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Occupational Radiation Protection in Severe Accident Management

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Occupational Radiation Protection in Severe Accident Management

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Radiological Protection

OCCUPATIONAL RADIATION PROTECTION IN SEVERE ACCIDENT MANAGEMENT

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NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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The OECD is a unique forum where the governments of 34 democracies work together to address the economic, social and environmental challenges of globalisation. The OECD is also at the forefront of efforts to understand and to help governments respond to new developments and concerns, such as corporate governance, the information economy and the challenges of an ageing population. The Organisation provides a setting where governments can compare policy experiences, seek answers to common problems, identify good practice and work to co-ordinate domestic and international policies.

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NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1 February 1958. Current NEA membership consists of 31 countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, Norway, Poland, Portugal, the Republic of Korea, the Russian Federation, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission also takes part in the work of the Agency.

The mission of the NEA is:

– to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes, as well as
– to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include the safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information.

The NEA Data Bank provides nuclear data and computer program services for participating countries. In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

FOREWORD

Since its creation in 1992, the Information System on Occupational Exposure (ISOE), jointly sponsored by the OECD/NEA and the IAEA, has been fostering the exchange of data, analysis, lessons learned and experience in occupational radiation protection at nuclear power plants worldwide. ISOE maintains the world's largest occupational exposure database and a network of nuclear utilities and regulatory authority radiation protection experts. Four ISOE Technical Centres manage day-to-day technical operations, located in Paris, Tokyo, Vienna and the US. ISOE is a Joint Project under the NEA's statute, and does not report directly to CRPPH nor request its approval for its programme of work.

As an early response to the Fukushima NPP accident, the following two items were identified as priority by the ISOE Bureau;

- Management of high radiation area worker doses: It has been decided to make available the experience and information from the Chernobyl and Three Mile Island (TMI) accidents in terms of how emergency worker /responder doses were legally and practically managed,
- Personal protective equipment for highly-contaminated areas: It was agreed to collect information about the types of protective suits and other equipment (e.g. air bottles, respirators, air-hoods or suits, etc.), as well as high-radiation area worker dosimetry use (e.g. type, number and placement of dosimetry) for different types of emergency and high-radiation work situations.

Detailed information was collected from the ISOE participating nuclear utilities and regulatory authorities and made available for Japanese utilities. With this, the Expert Group on Occupational Radiation Protection in Severe Accident Management (EG-SAM) was established by the ISOE Management Board in May 2011. The objective of the EG-SAM is to develop a report on best radiation protection management practices for proper radiation protection job coverage during severe accident initial response and recovery phases.

During its November 2012 meeting, the expert group decided to develop an interim (preliminary) report before the end of 2013 (with a general perspective and discussion of specific severe accident management worker dose issues), and to finalize the report by organizing an international workshop in 2014 to address national experiences, which will be incorporated to the report. The "International Workshop on Occupational Radiation Protection in Severe Accident Management", hosted by the Nuclear Energy Institute (NEI), was organized in Washington DC, USA on 17-18 June 2014. The objectives of the workshop, which was attended by 66 participants from 17 countries, were to identify best occupational radiation protection approaches in strategies, practices, as well as limitations for developing effective management, and to identify national experiences to be incorporated into the final version of ISOE expert group's report.

The work of the EG-SAM focuses on radiation protection management and organization, radiation protection training and exercises related to severe accident management, facility configuration and readiness, worker / responder protection, monitoring and managing radioactive releases and contamination and key lessons learned especially from the TMI, Chernobyl and Fukushima Daiichi accidents.

The interim report, which was accomplished during EG-SAM meetings through 2012-2013, was approved by the ISOE Management Board for publication during its 23rd annual meeting in 2013 and the report was completed with an international workshop findings and recommendations.

The ISOE Joint Secretariat wishes to acknowledge this work and co-operation, which helped to complete the drafting of this report in a timely fashion.

ISOE Network: www.isoe-network.net/

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LIST OF ACRONYMS

ALARA	As Low As Reasonably Achievable
ASN	French Nuclear Safety Authority
CNSC	Canadian Nuclear Safety Commission
CRPPH	Committee on Radiation Protection and Public Health
CP	Civil Protection
ECC	Emergency Control Centre
EG-SAM	Expert Group on Occupational Radiation Protection in Severe Accident Management
EH	Emergency Headquarters
EPD	Electronic Personnel Dosimeter
EPR	Electron Paramagnetic Resonance
ERO	Emergency Response Organization
ERP	Emergency Response Plan
ERM	Emergency Response Manager
FISH	Fluorescence In-Situ Hybridization
HEPA	High-Efficiency Particulate Air
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ILO	International Labour Organisation
INES	International Nuclear and Radiological Event Scale
INPO	Institute for Nuclear Power Operations
ISOE	Information System on Occupational Exposure
KI	Potassium Iodide
MCR	Main Control room
NEA	OECD Nuclear Energy Agency
NISA	Nuclear and Industry Safety Agency of Japan
NPP	Nuclear Power Plant
NRC	the U.S. Nuclear Regulatory Commission
NUREG	Nuclear Regulatory Guidance
OIL	Operational Intervention Level
ORP	Occupational Radiation Protection
OSC	Operational Support Centre
PAPR	Powered Air Purifying Respirator
PPE/PCs	Personal Protective Equipment and Protective Clothing
RCA	Radiation Controlled Area

REP	Radiological Emergency Preparedness Program
RP	Radiation Protection
RWP	Radiation Work Permit
SAM	Severe Accident Management
SAMG	Severe Accident Management Guidance
SAT	Systematic Approach to Training
SMC	Technical Support Manager in the Site Management Centre
SSC	Systems, Structures and Components
TDS	Teledosimetry System
TEPCO	Tokyo Electric Power Company
TLD	Thermo Luminescent Dosimeter
TMI	Three Mile Island
TSC	Technical Support Centre
WBC	Whole Body Counter

1. INTRODUCTION

Background

As an early response to the Fukushima Daiichi NPP accident, the Information System on Occupational Exposure (ISOE) Bureau decided to focus on the following issues as an initial response of the joint program after having direct communications with the Japanese official participants in April 2011:

- Management of high radiation area worker doses: It has been decided to make available the experience and information from the Chernobyl accident in terms of how emergency worker / responder doses were legally and practically managed,
- Personal protective equipment for highly-contaminated areas: It was agreed to collect information about the types of personnel protective equipment and other equipment (e.g. air bottles, respirators, air-hoods or plastic suits, etc.), as well as high-radiation area worker dosimetry use (e.g. type, number and placement of dosimetry) for different types of emergency and high-radiation work situations.

Detailed information was collected on dose criteria which are used for emergency workers /responders and their basis, dose management criteria for high dose/dose rate areas, protective equipment which is recommended for emergency workers / responders, recommended individual monitoring procedures, and any special requirement for assessment from the ISOE participating nuclear utilities and regulatory authorities and made available for Japanese utilities. With this positive response of the ISOE official participants and interest in the situation in Fukushima, the Expert Group on Occupational Radiation Protection in Severe Accident Management (EG-SAM) was established by the ISOE Management Board in May 2011.

Objective of EG-SAM

The overall objective of the EG-SAM is to contribute to occupational exposure management (providing a view on management of high radiation area worker doses) within the Fukushima plant boundary with the ISOE participants and to develop a state-of-the-art ISOE report on best radiation protection management practices for proper radiation protection job coverage during severe accident response. The IAEA defines a “Severe Accident” as a beyond design basis accident comprising of accident conditions more severe than a design basis accident, involving significant core degradation[1].

Preparation of the report

The expert group met several times to share their experience and develop an interim (preliminary) report by the end of 2013. The content of the report is thus based on current reflections and action plans undertaken by the ISOE participating utilities and regulatory authorities to improve the emergency response plans in the event of a severe nuclear accident from the point of view of occupational radiation protection. A specific attention has been given to the analysis of past nuclear

1. IAEA (2009), Safety Guide No.NS-G-2.15 *Severe Accident Management Programmes for Nuclear Power Plants*.

accidents (TMI-2, USA-1979; Chernobyl, USSR-1986 and Fukushima Daiichi, Japan-2011) and to the integration of the occupational radiation protection (ORP) lessons learned from these accidents into the various chapters of the report (See synthesis of these lessons learned in Appendix-1).

To finalize the report, an international workshop was organized in 2014 to present and discuss the content of the interim version and share national experiences on best occupational RP management practices and protocols for optimum RP job coverage during severe accident, initial response and recovery efforts (see Appendix-2). The workshop notably allowed to improve and complete the report which has then be submitted to the ISOE Management Board for approval.

Structure

This report comprises five main chapters. Chapter 2 provides essential information on radiation protection management and organisation. Chapter 3 establishes the goal of radiation protection training and exercises related to severe accident management. Chapter 4 discusses facility characteristics that must be considered when planning actions in response to a severe accident. Chapter 5 introduces an overall approach for the protection of workers / responders with its interpretation and application. Chapter 6 discusses monitoring and management strategies for the radioactive releases and contamination control during the emergency phase. Appendix-1 addresses key lessons learned from past accidents, including TMI, Chernobyl and Fukushima Daiichi and Appendix-2 includes information on the international workshop, which was organized in June 2014 to finalize this ISOE expert group report.

2. RADIATION PROTECTION MANAGEMENT AND ORGANIZATION

2.1 Emergency Response Plans (ERPs)

All nuclear regulators require nuclear power plants (NPP) to have developed specific emergency plans or Emergency Response Plans (ERP) in response to pre-defined potential emergency scenarios. The ERPs reflect the national and nuclear operator's strategies for dealing with a nuclear emergency. The procedures will normally cover both on-site and off-site responses to the emergency.

For example, in some OECD Nuclear Energy Agency member states which have licensed activities where potentially dangerous substances are present in significant quantities, it is necessary to establish an on-site and off-site emergency plan. For activities with a high level of risk, such as Nuclear Installations, the emergency arrangements, which can be considered the "ultimate" lines of defence, include special organisational arrangements and off-site emergency plans, involving both the licensee and the public authorities. These arrangements, which are regularly tested and assessed, are subject to regular revisions to integrate experience feedback from exercises and from the management of real-life situations. The on-site emergency plans describe the organizational requirements and processes dedicated to emergency response within the facility boundary. The off-site emergency plans describe the organization and processes to protect the public, the environment and estates/goods in case of nuclear emergencies.

These plans, which should be subject of regulatory authority approval, provide the high level strategies to be employed to protect the health and safety of workers and the public. Responsibilities for emergency plan development, review and distribution are established and emergency plans should be reviewed and revised as necessary on a regular basis.

The following are the minimum recommended aspects of the ERPs in the field of radiation protection. It is recognized that effective response to an emergency scenario may require flexibility in strategies, the use of informed judgement in deciding whether to take specific actions, and the consideration of all relevant risks (not just radiation-related risks) to workers and the public. Regardless, there remains the need to apply the requirements for radiation protection and safety to the extent reasonably feasible, including the maintenance of doses at levels which are ALARA given the circumstances.

2.1.1 Assignment of Emergency Response Responsibilities

Organizational structure and assignment of primary responsibilities for emergency response should be delineated in each NPP's emergency plan. This includes the roles and responsibilities of licensee/operator, emergency workers/responders, local and national agencies, and support organizations. In that planning, the licensee/operator and the regulator(s) may need to recognize that a nuclear emergency may involve a stage before which and during which any release to the environment occurs and a stage after the termination of any release of effluent to the environment. That may imply the consideration of changes in NPP and regulatory authority organizational structures that may be appropriate as the emergency moves from a pre-release/release situation to a post-release situation.

In this report, we refer to emergency workers as NPP, utility or contracted employees of the NPP or utility who are trained and qualified by the licensee to respond to an emergency. Emergency responders will be all other personnel responding to an emergency at a NPP such as police officers, firefighters, medical personnel, and drivers and crews of evacuation. The term emergency worker/ responder refer to both categories of personnel.

Emergency workers/responders are generally persons having specified duties as a responder to an emergency situation. Circumstances may lead to cases where an individual is needed as a responder who has not previously been designated for the role anticipated and to cases where members of the public willingly volunteer to respond. For both pre-designated individuals and for the ad hoc situations, the ERPs should be clear as to who designates individuals to fill which emergency response roles, who ensures their training and fitness for those roles, and who ensures the integration of the responders into an effective response team. (Reference may also be made to section 2.3.4.) Each position in the emergency response organization, whether on-site or off-site, should be task-analysed to ensure that there are adequate numbers of persons possessing the necessary skills to fill the emergency response role. In that regard, emergency response organizations will need to be manned 24 hours per day, 7 days per week and may need to respond to abnormal situations in all reactor units on the site.

In a severe accident scenario, the numbers of persons and the amount of equipment needed for effective response may be relatively large. The organization structure should be designed to ensure that procurement and logistics can be adequately addressed. Pre-planning for supplemental personnel and equipment may help ensure timely meeting of the needs of the emergency response organization.

2.1.2 Emergency Response Procedures

The procedures should include both on-site and off-site responses to an emergency. They should define critical criteria such as maximum radiation dose and the activity levels that would necessitate implementation of protective measures. It is important that procedures clearly designate who has authority for allowing emergency workers / responders to receive radiation doses in excess of those permitted during normal plant operation and for designating the chain of command or command and control in the emergency response organization [1].

Within or connected to the emergency plan, a Severe Accident Management (SAM) program, with appropriate implementing procedures, should be established to address mitigating actions after an accident that results in widespread physical damage to fuel and core structures accompanied by a large release of fission products into the facility and potentially to the environment. In addition, it is recommended that RP instructions in connection to the SAM program are established.

2.1.3 NPP On-Shift Emergency Response Staffing

NPP on-shift staffing should be unambiguously defined, with adequate numbers of trained and qualified personnel to provide initial facility accident response in key functional areas at all times. NPP management should assess the need for and have access to personnel to ensure timely augmentation of on-site response capabilities, interfaces and coordination among on-site response activities, and off-site support to local and national governmental agencies as delineated in the emergency plan. This is discussed in section 2.3.

2.1.4 Pre-arranged Assistance Resources

As part of the development of the emergency plan, arrangements for requesting and effectively using assistance resources should be made to accommodate local and national government agency emergency response and those organizations delineated to augment initial emergency response.

2.1.5 Standard Emergency Classification and Action Level Scheme

A standard emergency classification and action level scheme, the bases of which include facility circuit/system and effluent parameters should be well-understood and used by the NPP and governmental agencies for reliance on information to determine minimum off-site response measures.

2.1.6 Prompt Communications

Provisions should exist for prompt communications among principal organizations to emergency workers / responders and to the public. Various communications platforms, including social media, should be used with accompanying implementation procedures. Public communications is discussed in sections 2.1.7 and 2.6.

2.1.7 Periodic Public Information

Information should be made available to the public on a periodic basis describing how they will be notified and what their actions should be in an emergency and the principle points of contact with the news media for dissemination of information during an emergency. Procedures for dissemination of public information should be developed and reviewed on a regular basis. This is described in section 2.6.

2.1.8 Emergency Facilities and Equipment

Adequate on-site and off-site emergency facilities and equipment to support emergency response should be provided and maintained. Pre-established arrangements for additional or augmented RP instruments and equipment should also be established. In such planning, recognition should be given to the potential that severe weather may impede some transport of materials. Facilities and equipment are described in section 2.2 and Chapter 4.

2.1.9 Off-site Radiological Consequences

Adequate methods, systems, and equipment for assessing and monitoring actual or potential off-site radiological consequences should be used. Specific to airborne effluents, these methods should include processes to track and estimate exposures from all types of airborne releases of radioactive materials, including noble gases, radioiodines, and particulates. In addition to tracking airborne radiological plumes, methods should be in place to estimate radiological doses from the inhalation and deposition of radionuclides.

Similarly, for cases where releases of liquid effluents to the environment may credibly occur, the ERP should include processes to track and, as appropriate, estimate exposures from releases to groundwater and/or to on- and near-site surface waters. Deposition of airborne materials onto water surfaces may also need to be considered in some cases. Potential doses to members of the public are likely to result from ingestion of radiologically contaminated water or food crops produced using such water.

Chapter 6 addresses off-site monitoring in more depth. Regarding the ERPs, there should be clarity regarding the roles and responsibilities of the licensee/operator and regulator staffs in developing dose estimates for personnel off-site, recommending protective actions for emergency responders and members of the public off-site, and for ordering and ensuring the effective implementation of protective actions off-site.

2.1.10 Off-site Protective Actions

A range of protective actions should be developed for emergency responders and the public. In developing the range of actions, consideration should be made to evacuate, shelter in place, the prophylactic use of potassium iodide (KI), prohibition of eating fresh foods and water from affected areas, animal housing and temporary or permanent relocation. Evacuation time estimates should be developed and reviewed/revised on a periodic basis.

2.1.11 Controlling Radiological Exposures

Measures for controlling radiological exposures of emergency workers / responders during an emergency should be developed. These measures should include emergency worker / responder and lifesaving activity protective action guides, including established reference dose levels or emergency dose limits for lifesaving- actions or protection of large populations and equipment-saving actions that could prevent potential significant social and economic consequences. Emergency procedures should also include back-out dose rates for emergency workers / responders. These measures are discussed in Chapter 5.

2.1.12 Medical Response to Contaminated Injured Individuals

Pre-arranged details should be made for medical response to contaminated injured individuals.

2.1.13 Recovery and Re-entry

General plans and radiological thresholds should be developed for recovery and re-entry within the NPP and the areas surrounding the NPP.

2.2 Emergency Command Facilities

In order to establish command and control of a severe accident, there are command centres that are established both on-site and off-site to combat the event. These facilities will have different functions and decision making authority. The following are the basic facilities for management operating the NPP: Main Control Room (MCR), On-Site Emergency Control Centres (ECC), and the Off-site Emergency Headquarters (EH).

2.2.1 Main Control Room (MCR)

The MCR is typically the primary command and control centre for emergency response management immediately following an accident. Responsibilities of the on-shift operators of the facility are to make the initial diagnosis and mitigation of the abnormal conditions, perform immediate corrective actions and make initial off-site notifications. The facility has the key responsibility for activation of the other emergency response facilities when required.

2.2.2 On-Site Emergency Control Centre (ECC)

A key aspect to emergency response is the designation of an on-site Emergency Control Centre. ECC should be considered as a general coordination centre to coordinate activities of Operational Support Centre (OSC), Technical Support Centre (TSC), information centre, monitoring centre, etc. Based upon the severity of the event, key responsibilities are transferred to this facility to remove the burden from the MCR to direct on-site response to the event. There are typically two ECCs. One facility provides management oversight of the event and houses the on-site emergency director. The second facility[2] houses the necessary personnel to respond to the event.

The main ECC can be located close to the Control Room, providing longer term plant management and technical support to the operators in the Control Room during emergency

2. This second facility houses the key response personnel such as maintenance and RP and can be comprised of multiple smaller locations or one main location.

conditions. When activated, the ECC should become the primary communications centre for the plant during an emergency. The ECC provides space and resources for plant management to relieve and assist the Control Room operators by handling administrative issues, technical evaluations, and communications with off-site emergency responders and off-site agencies.

Other support areas sometimes referred to as operational support centres (OSCs) act as support areas separate from the MCR and the ECC where licensee operations support personnel (e.g. maintenance, instrumentation and control, RP, safety etc.) can assemble in support of emergency operations. OSCs are useful to provide additional locations where plant logistic support can be coordinated during an emergency, restricting Control Room access to those support personnel specifically requested by senior operations personnel in the Control Room.

2.2.3 Off-site Emergency Headquarters (EH)

The Off-site Emergency Headquarters (EH) (which is a generic term, such as Operations Support Centre-OSC- in the US) is established for the reason of prompt availability for action during management of the emergency response organization throughout the duration of the event. Main tasks of the EH, as a managing body, are to manage all activities in the NPP, to transfer information to superior and supervision bodies, to inform the public and to declare the protective measures for NPP employees and other persons present on the NPP premises at the time of the extraordinary event occurrence. The EH secures the deliveries of necessary material, special means, and personnel, as well as providing for their maintenance and supplies. The EH should be assumed to require maintaining its operation for 24 hours per day, 7 days per week, throughout the duration of the event. Separate staffs may be found to be appropriate for the initial emergency response and for the recovery phases.

Off-site EHs provide a support facility for the management of overall licensee emergency response. In some countries, such as the United States, this includes coordination with government officials, coordination of radiological and environmental assessment, and determination of recommended public protective actions. In other countries, such as Belgium, the coordination of the radiological and environmental assessment is performed by the plant and the public protective actions are recommended by the authorities. A senior licensee official in the EH organizes and manages licensee off-site resources to support the main on-site ECC and the Control Room operators.

Off-site EHs should have appropriate technical data and plant records to assist in the diagnosis of plant conditions to evaluate the potential or actual release of radioactive materials into the environment. This should include on-line information available from on-site plant information systems which should include key plant monitoring parameters including radiation monitoring system live time results. These command centres should also be equipped with computer and software which can predict the consequences of an effluent release from plant data.

2.3 Emergency Response Organization (ERO)

2.3.1 On Shift Staffing

The Emergency Response Organization (ERO) is comprised of the following complements of personnel: the on-shift minimum staffing, and the emergency responders to fill necessary roles to augment on shift staffing and the various facilities to support the site, such as the ECC and EH.

The ERP will define the minimum on shift staffing for the key personnel and functions determined to be needed for the initial response to an event. The number of personnel varies from country to country and may vary from site to site. Operations, maintenance and RP personnel will almost certainly be among the personnel to be required on shift, but organisations such as engineering, chemistry, security and fuels personnel may also be found to be required to be on shift or available in a very timely manner.

2.3.2 Emergency Facility Staffing

In the early stages of the event, the on-shift minimum staff should be responding to the event. The staff should be augmented based on the type of issue and emergency classification. The individual responsible for the classification should be a senior on-shift individual. In Canada and the United States, the Shift Manager is responsible for making the initial emergency declaration. In the Czech Republic and the Slovak Republic, this individual is the shift engineer. Once the event is declared, this person should assume the role of the lead emergency response director and assumes command and control of the emergency until these responsibilities are transferred to another senior company official.

Additional staff augmentation is based upon the severity of the event with declaration of the event. In general, additional staff should augment the emergency headquarters, the on-site emergency command centres and the support facilities, such as off-site monitoring centres.

2.3.3 Functions of the Emergency Support Staff

Operational Support Centres (OSCs) should be equipped with sufficient personal protective equipment and other required supplies and equipment to support personnel working in the area. Typical uses for OSCs include:

- Areas where plant workers can obtain the status of radiation parameters,
- Areas to support the shift supervisor during emergency classification from the radiation point of view,
- Evaluation of the doses received by on duty personnel,
- Evaluation of releases to the environment, and
- Monitoring of the weather conditions.

The Station Emergency Response Organisation (ERO) consists of station personnel who are involved with emergency response efforts necessary to control the plant during an incident. This organization provides for the following activities during an emergency:

- Plant systems operations,
- Radiological surveys and monitoring (in some cases, including environmental monitoring),
- Firefighting,
- Rescue operations and First Aid,
- Decontamination,
- Security of plant and access control,
- Repair and damage control,
- Personnel protection including assembly, accountability and evacuation, and
- Appropriate recordkeeping related to the above-listed activities.

In order to support these efforts, the tasks that are required by RP personnel would include the following activities:

- In plant radiological monitoring; this includes those actions necessary to determine the radiological conditions in the plant and to prescribe the appropriate controls.
- Field monitoring; this includes those actions to assess the radiological conditions outside of the power block and, where appropriate, off-site.

¾ Protective actions and dosimetry during response to the accident; RP needs to be prepared to issue dosimeters to workers, provide for respiratory protection, and provide protective clothing.

¾ Repair and damage control; this provides support to the teams entering the facility to address those actions to minimize and mitigate the emergency.

¾ Off-site dose calculation and plume tracking, including the capability for multiple unit dose assessment on the same NPP site.

2.3.4 Stakeholders in Radiological Emergencies

In an emergency situation, RP provisions for emergency workers and for the other emergency responders complement one another because they cover persons working under different statutes (workers under the responsibility of an employer and persons acting within the framework of agreements with the public authorities or within the framework of the requisitions).

Emergency workers / responders comprise the various categories of personnel likely to be involved in the management of an accident. This also includes persons acting either within the framework of agreements with the public authorities or within the framework of the requisitions, under the authority of the ERP-designated responsible director of emergency operations.

Emergency arrangements require a number of workers/responders to perform the emergency procedures to carry out essential plant evolutions, search for and rescue casualties, perform radiological monitoring, fight fires, etc. In many cases, the emergency arrangements will require emergency workers/responders in addition to on-site utility staff to support certain on-site evolutions. The operating experience from the severe accidents at Chernobyl and Fukushima demonstrate the critical (and potentially very hazardous) role played by national emergency services (e.g. fire brigade and military).

Utilities with multiple NPP sites may be able to mobilize emergency workers/responders from unaffected nuclear sites, and for sites with multiple units, it is almost certain that workers from other units will be called to respond. In the UK, support may be provided by other nuclear operators, for example from decommissioning sites or from military nuclear facilities. These arrangements are periodically exercised.

It is important that the emergency arrangements clearly state who can act as an emergency worker/ responder, what level of radiation dose they are permitted to receive, under what circumstances and who can authorize such radiation doses. There will be some individuals who will not usually be suitable for work involving emergency radiation exposures, for example female workers who are known to be pregnant or breast-feeding and young persons under 18 years of age. At minimum, emergency response procedures would need to specify the appropriate controls on such exposures, consistent with national regulations.

It is vital during severe accidents that emergency workers/responders attending the affected site are properly protected with appropriate radiological controls, notably to identify radiological risks, to assess and control radiation doses and to ensure suitable personal protective equipment is selected and worn. Emergency responders from external organizations with no experience of working with radiation can be put at significant risk because they may not appreciate the significance of plant conditions unfolding around them.

As described in Appendix-1, the operating experience from the Chernobyl nuclear accident shows what can happen if emergency responders are not adequately protected by the emergency response organization.

In order to determine their selection, training and medical and radiological monitoring conditions, emergency workers /responders could be for instance classified into two groups:

¾ The first group comprises personnel forming the special technical, medical and health intervention teams readied in advance to deal with radiological emergency situations (for example: firemen from public services with specific skills in radiological interventions, workers from the plant, etc.) ;

¾ The second group comprises persons not belonging to special teams but intervening as part of the tasks within the scope of their competence (for example: firemen from public services, experts in the field of measurements, medical assistance, etc.).

Practically, the emergency workers /responders of the first group should be involved in intervention on the damaged site (to secure the situation, to give first aid to victims, etc.) and the personnel of the second group should be more dedicated to intervention in the vicinity of the damaged site (environmental measurements, facilitation of the evacuation of people, etc.).

The emergency workers /responders belonging to the first group should have personal passive and operational dosimeters (provisions should be made to keep those dosimeters ready to use in case of emergency). In addition, they should be subject to radiological monitoring and a medical fitness check and should receive training (theoretical and practical, to be renewed regularly) on the risk associated with exposure to ionizing radiation. They should have appropriate equipment with regard to the particular nature of the radiological risk when they participate in an intervention and should receive special and relevant information on the risks at the beginning of the emergency situation.

