	kg/d L/d	the amount of a food *f* consumed by the person of interest per day
W	g kg	weight
X	m cm	distance; subscripts specify distances; sometimes letters r, d or a are also used for a distance
Δt	s h	time elapsed

CONTRIBUTORS TO DRAFTING AND REVIEW

CONSULTANTS MEETING
Vienna, Austria
14–18 April 1997

Kerns, K.	Iowa State University, United States of America
Martinčič, R.	J. Stefan Institute, Slovenia
McKenna, T.	International Atomic Energy Agency
Winkler, G.	Atominstitut der Österreichischen Universitäten

CONSULTANTS MEETING
Vienna, Austria
25 August–05 September 1997

Buglova, E.	Research Clinical Institute of Radiation Medicine and Endocrinology, Belarus
Kerns, K.	Iowa State University, United States of America
Martinčič, R.	J. Stefan Institute, Slovenia
Nogueira de Oliveira, C.A.	Instituto de Radioproteçáo e Dosimetria, Brazil
Roberts, G.	Oxford, United Kingdom

CONSULTANTS MEETING
Vienna, Austria
12–23 January 1998

Buglova, E.	Research Clinical Institute of Radiation Medicine and Endocrinology, Belarus
Lafortune, J	SAIC Canada, Canada
McKenna, T.	Washington, United States of America
Martinčič, R.	J. Stefan Institute, Slovenia

CONSULTANTS MEETING
Vienna, Austria
17–21 August 1998

Buglova, E.	Research Clinical Institute of Radiation Medicine and Endocrinology, Belarus
Martinčič, R.	J. Stefan Institute, Slovenia
Ricks, B.	Oak Ridge Institute of Science and Education, United States of America
Sinklair, M.	Illinois Department of Nuclear Safety, United States of America

CONSULTANTS MEETING
Vienna, Austria
8–12 February 1999

Buglova, E.	Research Clinical Institute of Radiation Medicine and Endocrinology, Belarus
Croft, J.	National Radiological Protection Board, United Kingdom
Martinčič, R.	J. Stefan Institute, Slovenia
Rozental, J. de Julio	Ministry of Environment, Israel

CONSULTANTS MEETING
Vienna, Austria
8 May–4 June 1999

Martinčič, R.	J. Stefan Institute, Slovenia

INDEX