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Accident Management Insights after the Fukushima Daiichi NPP Accident

Report of the CNRA Task Group on Accident Management

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NUCLEAR ENERGY AGENCY
COMMITTEE ON NUCLEAR REGULATORY ACTIVITIES

ACCIDENT MANAGEMENT INSIGHTS AFTER THE FUKUSHIMA DAIICHI NPP ACCIDENT

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FOREWORD

The Fukushima Daiichi nuclear power plant (NPP) accident, that took place on 11 March 2011, initiated a significant number of activities at the national and international levels to reassess the safety of existing NPPs, evaluate the sufficiency of technical means and administrative measures available for emergency response, and develop recommendations for increasing the robustness of NPPs to withstand extreme external events and beyond design basis accidents. The OECD Nuclear Energy Agency (NEA) is working closely with its member and partner countries to examine the causes of the accident and to identify lessons learnt with a view to the appropriate follow-up actions to be taken by the nuclear safety community [1].

Accident management is a priority area of work for the NEA to address lessons being learnt from the accident at the Fukushima Daiichi NPP following the recommendations of Committee on Nuclear Regulatory Activities (CNRA), Committee on the Safety of Nuclear Installations (CSNI), and Committee on Radiation Protection and Public Health (CRPPH). Considering the importance of these issues, the CNRA authorised the formation of a task group on accident management (TGAM) in June 2012 to review the regulatory framework for accident management following the Fukushima Daiichi NPP accident. The task group was requested to assess the NEA member countries needs and challenges in light of the accident from a regulatory point of view.

The TGAM members participating in this review included:

- Mr. Didier Degueldre, Bel V (Belgium)
- Dr. Alexandre Viktorov, CNSC (Canada)
- Ms. Minna Tuomainen, STUK (Finland)
- Mr. Francois Ducamp, ASN (France)
- Dr. Yves Guigueno, IRSN (France)
- Ms. Sophie Chevalier, ASN (France)
- Dr. Daniel Tasset, IRSN (France)
- Mr. Marcus Heinrich, GRS (Germany)
- Dr. Matthias Schneider, BFS (Germany)
- Mr. Toshihiro Funahashi, JNES (Japan)
- Dr. Akitoshi Hotta, JNES (Japan)
- Mr. Mitsuhiro Kajimoto, JNES (Japan)
- Dr. Dae-Wook Chung, KINS (Korea)
- Ms. Laima Kuriene, ILT (Netherlands)
- Ms. Nadezhda Kozlova, SEC NRS (Russian Federation)
- Mr. Tomi Zivko, SNSA (Slovenia)
- Mr. Santiago Aleza, CSN (Spain)
- Dr. John Jones, ONR (United Kingdom)

- Mr. Jack McHale, USNRC (United States)
- Mr. Ho Nieh (Chairman), USNRC (United States)
- Mr. Ghislain Pascal, JRC (European Commission)
- Mr. John Nakoski, OECD/NEA
- Dr. Victor Neretin, OECD/NEA
- Mr. Takayoshi Nezuka, OECD/NEA

The general objectives of the TGAM review were to consider:

- enhancements of on-site accident management procedures and guidelines based on lessons learnt from the Fukushima Daiichi NPP accident;
- decision-making and guiding principles in emergency situations;
- guidance for instrumentation, equipment and supplies for addressing long-term aspects of accident management;
- guidance and implementation when taking extreme measures for accident management.

The report is built on the existing bases for capabilities to respond to design basis events and accidents at NPPs, and what additional measures should be considered as an accident progresses to the severe accident stage. Insights are provided on the experiences and practices existing or being proposed in the NEA member states, as well as new findings from post-Fukushima studies.

Emphasis is placed on identifying commendable practices that support enhanced and integrated on-site accident management response and decision-making by NPP operators. The report provides information (including commendable practices) useful for regulatory authorities to consider as they implement enhancements to their regulatory framework in the area of integrated accident management building on the lessons learnt from the Fukushima Daiichi NPP accident.

The report’s insights also should be useful to regulatory authorities, operating organisations and others in the nuclear safety community for addressing accident management issues such as procedures and guidelines, equipment, infrastructure and instrumentation, and human and organisational resources. Factors such as accidents involving spent fuel pools, multi-unit aspects of accident management, the interface between on-site and off-site organisations and resources, and degradation of the surrounding infrastructure are also discussed.

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EXECUTIVE SUMMARY

The Fukushima Daiichi nuclear power plant accident demonstrated the importance of increasing the robustness of NPPs to extreme external conditions and beyond design basis accidents. In this respect, the development of the integrated accident management (IAM) approach is an important step in achieving the goal of increased robustness.

IAM is the expansion of existing accident management approaches into a comprehensive approach, combining current good practices and new findings coming from post-Fukushima studies that incorporates all arrangements needed to manage as efficiently as possible any accident affecting the NPP with potential release of radioactive material. The IAM approach intends to integrate all available on-site and off-site resources, even if not primarily dedicated for accident management: infrastructures, equipment, and human and organisational resources.

It addresses accidents resulting from all kinds of initiators, originating from failures of structures, systems or components (including human-induced failures) or natural and man-made hazards, affecting any part of the NPP, in particular the reactor(s) or the spent fuel pool(s), including possible combinations of affected installations (multi-unit accidents). It also addresses all operating states of the reactor (operating or shutdown), the kinetics, and the duration of the accident (long or short duration).

The IAM concept was developed through the joint efforts of member states' representatives who, in spite of their different experiences and backgrounds and the complexity of the problem, collaborated and agreed on a common view of the issues discussed. An important goal of IAM was considered to be the right balance and prioritisation of preventive and mitigating arrangements. The Task Group on Accident Management understood this to be the prevention of severe accidents as fully as reasonably possible, and at the same time, to be ready to minimise the consequences of a severe accident, should one occur.

This report was developed based on this approach and highlights commendable practices in the following areas: "Procedures and guidelines", "Equipment, infrastructure and instrumentation", and "Human and organisational resources".

Procedures and guidelines

Emergency operating procedures and severe accident management guidelines should cover all operating modes, cover accidents occurring in the spent fuel pool, long-term aspects, and multi-unit accidents.

Integrated accident management procedures and guidelines should take full advantage of existing plant capabilities (fixed or mobile), if necessary going beyond the originally intended functions of some systems and using some temporary or ad hoc systems to achieve the goal of enhancing plant safety for beyond design basis accidents.

Severe accident management guidelines should take into account additional factors, including: significantly damaged infrastructure, the disruption of plant level, corporate-level and national-level communication, long-duration accidents, and accidents affecting multiple units and nearby industrial facilities at the same time.

Emergency operating procedures and severe accident management guidelines should be comprehensively verified and validated taking due account of the potential long duration of the accident, the degradation of the plant and the surrounding conditions.

The transition between different sets of procedures and guidelines should be clearly specified and justified with regard to the design of the plant as well as the interactions between the different organisations (on-site and off-site) that have been established.

Equipment, infrastructure and instrumentation

The systems, equipment and instrumentation should be foreseen to prevent the escalation of an event into a severe accident and to mitigate the consequences of a severe accident. Systems and equipment would include those needed to cool the core and the spent fuel pool, maintain containment integrity, manage combustible gases (such as hydrogen) and provide for filtered containment venting. Also, instrumentation that enables performing well-timed operator actions, surveying the effectiveness of the actions and monitoring the progress of the accident should be included. The systems, equipment and instrumentation should withstand the harsh conditions of the accident (e.g. very high temperatures, high radiation levels etc.), taking into account that it may be required to remain operable for a considerable period of time (several months or more). Consideration should be given to both fixed and mobile equipment.

If the main control room (MCR) is lost, a secondary location (either a centralised control station or a distributed one making use of local measurements and controls) should be provided to monitor and control the plant state or accident progression. Whatever the arrangement, it should be ensured that the reason for the loss of the MCR (fire, smoke, high radiation, physical damage, man-made hazard, etc.) does not endanger the use of the secondary control location(s).

In beyond design basis accidents (BDBAs), systems and equipment for cooling the reactor core and the fuel pools should be independent of normal/emergency power supplies and heat sink (e.g. diesel- or turbine-driven pumps with alternate water sources). Sufficient battery capacity or portable power supplies need to support severe accident instrumentation and other essential systems and equipment in an extended period of station blackout.

Personal protective equipment and portable shielding should be ensured to allow site operations to continue in harsh conditions. The responders should be provided with emergency lighting in key areas of plant as required for emergency response.

To ensure the availability of the mobile equipment when needed, responsibilities and routines should be well defined for managing the equipment (e.g. storage, maintenance, testing, transfer, and training). A strategy for pre-emptive deployment of mobile equipment in the event of an anticipated hazard should be considered.

Human and organisational resources

Evaluation of staffing needs to ensure an adequate number of personnel are available to respond to a major event taking into account long duration and multi-unit accidents.

Use training needs analyses to identify gaps with regard to training for implementation of the IAM plan. Implement principles of the systems approach to training to develop appropriate training for each class of emergency responder based upon the individual’s role in the IAM response. Include an appropriate level of training for off-site responders, such as fire brigades, medical personnel and subcontractors. Use plant reference simulators to the extent possible in conducting training for beyond design basis accidents and desktop computer or table top exercises when limits of simulation are reached.

Use a combination of periodic drills and exercises to test the full range of emergency response capabilities. Enhance realism by including off-hours drills, reduced availability of responders, long duration and multi-unit accident scenarios. Include co-ordination with other response organisations as part of drill/exercise scenarios, to include local, state and national government counterparts, news media, and neighbouring countries.

Strengthen infrastructure to enhance readiness of the initial and sustained responses, to include diverse means of communication for personnel recall and event command and control, as well as hardened or alternate command and control centres. Evaluate and obtain needed resources (food, water, shelter, sanitation and medical care), instrumentation, radiation protection equipment for responders, monitoring devices and shielding to support a sustained response.

1. GUIDING PRINCIPLES FOR INTEGRATED ACCIDENT MANAGEMENT

1.1. Introduction

The Fukushima Daiichi NPP accident demonstrated the importance of increasing the robustness of NPPs to extreme external conditions and beyond design basis accidents. In this respect, the CNRA established the Task Group on Accident Management (TGAM) to review the regulatory framework for accident management following the accident. The TGAM considers developing the concept of "Integrated accident management" an important step in achieving the goal of increased robustness. This concept is intended to build upon existing good practices and take into account new findings from post-Fukushima studies. This report was developed based on an IAM concept and provides insights for regulatory bodies to consider in the following areas: "Procedures and guidelines", "Equipment, infrastructure and instrumentation", and "Human and organisational resources".

The report highlights the common views on IAM and considered feedback from participating NEA member states and associated countries. The TGAM developed a survey that was sent to CNRA participating countries and international organisations and the responses have been used in preparing this report. The main objective of the report is to identify commendable practices in the areas covered by the TGAM. In general, information in the report was derived from existing international standards and regulatory practices, survey responses and the experience of the participating TGAM members. In certain noteworthy areas of accident management, the TGAM identified commendable practices for consideration by member countries based on lessons learnt from the Fukushima Daiichi NPP accident.

The scope of the TGAM activities is primarily focused on NPPs, but some aspects of the report may also be applied for research reactors or transposed to other nuclear facilities. In principle the report is not design specific. However, it is related mainly to light water reactors, because most facilities in NEA member states are based on such technology. The report not only covers the reactors in operation; but also reactors that have been permanently shut down and still contain fuel; and reactors in the design phase or under construction as well as the spent fuel pool(s).

1.2. Definition of Integrated Accident Management

Integrated accident management is the expansion of existing accident management approaches into a comprehensive approach, combining current good practices and new findings coming from post-Fukushima studies that incorporates all arrangements needed to manage as efficiently and effectively as possible any accident affecting an NPP with potential release of radioactive material.

It addresses accidents resulting from all kinds of initiators, originating from failures of structures, systems or components (including human-induced failures) or natural and man-made hazards, affecting any part of the NPP, in particular the reactor(s) or the spent fuel pool(s), including possible combinations of affected installations (multi-units accidents). It also addresses all operating states of the reactor (operating or shutdown), the kinetics, and the duration of the accident (long or short duration).

The IAM approach intends to integrate all available on-site and off-site resources, even if not preliminary dedicated for accident management: infrastructures, equipment, and human and organisational resources. In this respect, it will also include the transition from preventive actions to mitigative actions.

1.3. Goals and objectives

The overarching goal of IAM is to extend the implementation of the defence-in-depth (DiD) concept to ensure that reasonable levels of safety can be achieved to protect people (workers and the public) and the environment from harmful effects of ionising radiation arising from NPPs, taking into account new lessons learnt from the Fukushima Daiichi NPP accident, to account for uncertainty in BDBA conditions, and to be prepared for unforeseen events. The IAM approach covers the whole spectrum of any accident affecting an NPP, but is focused on BDBAs. It applies to accident conditions more severe than a design basis accident (DBA), and may or may not involve nuclear fuel degradation. The objectives of IAM are to prevent the escalation of an event into a severe accident, to mitigate the consequences of a severe accident if one occurs, and to achieve a long-term safe stable state of the NPP. In accordance with the general DiD concept, IAM includes both preventive and mitigative arrangements in a graded approach emphasising preventing severe accidents first, and if this fails, to mitigate, as appropriate, the consequences. Therefore, as a guiding principle, priority should be assigned to the preventive arrangements, and if significant fuel damage has occurred, the priority should shift to mitigative arrangements.

The preventive arrangements of IAM aim to prevent significant fuel degradation or damage in the reactor core as well as in the spent fuel pool(s), or terminate the progress of fuel degradation or damage once it has started. The mitigative arrangements aim to ensure as efficiently as possible the integrity of the containment and the spent fuel pool building if any, in order to minimise radioactive releases into the environment.

1.4. Abstract of the report

While IAM as defined above covers the whole spectrum of events affecting the NPP, it is focused on the BDBAs that may or may not involve core or fuel damage.

1.4.1. Procedures and guidelines

In view of the definition given above and the overarching goal for IAM, the procedures and guidelines existing at NPPs should be reviewed to consider the main aspects of IAM. The procedures and guidelines should cover the whole range of possible accidents at NPPs, considering the possibility of fuel damage in all locations (i.e., in the reactor, in the spent fuel pool). It is also important to take into account the possibility of a long duration accident and the possibility of multi-unit accidents. All operating states (operating or shutdown) and the duration of the accident should be covered by these procedures. Emergency procedures and guidelines should cover the phases of the accident as it transitions to a BDBA, including severe fuel damage, by including appropriate preventive and mitigative strategies that identify priorities for preventive and mitigative measures as well as the balance between them at the different stages of an accident. Furthermore, criteria should be established for transitions from preventive to mitigative approaches. The strategies for BDBA management described in procedures and guidelines, including severe accident management (SAM) strategies (if appropriate), should be based on the results of respective accident analyses and experimental data.

The IAM approach intends to harmonise all procedures and guidelines existing at an NPP, providing consistency in strategies used at each stage of an accident as it escalates using defined criteria and rules for transition from one guideline or procedure to another. As the procedures and guidelines are developed, the format and content will depend on the existing level of knowledge of the phenomenology of the BDBA. The IAM approach should consider using all available on-site resources for accident management, and other means suitable for accident management that can be promptly delivered from outside (off-site). The IAM approach embodies the idea of routinely and consistently upgrading procedures and guidelines, taking into consideration implemented NPP modernisation, operational experience and upgraded knowledge of BDBA phenomenology. Integral to the IAM approach are the description of operational personnel’s responsibility in the procedures and guidelines, the transfer of responsibilities when transitioning from the preventive to the mitigative stage and the consideration of interrelations of on-site and off-site accident management actions.

1.4.2. Equipment, infrastructure and instrumentation

To achieve enhanced robustness of NPPs under BDBA conditions, the equipment, infrastructure and instrumentation that would be relied upon when implementing IAM should be able to withstand:

- phenomena, and combinations of phenomena, exceeding those considered within the plant design basis;
- situations with prolonged loss of electrical power or heat sinks affecting the reactors and/or spent fuel pools;
- multi-unit events;
- potential cliff edge-effects caused by such situations.

Implementation of actions to enhance the robustness of NPPs provides additional margins compared to the current baseline safety requirements to address the uncertainty and the unknown related to extreme external events. In particular, reinforced or alternative emergency management facilities and additional or alternative equipment dedicated to providing emergency electrical power supplies and water sources should be included. To that purpose, technical resources and arrangements to ensure the basic safety functions in these extreme situations should be defined to meet the overarching goal of IAM as described above. In particular, the systems, structures and components (SSCs), including mobile equipment, dedicated to IAM should be kept in a functional state and should be protected against on-site and off-site hazards. Accidents caused by internal failures and well as those initiated by external hazards, both natural and man-made, should also be considered.

1.4.3. Human and organisational resources

It is acknowledged, internationally, that the prime responsibility for nuclear safety remains with the licensee [2]. The experience from the Fukushima Daiichi NPP accident confirmed that within the NPP organisation, the roles and responsibilities of the operating personnel and the NPP response team(s) needed to be clearly defined, taking into account the degradation of the surrounding infrastructure, long-duration accidents and multi-unit events. It also showed that the ability of licensee organisations to work together during an emergency is a key factor in achieving a successful response. For this purpose, the licensee should define the required accident management response actions, supporting procedures and guidelines, who will perform them (its personnel, its subcontractors or other emergency responders), as well as taking into account crew shift changes and the required intervention logistics. In addition, the licensee should provide its personnel that are likely to intervene during extreme and stressful situations with education, knowledge, skills, training and support arrangements to assure their readiness for mobilisation in such situations, even though their probability of occurrence is very low.

Accident management arrangements should include provisions related to the psychological and health care to be provided for the NPP response team(s). The arrangements should also address measures to protect responders from radiation and industrial hazards or other extreme environmental conditions, and include appropriate communication and monitoring systems. The licensee should ensure that similar arrangements are provided for those subcontractors and corporate level emergency responders that are likely to intervene in the event of an accident. Such arrangements should be discussed with public emergency response organisations and local authorities that would be involved in off-site accident management as well.

The licensee's organisation and the response actions planned in case of a severe accident should be regularly tested through drills and exercises. This should also be used as an opportunity to test the strategies as well as the interface between on-site and off-site accident management organisations and local authorities.

2. PROCEDURES AND GUIDELINES

2.1. Introduction

The existence of appropriate procedures and guidelines for implementing the strategies based on fixed or mobile equipment is an important part of IAM. To achieve the goal of the IAM approach, a licensee should establish and maintain procedures and guidelines (operational procedures and practices as well as accident management procedures) and arrangements to ensure it is capable of implementing prevention and mitigation strategies for accidents under all conditions.

One of the conclusions of the European Union (EU) Stress Test and Peer Review process [3] is that “Basic SAM components including organisational, procedural and technical means are already well-established”. Nevertheless, in other conclusions based on this process, it is stated that one of the lessons learnt from the Fukushima Daiichi NPP accident is that the scope of SAM needs to be extended to take into account the following: plant shutdown states; multi-unit events; long-duration events; accidents initiated in spent fuel pools; devastated site and surrounding conditions; harsh environments; and widespread contamination. There is significant work ongoing in this area by Member countries and other international organisations [4].

This section covers the different aspects of procedures and guidelines for IAM. Within this section are commendable practices that have been identified by the TGAM to enhance procedures and guidelines building upon some already existing international practices and on the work performed after the Fukushima Daiichi NPP accident. Critical for the successful implementation of the strategies during an emergency is to ensure appropriate training of responders on the procedures and guidelines to be followed. This aspect of IAM is discussed in section 4, “Human and organisational resources”, of this report.