The emergency workers /responders belonging to the second group should be given appropriate information on the risk associated with exposure to ionizing radiation. They should receive special and relevant information on the risks at the beginning of the emergency situation (or upon their arrival near the affected site) and should have been given adequate individual protection equipment and dosimetry.

2.3.5 Restrictions

A process should be in place for the qualification of individuals to perform emergency activities. The qualification process should include assessment of the individuals' physical health and abilities, training, and intended job function. Individuals with conditions precluding their involvement should not be qualified and considered. The qualification process should, where consistent with national regulations, consider prioritization of individuals based on potential health effects from emergency tasks such as the use of respirators.

In addition to qualifying individuals on the basis of their current health, the process should use selective prioritization, where consistent with national regulations, based on the consideration of the potentiality of health effects after exposure due to respirator use, the wearing of protective clothing, heat stress, and other factors relating to reasonably potential working conditions.

2.4 Decision Making

The licensee/operator's ERP should establish decision making authority for the event. Specific to the RP perspective, the key decisions should include classification of the event, determination of protective action recommendations for members of the public, protective measures for on-site personnel, and notification of governmental authorities.

In general, the main control room has the initial responsibility for these decisions. As various on-site and off-site emergency response facilities are staffed and activated, these responsibilities should be transferred from the main control room. These responsibilities should be defined in the NPP ERP. For example, some activities could be delegated as follows:

¾ Event Classification and on site protective measures should transfer from the MCR to the on-site Technical Support Centre (TSC) and should not be delegated.

¾ Off-site protective action recommendations and off-site notification will transfer from the MCR to the on-site facility and then should be transferred to the operator's off-site emergency response centres.

2.5 Prerequisites for On-site Radiation Protection Decisions

2.5.1 Area Classification and Access Control

In order to quickly activate the required mitigating steps in response to an accident, on-site ERP should contain clear concise instructions for workers to move to the appropriate locations to conduct emergency response actions or to leave the site if their presence there is not needed for effective emergency response. Of utmost importance is the necessity for workers to be able to understand which areas on-site are or may shortly become dangerous and to be able to safely evacuate from those areas to safer on-site areas or to off-site locations. Workers who will be providing emergency response should also understand their roles and know what site areas will be used to perform certain functions. In addition, workers need to know where personnel protective equipment and key response equipment are located so they can perform their jobs. Workers leaving the site because their presence is not required should be asked to provide means of notifying them should their presence on-site later be needed.

In addition to understanding the location of key areas, workers should also be able to predict or obtain information about the hazards that will be encountered in on-site areas after a severe accident. Systems should be in place to minimize the entry into dangerous or life-threatening areas which could be encountered during an accident.

To effectively communicate the designation of areas, along with their associated dose rates and hazards during an emergency, a classification and access control system should be in place. Several variations of classification systems can be implemented but the goal is to establish a method for delineating zones within the site boundary where different habitability and use conditions exist. To the extent practice, zones, where predicted conditions during an accident could lead to high worker doses, should have access control restrictions which physically prevent the entry of unauthorised individuals during and after an accident.

Depending on reactor type and facility design, access controlled areas should typically include areas with credibly foreseeable substantive radiological hazards. These areas are those which typically house:

- the reactor and its auxiliaries,
- heat transport systems,
- moderator systems,
- spent fuel systems, and
- other systems and components which could be dangerous due to predicted high radiation levels.

In addition to area use, other on-site facility factors, such as the ability to isolate or alter system configuration, monitor and collect samples, communicate throughout the site, and provide safe work zones are important aspects which need to be considered in planning an effective response to a nuclear incident.

The following discusses recommended preparations that should be considered on site at a nuclear facility to prepare for response to a severe accident:

- The level of hazard in specific areas depends on the operating conditions. For instance, a zoning system may include areas designated as zones 1 through 3. During normal operations these zones may define radiological risks from radiation levels or contamination levels. As such, during normal operations zone 1 may be a public domain area, zone 2 a buffer zone and zone 3 an access restricted area due to radiological conditions. During an emergency, these zones may be redefined and designated field action controls may be applied which dictate RP requirements (dosimetry, PPE etc.).

- An appropriate access control system should be designed to guard against personnel unknowingly approaching sources of high radiation, and also against radiation sources being transported into areas where personnel could be present. Typical access control systems use key or electronic interlocks to prevent unauthorized access into areas or to reduce the potential for radiation exposure by moving equipment with high radiation areas into shielded locations, such as refuelling machines in some reactor designs.
- Access control systems should have monitoring methods to provide plant security or RP personnel awareness if entry into dangerous areas occurs.
- All personnel leaving controlled areas should be monitored using existing plant facilities if they are available and functioning (Chapter 6 provides more details). In severe accidents where this equipment is deemed inoperable, alternative off-site facilities can be used. In this case, monitoring of people and equipment is established via mobile off-site monitoring facilities containing dedicated tools, equipment and qualified staff. The severity of the event dictates the mobilization and degree of this resource deployment.

2.5.2 Establishing Reference Dose Levels in an Emergency

Reference dose levels, which are established by national regulatory authorities, are country specific and based broadly on the activity to be performed. These tend to be subdivided into two categories: those actions to save a life and those actions necessary to reduce the impact of the event, as discussed in Chapter 5.

According to the organization described above, it is the ERP-designated responsible Director of the emergency who authorizes doses to be received by workers/on-site responders which may exceed those criteria established for routine facility operations or for emergency response not related to life-saving or the avoidance of large consequences to the facility, its staff, and/or off-site. The Director should receive support by personnel who are responsible for the evaluation of the radiological conditions and the prescription of the protective means. The ERP should include the process by which personnel may volunteer for tasks where life-saving or similar doses are anticipated, are briefed on their tasks and appropriate protective measures, and the measures being used to estimate doses and provide for appropriate medical follow-up.

Examples of the various emergency reference levels are listed in table-1:

Table 1 Country Specific Reference Levels

Country	Emergency Response Reference Levels	Reference Levels for Life Saving Actions
Belgium	50 - 250 mSv	250 mSv (incl. prevent catastrophic evolution)
Brazil	100 mSv	Consider the thresholds related to the deterministic effects.
Canada[3]	500 mSv	
Czech Republic	100 mSv	200 mSv[4]
Finland	500 mSv	
France[5]	Group 1: 100 mSv during the time of their missions. Group 2: 10 mSv	Group 1: up to 300 mSv for protecting people. Group 1 & 2: exceeding reference values can be accepted for saving human lives.
Germany[6]	100 mSv	> 250 mSv[7]
Japan	100 mSv	
Pakistan	100 mSv	500 mSv
Republic of Korea	< 500 mSv	
Slovak Republic	100 mSv	500 mSv
Spain	Group 1[8]: 500 mSv Group 2[9]: 50 mSv	> 500 mSv[10]
USA	100 mSv	250 mSv

2.6 Public Communication

ERPs should establish provisions for prompt communications among principal response organizations to emergency personnel and to the public. Each organization should establish reliable and backup means of communications for licensees and response organizations. These must include provisions for 24-hour per day notification.

It is recommended that at least annually, information is made available to the public on how they will be notified and what their initial actions should be in an emergency (e.g. listening to the local broadcast station and remaining indoors), the principle points of contact with the news media for dissemination of information during an emergency, and procedures for coordinated dissemination of information to the public.

NPP operators have a responsibility to communicate with the public, media, stakeholders and employees during (potential) nuclear emergencies. To facilitate this, there should be a plan in place and a procedure that governs the emergency communications response. They should also be prepared to respond to questions and information (be it true or false) from social media outlets such as Twitter and Facebook. NPPs also participate with the federal and state or provincial officials and affected municipalities in a coordinated manner. Notably, regulatory or other designated officials (e.g. emergency management agency personnel) have generally the same responsibilities as do NPP personnel as outlined in this paragraph and the following paragraph.

3. The Canadian Nuclear Safety Commission (CNSC) has proposed amendments to its Radiation Protection Regulations (RPRs) in consideration of ICRP 103 (2007), IAEA BSS (2011), the Fukushima event, and other lessons learned since the RPRs came into force. The proposed revision to RPRs in the area of emergencies provided additional clarifications on dose control requirements according to the severity and phases of an emergency in line with the IAEA BSS-115 recommendations.
4. Saving human lives, preventing the development of radiological emergency potentially causing extensive social and economic consequences – operation intervention level: Hp(10) > 200 mSv.
5. Group 1 includes personnel of special technical intervention groups, medical or health fields, trained to cope with a radiological emergency situation. Group 2 includes personnel not belonging to special intervention groups, but intervening within their mission under their skills.
6. For measures averting danger to persons an effective dose of more than 100 mSv should only occurs once in a calendar year and an effective dose higher than 250 mSv only once in a lifetime (only volunteers, age over 18)
7. It is recommended that doses received by these workers should not reach more than 1 Sv.
8. Workers that could realize actions needed for the mitigation of the accident and its consequences. These workers, engaged in rescue works, are volunteers and are informed on the risk associated to their intervention.
9. Rest of the personnel in the emergency organization (ERO) who are assigned to support actions and auxiliary missions in the emergency management (actions not being part of the accident mitigation)
10. Doses received by these workers should not reach values that could give rise to deterministic effects.

The main target audience of the NPP's emergency public information program should be the public living or working near the nuclear sites. Another audience is its employees, who need to know about the state of the facility and who may be a conduit for information to external groups. Each site should establish areas around their facility expected to be impacted by both direct exposure and ingestion pathway exposures during and after severe accidents. Citizens should understand by this communication if they reside in critical areas and are to be ready to respond. To reach this audience, the NPPs should rapidly communicate with media outlets, employees and other stakeholders to ensure that they are informed quickly about developing issues. Communications should be as open, honest, and transparent as knowledge and circumstances allow.

NPP communications should provide information to address the following:

- What happened within the plant?
- What is the status of the rest of the plant?
- Has there been a release of radioactive materials to the environment or is a release imminent?
- Have off-site radiation surveys been completed?
- Have federal, state/provincial, and municipal emergency response agencies been alerted and what is their responsibility?
- Will this emergency have any effect on the electricity supply?

For those situations where a NPP site is located very near a state/provincial or international boundary or for those situations where the situation warrants consideration of protective actions or radiological monitoring across the boundary, communications with appropriate officials in the adjacent state/province or country are appropriate and should be initiated in a timely manner. Relevant radiological data and the basis for any protective action recommendation made for the area surrounding the NPP should be a part of that communication.

2.7 Self-Assessment of Radiation Protection Preparedness

After completion of a review of relevant documents on emergency preparedness and response and a review of relevant operating experience, a NPP operator (and its contractors where used) should develop a sense of what is needed in its ERP. More specifically, they should understand what is needed regarding RP of workers/responders and the control of radioactive effluents to the environment during an accident scenario.

The staff should develop a series of draft guidelines regarding the RP topics to be covered in the ERP and a series of draft system and equipment needs appropriate to emergency preparedness. Utility RP personnel may find it to be helpful to ensure that cross-functional discussions are held, to be aware of the thoughts of operations, maintenance, engineering and other personnel as their responsibilities intersect with those of RP in preparing for emergency response. Then, RP personnel may find it helpful to develop checklists of equipment needs and references to Emergency Response Procedures, Severe Accident Management Guidelines (SAMG), and other relevant procedures as the RP personnel develop their draft RP procedures for emergency preparedness and response.

When the RP procedures and checklists are drafted, an assessment should be planned, using utility and independent personnel, to determine if the drafted materials meet the needs as identified in regulations, international standards, industry-generated ERP preparation guidelines, and reviews of applicable operating experience. Deficiencies in the draft materials should be identified for resolution, as the details of the draft materials are thoroughly assessed against the list of specific items in the available required and best-practice documents.

3. RADIATION PROTECTION TRAINING AND EXERCISES RELATED TO SEVERE ACCIDENT MANAGEMENT

Trained and competent operations and maintenance staff are an important component in the "defence in depth" strategy for ensuring NPP safety and protection of the public.

Implementation of a comprehensive training and qualification program designed to address postulated emergency situations is necessary to provide assurance that NPP staff and personnel from external emergency response organizations (responders) are able to effectively respond in accident conditions. Training and exercises related to severe accidents should be integrated within an overall ERP. It should be an extension of the training plan contained in the ERP to include accident scenarios that are beyond design-basis accidents.

Emergency exercises and drills should be designed in order to verify that NPP staff and staff from other participating organizations possess the essential knowledge, skills, qualifications, and abilities required for the accomplishment of tasks under stressful and postulated emergency conditions. These drills and exercises should be used to test the effectiveness of the NPP's emergency response programs, clarify roles and responsibilities, identify gaps in resources needed to implement the emergency response plan, ensure activities can be performed under postulated accident conditions, and improve individual and team performance.

Training programs for severe accident management should carefully consider that certain personnel may be unavailable in the aftermath of the event. The selection and training of qualified personnel for key positions should consider alternative personnel and ensure that a sufficient number of individuals are trained to fulfil critical roles.

Training should be conducted at regular intervals which are compatible with the plant's overall operator and technical staff training program. Training frequencies should be established to ensure responsible persons remain qualified, well informed and prepared for responding during emergency situations and completing the tasks to which they have been assigned.

RP training should also be provided to on-site and off-site personnel assigned to emergency teams and positions, including identified alternates. The RP training program should be designed, supported by the NPPs in close collaboration with stakeholders and conducted either on-site or off-site.

3.1 Emergency Preparedness Program Activities (Anticipatory Training and Exercises)

Anticipatory training should be arranged during normal operation of NPPs by the licensee/operator as part of their emergency preparedness program activities. Emergency workers/ responders that may be confronted with severe radiological situations in the early phases of emergencies should be included in the anticipatory training and emergency exercises to prepare them for such situations. Relevant personnel may include:

- NPP staff (including RP personnel, maintenance crews, operational shifts, NPP fire brigade, etc.),
- NPP contract and support organization staff such as off-site laboratory staff, and

- NPP stakeholders and off-site emergency response authorities (including rescue departments, police forces, defence forces, medical support, radiation and nuclear safety authorities, local communities, etc.).

If subcontractors may be involved during severe accident management, anticipatory training specifications for these persons should also be required. In this case, anticipatory training specifications should require a description and justification of the scope of the subcontracting related activities during an emergency, demonstrating that this scope is consistent with the licensee's full responsibility for nuclear safety and RP.

All NPP staff should receive basic level emergency training which incorporates RP fundamentals including information on the associated health risks from exposure to ionizing radiation. However, personnel selected for specific roles in the ERO should receive additional training appropriate for the position. The training program for the emergency workers/ responders should include all actions planned for the management of the emergency including required RP provisions under postulated accident conditions.

As a fundamental part of anticipatory training, the roles of all organizations involved should be assessed and clearly defined to ensure there are no gaps in responsibilities that could undermine the effective implementation of severe accident management training programs. The roles of the licensee, local, national, and international organizations should be assessed with regard to severe accidents, which may depart from previously defined roles in design basis accident scenarios. In addition to identifying potential gaps in training responsibilities, the assessment should identify areas where redundant requirements or inconsistent policy may exist that may be exacerbate the challenges of clear communication and training during a severe accident. Countries may vary in the nature and interrelationship of these organizations and should assess this issue accordingly.

3.2 Development of Training Instructions

Emergency exercises and drills should be designed to ensure that NPP staff and staff from other participating organizations possess the essential knowledge, skills, qualifications, and abilities required for the accomplishment of tasks under stressful and postulated emergency conditions.

The development by the licensee of a SAM program should include a systematic identification of the training needs of personnel carrying out each function of the emergency response team. The development of the required training material and the schedule for the training, re-training and testing of staff should also be defined and documented.

The training program should be developed using the Systematic Approach to Training (SAT). This includes identifying training needs, defining the training objectives, identifying the technical basis for training material, developing training material, specifying the appropriate venue for delivering training and measuring the effectiveness of training to provide feedback to the training process.

In the case of SAM guidance, the phenomenology of the severe accident (i.e. beyond design basis accident) should be covered during the training of NPP personnel, however the topics covered and the level of detail devoted to each should be chosen carefully, always keeping the overall objective of the training in mind. However, it is imperative that potential radiological hazards (e.g. elevated dose rates) at specific locations within the plant should be discussed.

The training materials should provide clear and concise guidelines and include process charts for accident scenarios wherever possible. The nature of severe accidents and conditions in the aftermath heighten the importance of instructions that are straightforward in stressful situations compounded by time pressures.

3.3 Types of Training

The following types of training should be considered and included in SAM training.

3.3.1 General Training

There should be a general training program developed and delivered to all on-site and off-site emergency workers / responders which includes a description of the main objectives of the emergency plan, required actions for personnel, roles in the emergency response organization, and a review of basic RP requirements. Training should also include a module on conventional safety requirements and potential hazards encountered during accident conditions; in particular, for fire-fighters and medical aid staff. All employees should be trained on the communications warning systems and access control during a severe accident.

3.3.2 Emergency Exercises and Drills

Personnel assigned to specific emergency responses roles should demonstrate and maintain fitness for duty and competency to perform assigned tasks at all times. Periodic emergency exercises and drills (e.g. announced, unannounced, initiated outside normal hours, and /or include more than one shift cycle) simulating postulated accident conditions should be held to reinforce training principles and to assess the effectiveness of the emergency response capability.

A full scale emergency exercise should be used to test the integrated capability of the EROs and should allow for the identification of areas for improvement that could enhance the effectiveness of the response to an actual emergency. Full-scale emergency exercises normally involve a large number of on-site and off-site stakeholders, and may include regional, provincial/state, federal and, where appropriate, international authorities and agencies. A full scale emergency exercise should be conducted at least once every three years to five years or as required by regulatory authorities.

Emergency exercises do not always need to be full scale. Function specific drills can provide responders with important information to implement their jobs. For example, table top emergency exercises, such as on-site notification and communication, are intended to motivate discussion of various issues regarding a hypothetical emergency situation. As in a drill, a table top emergency exercise can be used as a training tool to achieve limited or specific objectives. Drills such as these should be conducted at least annually. Function-specific drills and training should include radiation protection tasks such as exposure projections and monitoring for workers and members of the public, sampling, and use of radiological equipment. Drills should be designed to test both the adequacy of the tasks and the usefulness of programs and procedures during emergencies.

Drills and emergency exercises should be based on a scenario that realistically simulates the postulated conditions present during an emergency. They may also include simulations of other unanticipated conditions, including elevated dose rates in the MCR, time constraints and stress.

Consideration should also be given to unlikely events; e.g. loss of power for the facility or in a localized area; loss of primary communication method; loss of outside roads; loss of key instrumentation. Elements of these unlikely events can be incorporated into drills, or in table top exercises. These events should also be discussed during the training session.

Exercise scenarios at the NPP as well as simulator scenarios should be prepared, including training objectives, exercise scope, safety expectations, conditions for termination of the exercise, and methods to obtain feedback appropriate to ERP and procedure refinement.

3.3.3 Theoretical and Simulator Training

Simulator training is an essential part of the programs for maintaining technical qualification. The training should be regularly updated to incorporate new findings and technical facts. The training should include methods for effective communication and provide coping mechanisms for dealing with stressful situations.

The simulators should reproduce the referenced NPP in appearance and also in its technical, physical and temporal behaviour. The operating personnel should encounter in the simulator the same working conditions and requirements as would occur in the operation and monitoring of their plant.

The training programs should contain the entire range of NPP operation: normal operation, operational disturbances as well as all incidents and accidents in any combination and under widely differing boundary conditions. Training should put equal emphasis on operating and understanding the technology as well as on human performance in particular the ability to work in a team, to effectively communicate, make decisions and demonstrate sound leadership.

Theoretical training should be included to ensure that personnel with special emergency assignments understand the conceptual basis and terminology and structure of the ERPs, and their own roles and responsibilities in the implementation of ERPs.

Plant emergency response using ERPs should be practiced in the simulator to provide operating personnel with the necessary knowledge and skills to demonstrate their competency during emergency actions. Specific in-depth training in ERPs should be provided to overcome the degradation of operating personnel's performance that can occur in stressful situations.

When available, simulation tools with the capability to simulate severe accident conditions (e.g. containment failure, fission product release, etc.) should be used in the development of training sequences (scenarios) and also for demonstration of accident phenomenology. Elevated dose rates should be incorporated into these scenarios. Larger scale exercises should practice responses to environmental consequences as a result of radiation releases. For the off-site dose projections relevant computer codes are used instead of simulators. The simulators should be used to support classroom presentations and individual training.

In the absence of a full scope simulator integrating both design basis accidents transients and severe accidents, emergency exercises should include both the use of ERPs and SAMG, through a realistic accident progression scenario, In this case, the ERP should be considered with the use of the full scope simulator while the SAMG should be used as a table top exercise.

If available special analysis simulators should be used to train personnel on action to take with core melt sequences and relevant severe accident phenomena (particularly for classroom teaching of the shift personnel and members of the crisis team including RP staff, RP manager, RP officers, etc.).

As an example and similar to the same type of training provided for the control room operators, a dedicated training facility can be composed of a control and observation room, surrounded by different working rooms including facilities such as listed below:

- access control,
- change clothes room,
- pre job briefing room,
- equipment and components room,
- hot shop room,
- personal decontamination room, and
- instruments and materials decontamination room.

In order to better evaluate the trainees, evaluators and instructors can watch the evolutions from the control and observations room, controlling radiofrequency generator devices, which signals would be read and/or heard by the trainees in field, increasing or decreasing the signal to simulate the variation of radiation dose rates.

A layout of such a facility design is given in Figure-1:

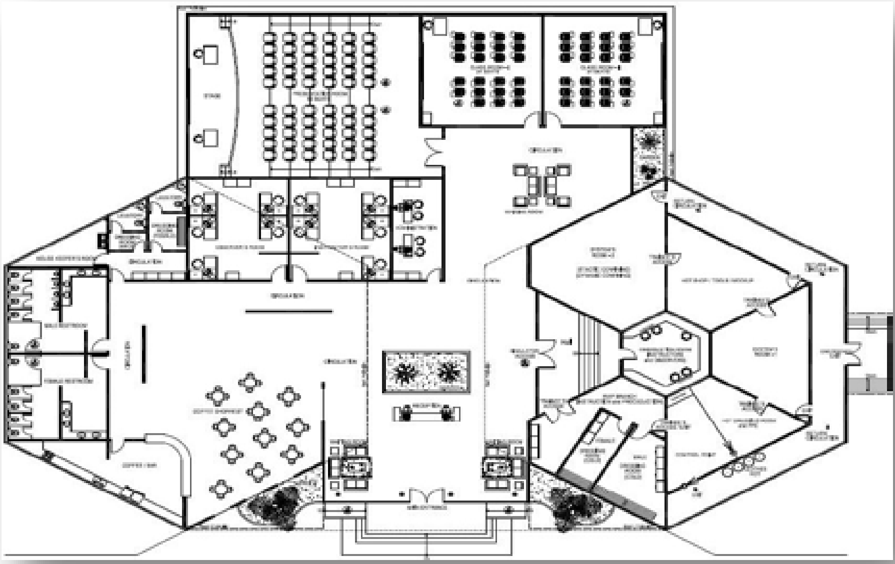

Figure 1 Layout of a training facility [2]

Advanced RP tools such as simulated radiation meters and simulated alarming dosimeters, should be made available by the licensee to simulate elevated exposure conditions in a training environment. Example of advanced RP tools available to some NPPs to simulate real exposure conditions in a training environment are dosimeter response profiles and gamma meter responses for different scenarios. Robotics and teledosimetry are other tools that are available to most NPPs and should be deployed during training, when required and when conditions allow.

3.3.4 Training for Stressful Situations

Emergency preparedness exercises should be designed to ensure that NPP staff and staff from other participating organizations possess the essential knowledge, skills and abilities required for the accomplishment of non-routine tasks under stressful emergency conditions. In addition to physical and psychological stress, training methods and conditions should reflect the urgency and time-dependency on quick decisions that will exist during a severe accident. The program should consider repetitive timed drills to reinforce the sense of urgency and increase familiarity with the procedures and decision making process under adverse conditions. It should be noted that various types of stresses may be compounded during a severe accident, such as temperature, emotional duress, lack of sleep, and lack of proper nutrition.

To help workers manage stressful situations, trainers should have requisite knowledge on the principles of stress management and a well formulated and clearly written check-list should be available to help the trainer enhance performance under stressful conditions. Consideration should be given to ensuring that the training exercises are not psychologically overwhelming, which may lead to negative consequences such as reduced morale and training effectiveness. The content of the material should be such that no special education or specific training is required to understand it. Pictures, graphs and symbols are better than plain written text. A quick reference aid should be made available to the trainees to help them execute their tasks easily during an emergency. These quick reference aids should be role specific.

Examples of features used to enhance training performance under the stressful conditions associated with severe accidents include:

- guideline steps are written in concise and easy to understand layman language intended to highlight step objectives, with required supporting details provided in attachments;
- guideline language has the same vocabulary and meaning as that in the emergency operating procedures;
- worksheets are provided to ascertain and track essential equipment status and to document the basis for decisions that have been made;
- easy-to-use information is provided to assess the positive and negative impacts of alternative SAM strategies; and
- information is provided to enable rapid evaluation of the effectiveness of implemented actions.

Typical RP related issues that may result from performing during stressful situations include but are not limited to:

- Non adherence to RP procedures/instructions;
- Misinterpretation of changing radiological conditions;
- Incorrect radiation monitoring/surveys;
- Failure to take appropriate measures to avoid exposures to airborne radioactivity;
- Failure to keep exposure within the authorized dose limit; and
- Spread of contamination.

3.3.5 Just-In-Time Training and Exercises

It is critical that a system for well-managed pre-job briefings be established for use in a severe accident. During an emergency situation, RP briefing becomes part of the pre-job briefing (i.e., emergency safety training).

3.3.5.1 During the Emergency Phase

In an emergency situation, neither the time nor locations may be available for normal class-room type training. The audio-visual tools for example may be unavailable due to the lack of power (e.g. electricity) and the normal training rooms may not be habitable due to adverse radiological conditions (e.g. high radiation fields, spread of radioactive contamination). Under such conditions, just-in-time training, or task-focused “toolbox” training may be necessary to concentrate on the absolute most important items only. The training must be as practical as possible with the understanding that emergency conditions will be stressful and actions must be taken quickly.

Activities undertaken during the control of an emergency which may result in a dose to a person greater than the applicable dose limit or reference level must be carried out on a voluntary basis. In these instances the volunteering individual(s) should be provided sufficient information/facts regarding the associated risks in order to make an informed decision. See section 3.5 below for a list the minimum content of the training and information on RP.

During the emergency situation, the training may be very stressful for both the trainer and the trainees. Therefore a well formulated and clearly written check-list should be available to support the trainer. For example, emergency task briefing checklists should be developed to cover the nature of the task and expected hazard conditions, PPE, instrumentation, dosimetry, back-out limits, etc. In the challenging conditions of a severe accident, RP personnel will need to assess rapidly changing conditions. Specific training in gross estimation of radiation hazards such as dose rates or potential dose from airborne radionuclides would be useful in helping RP staff have more experience and confidence in situations when access to reliable and accurate data may be limited.

3.3.5.2 During the Recovery Phase

As soon as the emergency situation transitions to the recovery phase, the requirements for training should be similar to those during the normal radiological safety training of the licensees.

Plans and procedures for re-entry in the recovery phase are required for both existing and potential conditions. All emergency workers / responders are required to be trained on specific actions described in the plant's recovery plan.