The type of guidance that is covered in this section is related, in principle, to all the possible guidance that is provided on-site to respond to an accident. There are different types of guidance documents for the management of an accident (operating, fire-fighting, radiological protection, on-site emergency plan procedures and guidelines, etc.). In this section, the focus is placed on operating guidance and in particular on Emergency Operating Procedures (EOPs) and Severe Accident Management Guidelines (SAMGs) that will be used in a broad sense.

It is important to state that for simplicity, this report generally describes procedures and guidelines as falling into one of two categories, either EOPs or SAMGs. Rather than the traditional convention of describing EOPs as purely responsive to DBAs or as functional recovery procedures, the distinction in this report is made based on the presence or absence of fuel damage. This categorisation stretches the conventionally understood scope of EOPs to cover other procedures and guidelines, such as abnormal operating procedures, extensive damage mitigating guidelines and any other procedures/guidelines used to prevent core damage, whether or not they are based on purely traditional DBA considerations. Thus, the use of EOP in the context of this report represents a broader scope than the traditional definition of the term. Similarly, SAMG is used to refer in a very broad sense to all procedures and guidance for situations involving fuel damage. Although the terms EOP and SAMG are used in this report to conveniently group sets of procedures and guidelines for discussion purposes, the TGAM is not suggesting that regulatory bodies require a complete restructuring or redefinition of the current set of procedures and guidelines in use at NPPs.

To simplify understanding within the content of this report, the term EOP is broadened to include all types of procedures and guidance for both DBAs and BDBAs without the onset of the fuel damage. The term SAMG is used to include all types of procedures and guidance for severe accidents that includes fuel damage either in the core or within the spent fuel pools (SFPs). The structure and format of operating documents may not be the same in all countries - manuals, handbooks, procedures and guidelines are typically used. For ease of discussion within this report, procedures and guidelines that may be used to manage the fixed or mobile equipment under the IAM approach where there is extensive damage to the site or surrounding infrastructure are included in the concepts of EOPs and SAMGs (i.e., Extensive damage mitigation guidelines [5] and the broader concept of "Diverse and flexible coping strategies (FLEX)" [6] being developed and implemented in the USA).

2.2. Scope and objectives of procedures and guidelines

The goal in managing an accident is to return the plant to a controlled state in which the nuclear chain reaction is essentially terminated, continued fuel cooling is ensured and radioactive materials are confined [7], the so-called safe stable state.

To achieve the goal of establishing and maintaining the safe stable state, a comprehensive, integrated set of accident management procedures and guidelines should exist. This set of procedures includes EOPs (including other procedures and guidelines as described in subsection 2.1) for DBAs and BDBAs without fuel damage, and SAMGs for BDBAs with fuel damage. EOPs are typically focused on the design basis realm, but the existing packages of EOPs include provisions for accidents where the design basis has been exceeded. Examples include the use of critical safety functions/objectives of protection/plant states (for PWR) or contingencies in symptom oriented trees (for BWR).

In accordance with the general DiD concept, the scope of IAM includes both preventive and mitigative procedures and guidelines in a graded approach emphasising first preventing severe accidents, and if this fails, to mitigate the consequences.

In line with the IAEA definitions [7], the purpose of EOPs is to guide the control room staff and other emergency response personnel in preventing fuel degradation, making maximum use of all existing plant equipment including equipment that is not part of the standard plant safety systems. In addition, SAMGs for use by the technical support centre (TSC) (or equivalent) or crisis teams during severe accidents should be implemented. The SAMGs would consider actions that may have potential positive and negative effects as well as operational and phenomenological uncertainties. According to the lessons learnt from the Fukushima Daiichi NPP accident [8] and the IAEA [4, 9, 10] and the European Nuclear Safety Regulators Group (ENSREG) documents [11], the TGAM considers that it is a **commendable practice** for EOPs and SAMGs to cover:

- all operating modes from full power to various shutdown and outage conditions [9, 10];
- accidents occurring in the SFPs [11];
- long-term and multi-unit accidents [11].

It is also a **commendable practice** that accident management strategies and especially accident procedures and guidelines take full advantage of existing plant capabilities (fixed or mobile), if necessary going beyond the originally credited operational limitations of the existing equipment and the design functions of some systems, and using temporary or ad hoc systems to achieve this goal.

In some countries, SAMGs are currently implemented on a voluntary basis rather than through a specific regulatory requirement. The Fukushima-Daiichi NPP accident highlighted the importance of establishing a regulatory framework covering SAMGs for severe accident scenarios.

2.2.1. Preventing fuel damage

In the prevention domain of accident management for DBAs (including some BDBAs without fuel damage and some unpredicted accident scenarios) EOPs are developed and provide instructions for actions to recover the plant state to a safe condition [7] with the objective of re-establishing or compensating for lost safety functions and to set out actions to prevent fuel damage.

The TGAM considers as a **commendable practice** that these actions include (for LWRs and PHWRs) as a minimum[1]:

- establishment and maintenance of reactivity control in the reactor and in the SFP;
- assurance of availability of heat sink for heat generated in the reactor core and in the SFP;
- control of pressure and water inventory in the primary heat transport system;
- control of pressure and water inventory in secondary heat transport system;
- assurance of containment isolation;
- control of the containment pressure and temperature;
- control of the concentration of hydrogen and other combustible gases;
- control of unfiltered releases of radioactive products;
- control of temperature and water inventory in the SFP.

Undergirding these actions is the importance of assuring that electrical power is available to effectively implement these actions and to monitor plant and environmental conditions during accident progression. The scope of the above mentioned actions should take into account internal and external events.

Deterministic and probabilistic approaches have been shown to complement one another and can be used together to provide input into an integrated decision making process and consequently support the development of accident management procedures and guidelines.

EOP development for each NPP can be supported by a plant-specific Level 1 probabilistic safety assessment (PSA), by safety analyses performed within the final safety analyses report (FSAR) and by specific analyses. The scope of EOPs also needs to be consistent with regulatory body requirements and with operational experience feedback (e.g. plant-specific, domestic, and international). Within the scope of EOP development, the possibility to cope with accidents as they evolve and to provide re-diagnostic capabilities for the operators to cope with potential mistakes should also be considered.

As a **commendable practice** the TGAM considers it important that the scopes of the plant-specific Level 1 PSA and of the deterministic safety analyses used for the development of EOPs consider, as necessary, external/internal events, all the plant states, multi-unit events, SFP and long-duration accidents.

2.2.2. Mitigating the consequences of severe accidents

SAMGs are provided to mitigate the consequences of severe accidents for the cases where the measures provided by EOPs have not been successful in the prevention of fuel damage. The main goals of SAM strategies and related procedures and guidelines in the mitigation domain are [9]:

- terminate the progress of fuel damage once it has started;
- maintain the integrity of the last barrier against the release of radioactive material (containment, confinement and SFP building if any), as long as possible;
- minimise the release of radioactive material;
- achieve a long-term safe stable state.

For LWRs, this would include having SAMGs covering as a minimum the following aspects [11]:

- injection to the steam generator/nuclear boiler/reactor core/containment;

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[1] Additional actions may be required for different NPP technologies.

- reliable depressurisation of the reactor coolant system in order to prevent high-pressure core melt;
- hydrogen monitoring and mitigation (inside and outside the containment);
- containment and the SFP building (if any) integrity and overpressure protection;
- molten corium stabilisation;
- mitigation of releases.

To develop SAMGs and determine their respective scope of coverage (in particular versus EOPs), a combination of deterministic and probabilistic assessments as well as engineering judgement are generally used. Furthermore, the scope of the above-mentioned actions should take into account internal and external events as SAMGs are developed.

To select and assess accident sequences that could lead to fuel damage states, and finally to containment and/or SFP building damage and the release of radioactive material to the environment, a plant-specific Level 2 PSA would be desirable to quantify containment damage states and the contribution of particular accident sequence categories to risks. However, even if a plant-specific Level 2 PSA has not been completed for the NPP, alternative methods should be defined to choose categories of sequences that contribute significantly to risks at the NPP and to define the scope of SAMGs accordingly.

As a **commendable practice** the TGAM considers it important to assure that the scopes of the plant-specific Level 2 PSA and the deterministic safety analyses used for the development of SAMGs consider, as necessary, external/internal events, all the plant states, multi-unit events, SFP and long-duration accidents.

Acknowledging that PSA is an essential tool for screening and prioritising safety improvements and for assessing the completeness of SAM strategy implementation, a recommendation coming from the EU Stress Tests is that low numerical risk estimates should not be used as the sole basis for excluding scenarios from consideration for SAMG development. This is especially important if the consequences are very high [11].

2.2.3. Additional points to be taken into account when developing procedures and guidelines

As a result of the lessons learnt from the Fukushima Daiichi NPP accident, the TGAM considers as a **commendable practice** that while developing plant accident management procedures and guidelines the following are clearly identified, included or considered [6]:

- site-specific actions necessary for the timely restoration of AC power to essential loads, including alternate AC power sources;
- the loads that need to be stripped from the plant DC buses (both safety graded and non-safety graded loads) for the purpose of conserving DC power;
- the need for a flow path to be promptly established for make-up flow to the steam generator/nuclear boiler/reactor core during the early stages of the event and the necessity to direct the operators to invest appropriate attention to assuring its initiation and continued, reliable operation throughout the transient since this ensures decay heat removal;
- the need to identify backup water sources in order of intended use, including clear criteria for transferring to the next preferred source of water;
- the use of portable equipment, (e.g., portable power supplies, portable pumps, etc.) including in particular the transitions from installed sources to portable sources used to extend the plant coping capability;
- the sources of potential reactor inventory loss, and specific actions to prevent or limit significant loss;
- the actions to permit appropriate containment isolation and safe shutdown valve operations while AC power is unavailable;

- the actions necessary to assure that the functionality of equipment relied upon for SAM strategies can be maintained (including instrumentation, support systems or alternate methods) in an extended loss of AC power (ELAP) or loss of ultimate heat sink (UHS). This could also include assuring that safety functions can be met without AC power or normal access to the UHS;
- the availability of portable lighting (e.g., flashlights or headlamps) and communications systems necessary for ingress and egress to plant areas required for deployment of IAM strategies;
- the effects of AC power loss on area access, as well as the need to gain entry to the protected area and internal locked areas where remote equipment operation is necessary;
- the effect due to loss of ventilation on specific energised equipment necessary for shut down (e.g., those containing internal electrical power supplies or other local heat sources that may be energised or present in an ELAP);
- the accessibility requirements at locations where operators will be required to perform local manual operations (due to radiation levels, damaged infrastructure, etc.);
- the loss of heat tracing effects for equipment required to cope with an ELAP[2];
- the appropriate monitoring and make-up options to the SFP;
- the monitoring of radioactive releases in case of ELAP.

In light of the Fukushima Daiichi NPP accident and as part of the ultimate target to achieve and maintain a stable plant state, it is also considered to be a **commendable practice** that SAM procedures and guidelines cover the potential usage of raw/salty water as a make-up water source.

Regarding accident consequences, as part of post-Fukushima Daiichi NPP accident studies, the development of procedures and guidelines covering the different methods for decontamination, post-accident fixing of on-site contamination and management of large volumes of contaminated water on site is also recommended.

2.3. Development

2.3.1. Generation of procedures and guidelines

The existence of appropriate procedures and guidelines for implementing strategies based on fixed or mobile equipment is an important part of the IAM concept. Procedures and guidelines for accident management, from the design basis up to the severe accident phases, should exist at operating NPPs. Their characteristics change based on lessons learnt from operating experiences, exercises and past accidents. Typically, the process for developing procedures and guidelines for accident management requires the completion of several steps, such as identification of plant vulnerabilities, identification of plant capabilities and the development of accident management strategies. According to the IAEA Safety Guide NS-G-2.15 "Severe Accident Management Programmes for Nuclear Power Plants" [9]:

- plant vulnerabilities should be identified, to find mechanisms through which critical safety functions may be challenged. In the event that these challenges are not mitigated, the fuel may be damaged and the integrity of fission product barriers may be compromised;
- plant capabilities under challenges to critical safety functions and fission product barriers should be identified, including capabilities to mitigate such challenges, in terms of both equipment and personnel;
- suitable accident management strategies and measures should be developed, including hardware features, to cope with the vulnerabilities identified.

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[2] For example, the loss of heating systems designed to avoid some pipes carrying water from freezing or reaching temperatures low enough to generate boron precipitation.

As a significant lesson learnt from the Fukushima Daiichi NPP accident, the feasibility of the actions included in the strategies (notably, the manual-local actions) should be carefully reviewed in order to take into account all the potential limitations and obstacles that may decrease the probability of the successful implementation of the strategy (e.g. physical barriers produced in devastated site conditions, or a harsh environment which may impede the accessibility and/or habitability in critical locations). Regarding these three generic steps from NS-G-2.15, a considerable amount of useful information on accident management strategy development and for procedures and guidelines development can be found in international documents on EOPs and SAMGs [7, 9, 10].

For the development of procedures and guidelines, the operator can proceed independently or follow existing accident management programs that, on a generic basis, have been developed by a plant vendor or organisations (e.g. owners' groups). When generic templates are adapted to individual NPP use, care should be taken that the transition from the generic program to the plant-specific one is correct and the differences (in the fields of plant vulnerabilities, capabilities and strategies) are properly taken into consideration. Documentation of this process may be valuable in order to maintain the bases for deviations from the generic background documents.

Additional aspects should be considered during the development of procedures and guidelines:

- The equipment and instrumentation characteristics are important aspects. They should be appropriate to allow the implementation of the accident management strategies in practical procedures and guidelines. The uncertainty of the information provided by the instrumentation may increase as the severity of the accident increases due to the fact that they may be subjected to a harsher environment than originally considered. Additionally, critical instrumentation may be lost during the severe accident. As a **commendable practice** procedures and guidelines should be verified to account for changes to critical instrumentation ranges and instrument survivability under severe conditions considering experiences from the Fukushima Daiichi NPP accident. Additionally, it is considered a **commendable practice** to provide alternative means (equipment or procedures) to obtain information about critical parameters;
- Plant walk-downs to assess the feasibility of operator actions before starting the development of procedures and guidelines;
- The different operating accident management procedures and guidelines should be integrated as part of the IAM strategy, including clearly defining transition points and transfer of responsibility between procedures and guidelines (see subsection 2.3.2);
- The technical background for the development of the procedures and guidelines is based on experiments and supporting analyses. As it is stated in the WENRA RLs issue LM [12], "EOPs shall be developed in a systematic way and shall be supported by realistic and plant-specific analysis performed for this purpose" and "SAMGs shall be developed in a systematic way using a plant-specific approach". One of the recommendations internationally accepted after the Fukushima Daiichi NPP accident is the extension of the scope of procedures and guidelines to include all plant operating states, multi-unit accidents, spent fuel pools and use of supplemental equipment. It is also considered a **commendable practice** that this extension be based on the appropriate analysis, experiments and generic or specific calculations;
- For multi-unit cases, the possibility of one unit supporting another unit of the same site should be considered in the development of procedures and guidelines. It is considered a **commendable practice** that this possibility is considered in the initial development or in the revision of existing procedures and guidelines for accident management;
- One very specific aspect, identified from the Fukushima Daiichi NPP accident (total loss of electrical power), that can be considered in the development of procedures and guidelines is the use of electronic aids in the control room or in the different emergency centres in the plant for operation during BDBA conditions. In the case of total loss of AC/DC power these aids may be disabled. To consider the possibility of losing dedicated power sources for this purpose, having

paper copies or having other non-electronic aids to allow access to guidance during a total loss of AC/DC power is considered a **commendable practice**. As an example, having some pre-calculated graphs, tables or simple formulas (notably the ones included in the documentation of the SAMGs) developed in advance would avoid the need to perform complex calculations during the accident in a potentially high-stress situation.

On a general basis, the accident management guidance should be set out in such a way that it is not necessary for the responsible staff to identify the accident sequence or to follow some pre-analysed accident in order to be able to execute the accident management guidance correctly. To facilitate the implementation of the actions, especially under stressful conditions, the approach to accident management should be based on directly measurable plant parameters or parameters derived from these indications by simple calculations. In order to provide coverage of DBA, BDBA and unpredicted accident scenarios, EOPs need to be symptom-based or a combination of symptom-based and event-based procedures. EOPs and SAMGs for BDBAs should only be symptom-based [10, 12]. This involves the monitoring of plant 'Critical Safety Functions' or 'plant states' that does not require the event progression to be diagnosed in order to decide on the necessary recovery actions [7].

2.3.2. Integration of different sets of procedures and guidelines

Integration of the different sets of procedures and guidelines is an important part of the IAM approach. It includes the identification of the different sets of procedures and guidelines, the definition of rules for the transition among them and the transfer of responsibilities. Integration also addresses the management of multi-unit accidents.

2.3.2.1. Identification of the different sets of procedures and guidelines

Operating accident management guidance generally includes a set of EOPs for DBAs and some BDBAs not involving fuel damage, and SAMGs for BDBAs with fuel damage (in the core or in the spent fuel pool). In some countries, additional operational guidelines and procedures have been developed to cope with extreme situations; they are considered in this document as an extension of EOPs and/or SAMGs. Within their respective scope, EOPs and SAMGs define, in a systematic way, strategies and actions to prevent and mitigate core melt and radioactive releases.

Generally, actions defined in EOPs aim at preventing fuel melt (either in the reactor or in the spent fuel pool), while actions defined in SAMGs aim at mitigating the consequences of a severe accident that include the onset of fuel degradation.

In the preventive domain (EOPs), the guidance consists of descriptive steps, as the plant status will be known from the available instrumentation and the consequences of actions can be predetermined by appropriate analysis. The guidance for the preventive domain, therefore, generally takes the form of procedures. In the mitigative domain, uncertainties may exist both in the plant status and in the outcome of actions. Consequently, the guidance for the mitigative domain is generally not prescriptive in nature, but rather proposes a range of possible mitigative actions and their expected positive and negative effects as well as allowing for additional evaluation and alternative actions in the form of guidelines [9]. The structure of SAMGs and the degree of evaluation and judgement needed by the responsible NPP staff should be defined taking into account organisational aspects, such as accident management organisational structure and the training program for personnel involved in the use of SAMGs [7].

Lessons learnt from the Fukushima Daiichi NPP accident highlight that it is a **commendable practice** that the IAM strategy procedures and guidelines identify actions to strengthen plant autonomy to compensate for long-term loss of off-site power and loss of the heat sink, along with the implications of the devastation of roads and infrastructure around the site. The guidance should take into account the minimum staffing necessary for the emergency team required to be permanently present at NPPs and the impact of an extreme event on the supporting infrastructure both on and off the site. The potential unavailability of instruments, lighting and power, and abnormal conditions including plant state and high radiation fields and contamination, should also be considered [4].

EOPs and SAMGs may be supplemented by other documents and procedures aimed at protecting or managing the plant for some specific situations (e.g. fire-fighting procedures or other procedures to cope with some specific situations or hazards). In any case, EOPs and SAMGs should be integrated and consistent with abnormal and other operating procedures as well as with the emergency plan. The need for a better integration of accident management procedures and guidelines has been highlighted by international experts after the Fukushima Daiichi NPP accident, including the need to establish clear scopes and definitions, establish or clarify transition criteria and goals, and identify accident progression scenarios [4]. As a **commendable practice** the different sets of procedures and guidelines and their objectives should be clearly identified, integrated, and harmonised.

2.3.2.2. Transition between different sets of guidance

Transitioning from EOPs to SAMGs leads to a change in the objectives of accident management. The objective changes from primarily the prevention of fuel degradation to emphasising the mitigation of the consequence of the accident. Activities continue to cool the fuel and prevent further fuel damage, but the focus shifts to minimising or eliminating the release of radioactive material.