3.4 Training and Qualification Program

The training and qualification program should consist of an appropriate mix of classroom training, self-study, field demonstrations and emergency exercises/drills to test individual capabilities. The training program topics should vary depending on the function being trained.

The objectives of trainings and exercises are:

- To test the integration of on-site and off-site responses to an emergency;
- To verify that all individuals participating in the emergency exercise are familiar with, and capable of performing, the emergency duties assigned to them;
- To verify that emergency response and all related duties can be carried out in a timely manner according to the planned schedule;
- To ensure that staff are familiar with the content of the emergency plan;
- To obtain and maintain the skills required for the activities in the emergency plan and relevant emergency practices;
- To demonstrate how effectively an emergency plan, or part of it, can be implemented;
- To confirm the adequacy of the plan to deal with the emergency and to identify potential improvements; and
- To verify that the appropriate lines of communication are established and maintained.

The emergency workers / responders should receive theoretical and practical training (to be renewed regularly) on the risks associated with exposure to ionizing radiation. They should receive special and relevant information on the risks during the initial phase of the emergency, including the topics described hereafter.

Topics to be integrated into the training material and tested during emergency exercises and drills should include (but are not limited to):

- Emergency response plan and procedures;
- Emergency communication and warning systems,
- Emergency categorization and postulated radiological situation(s);
- Emergency response facilities and equipment (on and off-site);
- Radiation personal protective equipment;
- Measuring instruments, communication devices and other equipment;
- Dose projection, measurement and control methods/techniques;
- Contamination control/monitoring and personnel screening requirements (e.g. facial frisking, bioassay submissions, whole body counting, etc.);
- Decontamination strategy (including self, contaminated casualties, vehicles, material);
- Fitness for duty for emergency work;
- Off-site dose calculations and methods of communicating this information to the public; and
- Off-site environmental monitoring.

Emergency responders intervening in the vicinity of the damaged NPP for environmental measurements and facilitation of the evacuation of people (e.g. off-site emergency resources such as fire-fighters, public services, experts in the field of measurements, medical assistance, etc.) should also be given appropriate information on the risks associated with exposure to ionizing radiation. They should also receive special and relevant information/training on the proper use of protective equipment and dosimetry.

RP Training programs for both on-site and off-site emergency workers / responders should include classroom instruction and practical drills in which each individual demonstrates ability to perform assigned periodic tasks.

The RP training program should include topics such as:

- Basic explanation of RP risks (in addition to the routine information during annual training on RP for normal operation) and emergency measures;
- Information on the expected radiological hazards (e.g. dose rates, airborne activity levels, etc.);
- A comparison between dose alarm level, legal limits and threshold of radiation illness in order to illustrate the actual risk;
- Use of personnel protective equipment, including how to properly don and doff radiation protective clothing and respiratory protection;
- Use of radiation instrumentation and radiological monitoring equipment;
- Dose monitoring requirements and how to use the devices;
- Actions to be taken if a dose alarm level is exceeded;
- Practical advice to reduce the worker’s exposure with time, distance and shielding;
- Contamination control / monitoring and personnel screening requirements (e.g. facial frisking, bioassay submissions, whole body counting, etc.);
- Personnel decontamination, basic techniques and procedures;
- Use of procedures and instructions; and
- Shift exchange and the effective transfer of information, especially concerning the results from recent radiological monitoring.

3.5 Radiation Protection Aspects Related to Severe Accident Management

The RP aspects related to a severe accident management should be included in the emergency preparedness training program and tested during emergency exercises under postulated conditions. These RP aspects should include, for example:

- Assessment of the status of the NPP and of the radiological situation within the plant and in the environment (e.g. neighbouring area) including the use of specialty software;
- Monitoring of radiation fields and tracking of radiation doses under severe accident conditions (e.g. loss of power, etc.);
- Estimation of external and internal radiological hazards based on pre-determined scenarios using a highest credible source term (extremely conservative conditions);
- Implementing radiological hazard control measures and contamination control measures including the use of remote tools and specialized equipment;
- Implementing back-out or mission-abort dose limits and protective actions when emergency reference levels are exceeded;

- Installation of temporary shielding particularly when the accuracy of radiation monitors could be adversely affected by the radiation levels during severe accident; and
- Identification and projection of the off-site consequences of the released radioactive materials.
  - The implementation of RP measures, necessary to manage radiological hazards due to the potential presence of fission products within the extended containment boundary, should also be included, such as:
- restricting access to the affected areas/rooms;
- wearing protective equipment if access is required;
- placing temporary shielding around high sources;
- using dryers for vaporized radiation; and
- ensuring ventilation flow in affected areas is directed through filters before venting to the outside environment.

In addition to specific RP functions, RP staff should be trained on the potential scenarios regarding severe accidents and key concepts in mitigation of the accident regarding core and spent fuel cooling. RP workers during severe accidents need to clearly understand potential areas requiring access for accident mitigations and major activities that would be performed by operators or maintenance people during early phases of the emergency.

The degree to which such measures are necessary and sufficient will depend on the importance and frequency of access requirements to the affected areas of the plant and the magnitude of the hazard.

Required field actions (such as valve operations, sampling, etc.) which are anticipated to be carried out according to the severe accident management strategies (e.g. deployment of emergency management equipment) should be analysed with regard to the radiological protection aspects. These actions should be included in the training program and tested during emergency exercises in order to verify the validity of procedures and to obtain realistic estimates of the crew response times and the potential doses to be incurred.

Training and exercises related to medical aid, transportation and care of contaminated patients should be arranged together with the rescue services and health care providers. A good practice is to equip every ambulance of local rescue services with appropriate procedures and basic protective equipment for the ambulance staff. For the purpose of training, the use of commercially available simulated alarming dosimeters and simulated radiation meters is recommended.

3.6 Management of the Administrative Aspects Related to Severe Accident RP Training

Drills and emergency exercises are part of the overall process for assessing the integrated performance of the organization and the capability of people, facilities, and equipment to respond to an emergency situation.

Exercise debriefing and critique should take place following all drills and exercises to allow the opportunity to evaluate the efficiency of the exercises and to learn from the experience gained during the exercises.

Results from emergency exercises and drills should be reviewed, analysed and incorporated into the training program and, if applicable, into the procedures and guidelines as well as into organizational aspects of accident management.

Emergency preparedness training programs should be audited or evaluated on a regular basis by the national regulatory authorities and reviewed by independent parties. Deficiencies and areas for improvement should be addressed by NPP operators to enhance their capabilities and readiness for a severe accident management.

The content of the emergency preparedness training programs should be kept up-to-date, taking into account:

- lessons learned from emergency exercises and drills carried out by other NPPs (nationally and internationally) including experiences from past severe accidents (e.g. TMI, Chernobyl, and Fukushima);
- new international recommendations; and
- advances in technology (e.g. radiation personal protective equipment, shielding and decontamination material, radiation devices, etc.).

4. FACILITY CONFIGURATION AND READINESS

The effective implementation of a RP programme at a NPP undergoing a severe accident can be significantly impacted by several facility factors including the:

- site structure layout,
- configuration and control of physical plant systems,
- ability to control access during emergencies,
- availability of installed and portable equipment necessary to evaluate radiological conditions,
- off-site facility capability to manage and perform emergency related actions,
- availability of necessary monitoring equipment and personnel protective equipment, and
- adequacy of programs and procedures for emergency facility activation and control.

This section discusses facility characteristics that must be considered when planning actions in response to a severe accident.

4.1 Facility Design Features

A severe accident can significantly change the habitability and use conditions of buildings, rooms, and areas located at a NPP. Radiological and hazardous material conditions change during an accident leading to higher radiation dose rates, temperatures and contaminant (radiological and non-radiological) levels. In addition, the release of energy in the form of gas, liquid, or electricity may make some areas extremely dangerous. These changing conditions can alter the use characteristics of areas rendering some normally-occupied areas as dangerous or “off-limits”. Other areas which may normally be minimally used during operations can turn into high use areas during and after the accident in order to house staff to perform critical functions in response to the accident. In addition, as demonstrated by the Fukushima accident, the effect of severe accidents on other site units should be evaluated and understood.

Certain facility factors, such as the ability to isolate or alter system configuration, monitor and collect samples, communicate throughout the site, and physically provide safe work zones are important aspects which need to be considered in planning an effective response to a nuclear incident. If a facility contains both a Main Control Room (MCR) and On-site Emergency Control Centre (ECC) they should be located in separate fire sections. They should be seismically qualified and protected against penetration of radioactive substances or other dangerous substances in the case of severe accident.

Since off-site facilities are used as command and control centres, assembly point areas, and monitoring and decontamination sites, it is also important to consider design features for these facilities to facilitate their effective use during severe accidents. In general, a back-up power source should be available for emergency response should the primary power source becomes unavailable. The back-up source should be capable of providing power for all emergency response functions and equipment necessary to respond to the emergency.

This section discusses the recommended design features that should be considered on site at a NPP to prepare for response to a severe accident and during the construction or establishment of off-site emergency facilities.

4.1.1 Facility Access Control Systems

As discussed in Chapter 2, on-site ERPs should contain a classification and zoning system to clearly communicate which facility areas are accessible and which are restricted during a severe accident. It should also contain instructions for workers so that they understand evacuation routes to leave site and know the on-site locations to conduct emergency response actions. In addition, workers need to know where personnel protective equipment and key response equipment is located so they can perform their jobs. All on-site response personnel need to know where the locations of on-site:

- Dangerous or “off-limit” areas.
- Plant areas containing vital equipment and switchgear.
- Assembly points.
- Emergency command and control centres.
- Job briefing areas.
- Critical plant system control areas.
- Emergency equipment storage areas.
- Key radiological and hazardous monitoring locations.
- Radiological and chemical decontamination areas.
- Other designated key response areas on-site.

Implementation of access control should use “defence-in-depth” techniques since access to certain areas during an emergency could have grave consequences. In addition to administrative controls and training, physical plant systems and controls should be available to warn and prevent individuals from gaining access to off-limit zones during an accident.

To facilitate proper emergency access control, plant systems should include the following equipment as appropriate:

- *Plant intercom systems which are adequate to communicate instructions to workers in all potentially unsafe zones.* Such systems should be designed to be audible over operating plant systems in areas where workers could be seriously affected during an emergency.
- *High range area monitors with local and remote warning mechanisms.* Warning systems should include both audible and visible indicators which communicate dangerous conditions to workers in potentially dangerous areas.
- *Electronic interlocks to prevent unauthorized access into areas.* Systems designed to automatically lock dangerous areas based on area monitor levels or plant emergency alarm systems should not be designed to prevent individuals from exiting the dangerous area.
- *Electronic or physical systems to demark safe exit routes.* Exit signs or travel path indicators which illuminate or otherwise communicate directions into safe zones should be considered if normal exit routes could lead individuals into unsafe zones during an emergency.

Electronic systems noted above should be tested to ensure operability on a periodic basis. They should be powered by emergency sources to ensure operability during severe accidents. Workers should be trained in the understanding of the systems by implementing periodic drills and retraining as appropriate.

If electronic or automated access control methods cannot be implemented, manual methods must also be in place to warn individuals and limit physical access. Such manual systems should include:

- *Manual key locks for areas to limit access.* As discussed above for electronic locking systems, manual locking methods should not be designed to inhibit individuals from leaving potentially dangerous areas.
- *Manual emergency signage to warn individuals of access controls.* If emergency postings or signage is used it must be designed to withstand conditions postulated for emergencies. It also must be staged in appropriate locations where it can be retrieved quickly. Methods should be established for the efficient implementation of such signage by trained technicians or plant workers. Manual signage should only be implemented in areas where dose rates and conditions will not be dangerous to workers and time will be available to establish such postings.

4.1.2 Facility Habitability Controls during Severe Accident

During and after a severe accident, there are key activities that must be performed expeditiously to mitigate the consequences of the event. Chapter 2 discusses the basic On-site and Off-site Emergency Command Facilities instituted to provide for command and control during emergencies. In order to maintain operability during emergencies, these facilities should be designed to provide a safe environment for individuals and emergency equipment necessary to carry out the intended duties for periods of time after an accident.

The habitability controls necessary to ensure proper protection after a severe accident should include:

- *Shielding to minimize personnel exposure.* Both the MCR and ECC areas should be designed with adequate shielding to reduce external exposure to radioactive plumes. Permanent off-site facilities should also be designed with shielding in mind if the facility could be impacted by radioactive plumes or fall-out from the accident.
- *Controlled and filtered ventilation systems*. Site ventilation should be designed to minimize internal exposure from radioactive particulates and iodine. Systems should be capable of providing clean air for the required number of individuals and time necessary to maintain operation facilities for severe accident management. Systems should maintain critical areas at positive pressure relative to affected areas to prevent penetration of hazardous substances.
- Depending on plant design, NPPs typically have multiple ventilation systems designed for various buildings and areas. Sometimes, these systems are tied together and discharge into a main plant vent stack. In other circumstances, multiple discharge points are used and can vary for elevated release points to ground level release points.
- There are two important radiological applications for plant ventilations systems. The first is to filter plant discharges prior to release to the environment to mitigate the consequences of a release of radioactivity in the event that buildings or areas contain airborne radioactivity or become pressurized. The other important aspect is to filter inside air to ensure habitability for workers at the site during operations and after an accident. Plant ventilation systems in most cases include high-efficiency particulate air (HEPA) and charcoal filters. The capacity of the installed ventilation filter systems depends on the postulated amount of particulates and iodines expected to be present in the area. Key ventilation systems used for habitability in areas like the MCR and the ECC usually have separate filtration systems to avoid saturation from higher concentrations of radioactivity in reactor and support auxiliary buildings. Another important characteristic and practice is the temporary isolation of the ventilation, in order to avoid the intake of outside air contaminated with noble gas that cannot be filtered anyway. This aspect should be part of the SAMG in case of containment filtered venting.

Emergency workers / responders need to understand the design of critical ventilation systems including the areas they are intended to ventilate, discharge points, and cross-ties. Normal and emergency alignment characteristics should also be understood. Access to ventilation system diagrams should be available. This information is important in being able to predict changing radiological conditions during certain alignments and configurations. Understanding the capabilities of ventilation systems will also help workers determine how to change flows and flow rates to minimize exposures during an accident. The impact of severe accidents on connected systems, including common ventilation between multiple units, must be evaluated. The ability to isolate effected buildings and units during an accident should be understood.

Permanent off-site facilities, such as off-site EH facilities, should be evaluated for habitability during a severe accident. They should be designed with filtered ventilation if the facility could be impacted by iodine or particulate releases from the site due to location and be equipped with proper shielding as necessary to protect individuals. Off-site facilities should also be able to quickly implement emergency power as necessary to operate monitoring and protection systems during a severe accident.

- *Potable Water and Food.* Severe accidents can significantly affect environmental conditions and can lead to contamination of normal water and food supplies. On-site and off-site water reserves needed for habitability of emergency workers / responders and for decontamination are critical. It is important that these reserves are available, tested, inspected and ready in the event of a severe accident which renders main plant water supplies non-usable. Water reserves are often stored in permanent tanks; the water system and can have the total volumes greater than 20,000 litres.
- Additional supplies of water must be available and staged for decontamination. Tanks used for this purpose must also be permanently filled with water, with water quality regularly checked. Water reserve for decontamination should be at least 2,000 l/day and sufficient and independent from the service water distribution systems.
- It is also important to classify systems where water may be used in an emergency. For example, an option to ensure additional water is available for decontamination is to consider the radiological classification and use of firewater or service water inventory that is verified to be radiologically clean. Another option is to use potable water sources filled in vessels in assembly areas or civil protection (CP) shelters.
- *Medical Facilities.* Both on-site and off-site facilities should be designed and equipped with appropriate facilities to allow for medical treatment of emergency workers / responders, including contaminated workers during accidents.

Off-Site Facilities and Support

- *Personnel and Decontamination Facilities.* Both on-site and off-site facilities should be designed and equipped with appropriate facilities to allow for monitoring and decontamination of workers. Facility design should consider bathroom and shower facilities located in shielded or minimally impacted areas on site to enable emergency workers / responders access for decontamination during response to a severe accident. Permanent off-site facilities, such as CP shelters designed to meet conditions for long-term stay of rescue staff, should also be designed with these considerations in mind. Temporary off-site facilities should be able to set up with portable equipment and power for the purposes of monitoring and decontaminating individuals as will be discussed in more detail below.

4.1.3 Communication Systems

Emergency Command Facilities must have reliable means for communication with other working places involved in emergency response. They should be equipped with technological information systems that provide enough operational data from the reactor units to be able determine appropriate actions and to protect workers. This data should include area radiation monitoring information, tele-dosimetry information, the status of ventilation and electrical units, critical plant systems, and computer with software for determination of the source term, event classification, prognosis and evaluation of accident consequences.

Telecommunication technology should be robust and consist of telephone lines with an access to public telephone network, transmitters for use of mobile phones, fax machines, radio and site specific radio-communication network.

Permanent off-site EH facilities should have adequate communications capabilities similar to emergency command facilities to ensure continued communication during command and control operations. Communication systems must be in place to support temporary off-site facilities set up for civil protection assembly points, monitoring and decontamination facilities, and other areas as designated by ERPs.

4.1.4 Installed Radiation Monitoring Systems

Information pertaining to radiation gamma dose rates, plant airborne radioactivity concentrations, and radioactivity releases to the environment can be obtained by the nuclear facility installed radiation monitoring system detectors. Most plants are equipped with area monitors that continuously measure and trend dose rates in a variety of plant areas including areas which will be inhabited by emergency workers / responders during an accident. Areas monitored typically include:

- Main Control Room.
- Emergency Control Centres.
- CP Assembly Points and shelters.
- Gate Houses.
- Other plant buildings and areas where it is important to understand radiation levels from a response perspective.

Fixed gamma area monitors are set up to alert personnel by audio and visual alarms which indicate changes in area radiological conditions that could result in unacceptable dose rates. The alarm criteria depend on the analysis of the potential hazard in the area in question. The monitors are intended to warn of hazardous changes in radiation levels under all operating and non-operating conditions.

Depending on plant design, different systems exist to measure or predict releases of radioactive material. Sites should be equipped with exhaust and liquid monitors which can directly measure releases that are postulated for severe accidents. Additional fixed gamma area dose rate monitors should be installed on key plant systems to provide information on increasing or decreasing radiological source terms within the systems during operations and after an accident. Models should be developed to use the data from these system gamma monitoring area detectors to predict volumetric concentrations of liquid or airborne radioactivity within plant systems which can be used to postulate the consequences of a release.

Systems which continuously indicate radiation dose rates and airborne radioactivity concentrations inside the facility are preferred during an emergency. Detector sensitivities should be able to distinguish the presence or absence of radioiodine at concentration as low as $3.7x10^{-3}$ Bq per cc.

Many sites also have instrumentation to monitor critical parameters in a post-accident environment. Many post-accident monitoring systems measure noble gases, particulates, iodine and tritium prior to and during release. These measurements permit pre-emptive measures to be taken to protect the public and prescribe on-site protective measures. Emergency response planning is also undertaken and emergency drills are run on a periodic basis to ensure staffs are prepared to respond as required.

Since off-site EH facilities may typically be used to evaluate the magnitude and effects of actual or potential radioactive releases from the plant and to determine off-site dose projections and may also be used for post-accident recovery management, the ability to obtain data from on-site installed radiation monitoring systems is critical. Off-site EH facilities should include acquisition, display and evaluation of all radiological, meteorological, and plant system data pertinent to determine off-site protective measures.

The effects of a severe accident must be evaluated against the operability of installed plant monitoring systems. Design bases for currents systems should be compared to harsh environment conditions predicted from severe accidents to understand which systems will be available during the beyond design-basis conditions of a severe accident. It is of utmost importance that RP emergency response individuals are trained on installed radiation detection systems and can clearly interpret data from the systems. They should have access to live time monitors or consoles where such data can be obtained. Mathematical models, used to convert dose rate data to concentrations, should be available in case modifications are necessary to accommodate unusual (not predicted) conditions resulting in the need to modify dose to concentration conversion factors. Fixed plant monitors are often the first data that a response team has to plan mitigating activities inside plant areas. Although they tend to be reliable, data from these monitors should be verified by portable instruments when responding to plant locations during an emergency.

Alternate methods, for assessing the radiological situation in the event that the primary instruments for areas are not working or are not reliable, should be considered in training and exercises.

4.1.5 Radiochemical Analytical Laboratory Capabilities

NPPs are normally designed with analytical laboratory capabilities to support operations at the facility. Sites will typically contain laboratories for analysing various types of liquid and solid chemistry and health physics samples from plant areas and systems. Since the analysis of samples is critical in determining plant status during accident conditions, site facility design should consider the availability of laboratory facilities during severe accident conditions. Emergency response radiochemical analysis capabilities should be located in shielded and protected areas of the site to maximize use during a severe accident. Typical analysis capabilities should include:

- Gross alpha and beta counting systems.
- Gamma spectroscopy systems (HPGe systems are highly recommended for emergency use).
- Liquid scintillation counting systems.

Systems should be able to handle the range of radioactivity that would be expected in liquid and solid samples during severe accident scenarios. Capabilities should be in place to handle types and shapes of samples that are significantly different than under normal operations; e.g. spectroscopy systems with flexible geometries and rapid mathematical calibrations.

Off-site EH facilities or monitoring facilities designed to respond to off-site investigations should also be equipped with adequate sample analysis capabilities to count off-site soil, water, food, and other samples to define environmental conditions related to the accident. Adequate capabilities should be available to support the real or perceived needs of the worried population nearby the facility. These include external contamination surveys, and internal contamination measurements. Methods should be developed for estimating activity in samples to expedite shipment of samples to off-site facilities during a severe accident.

During the initial days of a severe accident, most worker/responder and public dose can come from the release of radioiodine. It is important to consider the use of portable systems to be able to quickly evaluate airborne levels of iodine. It is also recommended that portable systems for monitoring worker thyroid levels of iodine be available and methods to estimate intakes from the results of these systems be implemented as necessary.

4.2 Portable Emergency Response Equipment and Supplies

Most NPPs maintain in ready condition (tested and calibrated) worker protection supplies, instrumentation and sampling equipment, and other necessary portable equipment for emergency situations. In addition to on-site and off-site staged equipment many plants also have mutual assistance agreements with other sites where additional equipment will be available if necessary. The proper staging of monitoring and protective equipment allows plant personnel to continue to function during the presence of airborne radioactivity and radioactive surface contamination, to make informed decisions, and to perform mitigating actions as required.

Both the Chernobyl and Fukushima accidents have shown that, in addition to the normally staged equipment and supplies, it may be necessary to consider additional equipment and controls to ensure supplies are available for extreme conditions brought on by severe accidents. The shelf life of certain protection equipment, such as charcoal filters, must also be considered. Operating facilities should evaluate the amounts and types of portable RP equipment against the needs during severe accidents. Additional equipment, such as small portable generators to operate RP portable equipment, may be needed to ensure adequate response during a severe accident.

4.2.1 Personnel Protection Equipment

To properly respond to an emergency, it is critical to have a variety of personnel protective equipment (PPE) and supplies staged at strategic points within the on-site facility and at specific off-site facilities where emergency workers / responders may need protection to monitor the environment outside the facility. PPE should include means for protection of breathing ways, eyes and body surfaces to assure adequate protection against contamination and internal dose. Adequate supplies of PPE should be available for people on the site and for off-site emergency response workers.

The list of PPE and other protection supplies need can vary by plant, but normally includes:

- Protective clothing for response workers (anti-contamination suits, gloves, footwear, etc.).
- Respiratory protection devices for response workers.
- Supplies to contain and collect radioactive material and for contamination control (including plastic sheeting, bags, containers, tape, step-off pads, etc.).
- Supplies to restrict access to areas and alert workers (ropes and barriers, radiological signage, etc.).
- Supplies for decontamination of personnel.

It is also important to consider that inventories of current emergency equipment may not be adequate for severe accidents. Certain types of protective equipment, such as respirators and iodine cartridges are critical during early stages of a severe accident and ample quantities should be available for emergency worker response. Other protection methods such as whole body and partial body shielding may be used by emergency workers/responders in severe radiation fields and should be evaluated. While whole body shielding is inherently heavy, partial body shielding is lighter in weight and selectively shields tissues of increased radiosensitivity (i.e. bone marrow) with substantial amounts of shielding material to protect hematopoietic functions; therefore, potentially preventing the acute health effects of exposure to gamma radiation (i.e. Acute Radiation Syndrome - ARS). Refer to section 5.3.1 for additional information on PPE selection.

4.2.2 Emergency Dosimetry

The ability to monitor and control emergency worker / responder radiation dose during a severe accident is a critical capability to maintain worker safety and to ensure workers can adequately perform their job to minimize the consequences of the accident. As discussed in Appendix-1, during both the Chernobyl and Fukushima accidents, the ability to determine both external and internal exposures of workers was hampered by the lack of available monitoring equipment and services necessary to perform dosimetry functions.

External Dosimetry

Both on-site and off-site facilities must maintain a protected supply of external dosimeters which can withstand accident conditions and operate adequately during emergency conditions. At Chernobyl, the vast supply of external dosimeters (film badges) were over exposed and could not be used to determine gamma doses from external radiation. At Fukushima, the facility maintained large supply (approximately 5000) alarming personnel dosimeters in various locations at the site. During the accident, the water from the tsunami damaged most of them, rendering them unusable during the accident.

During both the Chernobyl and Fukushima accidents, the lack of dosimetry required workers to perform duties while being unmonitored due to the lack of available dosimetry. It is recommended that adequate emergency supplies of both passive and direct reading external dosimetry be available and stored in protected on-site and off-site locations so that they are available during severe accident conditions. Dosimetry types should be sensitive to both low and high range gamma dose levels that could be encountered during severe accidents. Dosimetry storage locations should be designed with the following criteria:

- Shielding to protect devices from becoming overexposed during accident conditions.
- Protection against extreme temperatures that could be encountered during accident conditions.
- Protection against water and chemical intrusion.
- Easy accessibility to emergency workers / responders during accident conditions.

Emergency dosimetry should be inventoried and inspected periodically. For external dose control a set of pre-programmed electronic dose control devices (such as Electronic Personal Dosimeters or EPDs) should be available to support first event response. These dosimeters should be regularly tested and calibrated per normal procedures and an adequate supply of batteries should be maintained and ready for use during an accident. Sites that normally use electronic dosimetry activated by access control readers or tele-dosimetry systems should have the ability to enable use in “stand-alone” or “auto” modes during severe accidents. For self-reading dosimeters that require readers, these readers should be staged for use during a severe accident. Each NPP should have sufficient inventory to manage incident response but in the case of severe conditions alternate supplies should be available from other NPPs via mutual assistance agreements or stored in emergency centres. A process to gather and record dosimetry data during a severe emergency should also be developed and workers should be trained on the methods for recording and communicating dosimetry information.

Internal Dosimetry

Radioactive material released from NPPs during severe accidents can lead to significant internal exposures of emergency workers/responders. At both Chernobyl and Fukushima, significant delays were encountered in the identification of internal exposures. Timeliness is critical to obtain data in determining internal exposures due to the biological clearance of radioactive material intake. If in-vivo or in-vitro data is not collected soon after an intake occurs, the ability to accurately determine internal dose and the minimum detectable dose can be significantly affected.