First, the transition between EOPs and SAMGs should be defined in accordance with the respective scopes of EOPs and SAMGs. EOPs intend to take actions before fuel damage occurs. After the beginning of fuel degradation, some actions in EOPs or some equipment or instrumentation used in EOPs might be irrelevant. In any case, the scope of EOPs with regards to fuel degradation should be precisely defined in accordance with the plant design. It forms important input data for the definition of transition criteria between EOPs and SAMGs.

If preventive accident management is successful, exiting from EOPs is allowed once the plant has achieved a stable and safe shutdown condition and fuel damage has been largely prevented. If preventive accident management is unsuccessful, the transition to mitigative severe accident management measures should be made. Such transition is based on symptoms indicating the onset of fuel damage or the fact that fuel damage is imminent, consistent with the scope of EOPs. This is done by recognising certain representative and measurable plant parameters, e.g. the core exit temperature (typically for PWRs) or the failure to maintain a minimum level in the RPV (typically for BWRs) or by defining thresholds, or using recognised and predefined degraded states based upon the analysis of a set of related parameters. Concerning spent fuel pools, complementary symptoms and parameters should be defined.

It is desirable that the specification and assessment of transition criteria have the following characteristics:

- unambiguity;
- ease of use;
- timeliness: the transition should be made when the execution of preventive measures has become ineffective or impossible keeping in mind that the time of the transition may influence the magnitude and/or sequence of subsequent challenges to fission product barriers. The definition of transition criteria should also include the time necessary to identify the transition point;
- a basis founded on available and reliable information (uncertainties, potential misleading instrumentation readings[3] and loss of instrumentation should be assessed) [13].

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[3] For more information on the use of Core Exit Temperature (CET) instrumentation for accident management (NEA/CSNI/R(2010)9), 'CET Effectiveness in Accident Management of Nuclear Power Reactor'. The results of some experimental projects (e.g., ROSA Project Test 6.1) show that experimental facility Core Exit Thermocouples provided unexpected readings that were not representative of the cladding temperature under certain sequences and depending on the design of the instrumentation.

Regarding the transition between preventive and mitigative domains, preferably, there should be no formal transition back from the mitigation domain (SAMGs) to the preventive domain (EOPs) once the EOPs have been exited, although EOPs may still be used as judgement dictates [9].

Within the mitigative domain, it may be important to distinguish between short-term and long-term accident management. In this context, short-term means within a few hours to a few days (i.e. during the initial crisis) and long-term may imply a timescale up to years, when a stable state has been achieved or when the situation evolves slowly. In the long-term, objectives and organisations may change. As a minimum, monitoring and controlling of various plant parameters should be ensured. Guidance for the long-term accident management may, therefore, be defined as well as transition criteria. For example, long-term accident management may include treatment of large quantities of contaminated water.

With regards to interfaces with other documents that might be applied at the same time as EOPs or SAMGs (for example, Fire Fighting Procedures), analyses should verify that there are no actions within these documents that would not be appropriate for implementation in certain BDBA conditions.

2.3.2.3. Transfer of responsibility

The roles and responsibilities of the accident management responders regarding the use and decision making for procedures and guidelines is another important element of the IAM approach. It is advisable to analyse in advance the critical decisions for accident management from the viewpoint of the interactions among the different organisations and local authorities, on-site and off-site.

The execution of the severe accident management guidance is the responsibility of the emergency response organisation at the plant or the utility.

In the preventive domain (EOPs), decision-making is carried out by the control room staff (i.e., the shift supervisor or shift manager, or a particular dedicated person such as a safety engineer). For complex situations, where it is deemed appropriate, decision making may be placed at a higher level of authority [9].

In the mitigative domain (SAMGs), responsibilities and decision-making authority may be transferred from the control room staff to a higher level of authority at some specified point in time, as decision making is highly complex in view of the uncertainties involved, and because appropriate actions may require information that is not available in the control room or even at the plant.

A specialised team or group of teams (often referred to as the TSC) may provide technical support by performing evaluations and recommending recovery actions to a decision making authority, in both the preventive and mitigative domains. The TSC may also provide appropriate input to the people responsible for the estimation of potential radiological consequences.

It is advisable that roles and responsibilities for the different members/teams of the emergency response organisation involved in accident management are clearly defined and that co-ordination among them is ensured. The roles assigned to the members of the emergency response organisation may be different in the preventive and mitigative domains, and where this is the case, it is advisable that transfer of responsibility and authority be clearly defined. The definition and co-ordination of roles, responsibilities and authorities are sometimes referred to as “command and control”.

It should be noted that the decision-making authority should be placed at an appropriate level commensurate with the complexity of the task and the potential for on-site and off-site releases. This point may be a difficult issue for actions with a potential for large off-site radioactive releases, such as containment venting. Although, when implementing EOPs and SAMGs the decision making and the execution is the responsibility of the emergency response organisation at the plant or the utility, the Fukushima Daiichi NPP accident illustrated that it is difficult to make such decisions without co-ordination with the offsite emergency organisation and local authorities. Hence, it may be advisable to identify actions with a potential for large off-site radioactive releases, to inform the local authorities as soon as possible about the expected time for the unavoidable implementation of these actions, and to specify roles and responsibilities in decision-making for both the emergency response organisation at either the plant or the utility and at the off-site emergency organisation or local authorities.

It should also be noted that a transfer of responsibilities in the course of a complex accident in itself poses risks. Hence, such a transfer should take place at a point in time that minimises such risks and, thus, is optimal from the viewpoint of severe accident management. Formal transfer should not take place until the new decision-maker is ready to formulate the first decision. Any transfer of responsibilities should be consistent with the transitions required in the emergency plan.

2.3.2.4. Management of multi-unit accidents

Lessons learnt from the Fukushima Daiichi NPP accident highlighted that there is a need to take into consideration the special aspects of multi-unit accidents and the need for improved assessment of accident propagation to other units (e.g., an accident at one unit should be considered as a potential external hazard to an adjacent unit) and of the corresponding impact on emergency preparedness [4].

The management of a multi-unit accident might raise the following difficulties (this list is not exhaustive):

- guidance adequacy, including: use of common equipment (fixed or mobile), consideration about actions in one unit that may impact on the recovery actions of the other(s) unit(s) (see subsection 3.7.2);
- staffing adequacy (see subsection 4.2.3);
- capability of the TSC to face several simultaneous accidents;
- impact of filtered venting on other units (see subsection 3.7.2).

2.3.3. Verification and validation

All procedures and guidelines should be verified and validated [9]. The goal of verification and validation is to check if a certain product meets its intended purpose. In this report the TGAM used the definitions from the IAEA Safety Guide NS-G-2.15 [9] that clarifies verification as a process to confirm the correctness of a written procedure or guideline and to ensure that technical and human factors have been properly incorporated. Validation is defined as a process to confirm that the actions specified in the procedures and guidelines can be followed by trained staff to manage emergency events. It follows that verification must be done prior to validation [10].

The IAEA Safety Report Series N 48 “Development and Review of Plant Specific Emergency Operating Procedures” [10], states that licensing requirements concerning verification and validation differ between countries. One country’s regulatory body might require approval at each step of the process while another country’s regulatory body only requires consensus on the basic principles because they may interfere with existing documents and regulatory policies. The IAEA encourages an atmosphere of mutual co-operation between industry and the regulatory body.

The WENRA RLs [12], Issue LM, point 4.1 requires that EOPs and SAMGs shall be verified and validated in the form in which they will be used in the field, so far as practicable, to ensure that they are administratively and technically correct for the plant and are compatible with the environment in which they will be used.

Furthermore, in the WENRA RLs [12], Issue LM, point 4.2, it is required that the approach used for plant-specific verification and validation be documented. It is complemented by IAEA guidance [9] that the findings and insights from the verification and validation processes should be documented and used for providing feedback to the developers of procedures and guidelines for any necessary updates before the documents are brought into force by the management of the operating organisation.

One country also verifies and validates its SAMGs using a plant-specific simulator capable of real time simulation of severe accidents. Some other countries are now evaluating how to install a severe accident simulator.

2.3.3.1. Verification

A detailed description of EOP verification as well as practical advice is given in the IAEA Safety Report Series N 48 [10]. Verification of the consistency of procedures can be greatly facilitated by the use of dedicated procedure development tools specifically developed for procedures and guidelines writing. These software tools have standard format structures defined in the user's guide and are equipped with a connection to the support databases (with action verbs, set points, component identifications, standard steps and sequences, etc.). For example, the set points database allows the use of set point identifications during the writing of the procedures and guidelines and the exact values of set points are the referenced database items.

The verification process supports comparison of the procedures and guidelines with all of the documents used as sources in their development. These would include the plant-specific writer's guide, the reference/generic set of procedures/guidelines, plant difference documents, plant technical specifications, FSAR, relevant event based procedures, etc.

The assessment phase of verification may have two parts, with written correctness and technical accuracy being checked separately. Written correctness means that the procedures and guidelines are consistent with the plant-specific writer's guide. This means that the text is readable with no typographical errors and that information is consistently organised and presented throughout the text, etc.

Technical accuracy means that procedures and guidelines are consistent with the source documents. Specifically, it is required to check entry conditions, symptoms, states, sequences, steps, notes, warnings, quantitative information and hardware by:

- checking that entry conditions, symptoms or states are correct and not excessive;
- identifying and confirming support sequences, steps, warnings and notes from source documents and explaining possible differences;
- checking quantitative information to ensure that specified values are correct and plant-specific, that tolerance bands are included and computed accurately, and that this information is adequate for the operator;
- checking plant hardware information to ensure that the instrumentation exists at the plant, that the delineations are the same as those the operator will read and that the instrument is available during accident conditions.

Additionally, technical accuracy is meant to check that strategies are unchanged as plant-specific adaptations are incorporated. This check includes systems, instruments, limits, controls, indications, etc.

The TGAM considers that it is a **commendable practice** to independently review the overall process of verification and its documentation.

2.3.3.2. Validation

Detailed description of validation is given in the IAEA Safety Report Series N 48 [10] and US NRC NUREG-0899 [14]. Validation may be performed by one or any combination of the following methods, as appropriate:

- the simulator method is a validation method by which control room operators perform control functions on simulator equipment according to a scenario and are observed by a reviewer. Simulator validation provides a safe environment in which to test the procedure;

- the walk-through method is a validation method whereby personnel conduct a step-by-step enactment of their actions without carrying out the actual control functions. This includes equipment access and equipment staging when required. The included personnel are observed by a reviewer;
- the table-top validation method is a validation method whereby personnel explain and/or discuss procedure steps in response to a scenario or as part of an actual industry operating experience review. The table-top method may be used where access to plant equipment is not practical. The included personnel are observed by a reviewer;
- the reference method is a validation method by which similar plants use the data developed in a common procedures and guidelines validation programme.

The goal of validation is to ensure that the procedures and guidelines are usable and correct.

Usability encompasses two concepts: level of detail and ease of understanding. The level of detail should be sufficient, but not excessive. Ease of understanding reveals whether or not the material in the procedures and guidelines is presented properly and whether the operator can understand the information under emergency conditions.

The validation principle of correctness encompasses two aspects: plant compatibility and operator compatibility. In general, this is a test of whether the procedures and guidelines are compatible with plant responses, systems/instrumentation, shift manpower and control room information. The test of plant compatibility ensures that the operator is able to complete the required action with the hardware and systems that are in place. The test of operator compatibility checks whether shift manpower is adequate to comply with the actions specified within the procedures and guidelines and whether policies for operator duties and responsibilities conflict with actions specified in the procedures and guidelines. This evaluation also looks at whether time critical actions can be performed with the current shift and in the allotted time. It also tests whether actions assigned to specific shift personnel are co-ordinated by the procedure and whether the operating crews can follow the sequence of actions.

It is a **commendable practice** to independently review the overall process of validation and its documentation.

For the validation of SAMGs some ideas were collected in the paper presented by B. Krajnc, I.Bašić, J. Špiler at the International Conference Nuclear Energy in Central Europe 2001, Portorož, Slovenia [15]. The TGAM finds these ideas pertinent today and identified important objectives for SAMGs validation in this document including:

- verify the usability of the plant-specific SAMGs in terms of structure, content, clarity and format in as realistic an environment as possible, also taking into account the acceptable time frame for accident management;
- ensure that SAMGs strategies can be used as planned, taking into consideration such items as corrections or enhancements to strategies, feasibility of local actions, equipment availability, timing considerations, etc.;
- ensure that any conflicts or other problems are identified and addressed prior to formal implementation in the TSC and the main control room; areas of concern include, but are not limited to, missing or extra steps in the guidelines, interface with EOPs, interface with the Emergency plan, awareness of responsibilities, plant status information availability, and communication capabilities;
- provide confidence in the SAMGs material that satisfies plant management and other responsible authorities so they are assured that the SAMGs address challenges to the plant during a severe accident situation and would not aggravate the plant conditions;

- provide SAMG hands-on training to TSC staff, control room personnel and others implementing SAMG actions by validation exercises and collecting valuable feedback on the use of the SAMG materials.

The evaluation process and acceptance criteria for SAMGs validation should address issues related to the following topics during observation or participation in the validation exercises [15]:

- interfaces between EOPs, SAMGs and other guidelines: clarity of transfer points, appropriateness of timing, clarity of responsibilities during transitions;
- control room guidelines: availability of necessary plant parameters, logical order of decision steps, missing or extraneous steps, ability to accomplish steps, clear and understandable instructions, communication considerations;
- TSC diagnostics: availability of necessary plant parameters, usability of computational aids, appropriateness of parameters for plants conditions and threats, logical order of diagnostic priorities, missing or extraneous steps, ability to accomplish steps, timeliness of diagnostics cycle;
- TSC guidelines: availability of necessary plant parameters from the control room, logical order of decision steps, missing or extraneous steps, ability to accomplish steps, applicability of SAMG strategies, clear and understandable instructions, adequate consideration of negative impacts, clarity of SAMG decision-making process, usability and scope of computational aids;
- emergency plan - SAMG interface: conflicts of actions and priorities between the emergency plan and SAMGs for particular plant conditions, clarity of responsibilities for each SAMG step/action, coverage of guidance after exiting SAMGs.

The validation for control room guidelines and TSC guidelines can be partially separated to minimise its complexity [15]. For validation exercises, the involved scenarios have a different degree of participation by the TSC and control room personnel [9, 16]. Aspects to be considered are:

- EOP to SAMG transitions;
- communication between the TSC and MCR;
- recovery actions included in the strategies;
- use of alternative instrumentation methods to monitor severe conditions;
- SAMG transition times;
- computational aids performance;
- interfaces with the emergency plan.

The IAEA, in its safety guide for severe accident management programmes [9], mentions that on-site tests should be performed to validate the use of equipment. Scenarios should be developed that describe a number of fairly realistic (complex) situations that would require the application of major portions of EOPs and SAMGs. The scenarios should encompass the uncertainties in the magnitude and timing of phenomena (both phenomena that result from the accident progression and phenomena that result from recovery actions). Also, staff members involved in the validation of the procedures and guidelines should not be those who developed the procedures and guidelines [9].

The WENRA RLs, Issue LM [12], states that the effectiveness of incorporating human factors engineering (HFE) principles in procedures and guidelines shall be judged when validating them. The HFE aspects of IAM are covered in Section 4 of this report. Furthermore, the WENRA RLs state that the validation of EOPs shall be based on representative simulations, using a simulator where appropriate [12].

2.4. Updating and administrative control

An effective development process (including verification and validation) produces procedures and guidelines suitable for their purpose within the IAM framework. After the initial generation of procedures and guidelines, different aspects can bring about the necessity of modifications in order to maintain their quality. From enhancements due to operating experiences, to changes necessary to maintain fidelity to the plant, a number for changes may be identified. This is the reason why the operators should develop a program for update and administrative control of procedures and guidelines.

The basic components of the general update process are already well-established. One of the **commendable practices,** identified by the TGAM and noted in this section, is the establishment and fulfilment of the IAM procedures and guidelines update program. This section deals with the process itself rather than with the issues that may lead to major modifications of the guidance. Finally, since these procedures and guidelines are used during exercises and evaluations, results should be reflected in updates to procedures and guidelines.

2.4.1. Update

The operator should establish an updating program for its accident management procedures and guidelines. The aim of such a program is to continuously maintain the suitability of procedures and guidelines for their intended use. The program should be comprehensive, that is, it should cover all the possible procedures and guidelines for accident management.

In different documents issued by international organisations, the potential sources for changes to guidance and documents are identified [9, 10, 12, 17, 18] as follows:

- changes in plant configuration: the process of control of plant modifications should be adequately linked to the updating program for procedures and guidelines in such a way that plant modifications are properly and timely reflected in the appropriate procedures and guidelines;
- revision of background information, for instance the PSA or calculations specific to the definition of the strategies. The revision of these documents, due to periodic or exceptional revisions, may lead to the necessity of changes to procedures and guidelines;
- revision of generic documentation used for the specific procedures and guidelines. This can be the case of plants that have based their procedures and guidelines on a reference design or some other generic source of information, where the originator of the procedures and guidelines on the reference design issues a revision of the accident management programme. As an example, a significant number of plants base their EOPs and SAMGs on the Owners' Groups generic EOP/SAMG packages. After the initial development process, the plant operators should maintain the link with the Owners' Groups updating programs and review the specific procedures and guidelines when general revisions are issued. Furthermore, the operators should provide feedback to the Owners' Group on enhancements made to site specific EOPs and SAMGs that may have generic implications. After the Fukushima Daiichi NPP accident, Owners' Groups generic EOP/SAMG packages are being subjected to significant revisions to include the lessons learnt from the accident. As additional information, general revisions of EOPs and SAMGs developed by Owners' Groups are typically issued every 5 to 10 years. However, correction of mistakes or improvements of generic sets of EOPs and SAMGs are issued with higher frequency and many utilities already have procedures in place to update EOPs and SAMGs on a regular basis (e.g., once a year);
- international research on beyond design basis phenomenology, especially for severe accidents. The Fukushima Daiichi NPP accident has generated a new input for understanding severe accident phenomenology; an example is the evolution of severe accidents in the spent fuel pool. The results of the research efforts of the international community should be linked to the practical IAM procedures and guidelines used at NPPs;

- exchange of information between peers, for instance observers in drills or exercises, or international missions of experts to review accident management procedures and guidelines. The exchange of information among peers is an opportunity to enhance sharing good practices in the international community;
- feedback coming from internal (for instance, training sessions) and external (domestic and international) operating experience and other sources.

It is considered a **commendable practice**, and emphasised by the importance of having an appropriate set of IAM procedures and guidelines for severe accidents after the Fukushima Daiichi NPP accident, that the operators take into account all these elements in implementing timely updates to their procedures and guidelines.

2.4.2. Administrative control

In those cases where modifications to IAM procedures and guidelines are needed, it is necessary to determine the process for their implementation. As is stated in the IAEA Safety Requirements GS-R-3 "The Management System for Facilities and Activities" [17], "Changes to documents shall be reviewed and recorded and shall be subject to the same level of approval as the documents themselves".

As it has been said before, the general process for administrative control of procedures is well-established in the existing NPPs. In any case, the TGAM notes that it is a **commendable practice** for the revision process to be completed and be commensurate with the importance of the changes. In general, the following main actions should be considered when modifications to IAM procedures and guidelines are needed:

- the changes should be verified;
- the changes should be validated in agreement with their significance. Some very simple changes may not need validation, but the cumulative effect of many simple changes included in one revision or in different revisions should be taken into account;
- revised documents (procedures and guidelines) have to be updated in the appropriate locations (control room, technical support centre, alternative emergency centres, etc.);
- personnel should be trained on the new procedures and guidelines.

2.4.3. Periodic review

The TGAM considers that it is a **commendable practice** for operating organisations to perform periodic reviews of IAM procedures and guidelines. This is an important complementary element to the update and administrative control program. This periodic review can be performed internally or externally (with the help of external organisations and experts). In some countries, this process is controlled and monitored by the regulatory body. In some countries, this may be done during Periodic Safety Reviews (PSRs), typically conducted every 10 years or during other routine reviews of the licensing basis of the NPP.

2.5. Compilation of commendable practices

In this subsection, a compilation of the commendable practices identified in section 2 "Procedures and guidelines" are provided. These include:

- EOPs and SAMGs need to cover all operating modes, cover accidents occurring in the SFP, long-term aspects, and multi-unit accidents. This extension should be based on the appropriate analysis, experiments and generic or specific calculations;
- IAM procedures and guidelines need to take full advantage of existing plant capabilities (fixed or mobile), if necessary going beyond the originally intended functions of some systems and using

some temporary or ad hoc systems to achieve the goal of enhancing plant safety for BDBA scenarios;

- The licensee needs to identify the actions to achieve accident management objectives with respect to establishment and maintenance of reactivity control in the reactor and in the SFP; assurance of availability of heat sink for heat generated in the reactor core and in the SFP; control of pressure and water inventory in the primary and secondary heat transport systems; assurance of containment isolation; control of the containment pressure and temperature; control of the concentration of hydrogen and other combustible gases; control of unfiltered releases of radioactive products; control of temperature and water inventory in the SFP;

- It is important to assure that the scopes of the plant-specific Level 1 PSA and of the deterministic safety analyses used for the development of EOPs consider, as necessary, external/internal events, all the plant states, multi-unit events, SFP and long-duration accidents;

- It is important to assure that the scopes of the plant-specific Level 2 PSA and of the deterministic safety analyses used for the development of SAMGs consider, as necessary, external/internal events, all the plant states, multi-unit events, SFP and long-duration accidents;

- IAM procedures and guidelines should take into account additional factors, including: significantly damaged infrastructure; the disruption of plant level, corporate-level and national-level communication; long-duration accidents; and accidents affecting multiple units and nearby industrial facilities at the same time. They should also identify actions to strengthen plant autonomy to compensate for long-term loss of off-site power and loss of the heat sink, along with the implications of the devastation of roads and infrastructure around the site;

- Procedures and guidelines should be verified to account for changes to critical instrumentation ranges and instrument survivability under severe conditions or to provide alternative means (equipment or procedures) to obtain information about critical parameters;

- For multi-unit cases, the possibility of one unit supporting another unit of the same site should be considered in the initial development of procedures and guidelines or in the revision of existing procedures and guidelines for accident management;

- The possibility of having paper copies or other non-electronic aids (some pre-calculated graphs, tables or simple formulas) in the control room or in the different emergency centres in the plant to allow for the proper use of guidance should be considered in the case of total loss of AC/DC power;

- The overall processes of EOP and SAMG verification and validation and its documentation are independently reviewed;

- The program for updating procedures and guidelines should consider input from sources such as the control of plant modifications, revisions to Owners' Group generic EOP/SAMG packages, results of research efforts in the international community, relevant operating experience, peer information exchanges and feedback from training and exercises in making timely improvements and conducting periodic reviews;

- The feasibility of the actions included in IAM strategies (notably, manual-local actions) as well as the availability of the necessary information on key plant parameters to make a decision on initiating those actions need to be carefully reviewed in order to take into account all the potential limitations and obstacles that may decrease the probability of the successful implementation of the strategy (e.g., physical barriers produced in devastated site conditions, or harsh environment that may impede the accessibility and/or habitability in critical locations);

- EOPs and SAMGs are fully integrated and consistent with the Emergency plan, and the different sets of IAM procedures and guidelines and their objectives are clearly identified, integrated, and harmonised. The transitions between different sets of IAM procedures and guidelines are clearly specified and justified with regard to the design of the plant;

- It is advisable to analyse in advance, to the extent practical, the critical decisions for implementation of IAM strategies from the viewpoint of the interactions between the different organisations on-site and off-site (at plant level, corporate level, local level, and national level). The roles and responsibilities for the different members and teams of the emergency response organisations involved in IAM need to be clearly defined so that co-ordination within them and between them can be ensured. The roles assigned to the members of the emergency response organisation may be different in the preventive and mitigative domains, and where this is the case, the transfer of responsibility needs to be clearly defined.

3. EQUIPMENT, INFRASTRUCTURE AND INSTRUMENTATION

3.1. Introduction

The inherent hazards of nuclear power generation mandate a systematic approach to the provision, maintenance and operation of safety mechanisms and systems intended to protect the public, plant, and the environment. This systematic approach is informed by comprehensive studies of the nature of hazards associated with plant operation and the potential to use safety systems to mitigate the risk. These considerations inform the requirements for safety equipment and the guidance detailed below is based on consideration of both postulated plant faults and hazardous events occurring in the vicinity of the plant.

3.1.1. Fundamental principles

The starting point, in determining the equipment required for enhancements to improve plant robustness under BDBA conditions, is a systematic study of events that could challenge nuclear safety. If the potential consequences of an event represent a significant risk to the public, then consideration needs to be given to the following:

- prevention of the event;
- protection of the plant so that barriers to the release of radioactive material remain intact; and
- mitigation of the consequences of damage to the plant which potentially will lead to the release of radioactive material into the environment and to the uptake of activity by the public and the plant operators.

These requirements have been listed in order of priority, but the overall control of risk needs to recognise that prevention and protection will not always be successful and an appropriate control of risk will include measures at all levels. Furthermore, as far as reasonably practical, equipment intended for mitigation of the effects of plant damage should be independent from that intended to prevent the initial event (or to protect against plant damage). The reason for this is to provide a measure of DiD; where multiple barriers are maintained protecting the personnel, public and the environment.

Prevention is the primary driver for plant safety under an IAM approach and focuses on the capability of the NPP to effectively respond to DBAs. This aspect of DiD is generally addressed during the design of the NPP and as upgrades are implemented to fixed SSCs in response to operating experience or new information. A key lesson learnt from the Fukushima Daiichi NPP accident is that the unforeseen can occur and overwhelm all of these designed and built-in features. Therefore, this report also discusses measures intended to mitigate accidents where there has been some degree of damage to the reactor core or fuel degradation. Under these conditions, the focus of those responsible for emergency response changes from core cooling to containment of radioactive material and the off-site emergency response intended to limit the effect on the local population.

3.1.2. General considerations for severe accident mitigating systems

The selection of equipment to mitigate faults is generally based on consideration of reasonably foreseeable events. Where these events have the potential to lead to a large uncontrolled release of radioactive material, the plant design basis requires suitable protection to prevent damage to barriers to the radioactive release, or at least to preserve at least one barrier. It follows that severe accidents can only occur in either an event of very low anticipated frequency, or in an unanticipated event. This makes the mitigation of severe accidents a complex topic.

In developing the design basis generally, equipment selection includes some degree of cost-benefit analysis in order to ensure that the most effective protection is provided, but this becomes difficult in the case of severe accidents because the intent is to protect against events which may not have been anticipated. An approach a number of countries have adopted is to assume extensive damage to the equipment intended to mitigate design basis faults and to provide diverse protection; either by additional installed systems or by mobile equipment. This equipment is intended to be part of a DiD approach that accepts the possibility of errors in the original design process and to account for uncertainties and the unknown.

Most countries require a minimum level of protection against severe accidents as a basic regulatory requirement and some require that further conceivable measures be examined to determine whether they could reasonably make a useful contribution to safety. This examination can be a combination of cost-benefit analysis and expert consideration of relevant good practice. Here the IAEA standards and national standards can play an important role.

Historically, research and development in severe accidents has involved extensive international collaboration and SAMGs are often developed based on a wide consensus as to **commendable practice**.

3.1.3. Equipment qualification

It is widely held that equipment relied upon to protect against DBAs needs to be engineered, manufactured, and qualified to very high nuclear standards. For accidents that go beyond the design basis it may be reasonable to accept normal industrial standards. However, it is expected that the equipment will provide reasonable assurance that it can function under the conditions experienced during a BDBAs. Qualification parameters for such equipment could include:

- seismic acceleration;
- electrostatic, electromagnetic and ionising radiation fields;
- extreme temperatures;
- moisture and corrosive environments;
- debris in the environment;
- wind-blown missiles.

Maintenance and testing of equipment used to mitigate severe accidents is also an important consideration.

3.2. Fixed equipment and instrumentation

3.2.1. Preventing fuel damage

Fuel damage in accident conditions is caused by the imbalance of the heat generated within the fuel and the heat removed, by the coolant flow or other means. In the event of a fault[4], the NPP protection system responds by inserting control rods to stop the fission process (a scram) and by initiating safety systems for post-scram decay heat removal.

3.2.1.1. Reactor shutdown

If any of the following, the control-rod position indicator, the reactor power and the reactor pressure measurements, indicate failure of scram when the reactor needs to be shut down, then it is necessary to

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[4] In this document the term ‘fault’ is used interchangeably with the term ‘accident’, and sometimes ‘event’ or ‘transient’.

assume occurrence of anticipated transient without scram. In this case, in order to maintain integrity of the reactor pressure boundary and the containment, deploying of alternative systems for achieving sub-criticality of the core is required. Manual scram is the primary countermeasure. For BWRs and AGRs, the alternate rod insertion system, independent from the reactor scram system, is deployed. For PWRs, systems are used to increase the coolant boron concentration. CANDU reactors have two independent, fully capable shutdown systems. In light water reactors, negative moderator temperature feedback can be employed to reduce the power.

Several reactor types utilise systems to inject material with strong neutron absorbing properties to control reactivity. Some of these systems adversely affect the ability of the plant to be operated at a later date and therefore the injection criteria should be defined clearly in operating instructions.

3.2.1.2. Reactor cooling under high pressure

All the reactors have systems that are normally used for cooling the reactor under high pressure. However, if all power supplies and/or ultimate heat sink are lost, it is possible that none of these systems will be available. In this case an alternative way of cooling should be applied, one that is not dependent on normal power supplies or heat sink.

In pressurised water reactors, the secondary side can be used for reactor cooling, as long as there is a way to add water to the steam generator secondary side. A separate diesel- or turbine-driven feed-water pump would enable feeding the steam generators. If a separate pump is not available, water may also be added to steam generators from fire trucks if necessary connections are provided.

In boiling water reactors, isolation condensers or turbine-driven feed-water pumps (e.g., reactor core isolation cooling) can cool the reactor at high pressure and are not dependent (at least in the short-term) on an AC power supply or a primary heat sink. The isolation condenser consists of a heat exchanger located in a pool of water open to the atmosphere and of connection lines to the reactor (one to the steam region and another to lower parts of the reactor). The lower connection line is closed by a valve during normal operation; to start cooling with the isolation condenser the only action is to open the valve in the lower connection line. After that steam flows to the heat exchanger, is condensed, and the condensate flows back to the reactor by gravity. In the longer term, the pool on the secondary side of the isolation condenser will require refilling. A turbine-driven feed-water pump uses high pressure steam from the reactor, and can operate even if power supplies are lost. However, DC power (battery) is needed to operate control valves to maintain water level in the reactor within safe limits (to prevent overfilling). Some countries have considered having procedures and portable equipment to operate BWR reactor core isolation cooling pumps under station blackout (SBO) conditions. The water can be taken from the condensation pool or other coolant storage sources, and the steam can be returned to the condensation pool. In the longer term, the condensation pool will require cooling. Boiling of the pool will cause loss-of-vacuum for the turbines and will eventually lead to loss of the turbine-driven feed-water pumps.

High-pressure feed and bleed is possible, if a system exists that is able to pump into the pressurised reactor. Normally a plant has several such systems, but if power supplies and/or ultimate heat sink are not available, those systems are probably not available as well. Bleeding could occur through safety valves.

To operate the above-mentioned systems, it should be ensured that necessary valves can be operated, even if all normal power supplies and instrumentation and control (I&C) capabilities are lost. Charging the batteries that provide power to operate the valves should be possible by using mobile diesel generators or other charging systems, for example. Also, sufficient reservoirs of water as well as diesel fuel should be ensured, taking into account the possible long duration of the accident.

3.2.1.3. Depressurising reactor coolant system

If cooling of the reactor at high pressure is not possible, the reactor should be depressurised to enable low-pressure injection. Reactor depressurisation is also necessary to prevent a reactor pressure vessel rupture at high pressure if the severe accident cannot be avoided.

NPPs are equipped with different kinds of safety and relief valves. These valves can be used to depressurise the reactor, but it should be ensured, that they have sufficient capacity. The valves may require DC power or compressed air to be opened and kept open. It should be ensured, that it is possible to open the required number of valves even if normal power supplies are lost.

3.2.1.4. Reactor cooling under low pressure

Low-pressure emergency cooling systems and normal residual heat removal systems typically need power and the availability of the ultimate heat sink. If those are not available, alternative ways to cool the reactor should be used. Cooling can be achieved by pumping water into the reactor, and letting the water boil. Injection may be possible by using diesel driven fire pumps or other mobile pumps. To enable injection, it is necessary to provide connection points to suitable systems and at suitable and accessible locations.

3.2.1.5. Securing the ultimate heat sink

The main functions of an ultimate heat sink are to receive waste heat generated by the nuclear steam supply system and to provide cooling to water circulated in the containment, shaft seals, lubrication systems, ventilation and electrical equipment (including instrumentation).

In the case of the removal of decay heat from the reactor, the means used in the short and medium term generally differ:

- in the short-term, water is injected into the steam supply system and steam is vented to atmosphere (or the containment building sump);
- in the medium-term, water is generally recirculated through an external cooling system, which is either cooled by raw water from the immediate environment, or by forced-air heat exchangers.

Where sea water is foreseen for a heat sink, a number of natural hazards need to be anticipated:

- low sea water temperatures can potentially cause the build-up of ice in the inlets;
- shoals of fish or seaweed can block the filtering screens and entry plena; and
- environmental hazards can cause damage to the inlet structures and equipment.

The design of the sea water systems needs to include sufficient redundancy and diversity to meet the hazards identified and sufficient monitoring is needed to ensure that early manual intervention is taken before cooling water systems are lost. This may require sending operators out to the sea inlets to remove material blocking the inlets. In cold climates, the ability to recirculate some of the discharge water may be useful.

Where river water is used as a heat sink, drought conditions need to be considered and alternative water sources from bore holes can be used to supply critical equipment. Diversity can also be provided using closed loop systems and this may include fan coolers for certain functions. Thus, suitable diversity in the design of cooling water supplies to ensure the required level of resilience and flexibility is considered a **commendable practice**.

Flooding is a major hazard both for sea water and river water systems. By containing relevant facilities and equipment in buildings and rooms adequately sealed from water intrusion it is possible to enhance flooding resistance. It is also effective to protect seawater pumps and other fixed components by building a tide embankment and screens.

The design of many pumps is vulnerable to flooding because it is common practice to place pumps at low levels in buildings so as to maximise net suction head. However, it is good engineering practice to review the siting of pumps important to safety to ensure that their siting does not introduce the potential for common-mode failure.

3.2.1.6. Spent fuel pools

Although the grace time of spent fuel pools is large in comparison with that of the core, it is necessary to consider different environmental risks because of larger radioactive inventory and much poorer containment capability. It is necessary to assume not only failures of the cooling system and the make-up water system, but also loss of pool water caused by pipe breaks and the siphon phenomenon, where water level cannot be maintained. Loss of systems concurrent with fires and explosions needs to be assumed.

Countermeasures and documented procedures should be established to prevent fuel damage (maintaining a sufficient water level for cooling and shielding and also adequate boron levels for sub-criticality).

The SFP structure is invariably designed to a high standard. However, the possibility of damage to the SFP structure leading to leakage is considered. Leakage is usually mitigated by the provision of sealing systems; designed to provide temporary repair to breaches, or at least to minimise the leakage rate to levels within the capability of the make-up system. The likelihood of a loss of SFP water is reduced by minimising the penetrations in the SFP structure and when appropriate, fitting blanking plates to pipework that is not required.

For enhancing reliability of cooling and injection of SFPs, it is necessary to design water sources for conservative decay heat loads, distribute spent fuel evenly throughout the pool, deploy air-cooling systems and use dry casks when appropriate.

Generally the SFP water inventory is so large that it takes many days for the water to boil off and systems to cool and replace the water are invariably diverse and redundant. Addition of water from mobile sources (such as a fire tender or fire engine) or fire protection systems are considered as a back-ups for water injection. In order to cope with a loss of SFP water inventory, spray nozzles can be deployed at the top of SFPs to prevent fuel damage.

In most cases, fuel storage racks are designed with neutron absorbing materials in the structure so that the requirement to add boric acid is minimised.

The inability to adequately monitor conditions in the SFP can cause a distraction for control room operators. Therefore, it is necessary to provide reliable means of monitoring water level, temperature and dose rates so the condition of the SFP is known. It is also highly desirable to monitor states of SFPs by video cameras. The instrumentation should be provided with alternative power sources to ensure its availability in BDBAs.

3.2.1.7. Supporting functions

As part of fault analysis, it is necessary to assume loss of power from the main station supply and the backup diesel generators. Loss of all water sources normally allocated to post-trip cooling should also be considered. Alternative systems need to be tolerant to the conditions of a severe accident.

Fixed alternative power sources could include, but are not limited to:

- gas turbine generators;
- DC batteries; and
- battery recharging diesel generators.

Alternative water sources could include, but are not limited to:

- additional water tanks (such as firefighting systems);
- local reservoirs;
- boreholes; and
- seawater.

Additional support systems could include, but are not limited to:

- compressed air.

It is important to ensure that there are multiple supply routes to aid in accident response under harsh conditions.

3.2.1.8. Fuel damage during outage

The risk during refuelling outages differs from that of power operation in that the reactor is not generating large amounts of power, but the decay heat generated by fission products still needs to be removed and many systems normally available may be isolated for maintenance. The primary coolant circuit may also be open and, therefore, the possibility of using the normal steam generation system as a means of heat removal may not be practical.

It is therefore important to provide sufficient redundancy and diversity of equipment to ensure that the level of risk is suitably controlled. The use of specific PSA using a suitable model is helpful, as well as the specification of minimum available equipment levels in NPP documentation (e.g. technical specifications).

In some cases, it may be reasonably practical to bring portable equipment to the site to prevent increases in risk level associated with reduced plant systems availability during outages.

On the level of specific requirements, particular attention needs to be paid to preservation of sufficient levels of diversity in the ultimate heat sink under these conditions.

3.2.2. Mitigating the consequences of severe accident

After fuel damage, the main goal of accident management is to ensure containment integrity, and thus prevent releases to the environment (issues concerning the SFP will be discussed in 3.2.2.13). To achieve this, the temperature and pressure created inside the containment as a consequence of a severe accident should be limited to values the containment can withstand. When analysing pressure and temperature loads, the following in particular should be considered:

- decay heat yielded by the reactor and its debris;
- total volume of non-condensable gases; and
- heat and pressure loads arising from burns of combustible gases.

To limit the pressure and temperature in the containment, the following functions should be addressed:

- cooling of corium:
  - depressurising the primary circuit;
  - cooling of core debris.
- heat removal from containment:
  - heat transfer out of containment;
  - possible containment venting;

  - control of water level and temperature of the suppression pools for BWRs.
- control of combustible and non-condensable gases;
- ensuring containment isolation.

In addition, pH control of the containment sump can, to some extent, limit iodine releases.

3.2.2.1. Cooling of corium

The onset of fuel damage in the LWR core is generally determined by the use of thermocouples located in the coolant above the reactor core. Other types of reactors may have different parameters serving for indication of the onset of core damage. Severe accident management changes its focus to some degree when these temperatures are observed to exceed a pre-determined value. The focus becomes that of ensuring containment of fission products and fuel debris, rather than ensuring fuel cladding integrity.