Both on-site and off-site facilities should be equipped with adequate instrumentation and supplies to perform both in-vivo and in-vitro internal dosimetry analysis during and after a severe accident. For in-vivo analysis, access to counting systems such as whole body counters and thyroid scanners is important especially since internal dose, and more specifically from radioiodine, can dominate worker/ responder dose in the early stages of a severe accident. Systems should be available in protected on-site and off-site locations which include adequate shielding, emergency power sources, and other necessary requirements to keep them operable during accident conditions.

Lapel air samplers (or personal air samplers) are highly recommended to be used in situations where internal doses can be significant. They allow for rapid estimates of internal dose and can be implemented fairly quickly if staged appropriately. It is recommended that a supply of lapel air samplers be maintained available for rapid deployment during an emergency to monitor internal dose.

Adequate supplies of in-vitro sampling containers and equipment should be available to collect urine and faecal samples at on-site and off-site facilities. Off-site analysis facilities for in-vitro samples or lapel air samples should be designated and available to analyse in-vitro samples in large quantities to be prepared for severe accidents.

Except for situations involving radioiodine, tritium, and alpha emitters, it is unlikely that the committed internal dose will exceed the external dose. However, it must be recognized that some radiation workers and nearly all of the population consider internal contamination to be far more dangerous than external contamination. Training programs of the workers and public information for the population should be developed to place internal contamination in perspective, but that may not be fully effective. Air sampling can help but does not provide immediate information like an EPD or a survey meter. From experience at TMI, Chernobyl, and Fukushima, the most effective method is the use of Whole Body Counters (WBCs) with immediate explanation of the results to the subject.

4.2.3 Portable Radiation Monitoring and Sampling Equipment

On-site and off-site facilities should maintain an adequate supply of emergency radiation detectors and sample collection supplies stored in protected locations for use by emergency workers / responders during severe accidents. Portable equipment allows flexibility of use during emergency conditions and can be adapted for use easier than installed systems. Supplies and equipment should include:

- Low range and high range ion chamber detectors for gamma dose rate monitoring.
- Hand-held and large area portable contamination monitoring instrumentation.
- Transportable portal, external contamination, and internal contamination monitors for assessing personnel contamination of both workers and the general population.
- Contamination monitoring supplies (smears, masslin cloths, sticky rollers, sample bags and containers, etc.).
- Air sampling equipment (including pumps and filters for particulate and iodine and tritium and noble gas sampling apparatus); it is important that the iodine collectors and measurement instrument can measure radioiodine in the presence of noble gases.
- Sample collection supplies for soil, water, and other volumetric samples.
- Shielded caves and containers for portable scalers and for transporting and storing highly radioactive samples.
- Robotic inspection and sampling systems to facilitate information gathering during high dose rate and extreme environmental conditions.
- Transportable or mobile bioassay equipment.
- Portable thyroid monitoring systems (portable gamma spectroscopy instruments with shields).

An evaluation of increased radiation background effects on portable instrumentation designated for severe accidents should be performed to determine limitations. Individuals trained to use portable equipment should understand limitation of each type of system during severe accident conditions. Other ancillary equipment needed to facilitate the setup and operation of portable systems during a severe accident should also be considered. Such equipment could include small designated portable generators, flashlights, and long-handled grappling tools for handling high dose rate samples.

Off-site centres used for the deployment of monitoring vehicles should be equipped with adequate supplies of radiation detection and sample collection equipment necessary for roving vehicle survey teams. In addition to portable battery operated dose rate and contamination monitors, 12-volt sample pumps which run on vehicle batteries should be considered for obtaining air samples.

In case of power supply loss, on-site and off-site command centres and facilities should be equipped with an independent emergency power supply – e.g. a diesel generator isolated from the external grid. The off-site radiation monitoring centre building typically will not act as a shelter but rather an assembly area for the dispatch of vehicles, the monitoring of personnel and vehicles, and decontamination of personnel and vehicles. Responsibility delegation for assessing, monitoring, controlling, decontaminating, etc., and emergency responder's located off-site should be pre-determined and designated in the NPP and governmental emergency response plans.

4.3 Information Systems to Facilitate Emergency Response

On-site and off-site command centres and facilities should have appropriate systems to supply technical data and plant records to assist in the diagnosis of plant conditions to evaluate the potential or actual release of radioactive materials into the environment. Command centres should also be adequately equipped with computer and software which can predict the consequences of a release from plant data.

5. OVERALL APPROACH ON EMERGENCY WORKERS/RESPONDERS PROTECTION

5.1 Individual Exposure Reference Levels

The establishment of individual exposure reference levels (either guidance values or dose limits) is fundamental to guide the emergency response and to prevent exposures of emergency workers/responders[11]. Protective actions planed in advance and exposure control aim to avoid an excess of the dose reference levels and to keep doses as reasonably achievable (ALARA) under emergency situations. Reference levels and optimized protection strategies should be developed in advance of any emergency.

In an emergency, the relevant requirements for occupational exposure in planned exposure situations should be applied for emergency workers/responders, in accordance with a graded approach. Experience shows different approaches for the guidance values related to the effective dose to be applied:

1) different guidance values are defined for different types of measures to be performed;
2) different guidance values are defined for different emergency worker/responder categories;
3) one single guidance value is defined for any measure to be performed.

In the first approach, different guidance values are associated with different types of measures. Table 2 shows recommended guidance values from the IAEA requirement level standard; GSR Part 3 for specific types of operations [3].

Table 2 Guidance values for restricting exposure of emergency workers (IAEA GSR Part 3)

Aim of the operation	Guidance Value
Lifesaving actions	$H_p(10)$[12] < 500 mSv *This value may be exceeded under circumstances in which the expected benefits to others clearly outweigh the emergency worker's own health risks, and the emergency worker volunteers to take the action and understands and accepts this health risk*
Actions to prevent severe deterministic effects And **actions to prevent the development of catastrophic conditions that could significantly affect people and the environment**	$H_p(10)$ < 500 mSv
Actions to avert a large collective dose	$H_p(10)$ <100mSv

Also, guidance values for prevention of serious expansion of the accident progression (for example the operation of mitigating systems), the recovery of reactor safety systems or short term recovery measures, sampling and monitoring in the environment and urgent protective measures are defined in several countries or by NPPs. Measures not directly connected to the emergency

11. Emergency worker: A worker who may be exposed in excess of occupational dose limits while performing actions to mitigate the consequences of an emergency for human health and safety, quality of life, property and the environment. (IAEA Safety glossary, 2007 edition)

12. HP(10) is the personal dose equivalent HP(d) where d = 10 mm.

situation and long term recovery measures should be performed under the ALARA principle taking dose limits for normal operation into account.

The system of several guidance levels provides direction during the planning process to foresee adequate protection of the individual emergency worker/responder with regard to implementation of ALARA. Furthermore, the guidance values assist the decision making process on when an adequate level of RP will be achieved (under emergency situations).

For the second approach, different guidance values are associated with different categories of emergency workers/responders. All emergency workers /responders to be engaged in measures during an emergency situation are divided into categories with different guidance values and potentially dose limits. For example one group of emergency worker / responder could be the plant fire brigade and the shift rescue team. This group is associated with the highest guidance value, such as live saving actions. For other groups, such as monitoring groups, shift workers, or members of the ERO, a lower guidance value is recommended. For the group of emergency workers who perform recovery operation (i.e. liquidation or decontamination) work after the accident, limits for the effective dose and the organ doses for normal workers, should not be exceeded. In this case, the work is planned and performed in such a way that the exposure of individuals who are implementing this work is not higher than the limits of exposure for workers (normal situation). During all work, monitoring and health surveillance should be provided.

The guidance values should be exceeded only under exceptional circumstances in order to save human lives by volunteer emergency workers/responders who are informed of the risk incurred by their intervention.

For the third approach, all measures to be performed during an emergency situation and all emergency workers/responders affected are subject to the one single guidance value. The optimization process to implement ALARA (under emergency situation) becomes more qualitative but the tracking of the doses and the assessment of the overall dose of each individual emergency worker/ responder with the dose constraint is simplified.

For example the guidance value can be set equal to the guidance value for life saving, which should not be exceeded more than once in a life time. The guidance level is set for all emergency workers/responders as soon as the occurrence of a severe accident is declared. All individual doses at the time of declaration should be set equal to zero to simplify the managing of doses.

Independent from the question of one or several guidance values being used; the system of planning and exposure control strongly relies on the availability of reliable exposure data when conducting the measures, i.e. on dose values. As such, practices assume that the guidance values focus on the external exposure, which can – in general – be easily measured by an EPD, considering that internal exposure is avoided or can be conservatively calculated for consideration as part of worker’s total dose.

In practice, to compensate for uncertain doses due to a potential intake, different multiplying factors might be used for the guidance value when planning an operation and evaluating the results:

- If no iodine prophylaxis can be taken before conduction of the measure but the presence of iodine is reasonably likely, the value for the guidance values for the external exposure should be multiplied by a suggested factor of 0.2 to consider the internal exposure by iodine.
- If the presence of airborne contamination is reasonably likely and no breathing protection is used, the dose constraint or value should be multiplied by a suggested factor of 0.5, to consider internal exposure from intake of radioactive material.
- In some cases, NPP operators may have performed more specific calculations to estimate internal doses for selected emergency scenarios. The results of such calculations may be used where reasonable for the accident scenario actually encountered.

The risk of serious skin contamination or exposures from beta radiation to unprotected parts of the body also has to be taken into consideration. However, no multiplying factor is provided for this.

As shown above, understanding of the radiological conditions is necessary when planning emergency measures, related protective measures and the decision on who will perform the work. This emphasises the importance of avoiding intakes of radioactive material and of the monitoring of potential intakes.

5.2 General Protective Measures

During an emergency with release of radioactive material, general protective measures should be initiated to avoid any unnecessary exposure of personnel at the site.

Pre-defined action levels related to specific radiological conditions should be in place to initiate the conduct of protective measures. Some typical general protective measures are listed below:

- If a specific level for air contamination can be reached, personnel not classified as exposed workers, will typically be partially or completely evacuated from the site to ensure that their exposure is consistent with the relevant dose limits. In many countries this is equal to a projected internal annual dose of 1 mSv/year. Nevertheless, for voluntary personnel involved in supporting services (e.g. administrative work) dose should be maintained ALARA.
- Workers may be instructed to evacuate (partial or full evacuation) from the facility if they are not required to perform emergency measures or manage the emergency. [Note that in some NPPs, this approach is also incorporated in the concept of calling for emergency workers / responders. For a declared emergency, not all personnel are obliged to return to the NPP from home, but only pre-defined personnel. Any further personnel will remain at home unless requested to report to the plant.]
- For personnel staying at the site, adequate protected housing area should be pre-planned and accessible; On-site emergency facilities are discussed in Chapter 2. In addition, simple, easily-followed instructions should be prepared for personnel, for example :
    - Restrict the movement of personnel inside the NPP complex and at other on-site facilities (e.g. warehouses);
    - Close the windows and doors on buildings;
    - Switch off air-conditioning systems;
    - Stay inside the buildings and on the lowest floors;
    - Dress to cover the largest area of skin on the body;
    - No eating, drinking or smoking without RP authorisation;
    - Prepare an improvised protection of the respiratory system and wait for further instructions;
    - Place pregnant women in permanent civil protection shelters, or if they are in short-term civil protection assembly points, locate them in the points with the smallest dose rate; and
    - Leave buildings only as instructed by the head of the crisis team.
- Depending on the contamination levels or the risk of release, the use of personnel protective equipment (PPE) is instructed (refer also to section 5.3.1). It is advisable to base the decision-making on the use of PPE on ease of use and robustness of the tools. The use of PPE on-site and outside the reactor building will typically become relevant only for a small number of personnel, as personnel not needed for the management of the emergency will have already evacuated the site.
- Depending on the evolution of the emergency scenario the intake of potassium iodide (KI) pills needs to be considered, which should be pre-planned and prepared accordingly.

The approach for pre-defined action levels can be applied to guide measures based on air borne contamination with radionuclides such as ^{137}Cs and ^{131}I. This ensures that on-site personnel minimize exposure due to intake and allows for an estimate of the potential exposure due to the intake. Therefore, different action levels are defined in terms of fractions (e.g. 0 – 5%, 5 – 50%, 50 – 100%, more than 100%) of the dose limit for the annual effective dose and for the thyroid dose which guide different levels of evacuation of parts or the entire site. The dose is determined by (a) the airborne concentrations and (b) the assumed exposure (inhalation) time. Concentration of the radionuclides times the exposure time (under consideration of dose coefficients) results in an estimate of the effective / organ dose. This can be compared with the mentioned fractions of the applicable dose limits and measures of the respective tier to be initiated. With this concept, shielding/filter factors due to staying indoors or wearing of filter masks can be considered.

5.3 Work Planning, Work Permits and Work Execution and Control

While sub-section 5.2 addresses the general protection of personnel at the site against radioactive releases, sub-section 5.3 addresses the processes to establish an appropriate RP programme during conduct of individual emergency measures. These processes comprise work planning, work permits and work execution and control which can be defined as follows:

- *Work Planning*
  Process to plan work activities, including the planning of RP measures.
- *Work Permits*
  Instructions on the objectives of a work activity and how to execute the work activities.
- *Work Execution and Control*
  Execution of a work activity according to the related work permit and control of the execution of the work activity.

5.3.1 Work Planning

Planning principles

Emergency protective actions aim to avoid any significant release of radioactive material to the environment or to mitigate any consequences to the public and environment from such a release. The planning needs to consider the two principles of:

- keeping doses below dose limits or guidance values that have been set for the specific situation, and
- implementing the ALARA principle.

Further, it must be understood that achieving ALARA is part of an overall optimization process. In an accident situation there are other objectives that must be considered (e.g. the importance of rescuing a person or performing important plant safety operations vs. keeping the dose low; increased occupational safety risk from industrial hazards and heat stress from full face respirators and multiple PPEs vs. keeping the dose low.)

Due to the extraordinary conditions of an emergency, the implementation of the ALARA principle should vary from that of normal operation. But nevertheless, the planning should strive for doses which reflect the consideration and appropriate use of dose-reduction opportunities.

The ISOE symposia are resources available to the RP planner to obtain additional experience on radiological lessons learned from Radiation Protection Managers.

Planning process

With respect to an emergency situation, the planning process should follow similar principles and outline as the planning process for measures during normal operation as for example is described in several documents [4, 5, and 6].

During planning of measures for normal operation, aspects, such as the following, should be considered so as to understand the individual protective aspects and to optimize the intended measures for maintaining exposure to workers ALARA. Work planning should ensure that personnel, tools, equipment and further materials are available and ready for use when needed. Accordingly, the planning should also indicate the preparatory work, including the preparation of tools and equipment and the need for training and briefing on the work to be done. Work procedures should be in written format. A Radiation Work Permit (RWP) should be prepared containing RP specific aspects such as:

- anticipated elevated dose rates in the working area;
- expected duration and the personnel resources necessary;
- estimates of contamination levels and how they might change in the course of the work;
- additional dosimeters to be used by the workers / responders;
- protective equipment to be used in different phases of the work;
- possible restrictions on working time and doses;
- activity or job hold points;
- requirements and recommendations for industrial safety in general;
- communication procedures for ensuring supervisory control and co-ordination;
- instructions on when to contact members of the RP staff; and
- any mission-abort situations or emergency worker/responder back-out dose or dose rates.

The planning process for those emergency measures, which have been pre-planned as part of the precautionary activities related to the severe accident management programmes during design and commencement of plant operations, should follow the same principle as for measures for normal operations. The outcomes of the planning process should be incorporated into the emergency instructions as part of the operational manual.

While the main focus of these emergency measures is to gain control on the emergency scenario, it is advisable to prepare in advance measures related to work to be performed by RP staff (e.g. radiological surveys within the facility, replacement of filters (esp. after filtered venting) or the management / temporary storage of highly contaminated material). Accordingly, it is advisable to re-assess potential work activities so that RP staffs do not miss relevant activities.

For those measures which need to be planned during the emergency, a more simplified planning process might be applied, taking into account the specific limiting conditions of the emergency scenario. Such limiting conditions might include missing detailed knowledge on the radiological situation at work places or limited time with respect to a detailed (iterative) work planning. As a consequence, the formal procedure should be changed or optimization issues for deciding the workers' protection should be adjusted, so as to achieve the objective of the contingency measure (i.e. avoid the release of radioactive material or limit any consequences from releases.)

RP planning in case of an emergency should be performed using RP specialists, together with experts in mechanical engineering, maintenance, chemistry, reactor physics, reactor technology, I&C etc., to prepare detailed work plans and to provide them to the operational management. It is in this constellation that the optimization of protection measures for specific work activities takes place based on information about the radiological environment in the plant and the work activities that need to be performed. The RP specialists report to the emergency control centre, discuss opportunities and problems with the RP manager at the centre and give instructions to the RP technicians at the affected plant. In the early phases of an accident, still under normal radiological conditions, options to install additional equipment to remediate the exposure of the emergency workers/ responders in later phases should be considered.

The planning process should, if possible, be documented in the normal computer based systems. In case of malfunction, a paper-based support system should be prepared and utilized.

Work instructions

To allow an effective conduct of emergency measures, content and format of the work instructions on emergency measures should be defined within the operating manual (or emergency manual). If content and format deviate from that to be applied during normal operation, the deviations should be outlined clearly.

As an example, the pre-planned emergency instructions for workers to perform the work should contain at least information / descriptions on:

- the work to be performed;
- required number and qualification of personnel for conduct of the measure;
- job location;
- needed tools and equipment and where to find this equipment;
- lines of communication and reporting;
- further supporting material as maps, technical plans, photos.

With respect to RP measures, the documentation needed within the instructions is similar to that for normal operation. While to some extent cross references to the general RP sections within the operational manual will be practical and effective during normal operation, the following information should be provided:

- PPE and needed dosimeters (refer also to sub-section 5.4);
- RP requirements other than PPE and dosimetry;
- required preparatory work, including training if deemed necessary;
- clear instruction how to reach the work place as access routes used during normal operation may no longer be appropriate /available during the emergency (e.g. due to high dose rates, high contamination levels, inaccessibility);
- need for RP staff during preparation, conduct and post-processing of the work, especially in case of real time monitoring of the radiological situation and the exposure of the workers involved;
- main radiological conditions, especially to verify the radiological conditions assumed during the planning before start of / during conduct of the work;
- main issues (e.g. risks and hazards, urgency of work) to be addressed during the work briefing and later work de-briefing;
- requirements on the documentation of the work performed;
- follow-up concerning operational doses which can’t be exceeded; and
- any mission-abort situations or emergency worker/responder back-out dose or dose rates.

Work instructions should be in written format as much as possible to reduce the chance for failures. Required information and the format of checklists should be kept simple with a clear sequence.

Radiological conditions

One of the challenges to plan appropriate RP measures is to determine (or estimate) the radiological conditions, under which emergency measures will be conducted. It is vital to keep the information on the radiological situation updated as much as possible to ensure that the planning is based on valid data. Moreover, experiences from the Fukushima accident show that at the time of emergency measures executions, the radiological conditions must be verified to ensure the assumptions on which the RP measures are based continue to be valid.

Typically, NPPs are equipped with fixed monitoring systems to determine the dose rate at different places, especially in the containment. It is good practice to conduct in advance some simulations on potential contaminations of the containment or of other areas which are subject to monitoring and relevant for potential emergency measures. Personnel should be aware of fixed monitoring and portable monitoring system limitations (i.e. when radiation detectors become saturated due to high radiation and extreme environmental conditions and could no longer respond to radiation.)

These simulations should provide an understanding on which contamination will result in which dose rates and to allow estimation from measured dose rates to (gamma) contaminations. In addition, fixed sampling systems are foreseen to extract samples from the confinement atmosphere. It is advisable to have simple calculation tools available to estimate dose rates based on contamination results from the samples taken. Important areas for dose rate measurements are inside the containment, in the ventilation stack, in the off-gas system and around the unit because estimation of the core damage, tightness of the containment and the releases can be based on these. There can also be radiation and temperature measurements for monitoring the place and movement of the corium in case of a severe accident.

Practice also shows that mobile systems and measuring programmes are vital to determine the on-site radiological conditions under which emergency work need to be performed. Measuring programmes will comprise not only dose rate measurements but also contamination measurements e.g. by smear test. Especially for the latter, areas need to be available to allow the assessment of the smear samples without background radiation.

In addition to the measurements, many NPP teams exist to assess and estimate the source term, which provide important contributions to the understanding of the radiological situation within the NPP.

Selection of PPE or Protective Clothing (PPE/PCs)

Part of the planning process is the selection of the PPE/PCs. The selection of PPE/PCs follows the same rules as during normal operation with respect to industrial safety issues. Due consideration needs to be given to the specific circumstances during an emergency, e.g. increased radiological hazards, long duration for wearing filter masks and suits, long distances to reach the working place, no available infrastructure such as external air, high temperatures, serious non-radiological hazards like electricity, fire or water. As a consequence, some PPE/PCs may not be appropriate for use under these circumstances.

It is a good practice to have in place decision-making tools to easily and quickly select the appropriate level of PPE/PCs. A decision table on additional protective measures, depending on the dose rate and the expected duration of a measure in that dose rate, could be helpful. Within such a decision-making tool, only a few quantities should guide the selection of the individual PPE/PCs. Quantities should not require high precision numbers but should allow the use of estimates or data from initial measurements with some uncertainties.

With respect to the decision making on which equipment to use, in practice simple but effective decision-making tables should be developed. A progressive approach in the choice of the

PPE is recommended. Depending on the level of airborne or surface contamination, different types of PPE should be identified for when the threshold level will be exceeded. To avoid the intake of airborne radioactive substances respirators or filter masks should be worn wherever airborne radioactive materials may reasonably be present. The type of masks depends on the radioactive concentration in the air. The level of surface contamination determines the level of protective clothing.

Iodine prophylaxis

A specific protection measure is related to the risk of intake of radioiodine (^{131}I and the shorter but frequently more abundant iodine nuclides) which might be released in or from the NPP, possibly affecting the works/responders due to release into the environment (e.g. by suction from outside and distribution within the NPP). Sufficient quantities of KI for iodine prophylaxis, along with a clear and concise procedure for distribution, should be available on-site. Be advised that individuals who have previously exhibited allergic responses to shellfish (e.g. lobsters, crabs, clams, mussels, etc.) should never be administered KI without medical approval, as they may also be allergic to this thyroid-blocking agent. Furthermore, iodine prophylaxis for a longer period than a few days should be discussed with the medical authorities in advance.

Iodine prophylaxis should be administered within 30 minutes after the beginning of a radiation accident (radioactive releases in which radioiodine may reasonably be concluded to be present), depending on the radiation situation.

- Full-area use of iodine prophylaxis for radioiodine blocking in the thyroid is conditional by optimised averted equivalent dose of 100 mSv. To support the decision for prophylaxis, ambient dose rate measurements, iodine measurements on portable or teledosimetry systems should be performed. On-site iodine prophylaxis is an ERO responsibility, off-site is an authority's responsibility.
- 3 hours of delay of prophylaxis can reduces efficiency of radioactive iodine blocking approximately 50%.

5.3.2 Work Permits

The work permit system should be the system used during normal operation of the NPP. This helps to avoid confusion on altered procedures. But nevertheless, changes and simplifications of the procedures may be necessary during emergency situations, requiring expeditious issue of a work permit.

The work permit should be based on the proposed work instruction. The RP related part (refer also to the previous explanations, radiation work permit or RWP) should be verified and confirmed by an authorized RP person, who is sufficiently experienced and in charge of verification. The confirmation should be completed in writing, but for oral confirmations (e.g. due to necessary changes during conduct of the work), the confirmation should be documented in official emergency documentation.

5.3.3 Work Execution and Work Control

Conduct of the work should be based on the work instructions prepared by the responsible organisation of the NPP. Special emphasis should be given to the work pre-briefing and the work control.

Before the start of any work, it is of highest importance to inform the worker on the details of the work to be performed, stressing the specific radiological and hazardous conditions. Awareness of actual or potential changing conditions, including the assumptions made during the planning of the work should be promoted. The workers should become familiarized with changed warning and alert thresholds of their EPDs (if these thresholds have been changed) to strengthen the element of self-responsibility, and to ensure that this line of defence is in place. Even under normal operation, situations have occurred in which workers ignored the warnings and alerts of their EPDs.

Depending on the work to be performed, continuous work control by RP staff is necessary. Within areas with elevated radiation levels, the RP staff should always accompany the executing staff with appropriate measuring device(s). Additional supervision support should be requested when unexpected changes of the radiological conditions are encountered during evolving emergency situations or when an existing release of radioactive material is occurring within the NPP. It is a lesson learned from the Fukushima NPP accident that unanticipated conditions may occur, resulting in actions that must be addressed in work instructions so as to reduce additional risks to workers. Finally, during the work de-briefing the following issues need to be addressed:

- way of conducting the work, especially on success, changes, mishaps, mistakes;
- conclusions on the effectiveness of the work, on technical or managerial potential improvements and lessons learned;
- need for specific dose assessments, e.g. in case of potential intake of radioactive material;
- new insights in the radiological situation within the plan.

Use of standard checklists for the initial response to an event to brief the operation and repair teams on the tasks to be performed is recommended. Once the situation has been stabilized a return to normal work planning and execution processes and associated exposure limits should be applied. These processes should be documented in NPP internal procedures for radiological work.

5.4 Radiological Exposure Control

Radiological exposure control during an emergency should not deviate from that during normal operation. The main elements are:

- the measurement of the dose from external and internal exposure,
- the warning of high dose rate areas to avoid unforeseen doses,
- the assessment of dose in case pre-defined limits are exceeded, and finally
- the documentation of doses (dose records).

During emergency situations, radiological conditions can significantly change reference levels and the dose to the individual worker.

NPPs should be able to assess the doses from external and internal exposure in a timely manner. This requires that competent personnel, methods and equipment are available (or easily arrangeable), and are regularly trained, maintained, operational and calibrated even under difficult situations such as during loss of power or release of radioactive material to the environment, resulting in higher background radiation.

The following aspects of external exposure control and internal exposure control are addressed with respect to emergency situations.

5.4.1 External Exposure

Individual dosimetry

It is good practice that each worker/responder be equipped with a passive and an EPD. It is important to note that EPDs have limitations with respect to environmental conditions (e.g. temperature, humidity). In addition, passive dosimeters do not always respond in all dose rate fields. Prior to use of dosimetry, conditions should be carefully assessed to avoid relying on erroneous data.

Accordingly, it is important to compare the exposure data of all members of a working team after completion of the work. If differences are identified they should be addressed and clarified as soon as possible.

In addition to dosimeters to determine the effective dose, additional dosimetry may be required for inhomogeneous (i.e. non-uniform) radiation fields or organ doses, especially for the extremities.

Today the dosimetry systems related to EPDs use electronic readers that automatically set dosimeter properties (e.g. thresholds, reset of doses, dose rates) when the wearer is entering the controlled area and automatically reads dose and other exposure relevant data when the wearer leaves the radiation controlled area. These data are usually stored in centralized databases and are immediately accessible to the RP staff.

Based on the experiences from the Fukushima accident, due consideration should be given to alternative options to extract exposure relevant data (e.g. manually maintaining the electronic personal dosimeter). This includes manually setting thresholds, resetting dosimeters, and reading and recording dose data. Accordingly, instructions and templates should be prepared in advance and sufficient staff should be trained in performing these tasks. In addition, a process should be in place to track the exposure of each worker over a longer period of time to ensure that the dose limits / guidance values are not exceeded.

Dose rate measurements

Most EPDs provide dose / dose rate alert functionality. The related thresholds should be adjusted to the expected specific dose rates / doses. It is a general principle that any alert indicated by a system should result in an action by the wearer and should not be ignored. Incorrect threshold (i.e. set point), especially a low threshold, may jeopardize this principle if the wearer is instructed to ignore this under specific circumstances. The alert level should be adjusted properly to the radiological conditions in an emergency and the RP personnel should be trained for this purpose.

In addition to the dose / dose rate alert functionality of EPDs, separate fixed and mobile systems are used to monitor radiological conditions at the work place. If the wearer of an EPD is unable to immediately recognize an alert, additional RP staff should accompany the work group to take over the duty of monitoring and alerting the work group. This should also apply when radiological conditions change.

It is important that results of dose rate measurements, which primarily serve to protect the working group, are also provided to the RP staff responsible for planning of RP measures.

5.4.2 Internal Exposure

Who to measure

Should there be an emergency with release of radioactive material into the NPP and therefore potentially into the environment, there is a need to quickly identify and quantify potential internal doses due to possible intake of radioactive material. Accordingly, any person leaving contaminated areas should be subject to some internal dose assessment. Similarly, internal dosimetry measurements should also be made available to potentially affected members of the public.

If not all persons can be measured immediately, processes should be established to triage these persons - which persons are to be measured first and which persons are to be measured later. Measurements should be anticipated for those cases in which airborne contaminations could reasonably exist or are already known to exist. Personal protective equipment can fail or be improperly used. Experiences from the Fukushima accident show that internal exposure can significantly exceed the external exposure if radioiodines exist, and if not detected in time will limit the opportunities for counter measures.

An approach for selecting candidates for measurements of internal exposures includes the normal measurement of external contamination (if the normal exit monitors are in operation). To determine the effective dose of intervention workers from internal contamination, workers should be monitored using a WBC in these cases:

- if their external or expected total dose exceeds 50 mSv;
- after the rescue action; or
- after suspicion that internal contamination exceeded 1 ALI (e.g. due to faulty respiratory equipment, incorrect protective mask setting, damaged PPE, etc.).

Measurement should initially be carried out in a manner “in vivo”. However, internal contamination by radioiodine is suspected, and then either a full-body “in vivo” measurement or a measurement of the thyroid should be performed.

Measuring systems

The systems to be used are those already available from operation of the NPP (e.g. whole body counters, fast scanners). These systems should be operational, calibrated and well maintained, and qualified and trained personnel should be available to perform the measurements and assess the results. It is important to plan the process of monitoring large groups of persons well in advance because large groups may impose new challenges. As an example in an accident situation when many are waiting to be scanned for contamination control, the crowd of people may often be waiting too close to the equipment. This may result in disturbing the measurements by increasing the background. Background may also become elevated by a single person with a higher contamination level.

In addition, some arrangements for alternative measuring systems should be in place (e.g. use of measuring devices at different NPPs, mobile systems which can be transported to the site). These arrangements help to manage those situations; in which plant measuring systems become inoperable (e.g. due to loss of power or high background radiation). It is important that some RP staff be familiar with the alternative system, especially with respect to detection limits, sensitivity for radionuclides and understanding the results of the measurements.

Under normal plant conditions, the mix of radionuclides is generally well known and simple analysis methods and instruments are sometimes used to assess the presence or absence of internal contamination (e.g. non-spectroscopic whole body counters). It should be expected that accident conditions are different, and methods to assess the nuclide identity and magnitude of deposition should exist. NaI systems with proper interpretation were shown to be adequate at TMI, Chernobyl and eventually at Fukushima, but position-sensitive systems and high-resolution detectors should make the task faster and more reliable. (At Fukushima, plastic scintillation systems were not found to be fully satisfactory.)

Unless the whole body counter or thyroid counter is appropriately designed with a full shield surrounding the detectors, it will have reduced sensitivity under accident conditions due to an increase in the background at the counter location. Mobile or transportable systems should be available, as well as pre-planning for deployment.

The internal contamination facility should be prepared to handle large numbers of people. Workers arrive in groups during shift changes or when transportation vehicles arrive. Off-site facilities may be inundated with many concerned members of the public. Depending on the proximity to the NPP accident, these will likely exceed the capacity of the system in the early phases. Plans should be made to staff multiple shifts, use “handlers” to organize non-counting operations, and quickly obtain and train additional operators.

5.4.3 Dose Recording

Following international standards, response organizations and employers should take all reasonable steps to assess and record the doses received by emergency workers/responders. While doing so, the doses received and information concerning the consequent health risk should be communicated to the persons involved. The effective dose recorded should include all doses received by internal and external exposure.

In particular, after any intervention involving an established radiological risk, individual dosimetric assessment and medical monitoring of the emergency workers/responders should be carried out. The results should be communicated to each person and recorded in their dose-record file, medical file or equivalent, consistent with the requirements of the country.

If it is possible, the occupational dosimetry system used on-site to register the electronic dosimeters during normal operation should also be used in accident situations. It can be used to follow-up radiation doses in the short term than that of the individual passive dosimetry system. This also makes it possible to follow up doses linked to specific activities, systems, time intervals, departments and professions, which are essential for emergency situations.

5.5 Non-Radiological Health Aspects

During operation of a NPP, conventional/industrial safety should be implemented to avoid non-nuclear and non-radiological hazards scenarios which might affect workers' health. Specific requirements exist on how to ensure worker's health, on the international level established by the International Labour Organisation (ILO).

Depending on the emergency scenario, different hazards and related scenarios may impose further risk to the worker's health, which may not be present during normal operation of the NPP. Such hazards and scenarios may be related to hot water and steam, chemicals, fire, electric power and others. Protective measures should be determined based on the technical standards during preparation of the work plan.

As during normal operations, both RP measures and conventional safety measures must be considered simultaneously. This is manageable during normal operation, especially since many of the adverse consequences from RP measures on conventional health and safety can be compensated by extended work plans, including sufficient rest periods. However during an accident, the dynamics of an accident may not allow rest periods and processes should be in place to handle the situation, i.e. to balance conventional health and safety, RP aspects and the unavoidable need to manage the emergency situation. In a recent report of the OECD NEA titled as "Information and Regulatory Issues for the Management of International Outside Workers and Integration of Risk Management at Nuclear Power Plants" [7], addressing the integration of risk management at NPPs, the authors stated that "well-balanced solutions addressing the multiple contributors to overall risk are to be developed, optimising the risk to the affected stakeholders", including workers and members of the general public. They also supported the "use of a 'case-by-case' approach to risk evaluation and mitigation to reflect facility- and job-specific situations" and delineated multiple factors that should be considered in developing appropriate work plans to address the several risk factors that may be applicable to a specific situation.

5.6 Health Surveillance

5.6.1 Occupational Health Physician

Following international requirements, the operating organization should make arrangements for appropriate health surveillance in accordance with the rules established by the regulatory authorities. The arrangements should utilize the services of an occupational health physician (or approved medical practitioner) who has been adequately trained in RP and has the necessary understanding of the biological effects of radiation exposure and the risks associated with exposure, both in routine operations and as a consequence of an accident.

This physician should have specialist competence in general medicine, occupational medicine or specialist competence in internal medicine and can be the one performing medical examination for radiological work during normal operation. The occupational health physician should, when reasonably possible, also be consulted on iodine prophylaxis and on the use of protective clothing and respiratory equipment by the employer or the personnel who wear such clothing or equipment for performing their duties.

NPPs should be equipped with a treatment area within the station to deal with first aid and the decontamination of injured, contaminated and over exposed personnel prior to any transfer to an ambulance and off-site medical facilities. Treatment areas should be staffed at the time of use by on-shift personnel.

For emergencies, agreements should exist with local fire departments for on-site fire-fighting support. Arrangements and procedures also should exist for local ambulance service and hospital support for casualties (this could include the capability to deal with contaminated casualties, trauma, and acute radiation syndrome).

5.6.2 Measures for Medical Monitoring of Exposed Workers

Assessment of fitness

Following international requirements, health surveillance programmes should be in place and should be based on the general principles of occupational health. They should be designed to assess the initial and continuing fitness of personnel in normal operation but also of personnel involved in emergency measures (i.e. even for an emergency situation, a worker should be assigned to an ERO position which may expose him or her to ionising radiation only after having undergone a medical examination by the occupational health physician who certifies that he/she has no medical contraindication or restrictions for the intended emergency response position.). This should also include emergency worker/responder fitness for respirator use.

The medical examination should be done at least once per year (but consistent with national regulations), comprising a general clinical examination and, depending on the nature of the anticipated exposure, one or more additional specialist examinations carried out or prescribed by the occupational health physician. Previous exposures should be taken into account when deciding on the fitness of a person to carry out the tasks within his or her competence. Within the framework of the medical monitoring, the occupational health physician should receive the results of all the measurements or checks that he or she judges pertinent in order to assess the state of health of the emergency worker/responder.

The occupational health physician should compile and update an individual file for each examined person. This file should be kept for a sufficient period of time according to the respective national regulations (e.g. at least fifty years after the end of the period of exposure).

5.6.3 Exposure Registration

It is an international understanding that any measureable exposure should be reported to the national dose register(s) appointed to collect, analyse and archive the individual doses for occupationally exposed personnel. These data serve for analysis of the current situation on the occupational exposure but serve also for later investigations in case of occupational diseases.

6. MONITORING AND MANAGING THE RADIOACTIVE RELEASES AND CONTAMINATION

During the emergency phase and later post-accident mitigation phase of a severe accident, radioactive or contaminated materials will be released both internally and externally from the affected NPP, requiring radiological control to maintain radiation exposures of the workers and general public ALARA. The monitoring and managing of this radioactive release and contamination will be discussed in this chapter.

The structure of the chapter follows a time line approach. First, the radioactive release (gaseous and liquid) causing contamination is discussed. Second, advice upon the monitoring of the resulting contamination on-site and off-site is presented together with discussion on work precautions while working in contaminated areas. And finally the managing of the resulting contamination is presented.

Note that the chapter deals with radioactive releases to the on-site and off-site surroundings and not inside the buildings of the affected NPP. These aspects are found elsewhere in the report.

6.1 Monitoring and Managing the Radiological Releases

NPPs undergo an Environmental Assessment prior to construction which documents original conditions, environmental pathways and potential impacts the facility could have on its environment. During operation the NPPs continue to monitor environmental samples from various sources to validate their respective environmental impact assumptions. Experience has shown that the Environmental Assessment may require re-assessment once NPP operations have commenced due to changes in land use, etc.

During a severe accident, the pressure inside a plant containment vessel may increase, causing a planned or an unplanned release of radioactive gases and aerosols to the surroundings. The release can also happen due to a hydrogen explosion, a malicious act or other release scenarios. In addition, liquid radioactive discharges to the environment possibly combined with other pollutants may complicate the situation. All discharges require adequate monitoring and control to maintain the impact on the environment and the doses for humans and animals at levels which are ALARA.

It should be recognized that at Chernobyl, Fukushima and TMI, most of the radioactivity that was released (gaseous and liquid) came from un-monitored pathways. Therefore it is essential to plan for and to maintain the appropriate capability to know when this is happening, and to rapidly assess the amount of the release and the deposition to the near-plant and off-site environment.

6.1.1 Gaseous Releases

For the severe accident scenario, the NPP must control the containment pressure and also hydrogen concentration to avoid explosive mixtures. Preferable ways to reduce hydrogen concentration are dedicated SAM-systems like glow-plugs and recombiners. Explosive mixtures are also avoided in BWRs with nitrogen filled containment. Should containment pressure need to be reduced, planned releases should be considered, preferably through a containment filtered venting system (see section 4.1.2). A planned release is preferable since usually the pathways are well known. On-site areas which will be affected by the plume could be estimated and the emergency response could be arranged accordingly. Note that a strategy on how to perform the venting must be in place in order to minimize the risk of exposure of the emergency personnel and the public, and to protect workers who may need to intervene locally for a valve closure or opening.

A pre-approved calculation method should be used for estimation of doses for the public, allowing for the timely use of pre-planned protective actions such as sheltering or evacuation.

If the release happens through unmonitored pathways the initial knowledge of the impact on the surroundings will be limited. It is important that provisions should be in place to model the release by using default/estimated source terms and other available data, in order to estimate the activity released and the consequences in the surroundings. Some general computer codes (free access or commercial), or site specific developed codes, should be used to estimate the source term and the on-site and off-site doses, enabling the decision makers to recommend or order sheltering or evacuating for the public and advice on protective measures for emergency workers/responders.

During an ongoing gaseous release the effluent should be monitored by stack monitors, air sampling on-site and off-site, a network of dose rate meters and other activity detectors to enable an early characterization of the radiological situation. After plume passage, sampling dust and/or soil specimens and other measurements should be performed for the possibly affected areas as additional information and input to the estimation of the amount of activity released.

6.1.2 Liquid Releases

In normal NPP operation, systems are in place for the monitoring of liquid releases. Lessons learned from Fukushima show that huge amount of liquid radioactive effluents might be generated in the mitigation of a severe accident (e.g. cooling of core). Other circumstances (e.g. location of power plant, construction principles) of an accident may also lead to generation of large amounts of contaminated water. Monitoring systems are generally not foreseen for an accidental range such as the one of Fukushima, for several reasons:

- the accidental atmospheric radioactive releases occur in a shorter term than the liquid releases and therefore have to be dealt with in priority with respect to the potential health effect on the public,
- liquid releases, generally occurring after the atmospheric ones, create a sanitary concern in a longer term, with regard to the contamination of water intended for human consumption and with respect to contamination of the aquatic food chain.

The licensee should be prepared to perform proper draining of contaminated water into a container (e.g. tank, drum, etc.) wherein the radioactivity measurements take place, in severe accident conditions. The liquid release monitoring should be obtained through direct measurement of the released water (if measurement devices are available) and through sample measurements in laboratory (gamma spectrometry). This monitoring will be complemented by in-situ monitoring in the surrounding environment. It should be realized that in severe accident conditions the on-site laboratories might not be functioning due to radioactive contamination and/or power cuts and arrangements should be made so that samples (those necessary) can be transported to relevant laboratories.

6.2 On-site and Off-site Contamination Monitoring

Radioactive material and the contamination distributed within the boundaries of the affected installation should be monitored in order to:

- Prevent uncontrolled movement of radioactive material from place to place, which could increase the doses received by the emergency workers/responders and jeopardize the ALARA action plan;

- Allow for directed efforts for decontamination of the affected areas;
- Avoid unnecessary doses for the radiation emergency workers/responders and for the persons in the affected area;
- Organize and coordinate the mitigation actions for control of radioactive spills and spread of radioactive material; and
- Permit the clearance of affected area and equipment for reoccupation and reuse.

Off-site contamination monitoring is also relevant, not only for the public but also for workers when they enter and exit the affected area. Note also that in severe accident conditions the boundary of the radioactively controlled area, the RCA, might be far out in the off-site area around the affected facility.

The normal program for on-site and off-site contamination monitoring will not be adequate and specific routines for contamination monitoring should be planned in advance and should be part of the ERO's duties. Specialized survey teams should be deployed to monitor and collect pertinent data to assist in the prioritization of actions for public information and response, and for event recovery.

For severe accidents with large releases, other defence organizations may be required to provide the desired support to estimate consequences. It is preferred that robotic vehicles or drones equipped with radiation monitors and air samplers be used, instead of using people as first surveyors.

Robotic vehicles, equipped with cameras and radiation detectors are particularly important in the early phase of an emergency when the radiological situation is unknown, when the exposure levels are very high and when the situation might vary quickly. However, robotic systems are expensive and knowledge on how to use them should be maintained. Therefore, a plan should be developed prior to a severe accident on how to provide necessary robotic systems from an external supplier.

The radiological characterization in the environment after a severe accident should be focused on the ambient dose rate, potential hot spots, surface contamination, airborne contamination and contaminated water. Means to measure these sources of radiation should be pre-planned. These should include:

- Fix radiation monitoring systems for gamma dose rates,
- Mobile measurement equipment for gamma dose rates,
- Surface contamination measurement equipment,
- Transportable field laboratories for radiochemical analysis or off-site laboratories shielded, and protected from disturbing background, including field sampling possibilities.

Information on the equipment for characterizing the radiological environment is discussed in sections 4.1 and 4.2.

Arrangements should also be made with national and international organizations to rapidly deploy specialized equipment for off-site contamination monitoring, such as airplane or helicopter surveys, and ground-based measurements.

6.2.1 Operational Intervention Levels

In the initial phase of the emergency, prompt countermeasures may be required in order to be effective. In section 5.2, action levels in terms of individual dose and, for taking protective measures are discussed. However, estimation of individual dose requires not only information about the exposure situation for the potentially exposed person, but also information regarding potential time spent in different areas, use of PPE/PCs, etc.

Therefore the licensee should also coordinate the development of operational intervention levels (OILs) with governmental agencies for direct measurable quantities which promptly trigger protective actions. The OILs are typically expressed in terms of dose rates or activity of radioactive material released, time integrated air concentrations, ground or surface concentrations, or activity concentration of radionuclides in the environment, in food, in water or in biological samples [8]. The results from the radiological characterization should be compared with these intervention levels. If a specific level is reached (or a set of levels), it should lead to a direct action (e.g. decision for the personnel to take potassium iodide tablets).

The operational intervention levels should be set in advance and consistent with the action levels discussed in section 5.2. However they should be expressed in such a way to enable a graded approach of its use.

6.2.2 Ambient Dose Rate and Hot Spots

Lessons learned from previous accidents show that dose rate from some mSv/h to several tens of Sv/h can be expected after an uncontrolled release of radioactive material into the environment (see Appendix-1). Appropriate radiation monitors (e.g. gamma dose rate) should be read remotely in on-site ECC, and should be installed at fixed points on-site and off-site. In addition, mobile radiation monitors should be utilized since they are more flexible and will help to determine the areas of high exposure. In the initial phase of an emergency, prompt actions are of vital importance. OILs in terms of dose rates at specific points on-site and off-site should be established in the ERP. Reaching a specific dose rate should initiate an action or a consideration of an action in emergency response. The location, marking and shielding (or removal) of hot spots/high dose rate material on- and off-site is of crucial importance for the working conditions of emergency workers/responders.

6.2.3 Surface Contamination

The monitoring of surface contamination (not merely ground) could be performed either directly or indirectly (as smears). The measurement technique should be adapted to the type of contamination as in normal RP work.

After a radioactive release the ambient dose rates or close by hot spots could make surface contamination measurements on objects impossible due to background elevation. Arrangements should be in place to take smears or other samples and measure them in a laboratory/shielded areas elsewhere. Moreover, caution should be exercised not to contaminate the monitoring equipment itself, and to make an assessment that the equipment is not contaminated by the radioactive release.

6.2.4 Air Contamination

For air contamination, spectrometric information is even more important than for surface contamination, since personal protective equipment is strongly dependent upon the identification of the exposure. Monitoring techniques for air contamination vary for particles, iodine and noble gas and arrangement should be in place to have the possibility to measure all of them.

6.2.5 Contaminated Water

A lessons learned from Fukushima is the huge amount of contaminated water that was generated. In order to be able to treat the water the content of radionuclides needs to be determined. As pointed out earlier, the water is most likely contaminated with not only radioactive pollutants but also highly toxic chemical pollutants, biological material and other more rubbish-like material. This requires consideration when planning how to monitor the radioactive content in the water and in the planning of the clean-up.

6.2.6 Other Media

For long term recovery, other media should be investigated and considered in addition to those that are used for normal environmental monitoring (i.e. contamination of the food chain, surface water contamination, ground water contamination, soil, etc.).

6.3 Management of Contamination

The objective of contamination management is to reduce as much as possible the dispersion of the contamination after the releases occurred and determine the radiological situation through monitoring (as described in previous paragraphs). It is performed with the objective to:

1) maintain the affected area isolated and well posted,

2) confine the radioactive material in a known and well controlled space, and

3) decontaminate and handle the waste either as conventional industrial residues or as radioactive waste.

It is recognized that monitoring and management of contamination in some areas may not be feasible during the initial phases of an accident due to a variety of factors including high dose rates, recontamination due to ongoing releases, etc. It is important, however, to develop a strategy for monitoring and managing contamination from a severe accident and to implement this strategy as soon as practicable when site conditions allow.

It is also recognized that the boundaries of the radiological controlled area could be very different than in normal operation. A widespread area could be contaminated and the outer boundary of the RCA might be far away from the facility, generating logistic issues that should be considered. Inside the contaminated RCA there might be areas "islands" not contaminated and buildings used in the emergency response that should be protected from contamination spread. The on-site ECC should integrate the protection against the contamination in the design itself. Several measures have to be taken into account at this level such as using double doors and smooth floors for easy decontamination, lead shielded windows, appropriate filtered ventilation, etc. All these issues should be planned in advance and a strategy on how to handle these situations should be developed. It might also be of interest to arrange for temporary buildings or facilities initially not foreseen for the emergency response for a long term contamination protection; e.g. a building that could serve for the rest of workers such as the J-Village at Fukushima.

In the following subsections the management of the contamination is considered for four categories, including;

1) Systems, structures and components (SSC's),
2) Mobile equipment,
3) Emergency responders, and
4) Nearby reactor cooling source (river / sea).

This approach is adopted since those 4 categories are seen as the major contamination dispersion vectors after the radioactive releases phase.

6.3.1 Systems, Structures and Components

The licensee should determine a strategy for the management of the contamination of the SSCs. Several means may be used for this purpose and the licensee should adopt a logical time graded approach, taking into account the rework dose impact and the priorities. A distinction may also be made between internal and external structures. Several means are discussed below. However those do not constitute an exhaustive list.

Removal of the rubble: removal of the rubble must be performed as one of the first actions, in order to:

- Make the frequent pathways easier to use (saving time = saving dose)
- Not postpone the unavoidable re-aerosolization of the radioactive particles when the rubble is handled
- Allow a later reduction of the air contamination
- Allow successive easier arrangements of biological protections on those frequent pathways

Use of robotics may be recommended for this first step. Storage or disposal locations for the removed rubble should be planned taking into account that (i) they constitute a possible source for contamination dispersion and (ii) they constitute a possible significant dose rate source term for the emergency responders. Rubble may also constitute a significant part of the solid radioactive waste that should be treated.

Note: as a lesson learned from the Fukushima accident, cutting the trees down proved to be efficient as an additional means to reduce the ambient dose and air contamination.

- *Air purification:* Installation of air purification devices (new or existing) may be used in internal structures. These devices can be used to filter the ambient air or replace contaminated air with non-contaminated air. Licensees should foresee such an option in their emergency plans.
- *Contamination fixation:* as highlighted in Appendix-1 (1.3), TEPCO proceeded to the fixation of the deposited contamination on the entire site (external structures). This measure was employed in order to (i) prevent the further re-aerosolization of the radioactive particles that could have been transported farther away by the wind, (ii) limit a deeper soil contamination drained by the rain and (iii) improve the radiological work conditions for the emergency responders. Accordingly, the licensees should foresee in their emergency plan:
  - Potential fixation products, meeting relevant criteria, such as environmental impact, weather resistance, lifetime expectancy, etc.
  - Potential product providers (where are they located vs. affected plant, storage capacities, etc.)
  - Means for applying the contamination fixation (fire hoses, trucks with dispersal devices, etc.)
  - Guidelines to follow while proceeding to the fixation. Other guidelines should comprise the prioritization of the zones to fix.
- *Biological protections (Engineering controls):* biological protections such as shielding (lead or tungsten) and steel plates should be set, respectively to protect the emergency responders against hot spots and to reduce the ambient dose rate on frequent pathways. This measure is useful to prevent the further spread of contaminants by the emergency responders, especially when no contamination fixation has been performed.
- *Decontamination:* decontamination is one of the last actions to be performed for the management of the contamination. It intervenes at longer term and necessitates specialized techniques, depending on the type of SSCs that requires treatment. Specialized teams, already active in decontamination work in routine NPPs, should be involved to determine the best technique to be used (e.g. abrasive technique, chemical technique, foam, etc.).

6.3.2 Mobile Equipment and Material

General rule

As a general rule in the short term, one should take into consideration that any equipment or material entering the contaminated area should stay therein for several reasons:

- Priority of the emergency workers/responders in the short term is set on the stabilization of the situation; clearance of material leaving the RCA should not normally be a high priority;
- Background dose rates will increase significantly as a consequence of the radioactive releases, constituting a significant problem to assure clearance;
- The organization may not have enough time to set up the measuring instruments in suitable conditions to assure a proper clearance;
- All mobile equipment and materials constitute a vector for further contamination dispersion.

For all these reasons, clearance should be considered in the longer term or for recovery.

Decontamination

Mobile equipment and material that have been introduced into the contaminated area for the purpose of emergency response, should undergo decontamination such that they:

- do not accumulate excessive contamination, presenting radiological hazards for emergency workers/responders using them;
- present a contamination level commensurate with the contaminated area wherein they are located. A strategy on how to determine this level should be developed in advance.

Recommendations with regard to decontamination as mentioned in the previous paragraph also apply here. Use of humidified towels, when a water draining system is not in place, combined with mechanical action is considered as a relevant technique.

6.3.3 Emergency Workers / Responders

General rule

Emergency workers / responders also constitute a vector for the further dispersion of contamination and may be more directly exposed to the intake of radioactive contaminants. Therefore they have to be suitably protected (see chapter 5), monitored upon leaving the RCA and decontaminated, as necessary, for authorization to leave the RCA.

Decontamination

Decontamination for individuals should be organized, based upon the routine operation of RCA exit in NPPs (e.g. showers with water properly collected into a tank for contaminated effluents). However, the level of contamination in the case of a severe accident will require increased support of medical service (health physicians and nurses), and appropriate selection of proper decontamination products.

Control of personnel leaving contaminated areas

Persons leaving contaminated areas should completely remove protective clothing prior to exiting these areas. Dedicated staff is essential to assist removal of PPE/PCs to minimize contamination dispersion.

As in normal operations, after leaving a contaminated area, persons should pass through a portal contamination monitor. Trained and qualified technicians should also perform the monitoring for the person, ensuring use of a place with suitable background rates for this action. If respiratory protections were used or there is any doubt about radioactive contaminants inhalation, it is recommended to assess for internal contamination in the nose by using “nose-blows”, and counting that in an alpha-beta counter.

6.3.4 Contaminated Water

During a severe accident, the NPP may produce excessive amounts of radioactive liquid discharges, mostly water. Provisions should be made in advance of an emergency, to have the ability to confine the water in order to minimize the spread of activity outside the site and to enable later filtration and decontamination. A lesson learned from Fukushima is that contaminated soil and water need to be prevented from leaking into nearby water systems: lake, river, oceans etc.

Note that the waste water will consist of a mix of pollutants: oil, chemicals and radionuclides. In developing a strategy for radioactive water management this needs to be considered. Provisions/criteria for when filtered/treated water can be released into the environment should also be developed in advance, enabling a graded approach.