In the case of graphite-moderated reactors, one concern can be a return to criticality caused by rising moderator temperatures. This concern is temporary because once the core has melted and relocated, it returns to a sub-critical state and subsequently the corium cooling issues are similar to those of water reactors.

In water cooled reactors, the rise in coolant temperature is a concern because of the rate of oxidation of the fuel cladding in hot steam. At elevated temperatures, oxidation can release large quantities of hydrogen, which on ignition is a potential threat to containment integrity. Oxidation can also become a significant source of heat and can hasten fuel melting.

In some designs, it is practical to extract the decay heat by cooling the external surface of the melt pool. However, the amount of heat that can be extracted depends upon the critical heat flux for nucleate boiling and the geometry of the melt. Depending on the plant's design, it may be possible to remove the decay heat through the external surface of the vessel (in-vessel melt retention). To enable this, consideration needs to be given to the provision of adequate coolant flow around the outside of the vessel in a severe accident.

Where in-vessel melt retention is not feasible, the vessel lower head is assumed to fail and arrangements are made to receive the corium in the vessel pit and to cool it sufficiently to limit corium-concrete interaction. In cases where the vessel lower head is assumed to fail, ex-vessel steam explosions should be considered. However at this time no practicable accident management measures have been established to completely prevent steam explosions. The overall intent, however, is to ensure that the integrity of the containment building basemat is preserved and that contamination of ground water is prevented.

Optimising the water injection strategy during the severe accident progression

The water injection during the core degradation should not be considered only for the positive impact (cooling the corium, wash-out the containment atmosphere, etc.). All potentially negative impacts also should be considered. For example, water injection can:

- increase the kinetics of hydrogen production due to fuel oxidation;
- de-inert the containment atmosphere;
- increase the reactor coolant system (RCS) pressure;
- increase the containment pressure.

The presence of water in the reactor cavity before vessel rupture should be considered taking into account both positive and negative consequences:

- the water in the cavity can contribute to vessel external cooling and contribute to the corium stabilisation even after vessel rupture;

- it can induce a steam explosion in the vessel cavity and cause damage to cavity walls, associated containment structures and equipment, and affect containment tightness;
- it can limit the corium spreading on the available area below the vessel.

Depending on the plant design, these strategies related to water management need to be precisely justified.

3.2.2.2. Depressurisation of the primary circuit

In cases where flooding a damaged core is the favoured strategy, depressurisation usually allows additional sources of water to be used to flood the core and prevents fuel damage at high pressure. These may include parts of the safety injection system such as accumulators (if not already deployed) or possibly water drained under gravity from in-containment water sources. The extent to which gravity-driven water sources can be deployed depends on the design of the plant and its ability to vent steam generated in the core. Some plants include large vents designed specifically to depressurise the RCS in a severe accident.

Irrespective of core cooling strategies, it is usually necessary to depressurise the primary circuit when core melt is imminent. If the reactor pressure vessel ruptures under high pressure, the core material may disperse into the containment in a way that would make its cooling extremely difficult and would, thus, result in extremely large rises in temperature of the containment environment and of impacted structures. The remains of the core would heat directly the containment atmosphere, and pressure and temperature in the containment would increase rapidly (direct containment heating). Thus, for containment designs that are unable to withstand these conditions, if core melt is imminent, there should be a way to depressurise the reactor. Consequently, the provision of a reliable means of depressurisation is generally regarded as **commendable practice**. The ways to perform depressurisation were discussed above in subsection 3.2.1.3 of this report.

3.2.2.3. Control of water level and temperature of BWR suppression pools

In BWRs, steam that flows into the containment is directed into the suppression pool and is condensed there, mitigating the pressure increase in the containment. When the containment venting is conducted through the suppression pool and a hardened venting line, it is expected most fission products are removed by the scrubbing effect. This venting operation is called wet venting. In order for the scrubbing effect to work effectively, it is necessary to monitor and maintain temperature and water level of the suppression pool within a certain range.

In the case of a severe accident, steam from the reactor core isolation cooling system and/or safety relief valves is also directed to the suppression pool and its temperature and pressure increase. If the residual heat removal system is not operable, pressure inside the containment vessel increases even more. The vent line is typically established except for the opening of an exit valve. The purpose of this vent operation is not wet venting, but controlling the containment pressure by continuing water injection into the core and releasing steam through the suppression pool. In order for this operation to work effectively, it is also necessary to maintain the temperature and water level within a certain range. Accordingly, it is essential to ensure monitoring of status of the suppression pool.

When the suppression pool water temperature reaches levels above saturation, the scrubbing effect may not work sufficiently. It is necessary to take into account that prolonged accident conditions will lead to a localised high temperature zone caused by the temperature stratification within the suppression pool. The diesel-driven fire protection system and/or the make-up water system condensate can be used to spray the suppression pool and, thus, control its temperature. These accident management actions would provide a longer time for restoration of the residual heat removal system.

3.2.2.4. Heat removal from containment

Protection of containment integrity is one of the key objectives of accident management and, therefore, multiple diverse capabilities need to be provided to mitigate significant challenges to the integrity of the containment barrier. The main focus in countering challenges to containment is heat removal. Removal of heat from the containment atmosphere or structures causes condensation of steam and reduces the pressure.

Options and practices for containment cooling and pressure control include:

- assuring that the heat is removed from the fuel or core debris and transferred to a heat sink outside of containment;
- spraying of cold water using spray or dousing systems;
- cooling of containment atmosphere using local air coolers;
- potentially, cooling of the containment atmosphere though external portable coolers.

Venting of the containment atmosphere would also remove heat, but also mass from inside containment and thus, is an efficient means of reducing the containment pressure. However, to prevent uncontrolled release of radioactivity, venting should be done through an emergency filtered venting system (described in subsection 3.2.2.8).

Adequacy and sufficiency of equipment and consumables (water inventories as well as power for active systems) used to maintain or restore containment cooling is being assessed as part of accident management validation. The capability to replenish water inventories from outside sources via appropriate connections and pumps are being considered in many countries.

3.2.2.5. Containment pressure control

Control of containment pressure is achieved through removal of heat (described in subsection 3.2.2.4), venting (subsection 3.2.2.8), prevention of uncontrolled burns of combustible gases (subsection 3.2.2.6) and prevention of direct containment heating (subsection 3.2.2.2).

3.2.2.6. Control of combustible gases

A core melt event may lead to overheating of both metal and concrete structures. Both of these materials can cause the production of additional non-condensable and combustible gases in containment. In the presence of steam, the metal tends to reduce the water to hydrogen. Concrete releases hydrogen from water bound in its crystal structure and also carbon dioxide (which could be then reduced to carbon monoxide) from any carbonates present in the material. (Specific ways to manage carbon monoxide are not covered in this report).

When evaluating the volume and timing of non-condensable gases (mainly hydrogen) released, particular attention should be paid to metal-water reactions as such reactions may lead to fast generation of vast amounts of heat and hydrogen. Furthermore, radiation-induced radiolysis of water and molten core-concrete interaction should also be analysed.

For ensuring the containment integrity, creation of a mixture of gases that could burn or explode should be prevented. The amount of gases released also needs to be controlled to limit the containment atmospheric pressure. To prevent creation of a flammable gas mixture, in BWRs the containment is usually inerted with nitrogen. In PWRs and PHWRs inerting of containment is not practical, as their containments often are accessible during operation. In PWRs, the hydrogen concentration can be kept under control by promoting mixing throughout the containment volume, as well as burning or recombining the hydrogen in a controlled way while the concentration is low. Sometimes additional passive autocatalytic recombiners (PARs) are also included to complement containment inertisation and limit the risk of combustible gas combustion in the containment.

Igniters

Igniters are one type of device for achieving controlled hydrogen burning. Different types of igniters exist (e.g. glow plug or spark igniters), but all of them require a power supply. The glow plug igniter is the most commonly used type; however, spark igniters require much less power than glow plug igniters, and can thus be battery operated.

Passive autocatalytic recombiners

A PAR unit is typically an open-ended vertical box, inside which catalyst-coated recombiner plates are placed. On the surface of the recombiner plates hydrogen and oxygen react to be converted into steam; the reaction is greatly accelerated in the presence of a catalyst. The reaction is exothermic, and the heat produced generates a natural convection flow through the recombiner, thus, increasing efficiency of a PAR unit. The recombiners do not need any external power source or operator action for their operation. Several PAR designs are commercially available and used in many NPPs.

Location of igniters or PARs

The accident scenario and the geometry of the containment affect the distribution and mixing of hydrogen. Also, accident management actions have an effect on hydrogen distribution; containment spray strongly enhances mixing in the containment, but on the other hand spraying reduces steam content and can lead to high hydrogen concentration. These and other factors should be taken into account when placing the igniters and/or PARs within the containment volume. Special attention should be paid to dead-end compartments in the containment, where mixing may not be efficient and high hydrogen concentrations can emerge. For a well-mixed containment volume, a small number of PARs would be sufficient to control the hydrogen concentration; however, to assure that there would be no local high concentrations, a redundant number of PARs is usually installed. The number of PARs is plant-specific. It depends on the size of the containment and how well the containment atmosphere is mixed (which in turn depends on the inner structures in the containment, the accident scenario and the accident management actions, etc.). A number and locations of PARs are determined based on postulated hydrogen generation processes (Zircaloy-water reaction, molten core–concrete interaction, water radiolysis, etc.), simulations and experiments including major physical processes dominating local hydrogen concentrations. PARs installed at locations close to outlets of potential leak paths work effectively. The maximum number of PARs is eventually limited by available free space inside the containment.

Hydrogen transfer to other buildings

It is prudent to examine whether hydrogen ingress may occur from one unit to an adjacent unit through any shared piping. Countermeasures to prevent hydrogen inflow from the accident unit into any of the adjacent buildings should be established. Examples of such measures include keeping venting lines independent among different units sharing the same stack and prohibiting cross-connection of vent lines among different units.

In order to prevent hydrogen accumulation, a controlled release of hydrogen may be considered. However, venting of containment atmosphere would inevitably create a potential for release of radioactive material into the environment. At the same time, an evaluation is required to ensure that venting of containment with high hydrogen concentration through the emergency filtered system would not lead to an explosion that may destroy this system.

Hydrogen may also leak to buildings surrounding the containment. It may be useful to evaluate the risk of hydrogen explosions or burns in the adjacent buildings and whether some actions – for example additional ventilation or opening flow paths to atmosphere may be needed.

Hydrogen measurements

To be able to decide on actions to prevent hydrogen combustion or explosions, implementing provisions allowing for the measurement of hydrogen concentrations is recommended. Analytical simulations of selected accidents scenarios may be performed to define key locations for measurement of hydrogen concentration in the containment.

3.2.2.7. Ensuring containment isolation

Containments are designed to isolate automatically early in most accidents and the isolation may also be initiated by the operators, well before fuel damage occurs. However, a way to manually close containment isolation valves should also be provided (considering that normal I&C capabilities and power sources may be lost).

Containment by-pass is a special type of accident scenario, in which a path from the containment to the environment is created while the containment structure is still intact. Examples of possible release routes are:

- primary circuit to secondary circuit leakage in PWRs, in particular, through the steam generator tubing;
- via pipelines, if isolation valve(s) have failed; and
- through open/leaking containment penetration(s).

To reduce the risk of by-pass, the isolation valves and penetrations should be designed to withstand the severe accident conditions (e.g. pressure, temperature, radiation), keeping in mind that leak-tightness might be required for a very long time.

In PWRs the hot gases generated by the molten core that flow through the steam generator tubes can cause thermal loads that endanger tube integrity, thus causing a potential leakage path from the primary to the secondary circuit.

3.2.2.8. Containment venting

If actions aimed at cooling of the fuel debris, containment heat removal and control of combustible gases are not available or have not succeeded, then the containment pressure can increase to a level that threatens the integrity of the containment. Filtered venting is considered a **commendable practice** that allows lowering the containment pressure, preventing damage to the containment structures and limiting unfiltered leakage of radioactive products through bypass routes.

A filtered venting system consists of vent pipes from the containment atmosphere (in BWRs usually both from the drywell and/or from the wetwell gas space), filter unit(s), necessary valves and the piping from the filter(s) to the ventilation stack (or another exhaust location).

Isolation valves or rupture disks can be used in the line(s) from the containment to the filter. It is important to be able to determine the time and the duration of the venting to inform the off-site authorities (see subsection 2.3.2.3). Thus, it is advisable to have a line with isolation valves in addition to a release route with a rupture disk. If the valves are operated locally, attention should be paid to accessibility and radiation protection of the workers. It is important to ensure that the valves can be opened even if normal and emergency power supplies are lost.

After the isolation valves are opened, it is preferable that the venting system operates without further operator actions or maintenance for at least a few days and without reliance on power sources. The venting system (e.g., the piping) should be designed to withstand the harsh conditions of a severe accident. Consideration should be given to a possibility of high hydrogen concentration in the vented gas mixtures and potential for hydrogen burns, as well as to possible filter clogging. It should be noted, that if most of the non-condensable gases are vented out of the containment, steam condensation later on in the accident may lead to a sub-atmospheric pressure in the containment. For concrete containments this is probably not a problem, but for steel containments it should be ensured that the sub-atmospheric pressure does not damage the containment structure.

It is necessary to implement appropriate provisions for facilitating containment venting while assuming difficult conditions such as loss of electrical power supply and lighting, high radiation, exhaustion of air cylinders due to leakage, etc. Under those situations when venting is required, harsh environmental conditions should be assumed at locations where the vent valves are located.

Specific to BWRs, venting leads to depressuriing of the primary containment vessel, which facilitates use of the alternative injection systems and additional heat removal from the reactor core.

Venting from the primary containment vessel of BWRs would inevitably release a certain quantity of radioactive materials, in particular when the suppression pool conditions are close to saturation. When the wetwell is filled up, venting through the drywell may not be avoidable when needed to preserve the integrity of the containment vessel. To mitigate this condition, filtered systems should be used not only for the drywell, but also for the wetwell.

Multi-unit issues concerning containment venting are considered in subsections 2.3.2.4 and 3.7.2.

3.2.2.9. pH control in containment

Iodine is a major contributor to the doses caused by a severe reactor accident. This is due to the fact that iodine can exist in a highly volatile form that cannot be easily removed from the containment atmosphere. Its half-life is short enough to cause high specific activity, but at the same time sufficiently long so that iodine is present for a significant time after the accident. Furthermore, iodine, if consumed by humans, is predominantly concentrated in the thyroid and can cause thyroid cancer.

The sump pH is one important parameter in determining the formation of volatile iodine. The lower the pH of the sump water, the higher the fraction of volatile iodine. During the accident, the sump pH can be decreased as a result of HCl that can be produced by the pyrolysis of cable insulation. Radiolysis of organic solvents dissolved from painted surfaces can also increase the acidity of the sump. Organic solvents can also lead to the formation of organic iodines, which are very volatile and cannot be easily removed by the filters.

The sump water pH can be controlled by adding suitable chemicals to the sump. The equipment for feeding the chemical to the containment, as well as the storage tanks, should be protected against the hazards that may lead to, or result from, a severe accident. It should also be ensured that all the necessary operations (e.g., opening of valves) can be performed in situations where normal power supplies and I&C are lost, and the radiation level in the containment is high.

3.2.2.10. Ensuring sub-criticality

The control rod material, especially in BWRs, may melt at lower temperatures than the fuel itself. It is, thus, possible that the control material will melt and relocate to the bottom of the core while the fuel geometry is still mainly intact. If in such a situation un-borated or low-borated water is injected to the core, re-criticality is possible. A prompt re-criticality would cause a rapid power pulse that could lead to a complete shattering of the fuel rod. However, prompt re-criticality and the damage caused by it would probably be only local. The start of a more global stable fission production would have more serious consequences. Even if the power is low, it might be higher than the decay heat that is used as a design basis for the containment safety systems. A power input to the containment that exceeds the design basis could eventually cause failure of the containment. However, after the fuel has lost its original geometry, it is considered that the probability of re-criticality is low. The possibility of re-criticality should still be kept in mind when planning accident management actions. For example, if borated water is available for cooling of the corium, it would be preferred to un-borated water.

3.2.2.11. Instrumentation needed for managing severe accidents

For severe accident mitigation, the monitoring instrumentation should provide data to:

- support timely performance of operator actions;
- survey the effectiveness of the actions; and
- monitor the progress of the accident.

The instrumentation should indicate:

- the possible re-criticality of the reactor or its debris;
- the threat of a reactor pressure vessel melt-through;
- the location of the reactor debris;
- success of water injection into reactor and/or containment;
- success of cooling the core debris and containment;
- factors possibly endangering containment integrity, e.g. flammable concentration of hydrogen, temperatures that would endanger steam generator tube integrity.

For monitoring the progress of the accident, information on the following should be provided:

- to observe re-criticality:
    - neutron flux measurements (existing measurements can be used as long as the core is within the pressure vessel);
    - containment pressure and temperature behaviour (unexpected, sharp increase may be an indication of re-criticality);
- threat of pressure vessel melt through temperature measurements (e.g., outer wall of the RPV);
- location of core debris through temperature measurements (e.g., in different containment compartments and/or embedded in structures where the core is assumed to relocate);
- success of water injection and cooling functions:
    - reactor vessel pressure and temperature;
    - containment pressure and temperature;
    - water levels at relevant locations;
    - temperatures in the cooling chain, flow rates of cooling systems,
- gas concentration in different parts of containment (hydrogen, oxygen, steam, etc.);
- dose rates inside/outside containment;
- activity measurements in release routes;
- positions of isolation valves.

The instrumentation should be capable of functioning under severe accident conditions including high dose rates. Uncertainty caused by harsh conditions needs to be taken into account (see subsection 2.3.1). The instrumentation should have its own power supply (electricity, compressed air, etc.) and portable batteries for DC power can be allocated. Backup instrumentation and spare parts should be stored and readily accessible.

To further facilitate plant state detections, monitoring, video transmitters (VTRs) should be installed at key locations, including the containment.

3.2.2.12. Power supplies

The on-site power system should be protected against common cause failures. It is necessary to ensure diversity and redundancy of emergency electrical facilities. In enhancing redundancy of electrical facilities including AC power sources, DC power sources and switchboards, it is necessary to maintain separation of the equipment both within the structures and on the site (water-side/land-side, higher/lower elevations). Rooms housing important emergency electrical facilities need to be water-tight and protected from other environmental hazards. At the same time, drainage systems for coping with flooding are necessary for those rooms.

In evaluation of diversity and redundancy of the emergency AC power sources, it is necessary to take into account common causes that could affect supporting cooling systems, fuel supply, and DC supplies necessary for starting, controls and switchboards, and operations. Maintenance optimisation, such as allowed outage time, is worth discussing from the viewpoint of diversity and redundancy. Loss of functions or outage due to natural hazards should be taken into account.

Under a long-term SBO, loss of the emergency DC power leads to loss of instrumentation as well as control of depressurisation and injection systems. Securing DC power is crucial under a long-term SBO. To implement flexible countermeasures with enhanced capabilities and agility, charged backup batteries should be stored in safe places so they can be promptly installed when needed. Also, having the capability to recharge batteries using an alternative power supply can provide extended batteries and DC power for I&C systems. For vital systems, individual power supplies can be installed. Plant-specific conditions need to be taken into account in determining battery capacity. When an SBO occurs or is likely to occur, backup systems such as vehicle-mounted generators (AC generator, AC generator + rectifier) can be used to provide electrical power for both AC and DC powered equipment. Furthermore, to effectively implement accident management actions during an SBO, emergency storehouses should have spare equipment and cables to be prepared for a wide variety of harsh conditions. Provisions for increasing battery capacity and/or providing alternative AC and DC power supply capabilities appropriate to emergency response in an extended SBO event is considered a **commendable practice**.