7. CONCLUSIONS

The overall objective of the EG-SAM is to contribute to occupational exposure management (providing a view on management of high radiation area worker doses) within the Fukushima plant boundary with the ISOE participants. Safety and radiation protection are the most important factors for safe response to a severe accident at a NPP. Experience of past accident response has shown that comprehensive ORP measures should be adopted into nuclear power plant Emergency Preparedness Plans as to ensure radiation exposure to emergency workers/responders are maintained ALARA.

The purpose of this document is to provide a state-of-the-art report comprised of best radiation protection management practices for proper radiation protection job coverage during response to a severe accident. This includes essential information on RP management and organization, elements of training and exercises related to severe accidents, facility characteristics that must be considered when planning actions in response to a severe accident and an overall approach for the protection of workers/responders. This document is primarily, but not exclusively, directed to plant and emergency preparedness management and authorities regulating and implementing occupational radiation exposure. It identifies the following major issues that should be considered and incorporated into an ORP programme in SAM:

- Extensive ERPs should be developed for protecting emergency workers/responders and the public. These plans should thoroughly address emergency worker/responder staffing, command and control, emergency facility design, emergency response procedures, enhanced radiological controls including dose reference levels and instrumentation, on-site decision making, emergency worker/responder training and communications.
- The development of anticipatory training related to severe accident management is imperative for all emergency workers/responders. This includes development of a SAM training and qualification program that addresses emergency worker/responder actions within elevated radiation fields and response during stressful situations. Emergency drills and exercises should be routinely conducted to evaluate emergency worker/responder performance. These activities should be critiqued, and if applicable, lessons learned incorporated into training programmes, procedures and guidelines, as well as organizational aspects of accident management.
- Effective implementation of a RP programme during a severe accident may be significantly impacted by the plant’s facility configuration and access controls. Properly designed and operated habitability controls such as facility shielding and filtered ventilation systems, effective communications systems, installed radiation monitoring instrumentation, portable radiation detection equipment, radiochemical analytical laboratory capability for high activity samples, and a variety of worker PPE are essential for response to a severe accident.
- RP of the emergency worker/responder, including the establishment of individual exposure reference levels, extensive work controls, and thorough radiological exposure controls are necessary to maintain emergency worker/responder radiation exposures ALARA. State-of-the-art radiation detection equipment must be properly used to effectively detect external and internal exposure to emergency workers/responders.

- During the emergency and post-accident mitigation phases, radioactive and contaminated materials released internally and externally from the affected facility require extensive radiological controls to avoid or minimize radiation exposures to emergency workers/responders and the public. Radioactive releases must be monitored and controlled within the plant and offsite using robust monitoring equipment and engineering controls as necessary.
- The lessons learned from past accidents such as TMI, Chernobyl and Fukushima Daiichi teach us that comprehensive emergency plan development, routine training and exercising (including stressful, time-limited activities) of emergency all workers/responders, remote radiological monitoring, high dose detection equipment and robotic equipment are imperative when responding to a severe accident at a nuclear power plant. Continuing the collection and analysis of feedback experience from the past accidents is an essential source of improvement of the preparedness of severe accident management.

The implementation of approaches and actions to address these issues should follow available national and international guidelines. While not all countries currently conform to each practice described therein, this report provides discussions of best radiation protection practices for response to a severe accident as determined by a team of international radiation protection professionals.

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APPENDIX -1 KEY LESSONS LEARNED FROM PAST ACCIDENTS

The aim of this Appendix is to summarize the main lessons learned from past accidents regarding ORP in the emergency and early recovery phase of the nuclear accident. The intention is to recall the main steps of these accidents, the specificities of worker's exposures (in terms of individual and/or collective dose, number of worker exposed, specific exposure situations, etc.) and to extract the main lessons learned. It has to be noticed that this Appendix voluntarily does not depict a full picture of these accidents and ORP lessons learned, as each accident would deserve a specific report. For those interested, more detailed information can be found in the references of publications at the end of this Appendix.

1. TMI-2 ACCIDENT

1.1 Description of the accident

The Three Mile Island (TMI) NPP was built as a two-unit pressurized water reactor site near Harrisburg, Pennsylvania in the United States. Unit 2 at TMI was rated at 880 MWe. The unit began commercial power operations at the end of October 1978 and had accumulated less than 100 effective full power days of operation at the time the accident occurred on 28 March 1979.

At approximately 4 am on the 28th of March, 1979, TMI-2 was operating at almost full power when a relatively minor malfunction in the secondary cooling circuit resulted in a temperature rise in the primary coolant. This temperature change resulted in an automatic shut-down of the reactor. To control the expected rise in primary system pressure, a pilot-operated relief valve (on the top of the pressurizer that was used to maintain proper system pressure) was opened. The valve should have closed about ten seconds later, and apparently the valve received a signal to close. The valve actually remained open, unknown to the operators, and reactor coolant drained out of the primary system through that valve.

High-pressure pumps injected replacement water into the reactor system, and water levels began to rise in the pressurizer. Because there was not adequate instrumentation on water levels in the core, operators relied on the water levels in the pressurizer to conclude that the core was being adequately cooled. The operators responded to decrease system pressure by turning off the reactor coolant pumps, to protect them from damage due to excessive vibration. Rising water levels in the pressurizer were addressed by the operators via their reducing the flow of emergency cooling water into the primary system. The combination of these actions (given the unrecognized loss of coolant via the relief valve) resulted in inadequate cooling flow to the core and overheating of the fuel. The fuel cladding ruptured and the fuel pellets began to melt. About 45 percent of the core underwent melting during the early stages of the accident. The fuel remained within the reactor pressure vessel, which itself remained intact.

The loss of reactor coolant was stopped after about three hours; forced cooling of the reactor core was restored about twelve hours after the event began. Over the next few days, actions to relieve radioactive gas build-up in the auxiliary building resulted in the release of noble gases to the environment. There was little particulate or radioiodine released to the environment because of the effectiveness of plant filtration systems. The total release was on the order of 400 PBq of primarily short half-life and biologically inert noble gases.

The root causes of the event were said to be inadequate control room instrumentation and inadequate emergency response training [1].

Over the next 14 years, about 99 percent of the fuel was removed from the reactor and shipped off-site, accident-generated contaminated water was processed (decontaminated and evaporated), and monitored long-term storage began. The status of Post Defueling Monitoring Storage (PDMS) was given to the plant on 28th of December, 1993 [2]. Final decommissioning of the reactor is to be completed when the decommissioning of TMI-1 is performed.

1.2 Occupational Radiation Protection

Senior management at the TMI site (and from the federal Nuclear Regulatory Commission and the Commonwealth of Pennsylvania) demanded a strong safety culture as near-term and longer-term response actions were formulated. That safety culture was to consider nuclear safety, radiological safety, and industrial (conventional) safety (both for TMI-1 and TMI-2). Excellence in work management was to be a key element in ensuring that safety was maintained as the site moved from the initial response actions to the conditions at TMI-2, to all necessary later response and recovery actions for that unit. Among the items given priority by the management team were the following [3]:

1) Radiation protection policy,
2) Radiation protection plan,
3) Radiation protection procedures, which were to be complied with as written, or were to be modified prior to use,
4) Use of an ALARA committee,
5) Advanced radiation worker training,
6) Use of mock-ups for training when reasonably feasible,
7) Stop-work authority at the radiation protection technician level, and
8) Pre- and post-job briefings.

The main task to be performed by the “recovery workers” was those necessary, to decontaminate and defuel TMI-2. Primary objectives included a) maintaining the reactor in a safe state, b) decontaminating the unit, c) processing and immobilizing dispersed fission products, and d) removing and disposing of the reactor core [2, 3]. All of these objectives were subject to the full consideration of nuclear, radiological, and industrial safety to protect worker and public health and safety. Part of the work planning to meet the objectives noted above involved determining the state of the interior of the reactor vessel and developing means to ensure adequate shielding and cooling of the fuel while repair tasks and fuel removal were undertaken.

Work planning and radiological controls needed to be thorough and innovative to maintain exposures at ALARA levels and to ensure other elements of safety were not jeopardized. Examples of radiological controls include the following:

1) The use of unmanned robots equipped with cameras, meters, and other devices to move within the confines of the reactor building. The reactor building basement remains generally inaccessible even to date, with radiation levels on the order of tens of mSv/h, from contaminated water having been present during the early stages of the event. The spent fuel debris in the reactor vessel was highly radioactive, with radiation fields up to hundreds of Sv/h;
2) Design and construction of specially designed long-handled and other tools, with relevant pre-job training on their use, and with the tools designed to allow for shielding between source and personnel when feasible;
3) Dedicated oversight of access control for entries to the reactor building and other areas warranting such control;
4) Extensive use of digital reading dosimeters;
5) Extensive use of dosimetry placement at multiple points on the body where appropriate. Use of up to ten dosimeters was warranted depending on the variations in radiation levels during transit to and work at specific in-plant locations;
6) Assistance provided for the donning and removal of personal protective equipment (PPE) for entries to the reactor building and other areas warranting such assistance;
7) The use of breathing zone air (lapel / personal) samplers;

8) The use of powered air purifying respirators (PAPRs) and self-contained breathing apparatus;

9) Whole-body contamination monitors as a supplement to the more traditional (at that time) whole-body frisking using portable survey meters; and

10) Portable airborne contaminant sampling systems, for example, for measurement of concentrations of radioiodines.

As examples of conventional safety controls used in conjunction with the radiological PPE for highly contaminated and moist areas, the following may be cited: ice vests and vortex suits, and an emphasis on hydration, for entries into areas where temperatures may be elevated.

The chronology of the main phases of the project is synthetize in the following figure.

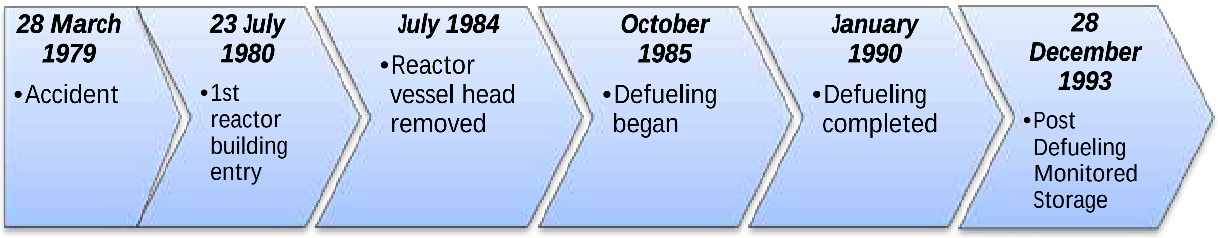

Figure 1 Chronology of the TMI-2 recovery operations

1.3 Doses to Workers

The total dose estimated to be received to reach Post Defueling Monitored Storage was about 66,000 man·mSv in the period from March 1979 to December 1993. Collective dose received in 1979 was on the order of 4,880 man·mSv. Major activities involved with decontamination and defueling in the mid-1980s (1986-1989) resulted in more than half of that total, including figures such as the following [1, 2 and 3]:

Table 1 TMI-2 Doses to Workers for Selected Activities in 1986-1989

Task	Dose (man·mSv)
Defueling operations – reactor vessel	6 980
Defueling support (tools, repairs, water clean-up)	10 580
Reactor Building miscellaneous (robotics, crane operations, radioactive waste, etc.)	7 650
Decontamination outside the Reactor Building	4 240
Routine operations (operation, chemistry, RP) outside the Reactor Building	2 770
Ex-vessel defueling (pressuriser, etc.)	2 160
TOTAL	**34 380**

Before describing the highest individual doses that were recorded, it is appropriate to state the radiation worker dose limits that were in place in the United States between 1979 and 1993, as promulgated by the Nuclear Regulatory Commission. At that time, there were no regulatory guidance values or dose limits such as 100 mSv during an emergency to protect infrastructure or prevent large releases to the environment or such as 250 mSv to save a life.

Table 2 US NRC Dose Limits for Workers in 1979-1993

Whole body (head, torso, and long bones-thigh)	Skin	Extremities
30 mSv/qtr	75 mSv/qtr	187.5 mSv/qtr
120 mSv/y (but not to exceed an average of 50 mSv/y)	300 mSv/y	750 mSv/y

Thirteen overexposures to workers occurred between the time TMI-2 began commercial operations and TMI-2 entered Post Defueling Monitored Storage. Twelve of those thirteen events occurred in 1979 and the last event occurred in the 1980s during the decontamination and clean-up operations. That is, there were no reported individual doses in excess of regulatory limits in any of the years between 1980 and 1988. In no year was the average annual worker dose in excess of 8 mSv [3].

Table 3 History of Reported Personnel Exposures in Excess of Dose Limits, TMI-2

Year	Type of Exposure	Number	Dose in 1 Quarter
1979	Whole Body	1	41 mSv
1979	Whole Body and Skin	1	39 mSv *(whole body)* - 261 mSv *(skin)*
1979	Skin	8	Range from 120 mSv to 1,660 mSv to portions of the skin. In one case, most of the skin received 132 mSv.
1979	Whole Body and Extremity	1	41 mSv *(whole body)* - 640 mSv *(extremity)*
1979	Extremity	1	200 mSv *(fingers)*
1989	Extremity	1	572 mSv *(palm of hand)*

The whole body doses noted in the above table were a result of exposure to gamma radiation. Doses to the skin resulted from exposures to gamma and beta radiation (usually from strontium-90/yttrium-90). The skin exposures were usually to a small portion or portions of the skin. In one case, the exposure was to most of the skin of the affected individual. Doses to the extremities were to fingers or hands.

There were six individual doses in excess of regulatory limits that occurred during the initial accident response in March 1979. Five of these individual doses were accrued while the individuals were investigating leaks or obtaining and preparing samples of reactor coolant for analysis. In one case, an operator received dose to the skin from exposure to a cloud of noble gases. In the summer of 1979, six individuals received doses to their thighs from yttrium-90 while they were performing work involving the closing of valves and photographing valve positions in a contaminated area. All of the reported doses from the summer of 1979 are to be considered the upper limit of values based on measurements and calculations made by persons with expertise in radiation dosimetry.

The listed dose in 1989 was in excess of regulatory limits occurred when a group of four individuals were decontaminating and cleaning up a Decontamination Flush area within the Decontamination Flush/Cut Facility. Two of the individuals inadvertently handled a piece of debris believed to be fuel debris. While thermoluminescent and self-reading dosimeter results showed no unusual exposure, a detailed dose assessment resulted in one individual's receiving an assigned extremity dose of 591.98 mSv for the third quarter of 1989.

No doses in excess of regulatory limits was identified that involved internal dose and no doses in excess of regulatory limits was identified that involved dose from discrete radioactive particles.

1.4 Effluents to the Environment

The primary contributor to airborne effluents was the deliberate release of radioactive gases from the stack of the auxiliary building, totalling about 400 PBq as stated above. There was one element of confusion caused by a dose reading of 12 mSv directly above the stack at the time of release, which was reported by some to be an off-site reading [4]. The reality was that measurements and calculations showed that no more than 1 mSv was the maximum dose to an individual off-site, and that the average dose to a member of the public living within 16 km of the site was about 0.08 mSv [3]. Independent studies over a number of years after the accident have verified that there is neither evidence of an unusually high number of cancers around TMI-2 caused by the event nor evidence of other adverse health effects (except psychological stress) caused by the event.

Waterborne effluents related to the event have not been a major environmental issue. Waterborne effluents were virtually non-existent during the event itself; water used and stored during the clean-up efforts (some 10 million litres, [5]) was processed and evaporated such that waterborne effluents to the environment were minimal. As part of the on-going radiological surveillance efforts, rainwater and groundwater continue to be monitored for indications of any elevations in the levels of radioactive materials related to the event.

The fuel (and fuel debris) removed from TMI-2 was shipped to the Idaho National Laboratory, where it remains in dry storage.

Contamination of the TMI site outside of the Reactor Building and other TMI-2 facilities was very limited, related to deposition of airborne releases within the site boundary. Decontamination and clean-up efforts were conducted to move the site toward approval for Post Defueling Monitored Storage, and there has been basically no contribution to any migration of radioactive materials off site from on-site contamination outside the primary affected facilities.

1.5 TMI Lessons Learned

As noted above, the root causes of the accident were said to be inadequate control room instrumentation and inadequate emergency response training. As a result, numerous plant design and equipment changes were undertaken across the nuclear fleet in the United States, to supplement and improve the information available to unit operators (both utility and regulatory agency personnel were involved in considering and implementing relevant design and other changes, and other initiatives as described below.) Also, the development of symptom-based emergency operating procedures was undertaken, and training on these procedures became a routine part of operator training and re-training (effective communications and effective teamwork among the operators are among the factors evaluated in the training). Protection of a plant's cooling capacity received additional focus during development of those procedures. Related directly to RP, design changes were made to enhance the ability for individuals to remotely monitor area radiation levels and to collect and analyse reactor coolant samples and other potentially highly radioactive samples without incurring unnecessary dose. Airborne effluent monitoring systems were also modified to address the need for monitoring of higher concentrations of radioactive materials in airborne effluents.

The frequency and complexity of emergency plan response training and the conduct of drills and exercises (which were much less robust and involved far less offsite response and coordination with government resources) were changed, to improve the ability of emergency response personnel to understand the roles and functions to be undertaken in emergency situations and to include practice in carrying out those roles and functions in time-limited (simulated stressful) situations. Decision-making aids were developed related to RP functions in writing radiation work permits in emergency situations and in estimating the off-site doses associated with existent and projected effluent releases.

Another lessons learned from the TMI-2 event was the need to timely and accurately communicate to the media and ultimately the public regarding event conditions that might cause confusion, stress, and even fear among members of the public. This may also include the ability to respond to rumours that begin outside of the designated communications centres but begin to result in public confusion or distrust regarding the planned communications of the utility and regulators. Often, both utility and regulatory authorities have representatives in joint information centres, so that there is less chance for miscommunication between primary parties as they carry out their responsibilities. Some utilities also began to train a cadre of local physicians near their reactor sites, to ensure that they had the understanding appropriate to provide good advice to their patients and others who might ask for such advice. Some other utilities opted to form committees consisting of credible local officials, to whom timely and accurate information could be given on an on-going basis, as a means of providing another source of information to which local citizens could turn to for information.

A lesson that was learned with direct applicability to RP was the advantage of having unmanned robots that could enter highly contaminated areas or areas with high radiation fields to perform tasks important to characterization of source terms and clean-up of such areas. During the period from 1979 to 1993, several robotic designs were developed and built, which aided the efforts at TMI-2 but also assisted utilities and suppliers in their identification of ways in which unmanned robots could be used in NPPs.

The Institute for Nuclear Power Operations (INPO) was established, in large part because of the TMI-2 accident evaluations. The Institute and its National Academy for Nuclear Training improved both the effectiveness of training at NPPs in the United States (and elsewhere) but also in promoting excellence in multiple facets of nuclear power operations via their a) tracking of important safety parameters, b) assessing (with the host utility) how processes and procedures are actually executed on-site, c) providing a forum for the exchange of operating experience and associated lessons learned, and d) providing helpful standards and guidelines for industry-wide application.

2. CHERNOBYL ACCIDENT

2.1 Description of the Accident

On 26 April 1986, an accident occurred at Unit 4 of the Chernobyl NPP in the former Ukrainian Republic of the Soviet Union. The explosions that ruptured the Chernobyl reactor vessel and the consequent fire that continued for 10 days or so resulted in large amounts of radioactive materials being released into the environment.

The cloud from the burning reactor spread numerous types of radioactive materials, especially iodine and caesium radionuclides, over much of Europe. Radioactive ^{131}I, most significant in contributing to thyroid doses, has a short half-life (8 days) and largely disintegrated within the first few weeks of the accident. Radioactive ^{137}Cs, which contributes to both external and internal doses, has a much longer half-life (30 years) and is still measurable in soils and some foods in many parts of Europe.

An estimated 350 000 emergency and recovery operation workers, including army, power plant staff, local police and fire services, were initially involved in containing and cleaning up the accident in 1986–1987. Among them, about 240 000 recovery operation workers took part in major mitigation activities at the reactor and within the 30-km zone surrounding the reactor. Later, the number of registered “liquidators” rose to 600 000, although only a small fraction of these were exposed to high levels of radiation.

More than five million people live in areas of Belarus, Russia and Ukraine that are classified as “contaminated” with radionuclides due to the Chernobyl accident (above 37 kBq m^{-2} of ^{137}Cs). Amongst them, about 400 000 people lived in more contaminated areas – classified by Soviet authorities as areas of strict radiation control (above 555 kBq m^{-2} of ^{137}Cs). Of this population, 116 000 people were evacuated in the spring and summer of 1986 from the area surrounding the Chernobyl power plant (designated the “Exclusion Zone”) to non-contaminated areas. Another 220 000 people were relocated in subsequent years [6].

2.2 Emergency and Recovery Workers

Workers involved in the Chernobyl accident emergency and recovery phases can be divided in two groups [7]:

a) Those involved in emergency measures during the first day of the accident (26 April 1986), who are usually referred to as “emergency workers”.

b) Those active in 1986-1990 at the power station or in the zone surrounding it for the decontamination work, sarcophagus construction and other clean-up operations. This second group of workers is usually referred to as “recovery operation worker” (although the term “liquidator” gained common usage in the former Soviet Union).

Emergency and early recovery workers were both military and civilian:

- Urgent response team - about 35 000 persons (13 000 military and 22 000 civil) between 27 April-20 May 1986,
- Recovery operation workers- about 89 000 persons (49 000 military and 40 000 civil) between 21 May–30 November 1986.

In total, until 1990, about 600,000 persons (civilian and military) have received special certificates confirming their status as “liquidators”, according to laws promulgated in Belarus, the Russian Federation and Ukraine. Of those, about 240,000 were military servicemen (most of them being reservists, called back to quicken the process of decontamination).

2.3 Issues in Measuring Exposure for Emergency and Recovery Workers

Emergency workers

The power plant personnel wore only film badges that could not register doses in excess of 20 mSv. All of these badges were overexposed. The firemen had no dosimeters and no dosimetric control. Dose rates on the roof and in the rooms of the reactor block reached hundreds of Gy per hour.

Because all of the dosimeters worn by the workers were overexposed, they could not be used to estimate the gamma doses received via external irradiation. Relevant information was thus obtained by means of biological dosimetry for the treated persons.

Internal doses were determined from thyroid and whole-body measurements performed on the persons under treatment, as well as from urine analysis and from post-mortem analysis of organs and tissues. Internal dose reconstruction was also carried out for 375 surviving emergency workers who were examined in Moscow.

Recovery operation workers (Liquidators)

Uncertainties in the evaluation of external effective dose from gamma radiation

The doses to the recovery operation workers who participated in mitigation activities within two months after the accident are not known with much certainty. Attempts to establish a dosimetric service were inadequate until the middle of June 1986. TLDs and condenser-type dosimeters that had been secured by 28 April 1986 were insufficient in number and, in the case of the latter type, largely non-functioning, and records were lost when the dosimetric service was transferred from temporary to more permanent quarters. In June 1986, TLD dosimeters were available in large numbers, and a databank of recorded values could be established. From July 1986 onwards, individual dose monitoring was performed for all non-military workers, using either TLDs or film dosimeters.

Estimates of effective doses from external gamma irradiation were generally obtained in one of three ways [7, 8 and 9]:

a) Individual dosimetry for all civilian workers and a small part of the military personnel after June 1986;
b) Group dosimetry: an individual dosimeter was assigned to one member of a group of recovery operation workers assigned to perform a particular task, and all members of the group were assumed to receive the same dose;
c) Prior assessment of dose to a group of recovery operation workers based on the dose rate at the work location and the planned duration of work

Methods (b) and (c), either separately or combined, were used to assess the doses to the majority of the military personnel at all times. Subsequently, retrospective assessments of dose were undertaken. The methods included:

d) Time-and-motion studies: i.e. measurements of gamma-radiation levels were made at various points of the reactor site, and an individual’s dose was estimated as a function of the points where he or she worked and the time spent in these places), and

e) Biodosimetry: i.e. electron paramagnetic resonance (EPR) measurements on teeth, or fluorescence in-situ hybridization (FISH) measurements on blood lymphocytes.

The main sources of uncertainty associated with the different methods of dose estimation were as follows: (a) individual dosimetry: incorrect use of the dosimeters (inadvertent or deliberate actions leading to either overexposure or underexposure of the dosimeters); (b) and (c) group dosimetry: very high gradient of exposure rate at the working places at the reactor site; (d) time-and-motion studies: deficiencies in data on itineraries and time spent at the various working places, combined with uncertainties in the exposure rates and for (e) biodosimetry: a relatively high signal from background radiation, which prevents additional low doses from being measured precisely, and a lack of knowledge of the doses from other natural and artificial sources of radiation exposure.

Uncertainties associated with the different methods of dose estimation are assessed to be up to 50% for method (a) (if the dosimeter was correctly used), up to a factor of 3 for method (b), and up to a factor of 5 for method (c) and (d). The uncertainty of the EPR dosimetry used in method (e) has been assessed to have an absolute value of 25 mGy (one standard deviation) at doses below about 250 mGy, and a relative value of about 10% at doses above 250 mGy.

External skin and eye lens dose from beta radiation

At the time of the clean-up, doses of external beta irradiation were not monitored due to limited technology and methodical capabilities of dosimetry services. However the Chernobyl mix of radionuclides included a wide range of high-energy beta radiators (^{144}Pr, ^{106}Rh, and ^{90}Y), which cause significant doses of beta irradiation of uncovered skin and the lens of the eye. It has been estimated that the beta dose exceeded whole body gamma doses, sometimes significantly.

Estimation of internal dose

Because of the abundance of ^{131}I and of shorter-lived radioiodines in the environment of the reactor during the accident, the recovery operation workers who were on the site during the first few weeks after the accident may have received substantial thyroid doses from internal irradiation. Information on the thyroid doses is very limited and imprecise. From 30 April through 7 May 1986, in vivo thyroid measurements were carried out on more than 600 recovery operation workers. These in vivo measurements, which are measurements of the radiation emitted by the thyroid using detectors held or placed against the neck, were used to derive the ^{131}I thyroidal contents at the time of measurement. The thyroid doses were derived from the measured ^{131}I thyroidal contents, using assumptions on the dynamics of intake of ^{131}I and short-lived radioiodines and on the possible influence of stable iodine prophylaxis.

The internal doses resulting from intakes of radionuclides such as ^{90}Sr, ^{134}Cs, ^{137}Cs, ^{239,240}Pu, and others have been assessed for about 300 recovery operation workers who were monitored from April 1986 to April 1987. The majority of them were staff of the power plant who took part in the recovery work starting on days 3 and 4 after the accident. The dose assessment was based on the analysis of whole-body measurements and of radionuclide concentrations in excreta.

2.4 Level of Exposure of Emergency and Recovery Workers and Health Effects

Emergency workers

The highest doses were received by the firemen and the personnel of the power station on the night of the accident. Acute radiation sickness was confirmed for 134 workers. The latter received whole-body (or bone-marrow) doses due to external gamma radiation ranging from 0.8 to 16 Gy. The skin doses to some individuals exceeded the bone-marrow doses by a factor of 10–30; some received skin doses that were estimated to be in the range of 400 to 500 Gy. Doses had been estimated mainly using clinical dosimetry methods, i.e. analysis of blood counts and/or cytogenetic parameters of blood lymphocytes.