3.2.2.13. Mitigating consequences of fuel damage in spent fuel pools

SFPs require water to cover the fuel not only to prevent fuel damage, but also to provide shielding against gamma and neutron radiations emitted by the spent fuel.

Depending on the shielding provided by the fuel-building structure, the loss of the shielding effect of the water can severely restrict the movement and operation of staff in the vicinity. The focus of mitigation measures is, therefore, generally on recovery and maintenance of water levels and temperature in the SFP.

The water level and temperature of the pools should be monitored. Dose-rate measurements in the fuel pool building should be considered if access to the building is required for the mitigation actions.

The requirement for cooling of spent fuel depends upon the reactor design, but diminishes as the fission products in the fuel decay. The time after fuel discharge is, therefore, a key factor. Gas-reactor fuel can generally survive in air after some days of cooling, but light-water reactor fuel requires several years before it can be stored in air without some degree of fuel damage. Moreover, when the fuel is freshly discharged from the reactor, without water covering the fuel and providing cooling, the zirconium cladding can reach ignition temperatures and the fire can spread to older fuel. Analysis suggests that distributing freshly-discharged fuel throughout the SFP can significantly improve the cooling of freshly-discharged fuel and hence increase the grace time before ignition. Segregation of the SFP into regions can also potentially affect the amount of fuel at risk.

3.2.2.14. Minimising release of radioactive material

One of the principal objectives of accident management is to reduce as far as practicable the amount of radioactivity released to the environment through the gaseous and liquid pathways. Many of the actions aiming to control the containment pressure and temperature are also influencing the concentration of radioactive materials in the containment atmosphere or sump water. Thus, the organisation, planning and implementation of accident management activities should be cognisant of the action's impact on the potential for radioactive releases. Heat removal from containment by spraying of water would transfer a significant portion of airborne radioactivity in the water accumulated in containment sumps to the containment atmosphere. Venting of containment would allow escape of radioactivity into the environment unless filtered. The impact of pH control on the volatility of iodine, a significant radioactive material release concern, is described in subsection 3.2.2.9. Special consideration should be given to the prevention of excessive accumulation of radioactive water in containment, which is likely to occur if water is added from external sources.

3.3. Mobile on-site/off-site equipment and instrumentation

Mobile equipment described in this subsection refers to equipment provided to give added protection against accidents that exceed the original design basis. The requirements for BDBAs and severe accident conditions given in the IAEA SSR-2/1 [19] are that consequences are mitigated to the extent reasonably practicable and that best estimate analysis may be used. In this document, these requirements are generalised to a more general principle of "reasonable confidence" in the design, analysis and operational requirements applicable to BDBAs. This standard is in contrast to the "high confidence" required for the control of design basis accidents.

Certain initiating events such as those triggered by extreme external hazards (e.g., earthquakes, flooding, extreme weather conditions, etc.) could lead to plant conditions that are beyond its design basis. It is essential to build up a diverse and flexible coping capability against those BDBAs to increase DiD. The aim is to ensure that a set of sufficient, supplementary equipment (e.g., pumps and generators) and consumables (e.g., fuel and water inventories) are identified, obtained, protected and stored on-site or off-site. These can be used to maintain or restore the cooling of the core, the containment, and the spent fuel pool when the installed SSCs are either damaged or become unavailable following a beyond design basis initiating event. After the consumables are used up, off-site resources should be obtained to sustain those cooling functions indefinitely.

The types of mobile equipment provided to address BDBAs, the design standards for the equipment, and the location of storage, depend on a number of factors and many different solutions are possible. Therefore instead of providing specific rules, general guidance is provided below.

On-site equipment is generally equipment that is intended for rapid deployment within the coping time of the NPPs installed equipment (typically about eight hours for new reactors and often somewhat less for older designs). Note that on-site equipment may include equipment held near the site and under the direct control of the NPP operating organisation provided it can be deployed in the available time. The on-site equipment should be self-sufficient for a defined period, typically about 72 hours, after which off-site equipment may be assumed to be available.

The safety classification of the mobile equipment should be based on its importance to safety. This takes into account such factors as:

- safety function(s) to be performed;
- consequence(s) of failure;

- probability that the SSC will be called upon to perform the safety function;
- the time at which the SSC will be called upon to operate, and the expected duration of that operation; and
- the functional performance under conditions following internal or natural external hazards under which the SSC is called upon to operate.

The requirements applicable to the procurement, design, operation, qualification, maintenance and testing of equipment used to respond to BDBAs are based on the safety classification and are established by (or approved by) the regulatory authority. The requirements for portable equipment should depend on a number of factors, such as the level of redundancy provided, coping time without the equipment and the mission time of the equipment. For example, equipment of a common type with standard connections could potentially be replaced with equipment brought in from off-site in the event of failure, provided there is time to do so.

3.3.1. Functions to be supported by mobile equipment

The functions to be supported by the mobile equipment are essentially the same as those identified for the fixed equipment and include the fundamental safety functions:

- control of reactivity;
- removal of heat from the reactor and spent fuel; and
- confinement of radioactive material, shielding against radiation and control of planned radioactive releases, as well as limitation of accidental radioactive releases.

In support of these fundamental safety functions, the following activities are important:

- monitoring of reactor conditions;
- assuring power supplies for equipment;
- providing consumable supplies for equipment (e.g. fuel and coolant);
- maintaining access to equipment;
- protecting of workers;
- repairing equipment; and
- securing barriers to flood, fire, radiation (shielding) and radioactive release (in water or air).

3.3.2. Mobile equipment and instrumentation

The subsections below discuss the common types of portable equipment that may be used to deliver the functions described above.

3.3.2.1. Electrical power

Electrical power may be needed for pumps, I&C, lighting, air conditioning, and a number of other duties. The capacity and voltages will depend on the NPP design. The power supply connection points and connectors should be standard and found at multiple locations outside of the reactor buildings. Portable power sources should be available in a timely manner after the onset of an SBO. The required mission time should take into account the possibility of widespread site damage and large-scale off-site disturbance such that off-site power recovery is not possible for an extended period. Since electrical power is needed to support many other functions, providing additional redundancy by the use of portable electrical equipment is considered a **commendable practice**.

3.3.2.2. Cooling water

Portable pumps are likely to be used to increase plant capability for coping with degraded cooling conditions. Consideration should be given to availability of water supplies, initially from dedicated reservoirs, with the capability to use a neighbouring body of water such as a river, lake or sea.

For a smooth and secure transition to alternative water injection, pumps with high discharge head should be procured, connection manifolds should be provided with standardised connections points, and sufficient hoses to connect the alternative water sources from the pumps to the alternate injection points should be provided. To the extent practical, connections points should be available outside of the reactor buildings in areas accessible to the NPP personnel.

Since cooling to the fuel in both the reactor and the SFP are critical functions, providing alternative cooling methods is considered a **commendable practice**.

3.3.2.3. Instrumentation and control

I&C equipment should be sufficient to support emergency operating procedures and severe accident management guidelines. Portable instrumentation can be provided for common functions such as monitoring criticality, radiation levels, water levels, temperature, pressure, hydrogen concentration, and electrical voltage. This can provide adequate information for severe accident response and is considered a **commendable practice**.

Portable equipment to provide instrument and motive power for control equipment (such as valves) should be available.

3.3.2.4. On- and off-site radiation monitoring

If a radioactive materials release event occurs at the NPP, radiation levels need to be appropriately monitored. It is necessary to provide for monitoring of radioactive releases from all sources, including those not discharged from the normal route (i.e., from the stack). These monitors should be designed to give accurate measurement even in highly radioactive environments.

Environmental radiation monitoring systems need to be supported with emergency power sources. Assuming loss of the stationary monitoring posts, alternative measures such as monitoring cars are considered a **commendable practice**.

Radiation monitoring should be prioritised in the areas most likely to be contaminated, using information such as the release locations and meteorological conditions.

Results of radiation monitoring should be processed quickly and communicated to those who may perform work in the contaminated areas.

3.3.2.5. Compressed air

Compressors may be needed to provide instrument air and breathing air. Sufficient supplies of bottled air for use by workers should be available. Means for recharging air bottles should be considered.

3.3.2.6. Tooling and consumables

Portable lighting may be needed to supplement emergency lighting. Tools for repairs to essential equipment should be available as well as a supply of spare parts. Lubricants and decontaminants should be considered.

The choice of tools, spare parts and consumables will depend on the NPP design and involve judgement. People with a wide range of expertise should be consulted, including people with expertise in severe accident progression, hazards analysis, emergency response, operation and maintenance.

3.3.2.7. Portable barriers

Providing barriers against flood, fire, radiation and to prevent transport of radioactive materials should be considered. Inflatable seals may be used for sealing damaged pipes or ductwork.

3.3.2.8. Personal protective equipment

Sufficient personal protective equipment (PPE) should be provided to respond to emergencies and protect the emergency responders, typically for about the first 72 hours without off-site assistance. PPE, personal dosimeters, radiation control equipment and other instrumentation should be appropriate for their intended use. Emergency response equipment, instruments, materials, and facilities should be available to provide search and rescue, decontamination and first-aid services when needed.

Stocks of protective clothing and shoes, dosimeters and portable shielding should be available. Larger stocks may be held at a central location to serve a number of NPPs. This is considered a **commendable practice**.

Preparation and supply of PPE are planned in accordance with considerations of radiation, extreme environmental conditions or adverse industrial conditions as described in subsection 4.6 of this report.

Personal dosimeters should be calibrated, staged and immediately available for designated emergency work. Systems used for maintaining, reading and charging these dosimeters should be in working condition at all times. For battery-operated equipment, sufficient numbers of batteries should be available. Backup facilities and emergency response equipment needed to maintain equipment for personal dosimeters, radiation instrumentation and laboratory services should be defined within the emergency response plan.

3.3.2.9. Supporting equipment

Conditions resulting from severe accident and weather conditions, such as high radiation levels, industrial hazards, snow or ice, can impede the implementation of accident management actions. The NPP operator should plan to use appropriate supporting equipment available when such types of conditions are possible.

Additional support equipment could include, but is not limited to:

- robots to perform tasks in high radiation areas;
- steam suits, ice vests, and breathing air apparatus;
- snow/ice removal equipment.

3.3.3. Management of mobile equipment on-site/off-site

On-site (or near-site) mobile equipment should be under the direct control of the NPP operating organisation.

Off-site mobile equipment may not be under the direct control of the operating organisation. If not, the operating organisation is responsible for ensuring that appropriate agreements are in place with the owner of the equipment and for verifying that the equipment is available and in an appropriate state of readiness.

Programmatic controls should be in place to ensure that mobile equipment can provide reliable coping capabilities. The controls would establish a baseline for quality, maintenance, testing of mobile equipment, configuration management and periodic training of personnel. These controls may be implemented using the following steps:

a) The technical basis for identification of mobile equipment required to increase plant coping capabilities is normally documented in accordance with the NPP modification process. This documentation specifies requirements and guidelines for procurement, installation, operation and maintenance, as well as any interfaces with the installed engineered SSCs. Codes and standards appropriate for mobile equipment (e.g., commercial/industrial grade) are also documented;

b) A plant-specific emergency equipment guideline document (EEGD) should be prepared to document all necessary details pertinent to installation, operation, maintenance, testing, inspection, storage, transportation, and protection of mobile equipment. In many instances, commercial or industrial equipment may be the only option available. Therefore, the required equipment details that mainly come from the manufacturer should be documented in the EEGD. Equipment operability and usability under upset plant conditions should be confirmed by acceptance/field testing and documented. Certain aspects such as utilisation of, or synchronisation with, off-site equipment and resources should be also documented in the EEDG;

c) Finally, use of on-site/off-site mobile equipment should be included in accident management documents such as EOPs, and/or SAMGs. If necessary, a separate accident management guideline document for use of mobile equipment may be developed. The EEDG that provides details about mobile equipment should be referenced in the accident management documents.

3.3.3.1. Responsibilities for storage, transportation and operation

It is the responsibility of the NPP operating organisation to manage mobile equipment and assure the continued viability and reliability of the added plant capability using mobile equipment.

A number of factors should be considered for selecting suitable storage locations, which include:

- internal and external hazards applicable to a site following an extreme external event (e.g., earthquake, flooding, tornado, snow/ice storms, severe weather conditions, etc.);
- transportation from the storage area to the deployment location under upset plant conditions;
- minimum time delay in hook-up following an external event; and
- conditions that do not lead to degradation over long periods of storage and equipment accessibility for periodic maintenance and testing.

Mobile equipment should be stored under the environmental conditions recommended by the manufacturer. It should be stored in a manner that protects it from internal and external hazards applicable to a site to provide reasonable assurance that the equipment will remain deployable. Redundant/multiple sets of equipment may be stored at different locations and secured/protected by different means to increase availability. For portable instruments, storage should include sufficient supply of consumables (e.g., batteries, filters, etc.) to keep them in service until resupply is assured. For equipment requiring fuel, the on-site fuel storage should be sufficient to sustain the operation of the equipment, typically for about 72 hours without off-site assistance. Spare parts/connection kits for the mobile equipment should also be maintained, coded, stored and protected. The basis for storage of equipment and associated supplies should be documented in the EEGD.

Equipment movement should follow the applicable transportation and work process requirements in NPPs.

Operation of mobile equipment should be commissioned by acceptance/field testing, and verified through periodic drills or exercises after storage.

3.3.3.2. Inspection, maintenance and testing

The operating organisation is responsible for ensuring adequate inspection, maintenance and testing of on-site mobile equipment. These activities should be appropriate for the safety classification of the equipment. It is expected that the inspection, maintenance and testing of on-site mobile equipment be performed directly by the operating organisation. For off-site equipment, other arrangements may apply, but the operating organisation remains responsible for ensuring that adequate measure are in place and effective.

3.3.3.3. Training and operating instructions

Detailed operating instructions from manufacturers should be obtained and documented in EEGD. They may also be used in training. Personnel qualification for deployment and operation of on-site mobile equipment should be confirmed by field testing and maintained through periodic drills or exercises.

Mobile equipment is assigned to appropriate operators (on-site personnel, emergency response organisations personnel and other emergency responders). Measures to ensure the competence, training and qualification of each class of emergency responder are discussed in subsection 4.3 of this report.

3.3.3.4. Transportation of equipment

Suitable transportation equipment and personnel protective equipment should be provided to ensure that mobile equipment can be moved safely and in a timely manner from its storage area to the points of use. Consideration should be given to the possibility that external events can result in obstacles restricting normal pathways for movement and that widespread site damage and/or extreme weather conditions can result in further delays in transporting equipment and putting it in service.

3.3.3.5. Pre-emptive deployment

Adequate provisions should be made in advance at each pre-selected equipment deployment site for water sources (e.g., intakes from lake or river, or fire hydrants), fuel tanks, connection fittings and lines, power sources, ground condition or structures required for equipment installation, operation and protection. Consideration should be given to the possibility that the deployment site may have been flooded or subjected to some anticipated hazards. If necessary, an alternate deployment site should be identified.

Some hazards can be anticipated (for example, approaching severe weather conditions) and some emergency maintenance states (such as a plant outage with a depressurised reactor and containment unavailable) can be identified as having an unusually high associated risk. In these cases, pre-emptive deployment of portable backup equipment to a holding station close to the site is considered a **commendable practice**.

3.4. Control rooms and emergency response centres

The response to an emergency is generally co-ordinated from a number of places:

- the MCR is used to monitor plant functions and to take control actions remotely;
- on-site emergency facilities are used for managing the situation in general and for other activities needed during emergency (technical support, decontamination, repair works, communications etc.); and
- off-site centre(s) may be used for different functions (providing additional technical support, communicating with other organisations and the media, etc.).

It is necessary that these facilities withstand major natural hazards, like earthquakes and flooding. They should also provide sufficient space for personnel, contain sufficient power sources, prevent the inflow of radioactive materials, and have monitoring functions for surrounding situations (such as on-site damage, movement of workers and equipment, etc.). It is crucial to maintain communication between the different facilities and relevant organisations.

3.4.1. Control rooms

Usually the plant is monitored and controlled from the MCR. However, during an emergency the use of the MCR may become impossible for several reasons: high radiation levels, presence of smoke, fire, total loss of power or some intentional man-made hazard. The MCR itself can be protected against some of the threats. A filtered ventilation system can be used to enable working conditions in the MCR in case there is a release of radioactivity on site. The control room can also be fitted with over-pressure ventilation, which is designed to prevent smoke from getting into the control room in the event of a fire outside the control room. Detectors and filters for toxic gases can also be installed. However, it should be noted that in an extreme situation these systems may be unable to operate if, for example, all power sources are lost.

If the MCR is lost, it is a **commendable practice** to have a secondary location to monitor and control the plant – either a centralised control station or a distributed one making use of local measurements and controls. Whatever the arrangement, it should be ensured that the reason for the loss of the MCR (whether fire, smoke, radiation, physical damage, man-made hazard or some other reason) does not endanger the use of the secondary control location(s).

The functionality of the secondary control location should cover shutting down and cooling the reactor and removing residual heat from the fuel. Also, the MCR and secondary control location(s) should be separated in a way that the probability of losing them both due to same event (internal or external) is extremely small.

It is necessary to plan in advance the transfer of personnel to the secondary control location(s). Access routes to be used by personnel from the MCR and from elsewhere on-site or off-site should be taken into account.

It should be ensured, that possible spurious actuations (e.g., due to fire) from the MCR do not prevent or disturb controls from the secondary control location(s).

Necessary documentation, tools, communication devices and consumables should be available both in the MCR and in the secondary control location(s). Protective equipment, flashlights, food and drink should be provided.

It is a **commendable practice** to ensure through the installation of proper equipment and infrastructure (e.g. filtered ventilation, airtight enclosure, decontamination equipment at the entrance, sufficient wall thickness for shielding, sufficient sanitation, clean water sources, etc.), the habitability of at least one control room. In addition, other rooms/plant locations strictly necessary to manage the accident should be established to at least the extent necessary for successful implementation of the envisaged accident management actions. For some of those locations, long-term habitability might be required and reliance on personnel protective equipment may be appropriate.

3.4.2. Emergency facilities

This report considers the emergency facilities under the control of the NPP operating organisation. There are numerous other emergency facilities that may be activated in an emergency at the municipal, regional, national and international level, depending on the scale of the accident. The roles and responsibilities of these organisations and their facilities are not discussed here.

3.4.2.1. On-site emergency facilities

During an emergency, suitable premises are needed for the different activities that take place on-site. These activities include, for example, overall management and co-ordination of the situation, technical support for evaluating the plant state and the evolution of the accident, repair works, fire protection, decontamination of personnel and equipment, first aid, dose monitoring, laboratory activities, etc.

The premises needed for the emergency response can be arranged in several ways and locations. If the different facilities are separated by some distance, safe access between them should be guaranteed. The facilities also need to be available in extreme weather conditions, during total loss of on-site and off-site power and when there has been a release of radioactivity on-site.

To support the management and co-ordination of the emergency, facilities for technical support are usually needed. Equipment should be provided for the acquisition, display, and evaluation of all radiological, meteorological, and plant system data. Equipment is also needed for gathering, storing, and displaying data needed to analyse plant conditions. It is good to have a complete and up-to-date repository of plant documentation, sufficient to aid the technical analysis and evaluation of emergency conditions. Reliable communication means are needed, especially if the facilities for overall accident management and for technical support are separated from each other. If VTRs are used at the plant, it might be useful to have access to them from the technical support centre (and/or other appropriate emergency facilities).

It is important to have access control on-site to know how many persons are working on-site and their whereabouts. It is also useful to have facilities to brief and debrief staff and dispatch them into damaged areas of the plant, to receive and treat casualties and to ensure adequate decontamination. This requires suitable facilities with decontamination and monitoring equipment.

Necessary personal protective equipment should be stored in the emergency facilities.

3.4.2.2. Off-site Emergency centre

The utility may also have an off-site centre for emergencies. It could be used for providing technical support, for management of off-site emergency response until municipal, regional and national agencies are functional, for co-ordination of emergency response activities with other involved organisations and for providing information for civil authorities, government and press offices. The duties of the off-site centre may vary from country to country depending on how the responsibilities are shared among the different involved organisations. Whatever the duties of the off-site centre are, reliable communication tools and access to necessary plant data should be provided.

3.5. Communication

Management of an accident may occur from several control points on the plant site as well off-site locations, each with different specific responsibilities and functions (see subsection 3.4 for more details). In addition, a large number of teams and individuals would be performing tasks in the field, making reliable communication indispensable.

3.5.1. Communication tools

In order to enhance reliability of communication means, it is necessary to consider and assess the following:

- The provision of diverse communication methods, including land lines (phones and faxes), mobile radios, satellite phones, microwave phones and voice-powered phones, should be considered a **commendable practice**;
- Secure emergency power sources, including uninterruptible power supplies. Provision of sufficient batteries for a prolonged event and/or hand crank battery chargers/generators is necessary;
- In widespread disasters brought about by large earthquakes, for example, overload of telecommunication channels is likely to occur. Some countries reserve part of the bandwidth for selected emergency services. However, the possibility that this will not be sufficient needs to be considered;
- It is required to implement appropriate countermeasures to ensure survivability of communication equipment under harsh conditions such as earthquake and flooding;
- Extreme severe accident conditions can render all telecommunication means unusable. As an ultimate backup option, handwritten, courier-dispatched communication should be considered.

3.5.2. Transmitting plant data

Ability to diagnose the plant state during the accident progression is indispensable for implementing the most appropriate accident management measures. A limited set of plant parameters that allows diagnosing the state of the plant needs to be transmitted to the different emergency organisations; this is considered as a commendable practice.

It is necessary to prepare alternative methods that do not solely rely on the electrical data transmission system. Microwave transmission of data is one possibility.

It is worth considering using prepared information communication templates to facilitate the sharing of information among responders. Simplified system drawings with symbols indicating status of equipment and whiteboards with commonly shared templates can be prepared for use.

3.5.3. Information storage/retrieval

In the event of an accident, necessary basic plant information such as drawings, manuals, repair records, etc. need to be promptly available to the accident management teams. It is desirable that such plant data will be prepared in both digital and hard-copy formats. This information should be available in the plant control rooms (both main and supplementary), the emergency control centre, the company headquarters, etc.. In order to enhance portability of the plant database, it is worth considering advanced mobile electrical appliances such as tablet computers.

3.6. Logistics and infrastructure

Securing access routes inside and outside the plant site is crucial for implementing emergency responses smoothly. Accident management procedures should be based on estimated times for providing necessary personnel and equipment through these access routes. Those estimations should be established via training and drills simulating harsh conditions to be postulated for individual plant sites. In particular, subsections 3.6.1, 3.6.2 and 3.6.3 are discussing the logistics and infrastructure aspects of supporting the sustained response operations described in subsection 4.5.1 of this report.

3.6.1. On-site access routes

Multiple access routes need to be secured for transporting on-site mobile equipment from storage locations to the points of use. It is necessary to postulate harsh conditions where those routes are destroyed due to earthquakes, closed due to huge flotsam caused by tsunami or flooding, and obstructed due to structures carried by tornados, etc. In order to remove obstacles and repairing cracked and buckled roads as soon as possible, provisions for operating heavy equipment such as earth movers (located on-site or near-site), is considered a **commendable practice**.

Alternative countermeasures should be provided when an excessively long time is required to recover on-site access routes. In designing these countermeasures, identification of equipment, its functions and accessibility is essential to ensuring success. A plant walk-down is indispensable to evaluate feasibility of these alternate success paths.

3.6.2. Off-site access routes

When long-term accident management is demanded, it becomes difficult to cope using only on-site personnel and equipment. Under such conditions, it is necessary to secure multiple access routes to call-up supporting personnel from lodgings and transport additional equipment and survival supplies (such as food, water and medicine) from their storage locations.

It is necessary to identify and address concerns potentially affecting access routes, such as collapse of bridges and structures, obstacles and gates for nuclear safeguards, landslides, subsidence of roads, etc. By postulating which access routes will be cut and which lodgings and relay centres will be destroyed due to wide-area disasters such as hurricanes, flooding, heavy snow and landslides, alternate routes to the facility to cope with these situations can be identified, including making appropriate arrangements for air-lifting of heavy equipment.

3.6.3. Secure delivery, relay centres

Several locations should be selected for transport relay centres considering land contamination and bad road conditions. Under severe accident conditions, direct delivery of materials and equipment may be difficult due to problems in communication and difficulties in finding access routes. Deployment of transport relay teams enhance reliability in receiving and storing materials and equipment on behalf of plant personnel. Clear display of information such as dispatch details, contents, function, etc. should be considered.

3.6.4. Lighting

When lighting is lost in the MCR, buildings and other plant facilities, accident management may become extremely difficult. To cope with accident conditions safely, quickly, and reliably, provision of a wide variety of lighting equipment such as spotlights, LED lights, and floodlight balloons is considered a **commendable practice**. It is necessary to prepare both local and wide area lighting equipment. For example, spotlights can be regarded as essential because they free up both hands of the field personnel, while lighting equipment that illuminates a wider area is also important to help identify hazards in the workers' surroundings.

3.7. Other issues

3.7.1. Recovery of off-site power

Although the emergency DGs can be expected to supply AC power during absence of off-site power, a long-term loss of off-site power can be a major factor that hampers the accident management efforts. Considering many un-definable off-site failure modes, it is not prudent to count too much on the immediate and continuous availability of external power supplies. However, it is also true that availability of off-site power can tremendously change response time margins and therefore the accident management strategy.

In principle, off-site facilities are not subject to nuclear regulations. It is prudent to analyse the off-site facilities as a hierarchical structure and identify important facilities such as substations directly connected to the NPP that should be enhanced in their reliability. Receiving power from two substations or switching transmission systems will enhance the reliability of off-site power and facilitate quicker restoration from accidents. Hardening of disconnecting switches, lines, breakers, etc. against natural disasters and man-made disasters can be enhanced. Foundation of power transmission towers should be assessed for stability against landslides, earthquakes and other potential hazards.

3.7.2. Multi-unit considerations

Development and implementation of accident management at multi-unit NPPs requires consideration of several additional aspects. On the one hand, multi-unit plants possess larger material and organisational resources to respond to the accident. The operational units may assist in coping with the emergency, for example, by providing power through inter-unit power lines. Multi-unit plants would have larger easily available expendable resources, such as fuel for emergency generators, and may have extra portable on-site equipment. On the other hand, in case of wide-area damage and simultaneous accidents on several units, the response organisations would be confronted with multiple challenges requiring actions and resources at several units at the same time. Hence, the equipment that would be used in case of an accident to prevent or mitigate significant core damage, damage to fuel in SFPs, and challenges to containment and the SFP building, should be sufficient to simultaneously deal with accidents occurring at all units at a given site.

When an NPP is under construction adjacent to an operating plant, and sharing of equipment or resources between reactors has been justified, the availability of such equipment/resources and their capacity to meet all safety requirements for the operating units is assessed during the design and construction phases.

3.7.3. Liquid radioactive effluents

Management of a very large quantity of liquid radioactive effluents, as encountered in the Fukushima Daiichi NPP accident, would pose significant and site-specific challenges because it depends on the accident, geographical and hydrological conditions at each plant site. It is useful to develop general procedures based on assumptions to prevent release of a significant quantity of liquid radioactive effluents into the environment by preparing and employing suitable means. Detailed procedures depend on configuration of leak paths and a quantity and the radioactivity level of liquid effluents. It is not practicable to define any specific method. Inflow of the ground water into the buildings from the mountainside caused a large obstacle in Fukushima Daiichi NPP accidents. So far, three general methods and goals have been sought:

- detect leaks and close leak paths;
- if it is difficult to close all leak paths, collectible liquid radioactive effluents should be collect and a significant quantity of radioactive materials should be filtered off, stored and monitored them;
- minimise environmental influences of liquid radioactive effluents by confirming their release remains under an allowable level.

Intrusion of rain and groundwater may increase the liquid radioactive effluents as observed at the Fukushima Daiichi NPP site. In such cases, as an emergency counter measure, reinforcement of water preventing devices or systems should be planned by the operating organisation with involvement of the appropriate design or engineering organisation. Its design will depend on the specific situation.

3.8. Compilation of commendable practices

The TGAM considers provision of the following accident management equipment, infrastructure and instrumentation to be commendable practices:

- In BDBAs, to prevent fuel melt, make available systems/equipment for cooling the reactor and the spent fuel pools that are independent of normal/emergency power supplies and heat sink (e.g., diesel- or turbine-driven pumps with alternate water sources);
- It is commendable to have systems/equipment available to mitigate the consequences of a severe reactor accident. Systems/equipment would include those needed to cool the corium and the containment, to manage combustible gases like hydrogen (e.g., passive autocatalytic recombiners) and control containment pressure. The systems/equipment should withstand the harsh conditions of the accident (e.g., very high temperatures, high radiation levels, etc.), taking into account that some equipment may be required to remain operable for a considerable period of time – several months or even years;
- Design cooling water supplies with suitable diversity to provide the required level of resilience and redundancy;
- Provide a reliable means of depressurising the reactor;
- If containment venting is used to limit the containment pressure, it is commendable to use a filtered vent instead of an unfiltered system;
- It is commendable to have severe accident instrumentation that enables performing well-timed operator actions, surveying the effectiveness of the actions and monitoring the progress of the accident. The instrumentation should withstand the harsh conditions of the accident (e.g. very high temperatures, high radiation levels, etc.), taking into account that some instrumentation may be required to remain operable for a considerable period of time – several months or even years;
- Portable power supplies are provided for essential systems, and sufficient battery capacity to support severe accident instrumentation and other essential systems in an extended period of station blackout is available;

- If the MCR is lost, it is commendable to have a secondary location to monitor and control the plant – either a centralised control station or a distributed one making use of local measurements and controls. Whatever the arrangement, it should be ensured that the reason for the loss of the MCR (whether fire, smoke, radiation, physical damage, man-made hazard or other reasons) does not endanger the use of the secondary control location(s). Provide for suitable habitability of at least one control room, employing appropriate personnel protective equipment as needed;
- Personal protective equipment, dosimeters and portable shielding should be provided to allow site operations to continue in harsh conditions;
- Employ satellite, microwave phones and other diverse communication systems for voice and data;
- Provide for transmission of a limited set of plant parameters to the different emergency organisations;
- Use of alternative measures for environmental radiation monitoring such as monitoring cars should be considered;
- Heavy equipment, including earth movers, should be available for site damage repair;
- Provide emergency lighting in key areas of plant as required for emergency response;
- To ensure the availability of the mobile equipment when needed, it is commendable to have well defined responsibilities and routines for managing the equipment (e.g., storage, maintenance, testing, transfer, and training);
- A strategy for pre-emptive deployment of mobile equipment in the event of an anticipated hazard is considered commendable.

4. HUMAN AND ORGANISATIONAL RESOURCES

4.1. Introduction

As described in Section 1 of this report, IAM refers to all arrangements needed to manage as efficiently as possible any accident affecting an NPP with potential release of radioactive material. These arrangements entail procedures and guidelines to implement various accident management strategies, as well as supporting equipment, infrastructure and instrumentation. Details and commendable practices related to each of these key aspects of IAM are described in Sections 2 and 3 of this report, respectively. An overlying essential component of the entire set of arrangements needed to effectively and efficiently manage an accident affecting an NPP involves the human and organisational resources necessary to successfully carry out accident management strategies. Employment of accident management equipment using procedures and guidelines relies on understanding and consideration of the role the human element plays in the overall response. This section of the report focuses on some of the human and organisational resources considerations needed to ensure an integrated response consistent with the definition and goals of IAM; namely, staffing, training and qualification, drills and exercises, resources to ensure sustained response operations, and measures to protect responders.

4.2. Staffing needs for accident management

An effective approach to IAM relies, in part, on an appropriate level of human resource commitment to ensure that the situation is able to be managed. Identification of roles and responsibilities, as well as the appropriate depth of staffing to respond to a widespread or extreme event over a protracted period of time, are essential to ensuring success in reaching the overarching goals and objectives of IAM. Evaluation of staffing needs and planning for long-term response during complex, multi-unit events is considered to be a **commendable practice**.

4.2.1. Identification of key accident management tasks and response personnel

Several countries have recognised the need to enhance the understanding of staffing levels to carry out accident management responsibilities under extreme or beyond design basis conditions. The experience gained from the Fukushima Daiichi NPP accident has highlighted the importance of evaluating staffing needs in light of beyond design basis initiating events that present significant challenges to preventing or mitigating core or spent fuel damage. Staffing studies required of plant operators by regulatory bodies can inform the composition of response staff during operational states and during accident conditions or extreme events. For example, training of the plant staff to perform auxiliary roles may be an effective means of ensuring adequate personnel are available to perform immediate response activities upon initiation of a beyond design basis event, particularly if it involves a natural disaster or other challenge that could hamper the ability of additional responders to report to the site. Furthermore, as severe accident prevention and mitigation strategies evolve in response to lessons learnt from the Fukushima Daiichi NPP accident, additional staff may be required to install and operate special equipment or other features employed by these strategies. Beyond the initial response by the plant operating staff, it is also important that essential emergency response roles and associated tasks be identified and properly covered by staffing plans to ensure effective longer term management of accident response.

In addition to providing confidence that at least a minimum number of qualified personnel would be available to respond to a given event, some special considerations may also be valuable when informing staffing decisions. Some examples are:

- establishment of contingency plans to identify substitutes should an extreme weather, seismic, or industrial event make some of the normal population of trained and skilled workers unavailable;
- review of operator action commitments during seismic and extreme hazard scenarios to ensure the ability to carry out these actions under such circumstances;
- establishment of plans to provide reinforcements in the event of casualties to immediate responders as a result of the event;
- establishment of a support network with vendors and contractors;
- establishment of mutual aid agreements to obtain qualified responders from other nuclear power stations.

4.2.2. Staffing for long-duration accident

The experience at the Fukushima Daiichi NPP called attention to the importance of maintaining the capability to sustain accident and emergency response for an extended period. Events leading to a sustained station blackout condition or fuel damage scenario could involve significant recovery time until plant stabilisation occurs. Staffing needs should carefully consider this aspect of IAM in order to ensure that accident management activities can be carried out without undue challenges from reaching the limits of human endurance. Several countries have recognised the importance of providing relief for initial responders and have taken measures to specify criteria for the capability to maintain on-site response for an extended period without outside assistance. Additionally, the use of off-site emergency centres as assembly points for relief personnel, as well as the use of backup response forces to provide additional resources during long-duration accidents, may facilitate staffing capabilities for long-duration accidents. Use of qualified staff from other nuclear stations via mutual aid agreements is another consideration when seeking solutions to staffing challenges related to long-duration accident response. Throughout a long-duration event, responders will have a hierarchy of needs to be addressed to support effective performance. Subsections 4.5 and 4.6 provide additional considerations for meeting basic human needs to support a sustained response and for protecting staff responders throughout an extreme event.

4.2.3. Staffing for multi-unit accidents

Past thinking in the context of DBAs was largely centred on a single unit at a site being affected by the event. The accident at Fukushima Daiichi NPP clearly illustrates the potential for BDBAs, particularly those caused by large scale external events initiators, to affect all units at a site. The earthquake and tsunami off the coast of Japan on 11 March 2011 also showed that large scale seismic or weather events can affect multiple units in a geographic area, even if they are not necessarily co-located at a single site. In response to this event, many regulatory bodies and plant operators around the world have established plans to consider multi-unit scenarios when determining appropriate staffing levels. In addition to establishing appropriate numerical size for staff contingents, such plans should also evaluate strategies for prioritising the assignment of staff resources among the affected units.

4.3. Training and qualification

The IAM strategy relies upon appropriate procedures, guidelines, equipment and staff resources to carry out actions to prevent or mitigate accidents extending to beyond design basis conditions. In order to achieve an effective and comprehensive response, the human implementers must be properly trained to carry out their respective roles. Clear identification of tasks, an assessment of training needs and implementation of an appropriate training program are essential to achieving the goals and objectives of the IAM approach and is considered to be a **commendable practice**.

Basically, training and qualification programs should be established and implemented to ensure the competency of each class of emergency responder in fulfilling its respective role in the IAM approach. General considerations include:

- understanding of roles and responsibilities within the IAM strategies, procedures, and guidelines;
- pertinent knowledge of accident phenomena and processes;
- proficiency in performing specific activities required by the IAM plan;
- ability to take proper actions in stressful situations;
- testing the effectiveness of procedures and guidelines, including making suggestions for improvements if necessary;
- understanding of command and control practices and protocols.

4.3.1. Training and qualification requirements for NPP control room and auxiliary operators

As first responders to any event, NPP control room and auxiliary operators have a key role in any IAM strategy. Therefore, the training and qualification of these personnel is an important consideration in ensuring their readiness to carry out required actions. Training and qualification programs are well established to support plant operations within the traditional design basis. With the extension of the spectrum of potential situations into the beyond design basis realm, many countries are developing requirements related to operator training and qualification to support performance under these conditions.

As with existing training programs, a task analysis of new responsibilities to be carried out by control room and auxiliary operators is essential to identifying job duties related to accident management. The principles of a systems approach to training[5] (SAT) can then be applied to develop and implement changes to existing operator training and qualification programs that cover these additional job requirements. SAT has many advantages in that it promotes training consistency, provides confidence that training matches actual needs, and involves management in the monitoring and evaluation of personnel training.

Existing operator training programs primarily cover actions required during normal and abnormal plant operations, up through the use of EOPs in response to DBAs. However, regulatory requirements and industry practices related to training and qualification for control room and auxiliary operators to respond to beyond design basis situations, such as employment of SAMGs, are more variable in their depth and coverage. Several countries are planning to strengthen requirements in this area as a means of enhancing readiness to respond to beyond design basis conditions. A training needs analysis can be performed to identify and correct gaps in existing operator training programs to cover the expanded scope. One particular area of focus for control room staff training is the transitions from EOPs to other procedures and guidelines covering the beyond design basis conditions, as well as transitions and co-ordination related to parallel use of various procedure/guideline sets. Another important area is the transition of roles and responsibilities from the initial response by the control room staff to the augmented response when additional on-site support organisations, such as a TSC, are manned. Training needs in the areas of severe accident diagnosis and the special hazards that may result from severe accident phenomena should also be included in this assessment.

Although auxiliary operators may not require the same degree of training as control room operators in regard to overall initial accident management strategies and event diagnosis, additional training is warranted on newly identified duties that are part of the accident management response. Topics for consideration include the use of specialised or portable equipment used for accident prevention or mitigation, and off-normal plant system configurations that may result from employment of BDBA management strategies. Also, since auxiliary operators are likely to perform field actions as part of the accident management response, it is appropriate that they receive training on the special hazards they may encounter and on the means available to protect themselves.

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[5] SAT is a five element process designed to provide appropriate training based on requirements of the job. The elements are: (1) systematic analysis of the job; (2) derivation of learning objectives from the analysis; (3) design of training based on the learning objectives; (4) evaluation of trainee mastery of the objectives; and (5) evaluation and revision of training based on feedback from performance in the job setting.