Of these 134 patients, 28 died within the first four months, their deaths being directly attributable to the high radiation doses (two other workers had died from injuries unrelated to radiation exposure in the immediate aftermath of the accident).

Recovery workers

The main pathway of exposure of the recovery operation workers was external gamma irradiation from the radioactive material deposited on the ground and building surfaces. These external doses were recorded in national registries for about half of the workers. Effective doses and absorbed doses to the skin and the lens of the eye from external beta irradiation and to the thyroid from internal irradiation were only estimated for a limited number of workers.

The collective dose due to external exposure received in 1986–1990 by the 526 250 registered emergency and recovery operation workers is estimated to be about 60 000 man·Gy. Of that dose, 73% was incurred in 1986, 22% in 1987 and the remaining 5% in the subsequent three years. About 85% of the collective dose to all the workers with recorded doses was delivered to those in the interval 50 –500 mGy.

Table 4 External dose to recovery operation workers as officially recorded in national registries [10]

Period	Number of recovery operation workers	Percentage of workers with recorded doses (%)	Mean external dose (mGy)	Collective dose (man·Gy)[13]
1986	305 826	35	146	44 535
1987	138 173	64	96	13 240
1988	51 278	71	43	2 200
1989	24 128	69	41	993
1990	5 766	66	47	271
1991	5	-	-	0
Unknown	1 074	-	-	18
1986-1991	526 250	48	117	61 256

2.5 Main Tasks Performed by the Emergency and Recovery Workers

The main actions undertaken by the emergency workers include [11]:

- Fire control,
- Saving life,
- Cut-off ventilation / electricity, switching of cooling system,
- Examination of equipment,
- Radiation survey, and
- Water supply.

Noted that the first measures taken to control the fire and the radionuclide releases consisted of dumping neutron-absorbing compounds and fire-control materials into the crater formed by the destruction of the reactor. About 1 800 helicopter flights were carried out to dump materials onto the reactor. During the first flights, the helicopters remained stationary over the reactor while dumping the materials. However, as the dose rates received by the helicopter pilots

13. For 1986-1990, the statistical parameters and collective effective dose values are given assuming that dose distribution obtained for the workers with recorded doses apply to the entire population of workers. For some population, this assumption might be rather questionable.

during this procedure were judged to be too high, it was decided that the materials should be dumped while the helicopters travelled over the reactor. This procedure which had a poor accuracy caused additional destruction of the standing structures and spread the contamination. In fact, much of the material delivered by the helicopters was dumped on the roof of the reactor hall, where a glowing fire was observed, because the reactor core was partially obstructed by the upper biological shield, broken piping, and other debris, and rising smoke made it difficult to see and identify the core location (see Figure 2).

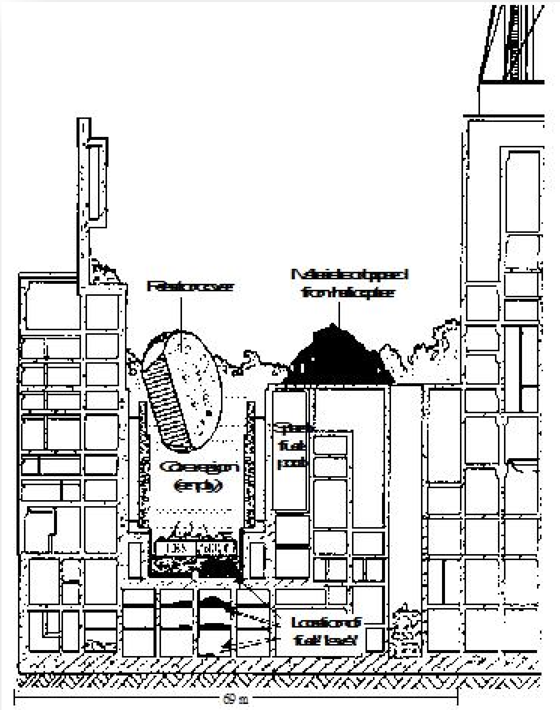

Figure 2 Cross-section view of damaged Unit 4 Chernobyl reactor building [7]

The principal tasks carried out by the recovery operation workers (liquidators) included:

- Decontamination of the reactor block, reactor site, and roads (1986-1990),
- Construction of the sarcophagus (May- November 1986),
- Construction of a settlement for reactor personnel (May-October 1986),
- Building of Slavutich town (1986-1990),
- Construction of waste repositories (1986-1988),
- Construction of dams (July-September 1986) and water filtration systems (1987),
- Radiation monitoring and security operations (1986-1990).

2.6 Elements on Working Conditions

Dose rates [12]

Just after the accident, the dose rates on the site were of this order of magnitude [12]:

- At the site boundary: 10 – 1 000 mGy/h
- On the site: 30 – 3 000 mGy/h

- Turbine hall: 10 – 1 000 mGy/h
- Premises: 1 – 4 000 mGy/h

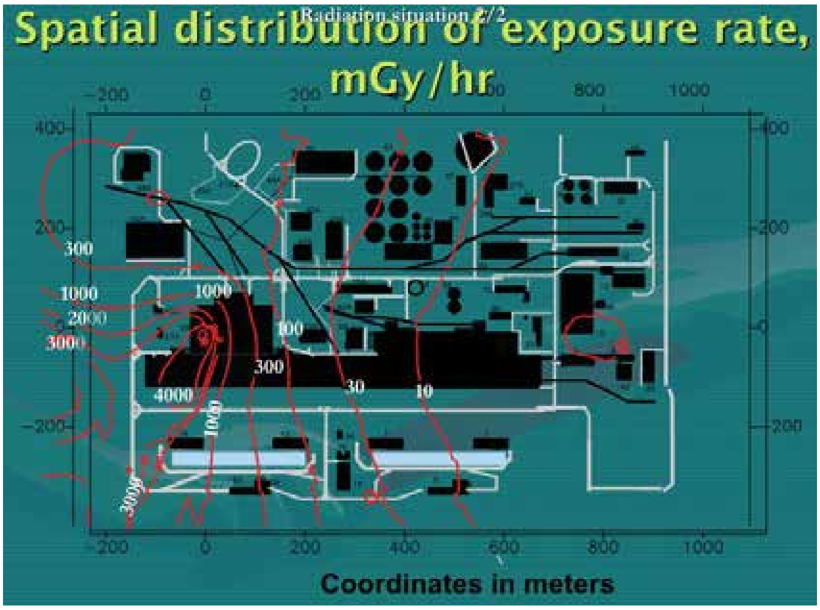

Figure 3 Spatial distributions of exposure rates [12]

Robotics

It seems that the use of robots was initially attempted, but did not withstand high dose rates and their use was abandoned [12].

Chemical exposure

The following table-5 summarizes the chemical factors at the working place [12].

Table 5 Chemical pollutants during emergency and recovery phase of Chernobyl accident

Origin	Initial materials	Pollutants
Fire at the Unit 4	Graphite, building and organic containing materials, bitumen	Co, NO_2, hydrocianide, phosgene, smoke superfine aerosols
Sublimation of materials dumped on the reactor	Sand, clay, lead, dolomite, boron compounds	Deposition of lead
Dust catching for building roof, industrial site and roads of the 30-km zone	Sulphite-alcohol bard, oxalic and hydrochloric acids, formalin, resins, oil-slime	Superfine acid aerosols, sulphur/organic containing vapour

Physical factors

Due to air ionization (which exceeded many times the Permissible Level), an increase level of ions and ozone was generated. A questionnaire sent to 3, 000 recovery workers, revealed that 58% of them suffered from oropharyngeal syndrome in 1986 [12].

2.7 Chernobyl Lessons Learned

Lessons learned from the Chernobyl accident in the field of occupational radiation protections have been synthesise by Savkin [12], bases notably on the publication of Kryuchkov et al [11]. The main elements are summarized below.

Emergency and recovery workers, from both civil and military workers, were not a homogeneous cohort of workers. They were independent groups, having to perform specific tasks with their own management and a different dose control system according to the group. This created difficult situations for the coordination of the short term recovery measures, and also the recording of workers' doses. The latter issue is of importance as almost half of the workers didn't have their dose recorded, and, within the recorded dose, part of it of resulting from quite uncertain estimates or reconstruction. It is thus essential to create rapidly a centralised dose recording system.

The emergency and recovery workers had no specific training for radiological emergency management. Even the military workers who were for a large majority called from the Reserve (i.e. civilians) were not prepared for such type of actions. It resulted in incorrect behaviour under such radiological conditions, together with an increase of individual stress. The lessons learned is the necessity to reinforce the training of those workers who will be potentially involved in the emergency and recovery phase of an accident.

A very large number of recovery workers were finally necessary (firemen, militaries, civil, etc.). Not all of them could be trained in advance. A specific RP training adapted to the planned working conditions should thus be implemented before to allocate them to any recovery job. A Dosimetric Work Permit System for the management of any recovery job should also be developed aiming at planning the jobs, estimating the worker's dose of the future jobs, on the bases notably of computerized data bases of the mappings of the area dose rates.

This type of accident generate specifically high dose rate, not encountered in normal situation. The plants should have available dose and dose rate measurement systems able to cope with high level of dose rate. There may be also the need to plan an instrumental dosimetry for beta exposure. Specific robotics should also be developed taking into account these particular radiation levels.

3. FUKUSHIMA DAIICHI NUCLEAR POWER PLANT ACCIDENT

3.1 Description of the Accident

On March 11, 2011, the Great East Japan Earthquake triggered an extremely severe nuclear accident at the Fukushima Daiichi NPP, owned and operated by the Tokyo Electric Power Company (TEPCO). This devastating accident was ultimately declared a Level 7 ("Severe Accident") by the International Nuclear and Radiological Event Scale (INES).

When the earthquake occurred, Unit 1 of the Fukushima Daiichi plant was in normal operation at the rated electricity output according to its specifications; Units 2 and 3 were in operation within the rated heat parameters of their specifications; and Units 4 to 6 were undergoing periodical inspections. The emergency shut-down feature, or SCRAM, went into operation at Units 1, 2 and 3 immediately after the commencement of the seismic activity.

The seismic tremors damaged electricity transmission facilities between the TEPCO Shinfukushima Transformer Substations and the Fukushima Daiichi NPP, resulting in a total loss of off-site electricity. There was a back-up 66kV transmission line from the transmission network of Tohoku Electric Power Company, but the back-up line failed to feed Unit 1 via a metal-clad type circuit (M/C) of Unit 1 due to mismatched sockets.

The tsunami caused by the earthquake flooded and totally destroyed the emergency diesel generators, the seawater cooling pumps, the electric wiring system and the DC power supply for Units 1, 2 and 4, resulting in loss of all power - except for an external supply to Unit 6 from an air-cooled emergency diesel generator. In short, Units 1, 2 and 4 lost all power; Unit 3 lost all AC power, and later lost DC before dawn of March 13, 2012. Unit 5 lost all AC power.

The tsunami did not damage only the power supply. The tsunami also destroyed or washed away vehicles, heavy machinery, oil tanks, and gravel. It destroyed buildings, equipment installations and other machinery (Figure 4). Seawater from the tsunami inundated the entire building area and even reached the extremely high pressure operating sections of Units 3 and 4, and a supplemental operation common facility (Common Pool Building). After the water retreated, debris from the flooding was scattered all over the plant site, hindering movement. Manhole and ditch covers had disappeared, leaving gaping holes in the ground. In addition, the earthquake lifted, sank, and collapsed building interiors and pathways, and access to and within the plant site became extremely difficult. Recovery tasks were further interrupted as workers reacted to the intermittent and significant aftershocks and tsunami. The loss of electricity resulted in the sudden loss of monitoring equipment such as scales, meters and the control functions in the central control room. Lighting and communications were also affected. The decisions and responses to the accident had to be made on the spot by operational staff at the site, absent valid tools and manuals.

The loss of electricity made it very difficult to effectively cool down the reactors in a timely manner. Cooling the reactors and observing the results were heavily dependent on electricity for high-pressure water injection, depressurizing the reactor, low pressure water injection, the cooling and depressurizing of the reactor containers and removal of decay heat at the final heat-sink. The lack of access, as previously mentioned, obstructed the delivery of necessities such as alternative water injection using fire trucks, the recovery of electricity supply, the line configuration of the vent and its intermittent operation.

The series of events summarized above are an overview of the severe accident that ultimately emitted large amounts of radioactive material into the environment.

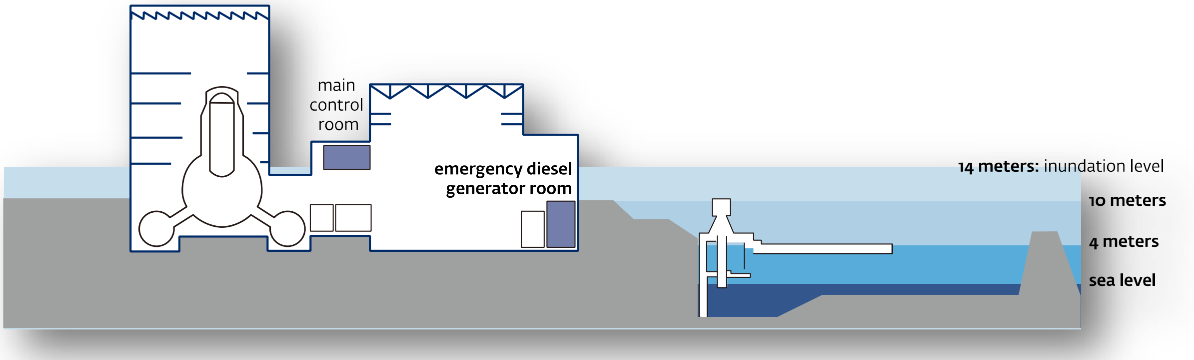

Figure 4 Cross section of the plant showing the inundation level [13]

3.2 Occupational Radiation Protection Aspects

3.2.1 Access Control

System of radiation control measures at Fukushima Daiichi Nuclear Power Plant [14]

In this accident, tsunamis reached buildings facing the sea coast which provide access to the controlled areas, depriving the function of the radiation control system, and rendering many of the EPDs and dose reading devices unusable as they became submerged in seawater.

Also, due to the increase of radiation and contamination levels in the power plant, it was decided that workers centralize and conduct all operations in TEPCO’s response headquarters established in the quake-proof building, including distribution of EPDs and recording of doses.

From March 11, shortly after the earthquake, dose management for workers had to be performed manually by recording the names of individuals and their daily dose values on paper to accumulate data. Moreover, such daily individual doses which were manually recorded had to be manually inputted into PCs (using Excel sheets) and saved as a database.

Evaluation of the status of radiation exposure [14]

At Fukushima Daiichi NPP, along with the increase of the radiation dose, the situation required controlling the non-controlled area in addition to the controlled areas. Against this background, workers who were not designated as radiation workers performed work in places that should have been controlled at the same level as the controlled area, and this work resulted in exposures exceeding 1 mSv per year, or the yearly dose limit for the public. This is because, in the beginning, individual dose controls were not changed in line with the enlargement of the target area for radiation control measures.

Registration as a radiation worker [15]

At the Fukushima Daiichi NPP, (although there is no legal obligation to do this) there was a delay in radiation workers getting registered as professional radiation workers with a radiation worker certificate provided by the Central Registration Centre of Radiation Workers and so some radiation workers performed their duties without a radiation worker certificate.

3.2.2 External Dosimetry

EPD (electronic pocket dosimeter) [16, 17 and 18]

TEPCO had about 5,000 EPDs installed at the entrance of the controlled zone of Units 1 to 6 at the Fukushima Daiichi NPP and in the centralized waste treatment facilities, but most of them were covered with water and damaged by the tsunami. Hence, as a temporary arrangement, it was decided to perform radiation control measures for workers using about 320 EPDs that had been kept in the Seismic Isolation Building.

System of radiation control measures at Fukushima Daiichi Nuclear Power Plant [14, 17 and 18]

Because many EPDs became unusable for reasons described above, not every worker was able to wear an EPD and TEPCO has thus been managing radiation doses of all the personnel by making leaders of operational groups wear EPDs on behalf of the entire group. As controlling workers' radiation exposure is very important to ensure safety on the site, the Nuclear and Industry Safety Agency (NISA) gave oral instructions to TEPCO to make every effort to manage its workers' radiation exposure and dose. TEPCO procured the necessary dosimeters by April 1 so that all the workers conducting operations then carried portable dosimeters.

3.2.3 Internal Dosimetry

Evaluation of the status of radiation exposure [14, 17 and 18]

At Fukushima Daiichi NPP, WBCs became unusable due to the shielding geometry and the increase of the background level. Furthermore, the plant WBCs were not programmed to determine all of the nuclides associated with all of the identified spectral peaks. Therefore, one WBC mounted on a vehicle (a NaI spectroscopic system with a shield fully surrounding the detectors) was borrowed and used for measurements. But this did not start until 2 weeks after the accident. WBC measurements were also performed at another power plant. There were too many people to be measured. Thus, a sufficient measurement system was not established despite parallel efforts to measure WBC in a timely manner at different plants and assess internal exposure.

Internal exposure measurements

The operator established a lesser reference level (200 mSv) to assure the requirements as determined by authorities. Internal dose is measured by WBC for those individuals with external doses above 100 mSv [19].

Delays in WBC measurements caused delays in the identification of plant workers with high internal doses. As a consequence of the accident, workers who received a dose in excess of the legal limit included a TEPCO worker who received an internal dose as high as 590mSv, highlighting the importance of internal exposure measurements [13].

The delays in the WBC internal exposure tests are thought to have been caused by two factors: a shortage of working WBCs in the near-term after the accident; and the time consuming process to go to the off-site locations of the working WBCs [13].

There were significant delays (about 6 months) in obtaining an adequate number of near-site WBCs for the plant workers. Two years after the accident there were a total of 11 counters.

There were even more significant delays obtaining an adequate number of WBCs for the public. Two years after the accident, there were more than 60 WBCs, with approximately 20 of them mobile.

3.2.4 Radiation Instrumentation and Area survey

Exposure of nuclear power plant workers [13]

It is worth pointing out that at the Fukushima Daiichi plant, TEPCO workers and others (mainly contractors) took protective actions to reduce the exposure of the plant workers at their own discretion, including measuring the contamination level within the premises and creating a dose map.

3.2.5 Liquid Effluents

A number of actions have already been adopted by TEPCO and additional actions are included in the recovery road-map for achieving efficient control of the contaminated water. In this aim additional consideration should be done to some remarkable matters, such as those presented below [19]:

- Minimization of the inventory and production of contaminated water in a way compatible with the cooling of the Reactors and the Spent Fuel Pools. In minimizing contaminated water, the final objective should be the establishment of closed cooling systems, and intermediate objectives should consider the reuse and the recycling of contaminated water.
- The installation of temporary additional storage and decontamination capabilities should strengthen the application of specific safety criteria, both to assure highly reliable and efficient operation of systems and to prevent accidental leaks. The potential of natural events, such as earthquakes and tsunamis, should be considered in the design and operation procedures of those systems.

Specific actions have been implemented or planned to contain the spreading of contaminated water, including [24];

- Improvement of the soil of the contaminated area using water glass.
- Pumping up of groundwater from the mountain side to decrease the amount of groundwater flowing into the building (groundwater bypass).
- Installation of the land-side water-shielding walls by the frozen soil method.
- Installation of the equipment with higher-processing efficiency (multi-nuclide removal equipment-ALPS) for contaminated water purification.

3.2.6 Management of Large Scale Contamination

The Fukushima site has been highly contaminated by the deposition of uncontrolled radioactive releases. TEPCO promptly decided to fix the deposited contamination on the whole site (external structures).This measure was decided in order to (i) prevent the further aerosolization of the radioactive particles that could have been transported farther away by the wind and (ii) limit a deeper soil contamination drained by the rain and (iii) improve the radiological work conditions for the recovery workers.

TEPCO used two products on the affected site:

- *a synthetic plastic emulsion*: This product is a dust inhibitor, usually used for non-nuclear applications, in activities such as construction of roads. It is also used in land reclamation and for preventing dust from scattering around. This product was sprayed on the whole site (~ 140 000 m^2), with the exception of the parts covered with buildings.
- *an encapsulant usually used for asbestos*: which was chosen by TEPCO for, amongst others, its incombustibility and stable performance under elevated temperature and high radiation. This product was sprayed over the buildings (~ 160 000 m^2).

3.2.7 Training

Large scale RP training for workers on sites under severe accident conditions can be effective if appropriately organized and with well led and suitable trained staff [19].

Exercises and drills for on-site workers and external responders in order to establish effective on-site radiological protection in severe accident conditions would benefit from taking account of the experiences at Fukushima [19].

Radiation education [13]

With regard to work conducted in March 2011, TEPCO provided the minimum necessary radiation education to workers of affiliated companies involved in emergency operations, including the restoration of the electrical power supply. An approximately 30-minute explanation was provided with the following content.

- Dose limits during emergencies: health effects caused by 100mSv exposure, etc.,
- Necessary protective gear: full face masks, Tyvek, rubber gloves, etc.,
- Management of work hours: how to improve work efficiency to avoid unnecessary over exposure,
- On-site doses: outdoor air doses at the Fukushima Daiichi NPP, and
- Wearing of mask: how to confirm the mask is on correctly.

The Fukushima Nuclear Accident Independent Investigation Commission does not believe that training on the above items fully fulfilled the requirements of what should be taught to workers working in radiation controlled areas. Missing, for example, are training items on the “relevant laws and ordinances” and the “effects of ionization radiation on human health” as set forth in the "Rules for Prevention of Damage from Ionizing Radiation” [20].

3.2.8 Worker Doses

Workers in the emergency and recovery phase of the accident

The response required exceptional dedication by workers on-site and elsewhere. Immediately after the tsunami, approximately 400 workers (about 130 operators and 270 maintenance personnel) were available for recovery operations. They had to work in exceptionally long hours in very adverse conditions [21].

After the very first phase of the accident, the recovery operations employed between 600 and 8000 workers per month (number of workers reported by TEPCO with a registered dose [22], see Figures and Table below).

Six people confirmed to have exceeded 250 mSv [17, 18 and 23]

For the six people who were confirmed to have exceeded 250 mSv (of which three people were operators and three were from the maintenance department), it is presumed that they each had intake of radioactive materials as a consequence of the following factors coming together simultaneously:

1) In the light of the rapid progress of the event, it was very difficult to take correct protective measures for radiation control such as the proper selection, wearing and deployment of masks.
2) The workers took off their masks in order to eat and drink in the main control room while working in the room for extended periods as they worked to bring the abnormal situation under stable control.

3) While wearing their masks, gaps may have arisen as a result of the temples of the glasses worn by two of the workers.

4) Four people worked near the emergency door of the main control room, where the concentration of radioactive materials in the air is presumed to have been so high that they were unable to respond to the contingencies such as the explosion at the top of the reactor building of Unit 1.

5) Two people created a gap between their face and their mask, albeit for a short time, in order to work safely.

Subjects exposed to contaminated water from the Unit 3 turbine building [15]

On 24 March, three workers from a TEPCO partner company (male staff member A in his 30s, male staff member B in his 20s, and male staff member C in his 30s), who were installing electric cables under the surface of the basement floor of the Unit 3 turbine building, were exposed to high radiation dose while working immersed in contaminated water. In terms of radiation dose (external exposure), staff member (A) received 180.1 mSv, staff member (B) received 179.34 mSv and staff member (C) received 173 mSv before they had finished working.

Their EPD sounded before they started working. However, they thought that either their EPD had sounded to tell them that its battery was flat or that their EPD had malfunctioned due to the following reasons: they were informed in advance that the air radiation dose rate at the work site was about 2 mSv/h, and they had heard alarms before indicating an EPD malfunction or as an alert to charge a flat EPD battery. Thus they proceeded with installing the electric cables despite receiving EPD alarms. Later staff member A heard the EPD sound continuously and wondered if the air radiation dose at the work site could be higher than expected. However, he thought it was important for them to complete their job to restore the power supply so they continued working.

Individual Dose distribution from March 2011 to May 2014

Table 6 and the following figures depict the number of workers and total dose (internal and external) ranges from March 2011 to March 2014 [22].

Table 6 Exposure dose distribution of workers at Fukushima Daiichi *(March 2011- March 2014)* [22]

Classification (mSv)	TEPCO	CONTRACTOR	Total
Over 250	6	0	6
Over 200 - 250 or less	1	2	3
Over 150 - 200 or less	25	2	27
Over 100 - 150 or less	118	20	138
Over 75 - 100 or less	268	129	397
Over 50 - 75 or less	318	949	1,267
Over 20 - 50 or less	614	4,457	5,071
Over 10 - 20 or less	551	4,173	4,724
Over 5 - 10 or less	444	3,901	4,345
Over 1 - 5 or less	727	7,248	7,945
1 or less	1,066	8,245	9,311
TOTAL	**4,138**	**29,126**	**33 264**
Maximum (mSv)	**678.80**	**238.42**	**678.80**
Average (mSv)	**23.66**	**11.04**	**12.61**

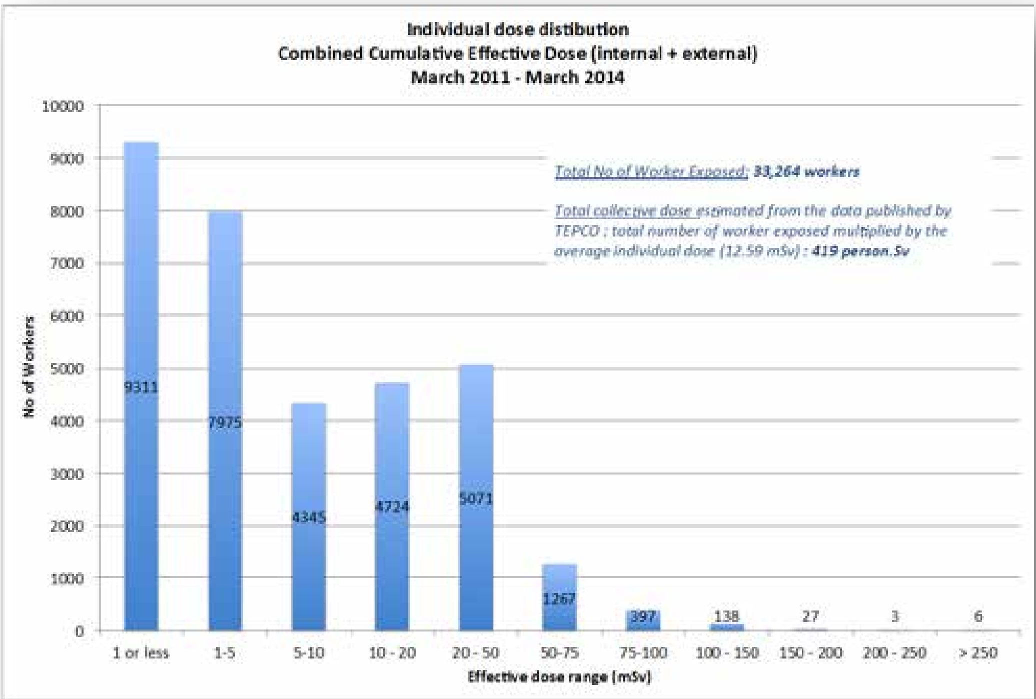

Figure 5 Individual Dose Distribution for Total Exposure (internal and external) *(March 2011- March 2014)* [22]

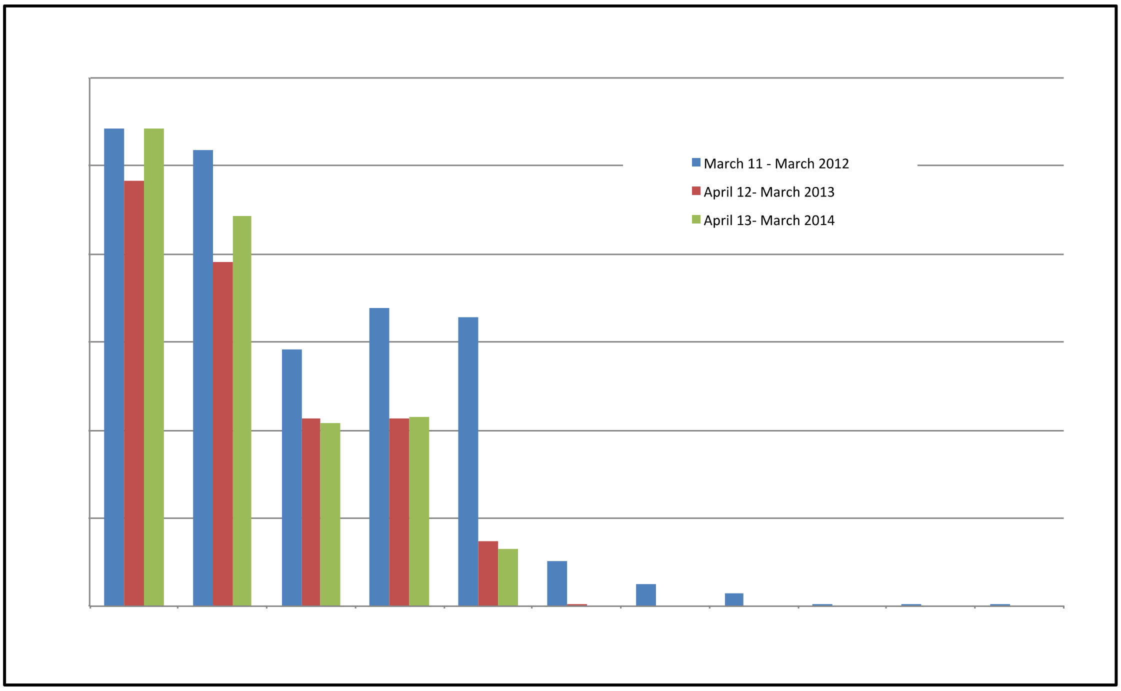

Figure 6 Annual Individual Dose Distribution for Total Exposure (internal and external) *(March 2011 - March 2014)* [22]

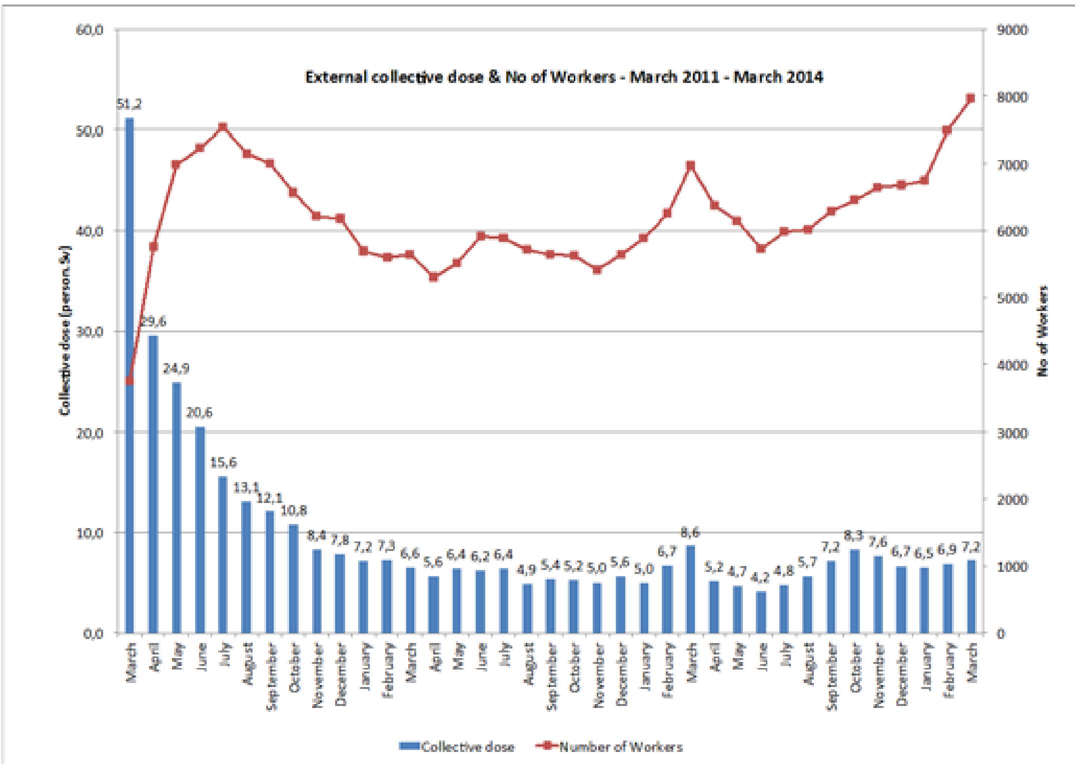

Figure 7 Collective dose (from external exposure) and number of workers *(March 2011 - March 2014)* [22]

3.2.9 Worker Fatigue/Heat Stress

From May to September 2011, heat exposure became an extremely important hazard [21]. This was because of the hot summer weather and the workers had to work outdoor wearing double-layer Tyvek protective overalls and full-face respirators.

Establishment of multiple rest areas [23]

To prevent heat stroke, as a rule, work was not to be performed under the sun during the day from 14:00 to 17:00 in July and August, while giving proper consideration for plant stabilization. Air-conditioned rest areas were established, and expansion of operations conducted to improve the work environment.

Protective equipment [23]

Staff members wear cooling vests, cooling scarves, and masks with blowers to prevent heat stroke while they are at work.

Doctor stationed on the premises at all times [23]

A medical Emergency Room was established in Fukushima Daiichi NPP (Units 5 and 6 Service Building) on 1st of July. Through cooperation with the government, doctors serving in the Emergency Room have been secured from among doctors having expertise in emergency exposure medical treatment from all over the country. They are engaged in medical care through a rotation of approximately two days.

3.2.10 Use of Robotics

Time of work in the RCA is limited to a maximum of 2 hours for every worker. Gradually, specialty tools were introduced to support work in areas with the highest radiation levels or serious contamination, such as robots and unmanned equipment [19].

Protection of workers in emergency situations should be considered a key issue to prevent unnecessary exposures and to support mitigation activities. In the optimisation (ALARA) process for exposure of workers in emergency situations, flexible application of dose reference levels should be considered. In addition, the introduction of practical tools, such as the extensive use of radiological maps of the site or the use of special equipment (robots and unmanned tools) should be considered [19].

3.2.11 Adequacy of Post-Accident Zone Maps

Monitoring of dose rates in different areas of the plant is accomplished on a continuous basis and results are represented in useful radiation maps [19].

Establishment of radiation controlled zone [15]

After the nuclear accident at the Fukushima Daiichi NPP, radiation levels increased throughout the entire premises of the NPP. However, TEPCO was not initially willing to redefine a controlled area as stipulated in its in-house safety regulations. On April 27, however, based on the fact that a female radiation worker received radiation dose greater than the allowed dose limit, NISA instructed TEPCO to validate its organizational framework for radiation control and implement measures to rectify this situation. In response to this, on May 2, TEPCO designated the entire premises of the Fukushima Daiichi NPP as a temporary and emergency radiation controlled zone to be controlled in the same manner as a radiation controlled zone. It was decided that the temporary and emergency controlled zone should be treated as a controlled zone stating that it would be marked with a sign showing that access to the designated area is restricted to those individuals who require access in order to perform their duties, other necessary signs would be installed, and that radiation workers must be equipped with an EPD and other protective equipment.

3.2.12 Off-site Support Facilities

The response on the site by dedicated, determined and expert staff, under extremely arduous conditions has been exemplary and resulted in the best approach to securing safety given the exceptional circumstances. This has been greatly assisted by highly professional back-up support, especially the arrangements at J-Village to secure the protection of workers going on site [19].

The J-Village, a former soccer training complex serves as an operation base for those working at Fukushima. J-Village has 12 soccer fields, which are now used as helipads, storage for heavy equipment, parking lots, a place to decontaminate cars, and another to decontaminate helicopters. There is 400 staff, including a doctor and two nurses. The medical centre used to be the sports medical centre of the Japan Football Association. Every day, up to 3 300 workers pass through J-Village to go to the stricken plant.

One soccer stadium has been converted into dormitories for employees of TEPCO. There are 1 000 rooms in prefabricated, two-story buildings built on the field. In nearby prefabricated buildings, there’s a cafeteria and a laundry for workers. A comprehensive protocol between J-Village and Fukushima Daiichi was established for a strong coordination of RP controls of all personnel entering the restricted area and the facility. Around 2 000 workers per day are provided with RP equipment in J-Village.

As for RP of outside workers and workers who enter the Fukushima Daiichi NPP for radiation work for the first time, TEPCO provides a short training session before entering the NPP on the use of protective clothes, radioactivity and relevant work processes. J-Village is used for this training. Registration is going on for retroactive health care [19].

3.2.13 Application of the Principle of Optimization

Protection of workers in emergency situations should be considered a key issue to prevent unnecessary exposures and to support the mitigation activities. In the optimization process for exposure of workers in emergency situations consideration should be done to a flexible application of the dose reference levels and the introduction of practical tools, such as the extensive use of radiological maps of the site or the use of special equipment (robots and unmanned tools). Classification of workers in different groups of risk could help to optimize the dosimetry and protection resources [19].

3.3 Fukushima Lessons Learned

After the tsunami, there were no only few EPD's and dose / dose rate reading device available (flooding and loss of electrical power) and the computer systems for activating and recording doses from these device were also lost. Worker dose registration had to be performed manually, and workers had to share one EPD for one team of workers. This situation shows the need to have on site in a secure environment enough monitoring devices, able to function without electricity supply (battery, etc.) or with external electricity generator, also installed in a safe place.

The elevation of the background level of radiation as well as the specificities of the radionuclides made it impossible to use the WBC. One possibility to cope with this situation would be to plan to have organised the possibility to use alternative measuring systems (e.g. use of measuring devices at different NPPs, mobile systems which can be transported to the site). When planning those arrangements, it is important to keep in mind that the numbers of workers to be monitored can be much higher than in normal operation.

Due to the high number of workers needed and the specificities of the recovery operation a crucial lack of RP training was noticed. This calls for a better preparation of emergency teams regarding RP, as well as for the organisation of specific RP training for those workers arriving on the site after the accident.

In the aftermath of such an accident, specific working conditions have to be taken into account when planning the recovery activities. Some conditions encountered at Fukushima are summarized below:

- Major hazards: radiation, heat, stress, machine operation and manual handling,
- Highly contaminated site by deposition of uncontrolled radioactive releases,
- Increase of radiation levels on the entire site, and
- Very high number of workers needed.

Finally, the Fukushima Daiichi accident shows that in the work management of recovery activities the RP optimization process can be applied. It may be useful to use flexible application of the dose reference levels (recovery activities are to be considered as existing exposure situations) and to define several groups of exposed workers according to the risk level. Within the means used to reduce worker exposure, the use of special equipment (robots and unmanned tools) as well as the extensive use of radiological maps of the site.

4. CONCLUSIONS

These three accidents present major differences in terms of magnitude of the radiological consequences (for workers and the population), the extent of recovery operations (duration of recovery period, number of workers involved, occupational individual and collective dose, etc.). However, some similarities in the ORP issues faced in the emergency and recovery phases, and lessons learned can be identified, including:

Monitoring and recording of doses

Severe accidents can give rise to major release in the environment -increasing considerably the dose rates and contamination / airborne activity-, loss of electricity supply and/or potential destruction of the site – monitoring and recording devices being out of order -. Lessons learned are dealing with the availability on site (or to be provided rapidly from other places) of monitoring devices able to cope with very high dose rates or contamination levels, not relying only on electricity supply (eg use of battery), and the need to secure an access to a centralised recording system for the emergency worker's dose. It is also essential to plan that a very high number of workers might be involved in the emergency and recovery phases, implying the need to have a sufficient number of monitoring devices (external and internal dose monitoring) available.

Working Conditions

These accidents show the necessity to be planned to work in extremely difficult conditions, not only from the RP point of view (high dose rates and/or contamination levels), but also facing other hazards such as heat or stress. Adapted protective equipment (against radiation, contamination, heat, etc.) needs to be developed and available on site (or to be provided rapidly from other places). The use of remote tooling and robotics has also to be considered in emergency/recovery plans, integrating again the need for this equipment to be able to resist to high radiation / contamination fields.

RP Training

According to the extremely difficult RP conditions which can arise in a severe nuclear accident, RP training plans for emergency workers need to be elaborated, incorporating exercises simulating the potential working conditions which may be faced by these workers (using notably examples from the past accidents). Furthermore, as many other workers than those initially trained might be involved in the recovery phase, RP training plans should be elaborated to be performed for these new workers, who may not have been before involved in such type of activities.

Continuing the collection and analysis of past experience

It finally appears that it is still necessary to continue the collection and analysis of feedback experience from these past accidents as an essential source of improvement of the preparedness of nuclear accident management. It is notably important to understand much better how and when workers are exposed (emergency and recovery phases) as well as which actions implemented to manage their protection are the most efficient. Such analysis would benefit of a sharing at an international level among the RP community.

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APPENDIX -2 INTERNATIONAL WORKSHOP ON OCCUPATIONAL RADIATION PROTECTION IN SEVERE ACCIDENT MANAGEMENT, "SHARING PRACTICES AND EXPERIENCES"

The interim report of the EG-SAM, which was accomplished during meetings from 2012 to 2013 and approved in the 23rd Annual Session of ISOE Management Board, includes perspectives of the group and discussions on:

- radiation protection management and organisation;
- radiation protection training and exercises related to severe accident management;
- facility configuration and readiness;
- overall approach on the protection of workers;
- radioactive materials, contamination controls and logistics; and
- lessons learned from the past accidents.

With the completion of the first step, the Management Board decided to organize an international workshop to introduce the interim report and to incorporate the national experiences that will be presented during the workshop for the finalization of the report.

On 17-18 June 2014, the "International Workshop on Occupational Radiation Protection in Severe Accident Management", organized by the Information System on Occupational Exposure (ISOE), co-sponsored by the OECD Nuclear Energy Agency (OECD NEA) and the International Atomic Energy Agency (IAEA) and hosted by the Nuclear Energy Institute (NEI), was organized in Washington DC, USA.

The objectives of the workshop, which was attended by 66 participants from 17 countries, were to identify best occupational radiation protection approaches in strategies, practices, as well as limitations for developing effective management, and to identify national experiences to be incorporated into the final version of ISOE expert group's interim report.

In parallel to workshop objectives, four plenary session and five break-out sessions (by taking into account the chapter structure of interim report) were organized to capture global, utility and regulatory authority perspectives. The workshop provided suggestions for improvement and some additional points to extent the view of interim report. Proceedings of the workshop are available at the ISOE website: www.isoe-network.net.

International ISOE Workshop (Washington DC, US)

WORKSHOP SCIENTIFIC PROGRAM

17 JUNE 2014

08:30	OPENING SESSION
	Session chaired by Ellen P. ANDERSON *(NEI – EGSAM Chairperson)*
08:35/0.01	NEA WELCOME AND REMARKS Kazuo SHIMOMURA *(NEA Deputy Director)*
08:45/0.02	IAEA WELCOME AND REMARKS Pil-Soo HAHN *(IAEA NSRW Director)*
08:55/0.03	NEI WELCOME AND REMARKS Ralph ANDERSEN *(NEI Senior Director)*
09:05/0.04	ISOE WORKSHOP BACKGROUND, OBJECTIVES, SCOPE, GOALS & LOGISTICS Ellen P. ANDERSON *(NEI – EGSAM Chairperson)*
Plenary Session 1	GLOBAL VIEW ON OCCUPATIONAL RADIATION PROTECTION IN SEVERE ACCIDENT MANAGEMENT
09: 20	**Session chaired by *Kazuo SHIMOMURA (NEA)***
09:25/1.01	ICRP RECOMMENDATIONS FOR OCCUPATIONAL RADIATION PROTECTION IN AN EMERGENCY Donald COOL *(USNRC, US)- ICRP Committee 4*
09:45/1.02	PROTECTION OF EMERGENCY WORKERS AND HELPERS: RECENT DEVELOPMENTS IN INTERNATIONAL STANDARDS IN EMERGENCY PREPAREDNESS AND RESPONSE Svetlana NESTOROSKA MADJUNAROVA *(IAEA IEC)*
10:05/1.03	CNSC RESPONSE TO FUKUSHIMA AND ENHANCEMENTS TO THE REGULATORY FRAMEWORK FOR THE PROTECTION OF WORKERS Terry JAMIESON *(CNSC, Canada)*
10:25/1.04	LESSONS LEARNED FROM TMI AND HOW IT CHANGED THE REGULATORY FRAMEWORK IN THE US Roger PEDERSEN *(USNRC, US)*
Plenary Session 2	ISOE EXPERT GROUP INTERIM REPORT
11: 15	**Session chaired by Ellen P. Anderson (NEI), EG-SAM Chair**
11:20/2.01	RADIATION PROTECTION MANAGEMENT AND ORGANISATION David MILLER *(NATC, Cook NPP, US)* - EGSAM Vice-Chair
11:30/2.02	RADIATION PROTECTION TRAINING AND EXERCISES RELATED TO SEVERE ACCIDENT MANAGEMENT Salah DJEFFAL *(CNSC, Canada)* - EGSAM Vice-Chair
11:40/2.03	FACILITY CONFIGURATION AND READINESS James P. TARZIA *(RSCS, US)*
11:50/2.04	OVERALL APPROACH ON THE PROTECTION OF WORKERS Claudia SCHMIDT *(GRS, Germany)*
12:00/2.05	MONITORING AND MANAGING THE RADIOACTIVE MATERIALS RELEASES AND CONTAMINATION Karin FRITIOFF *(Vattenfall AB, Sweden)*
12:10/2.06	KEY LESSONS LEARNED FROM PAST ACCIDENTS Caroline SCHIEBER *(CEPN, France)*
Plenary Session 3	EXPERIENCES, VIEWS AND APPROACHES – UTILITY PERSPECTIVES

13: 30	**Session chaired by Caroline SCHIEBER (CEPN)**
13:35/3.01	RADIATION PROTECTION MANAGEMENT IN FUKUSHIMA DAIICHI NPS AND POST-ACCIDENT MEASURES Shiro TAKAHIRA *(TEPCO, Japan)*
13:55/3.02	POST-FUKUSHIMA IMPROVEMENT OF THE EMERGENCY PLAN FOR THE ELECTRABEL NUCLEAR POWER PLANTS – FOCUS ON THE RADIOLOGICAL ASPECT Benoit LANCE *(Electrabel, Belgium)*
14:15/3.03	EDF FARN (FAST ACTION FORCE IN CASE OF NUCLEAR ACCIDENT) - FOCUS ON RADIATION PROTECTION OF WORKERS Bernard LE GUEN *(EDF, France)*
14:35/3.04	SEVERE ACCIDENT MANAGEMENT: RADIATION DOSE CONTROL, FUKUSHIMA DAIICHI AND TMI-2 NUCLEAR PLANT ACCIDENTS Roger SHAW *(Shaw Partners LLC, US)*
14:55/3.05	ONTARIO POWER GENERATION FUKUSHIMA EMERGENCY RESPONSE DRILL STRENGTHENS AND LESSONS LEARNED David MILLER *(NATC, Cook NPP, US)* - EGSAM Vice-Chair
16:00 – 17:30	BREAKOUT SESSIONS BREAKOUT SESSION 1: RADIATION PROTECTION MANAGEMENT AND ORGANISATION Rapporteur: David MILLER *(Cook NPP, US)* - EGSAM Vice-Chair Co-Rapporteur: Ellen ANDERSON *(NEI, US)* BREAKOUT SESSION 2: RADIATION PROTECTION TRAINING AND EXERCISES RELATED TO SEVERE ACCIDENT MANAGEMENT Rapporteur: Albert WILEY *(ORAU,REAC/TS, US)* Co-Rapporteur: Derek HAGEMEYER *(ORAU, US)* BREAKOUT SESSION 3: FACILITY CONFIGURATION AND READINESS Rapporteur: James P. TARZIA *(RSCS, US)* Co-Rapporteur: Terry BROCK *(NRC, US)*
17:30	Closure of 1st day

18 JUNE 2014

Plenary Session 4	VIEWS AND APPROACHES – REGULATORY AUTHORITY PERSPECTIVES
08: 30	Session chaired by Marie-Line PERRIN (ASN)
08:35/4.01	CNSC EOC TECHNICAL ASSESSMENT AND EVALUATION INITIATIVES Christopher COLE *(CNSC, Canada)*
08:55/4.02	FRENCH REGULATORY REQUIREMENTS FOR THE OCCUPATIONAL RADIATION PROTECTION IN SEVERE ACCIDENT SITUATIONS AND POST ACCIDENT RECOVERY Olivier COUASNON *(ASN, France)*
09:15/4.03	SEVERE ACCIDENT MANAGEMENT GUIDELINES Jennifer UHLE *(NRC, US)*
09:35/4.04	RADIATION PROTECTION ISSUES RAISED IN KOREA SINCE FUKUSHIMA ACCIDENT Byeongsoo KIM *(KINS, Republic of Korea)*
09:55/4.05	FINNISH EXPERIENCE ON EMERGENCY PREPAREDNESS CO-OPERATION WORK AND RESULTS Jukka SOVIJARVI *(STUK, Finland)* - EGSAM Vice-Chair
10:30	*Networking Break*
11:00 – 12:30	BREAKOUT SESSIONS (Cont'd) BREAKOUT SESSION 4: OVERALL APPROACH ON THE PROTECTION OF WORKERS Rapporteur: Rick DOTY *(NATC, US)* Co-Rapporteur: Jerry HIATT *(NEI, US)*

	BREAKOUT SESSION 5: MONITORING AND MANAGING THE RADIOACTIVE MATERIALS RELEASES AND CONTAMINATION
	Rapporteur: Karin FRITIOFF *(Vattenfall AB, Sweden)* Co-Rapporteur: Caroline SCHIEBER *(CEPN, France)*
Plenary Session 5	BREAKOUT SESSIONS SUMMARY REPORTS
13: 30	Session chaired by H. Burçin OKYAR (NEA)
13:35/5.01	Breakout session 1 Report David MILLER *(Cook NPP, US)*
13:55/5.02	Breakout session 2 Report Albert WILEY *(ORAU, US)*
14:15/5.03	Breakout session 3 Report James P. TARZIA *(RSCS, US)*
14:35/5.04	Breakout session 4 Report Rick DOTY *(NATC, US)*
14:55/5.05	Breakout session 5 Report Karin FRITIOFF *(Vattenfall AB, Sweden)*
16:00	CONCLUDING SESSION
	Session chaired by Ellen P. ANDERSON (NEI), EG-SAM Chair and co-chaired by Patricia JONES (Exelon Corp)
16:05	DIRECTION FORWARD FOR THE FINALIZATION OF THE EXPERT GROUP REPORT H. Burçin OKYAR *(NEA)*
16:25	OPEN DISCUSSION, COMMENTS AND RECOMMENDATIONS
17:30	*Closure of the Workshop*

WORKSHOP PROGRAMME COMMITTEE

Willie O. HARRIS
ISOE Chair, Exelon Nuclear, United States of America

Ellen P. ANDERSON
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James P. TARZIA
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Workshop Scientific Secretary

Halil Burçin OKYAR, OECD NEA, France

APPENDIX - 3 ISOE PROGRAMME

ISOE was created in 1992 to improve the management of occupational exposures at nuclear power plants through the collection and analysis of occupational exposure data and trends, and through the exchange of lessons learned among utility and national regulatory authority experts. Since then, the system has grown continuously and now provides participants with a comprehensive resource for optimising occupational exposure management at nuclear power plants worldwide.

Membership in ISOE includes representatives from nuclear electricity utilities and national regulatory authorities who participate under the ISOE Terms and Conditions. The ISOE programme includes the participation of utilities and regulatory authorities in 29 countries. The ISOE database itself contains information on occupational exposure levels and trends at 482 reactor units worldwide (401 operating units and 81 units in cold-shutdown or some stage of decommissioning), covering about 91% of the world's operating commercial power reactors. To find out more about the ISOE programme: www.isoe-network.net

ISOE is jointly sponsored by the OECD Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA). ISOE operates in a decentralized manner. A Management Board of representatives from all participating countries, supported by the joint NEA and IAEA Secretariat, provides overall direction.

ISOE JOINT SECRETARIAT

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Four ISOE Technical Centres (Europe, North America, Asia and IAEA) manage the programme's day-to-day technical operations, serving as contact point for the transfer of information from and to participants.

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APPENDIX – 4 ISOE EXPERT GROUP ON OCCUPATIONAL RADIATION PROTECTION IN SEVERE ACCIDENT MANAGEMENT, MEMBERS LIST

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Vice-Chairs:	DJEFFAL, Salah (Canada), MILLER, David (US), SOVIJARVI, Jukka (Finland)

ARMENIA		
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	THOELEN, Els	Electrabel, DOEL NPP
	LANCE, Benoit	Electrabel, Corporate Nuclear Safety Department
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	DO AMARAL, Marcos Antonio	EletrobrásTermonuclear S.A.
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	DJEFFAL, Salah	Canadian Nuclear Safety Commission (CNSC)
	PRITCHARD, Colin	Bruce Power
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	FUCHSOVA, Dagmar	State Office for Nuclear Safety (SÚJB)
	HORT, Milan	State Office for Nuclear Safety (SÚJB)
	KOC, Josef	National Radiation Protection Institute (NRPI)
FINLAND		
	SOVIJARVI, Jukka	Radiation and Nuclear Safety Authority (STUK)
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	BELTRAMI, Laure-Anne	CEPN – ISOE ETC
	COUASNON, Olivier	Autorité de Sûreté Nucléaire (ASN)
	LECOANET, Olivier	EDF - DPN / UNIE - GPRE
	SCHIEBER, Caroline	CEPN – ISOE ETC
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	ITOH, Kunio	Japan NUS Co., Ltd.
	SUZUKI, Akiko	JNES – ISOE ATC
	USUI, Haruo	JNES – ISOE ATC
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	KONG, Tae Young	KHNP Central Research Institute

PAKISTAN		
	MUBBASHER, Makshoff	Chashma NPP
ROMANIA		
	SIMIONOV, Vasile	Cernavoda NPP
RUSSIAN FEDERATION		
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	GRUBEL, Stefan	Slovenské elektrárne, a.s.
SPAIN		
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	RENN, Guy	Sizewell B NPP
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	BRONSON, Frazier	Canberra Industries
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ISOE SECRETARIAT		
	OKYAR, Halil Burçin	OECD NEA