With regard to control room and auxiliary operator training, it is important to recognise there is a need to achieve an appropriate balance of training resources spent between beyond design basis and more traditional topics. Given a finite amount of time available for crew training and qualification activities, new activities related to beyond design basis events will compete for limited resources. NPP licensee's will need to consider the potential impacts and develop an effective means of training on new aspects of accident management without causing harm to the operator proficiencies already established for within design basis operations. In other words, caution should be exercised such that over-training on very low probability events does not cause a loss of proficiency in handling normal or more probable events.

When new accident management actions are identified for control room and auxiliary operators, application of a SAT-based process will likely lead to changes in both initial and continuing training programs. Initial training is important to the development of new skills within the operating crews to implement accident management actions that may not have been covered by traditional operator training programs. Some degree of recurring training is also important in ensuring these newly developed skills are maintained over time. In addition to the drills and exercises, described in more detail in subsection 4.4, a periodic refresher training on specific accident management tasks may be useful in developing and maintaining the proficiency of plant control room and auxiliary operators.

The value of using a plant reference simulator in training control room operators has been widely demonstrated. Countries have noted the benefits of using simulators, within the constraints of their simulation capability, to provide training on the transition from design basis to beyond design basis accident conditions as well. At appropriate points when simulation limits are reached, training on beyond design basis scenarios may be continued using desktop simulators or table top discussions and is considered to be a **commendable practice**. As simulation capability within the industry is further developed, potentially to include fuel melt and ex-vessel effects, their use in training of control room crews on severe accident management will gain importance.

4.3.2. Training and qualification requirements for emergency response organisation personnel

Although training programs for control room and auxiliary operators have generally been well established, many countries are considering more formal training programs for emergency response organisation personnel. A systems based approach, similar to what is already used in operator training programmes, can be applied to develop training and qualification for these personnel. Training programs should be commensurate with an individual's respective role in the overall accident management strategy and should consider:

- understanding of roles and responsibilities within the emergency response organisation and how they relate to the overall IAM plan;
- basic understanding of severe accident phenomena and processes to assist in decision making;
- familiarity with specific activities that need to be executed as part of the IAM plan;
- co-ordination with other on-site and off-site responders.

It may be beneficial to develop a training plan for each emergency team member based upon that individual's specific role in IAM response. A qualification card or training notebook can be used to track individual progress toward developing the required competencies and skills and can also serve as documentation of completion of any required certifications. Implementation of such training plans and qualification journals is considered to be a **commendable practice**.

The TSC staff is a key emergency response organisation resource essential to effective on-site accident management given their integral role in accident diagnosis and interface with the NPP control room staff and other emergency response organisation decision-makers. Depending on the command and control arrangements in place at different NPPs, the TSC functions in either an advisory role or provides direction to plant operators. Effective performance of TSC duties, therefore, relies upon both an understanding of accident progression and phenomena and in-depth knowledge of the accident management procedures and guidelines to be employed. Several countries have, therefore, identified a need to provide initial and refresher training on the TSC accident management responsibilities to these key staff members.

Ultimate decision makers in implementing the IAM strategy must also have a strong understanding of accident management principles and mitigation capabilities. Some countries are considering some level of formal qualification for these individuals since they could be faced with making decisions impacting plant safety as well as that of members of the public. An in-depth technical knowledge of the NPP and all available mitigating strategies is essential for these individuals to perform in an effective manner, and could be demonstrated by some sort of formal certification or licensure.

4.3.3. Training and qualification for other emergency responders

A widespread or BDBA at an NPP has the potential to involve a large number of responders from both on-site and off-site sources as part of the overall IAM approach. Although many of these workers may not routinely exercise decision-making authority for strategic elements of the IAM plan, they nonetheless have important roles in carrying out IAM activities. These individuals are not necessarily accident management specialists, but rather, carry out tasks that may be more generic in nature. However, due to the special challenges that are likely to accompany a BDBA at an NPP, many countries have highlighted the need to provide additional training on certain aspects of accident management for responders such as:

- site fire brigade – access routes during radiological or widespread event response, prioritisation of activity based on IAM objectives (protect certain equipment);
- site security force – providing access for off-site responders, potential radiological or wide-spread event impact on normal security perimeter and response;
- maintenance workers – special considerations when setting-up portable equipment, conducting evolutions under extreme conditions (radiation, temperature, humidity, low visibility, etc.) and employing heavy machinery for debris removal to secure access for fire engines and power source vehicles in the aftermath of earthquake or flooding events;
- subcontractors – training on specific roles and responsibilities, including hazards, should be extended to subcontractors used by the NPP operator to fulfil accident management duties;
- off-site medical and fire responders – site access procedures, radiological hazard awareness, procedures for dealing with contaminated injured persons.

Accident management training for these groups would largely concentrate on performance of duties under extreme conditions, including the presence of severe environmental and radiological hazards. Although specific training on new tasks, such as setup and operation of portable or specialised equipment, would be expected, training on the unique circumstances that could be found in a beyond design basis scenario is considered by the TGAM as a **commendable practice** for improving the overall readiness of responders. Some countries have also found it beneficial to consider conducting training and co-operative information exchanges with local authorities and rescue services. These activities foster understanding of a common language regarding accident management, which can lead to more effective co-ordination of on-site and off-site resources by the entire emergency response organisation. The TGAM considers this to be a **commendable practice**.

4.4. Drills and exercises

The Fukushima Daiichi NPP accident highlighted the importance of human interactions in order to regain control of the plant following a severe accident. Periodic drills and exercises are important tools in developing and maintaining key skills, as they are in evaluating major portions of emergency response capabilities. Correction of performance deficiencies identified as a result of exercises and drills will lead to improvement of overall response capabilities.

4.4.1. Scope and degree of realism of drill and exercise programmes

Effective IAM involves a drill and exercise program of sufficient scope and realism. The scope of drills and exercises should include the use of all procedures, personnel protection equipment, response equipment and facilities, and provide for the demonstration and evaluation of the license holder's ability in responding to and mitigating beyond design basis and severe accidents. Because the range of licensee response to BDBAs or severe accidents is wide, a combination of drills and exercises is usually an effective means of meeting objectives for development of proficiency and conducting evaluations. While full-scale exercises can provide a high degree of realism and test interfaces between on-site and off-site emergency responders, the conduct of more limited scope drills are an effective means of ensuring preparedness to perform more specific or narrowly defined tasks. It is recognised that full-scale exercises involving all responders require a significant resource commitment to schedule and implement, usually resulting in performance on a less frequent basis than may be practical for more limited scope drills. This consideration illustrates the value of using a combination of drills and exercises to achieve program goals.

With regard to ensuring the scope of exercises and drills is sufficient, several countries have identified program attributes aimed at providing assurance of an effective response to BDBAs and severe accidents:

- Drills/exercises should cover multi-unit accidents and external events, including the combination of natural disaster with a nuclear event;
- An appropriate frequency for full-scale and limited-scope exercises and drills should be established;
- Plan drills/exercises to cover situations where operational protocols change during an event. As examples, consider those involving transitions between procedures of different types, command and control authority changes, and co-ordination of different procedures implemented by different personnel that may be physically separated;
- Use of full scope simulators to practice severe accident/BDBA response, with transition to desk top PC-based or table top exercise at an appropriate point when the full scope simulator capability limits are reached;
- Consider conducting both on-site and local government or national level exercises to cover licensee response capabilities, as well as those of other organisations. For exercises involving governmental organisations, the level of involvement (national, state/local, neighbouring countries) should be commensurate with the emergency response structure in place in the individual country;
- Drills and exercises involve all parts of the emergency response and support organisations, including radiological monitoring and protection teams, firefighters, medical responders, site security personnel, local authorities (control of roads, evacuation and protective measures), and special police forces (hostile action based scenarios);
- The scope of exercises may also include aspects related to dissemination of public information regarding the emergency, such as media centres and communications with local residents.

The drill and exercise programme should also include realistic scenarios and conditions that challenge the license holder's ability to carry out its accident management actions. Such scenarios might include extended duration exercises, multi-unit accidents, protection against hostile actions and response to natural disasters (earthquake, tsunami, tornado, flood and a combination of such disasters). Regulatory and industry practices in several countries have identified specific areas for consideration with respect to enhancing the realism of exercise/drills, which are considered to be **commendable practices**:

- Periodically conduct exercises unannounced and outside of normal working hours; i.e., the exercise timing and scenario is only known to the cognisant exercise management and preparation staff;
- Include in the drill/exercise scenario elements such as a reduced number of available emergency response staff on-site and reduced accessibility of the site;

- Exercise performance of actual special actions and co-ordination with off-site responders that could be needed during a severe accident, such as deployment of emergency medical/rescue personnel, manual operation of physical security barriers by security personnel to permit access/egress to the protected areas, distribution of dosimeters and potassium iodide tablets among responders, and site assembly and evacuation procedures;
- Include challenges such as reduced availability of instrumentation and pre-determined equipment malfunctions which will complicate the response. Practice the ability to set up or install portable equipment in accordance with the IAM plan. Also include challenges involving degradation of communication systems, particularly during times when co-ordination of actions using multiple procedures and responders is essential;
- Use real time weather data for radiological calculations during the drill/exercise;
- Construct scenarios to test response to long duration events, such as an extended station blackout condition affecting multiple units. For example, in one case, a tornado was postulated to strike more than one nuclear unit at a site, causing extensive damage to the infrastructure, including standby emergency generators, switchyards and commonly shared site facilities. This scenario provided the opportunity to conduct an exercise lasting for multiple days, testing the ability to replenish emergency response resource and the deployment of emergency mitigating equipment for an extended period.
- Include the introduction of organisational challenges, such as unavailable of some key staff members with extensive training in crisis management, to test the resilience of the organisation. Experience from major accidents outside the nuclear field shows that organisations can become de-structured, degraded and challenged, so "preparing to be unprepared" may be a useful dimension to add for drill/exercise realism.

4.4.2. Co-ordination with other response organisations

Drills and exercises should involve co-ordination with all on-site and off-site response organisations, and sometimes with response organisations of neighbouring countries and residents of the influence area. The degree of co-ordination required will vary across the range of drills, table-top exercises, field exercises, and partial and full-scale exercises being conducted.

Many countries have recognised the importance of periodically conducting drills or exercises that involve key partners and stakeholders, including neighbouring municipalities, the affected nuclear utility (including its suppliers and support vendors), state/local/provincial governments, military responders, non-government organisations and critical infrastructure partners. The many interactions among these groups that may exist during an integrated response to a widespread or beyond design basis event involving an NPP provide a basis for ensuring the communications and co-ordination efforts between these organisations are periodically exercised. As a commendable practice, several countries either have conducted or plan to conduct national level or "major scale" exercises as a means of simultaneously engaging the vast majority of key partners and stakeholders. These exercises can also involve participation by high level decision makers, which may prove beneficial in preparing these individuals should an actual event occur. Additionally, limited scope drills or interactions with individual stakeholders are an effective means of developing proficiency and assessing performance in their specific IAM areas.

Several countries have emphasised the importance of including neighbouring countries in exercises, particularly in situations where an NPP is located near an international border. In addition, several countries participate in international information exchanges or exercises, such as those sponsored by the NEA, IAEA or EU. These practices can lead to enhanced international co-operation and mutual assistance in the event of a significant nuclear event.

4.4.3. Evaluation of drill and exercise performance

One of the major purposes of conducting regular drills and integrated exercises is to confirm that each of the essential elements related to procedures and guidelines, equipment and personnel that are part of the IAM plan will have a high degree of effectiveness should an actual accident occur. As part of this confirmation, evaluation of drills and exercises identifies areas for improvement or where enhancement is needed. It is the responsibility of each organisation involved in the IAM plan to review drill/exercise evaluation results and implement corrective actions as needed.

A **commendable practice** in this area by several regulatory bodies is the establishment of requirements related to periodic evaluation or inspection of licensee emergency response exercises or drills by the regulator. Some regulators have found it beneficial to utilise a permanent group to review observations and conclusions from exercises/drills. This group meets throughout the year and identifies weak points and lessons learnt from the exercises/drills and proposed improvements to the regulatory oversight and involvement in emergency response. Use of a core group of specially trained and qualified inspectors and evaluators contributes to a consistent and informed review of licensee performance.

Licensees are expected to assess the results of drills and exercises and take actions as appropriate to ensure readiness. These actions may involve changes to training programs, the approach to IAM, or practical aspects of implementing various elements of the IAM strategy. Normally, opportunities for improvement are captured in action tracking requests or station condition reports and are resolved through a corrective action process. In all cases, thorough documentation of performance during drills and exercises is essential to supporting effective actions to improve performance.

For large-scale or national level exercises, it is important that lessons learnt be documented and shared with participating organisations. Some countries have processes whereby key lessons learnt from major exercises are circulated on a periodic basis among key government ministries, including the nuclear regulatory body. These lessons learnt are factored in to the planning for subsequent emergency exercises as a means of achieving continuous improvement.

4.5. Resources for ensuring sustained response operations

The nuclear accident at the Fukushima Daiichi NPP showed that accident management activities can be necessary for many months. Therefore, it is important that sufficient resources are available to support sustained emergency response operations over a long period of time.

4.5.1. Personnel recall and site access

On-site emergency response operations are typically carried out by main control room operators, auxiliary plant operators, maintenance workers, radiation protection personnel, firefighting brigade members and security guards. In addition, on-site response operations are usually supported by the license holder's emergency response organisation, which provides for on-site technical and administrative support.

Effective IAM relies upon the ability to initially staff and rotate on-site emergency response personnel over potentially long periods of time. Personnel recall is accomplished using voice and data communication systems to contact response personnel off-site in order to notify them of an emergency condition and request their presence on-site to support accident management activities. Personnel recall systems may consist of mobile, terrestrial-based and satellite phones, pagers and mobile computing devices, as well as the associated hardware and software to support the communication systems. Maintenance of personnel recall capabilities that include diverse communication means, are kept up to date and are periodically tested is considered to be a **commendable practice**.

In addition to the ability to recall personnel to the site, facilities should ensure that responding staff have the capability to safely access the site. This consideration can become extremely important during a widespread event, such as extreme weather, flooding or seismic activity, which can impact the integrity of roads, bridges and other transportation systems used for normal site access. Some regulatory bodies have developed requirements for NPP licensees to analyse potential effects from extreme events on access routes and to plan accordingly for alternate site ingress and egress paths. Contingency planning in the event that land access is severely disrupted could include deployment of off-road vehicles, debris removal equipment to clear access routes, transportation assistance from military sources, and the option for air (helicopter) transportation of personnel and equipment. Additionally, consideration may be given to strengthening existing infrastructure to harden it against potential extreme events. One such example is making structural modifications to improve the seismic capacity of a bridge that is part of a site access route to boost the resilience of this important structure and enhance its availability. In the event that site access is disrupted, contingency plans should be formulated to ensure that response can be sustained for some period with the site isolated. Action plans should consider both access routes and transportation time for external resources, both human and material, needed at the site and the corresponding on-site resource depth required until relief is obtained. This topic will be discussed in more detail below (in subsection 4.5.2).

Requirements for alternate command and control centres are also being considered by some countries; this is considered to be a **commendable practice**. In the event of damage to or inaccessibility of normal facilities, these alternate centres would provide locations for management of accident response resources. In addition to providing back-up locations for decision-makers, these centres could also serve as assembly and accountability points for recalled responders. Availability of the alternate command and control centres can be enhanced through location away from the immediate vicinity of the NPP or through hardening against extreme events, including those involving radioactive releases, to ensure they remain accessible and habitable throughout the duration of the emergency. Such centres would also be equipped with diverse and redundant communications systems to facilitate personnel recall and direction of event management.

4.5.2. Basic human needs

The increased staffing required to respond to accident conditions will place additional demands on resources needed to support basic human needs, such as food, water, sanitation and shelter. Additionally, access to these resources may be challenged by the event itself, whether due to extreme weather, degraded site conditions or radioactive releases. Prolonged around-the-clock staffing of the many roles that constitute the integrated accident management response will require the availability of basic services to satisfy basic human needs. As a **commendable practice**, several countries have established or are planning requirements for licensees to identify and make appropriate arrangements that include:

- food – including supply, storage, preparation and disposal;
- water – for drinking and sanitation;
- shelter – on-site for immediate responders and nearby locations for relief responders;
- sanitation – toilet and shower facilities;
- medical – first-aid and adequate treatment for reasonably foreseeable casualties.

As previously mentioned in subsection 4.5.1, an extreme event has the potential to cause the NPP site to become isolated from outside support. Until such time that access can be restored and supplies replenished, it is essential that arrangements be in place to ensure self-sufficiency in meeting the basic needs of all personnel located at the site. These arrangements may involve the storage of non-perishable food items (such as ready-to-eat meals or canned items), protected water supplies (bottled water or on-site tanks), temporary sleeping facilities (such as cots) and basic first-aid medical drugs and appliances as well as decontamination means. Some countries have found it helpful to designate an assumed time frame, such as 24 hours or several days, to be used in planning resources to meet basic human needs until site access is restored. The time frame selected is based on the evaluation of normal access methods, potential hazards and the challenges they could pose to site access.

For long duration events, some countries have considered deployment of temporary support structures that among other purposes contain facilities to support basic human needs. One such structure is in the form of a military-style tent city with modules dedicated to specific needs, such as shower facilities, toilet facilities and rest areas. Besides the addition of temporary on-site facilities, some site emergency plans have identified local hotel arrangements to house responders during extended events.

In addition arrangements to meet these basic human needs, personnel protective arrangements will be discussed in subsection 4.6.

4.5.3. Emotional and psychological support

The widespread devastation and loss of life associated with the 11 March 2011 earthquake and tsunami in Japan illustrated the potential for there to be a significant impact on the emotional and psychological health of affected plant staff and their families. Immediate on-shift responders and personnel being recalled to the site in an emergency are very likely to be concerned about the well-being of family and friends in the affected area, and may be under extremely high stress while executing accident management actions. For certain situations, there may be significant delays in obtaining relief for response workers, further adding to stress and fatigue levels. The combination of all of these stress-inducing factors has led some regulatory bodies to plan or consider requirements for licensees to define and plan appropriate emotional and psychological support for emergency responders. Additionally, some degree of education for emergency teams regarding emotional and psychological issues has been identified as an appropriate measure for enhancing awareness of this potentially significant impact on accident management personnel and for mitigation of its effects.

Although emotional and psychological support has not been a traditional area of consideration in the discussions on approaches to accident management, expansion of scenarios into the realm of beyond design basis accidents and extreme events elevates the importance of this topic. The importance of the human element in achieving a comprehensive and successful emergency response provides a basis for applying additional attention to this area, which can be essential to the well-being of response personnel. Recognising and addressing these aspects of human needs is an area that requires further research and development. Consultation with military experts experienced in dealing with the psychological effects of traumatic situations may be a valuable resource.

4.6. Measures to protect responders

Severe accidents or widespread events have the potential to create significant hazards that may be encountered by responders. These hazards may be in the form of radiation, extreme environmental conditions (e.g., high heat and humidity), or adverse industrial conditions (e.g., presence of toxic gases or fall hazards). Protection of workers performing duties under the IAM plan from these hazards is a high priority.

4.6.1. Radiation protection

Licensees should develop and document emergency radiation protection measures that align with their radiation protection programmes and have sufficient personal protective equipment and communication systems. The administration of a compound of stable iodine (usually potassium iodide) may be used as a supplementary protective action in the event of an accident involving the release of significant quantities of radioactive iodine. Some protective actions may begin prior to the release of radioactive material when there is advance notice. Within the EU, the incorporation of the WENRA RLs related to severe accident management into national legal frameworks includes the provision for radiation protection of operators and all other staff involved in implementing IAM and emergency actions. The TGAM considers that including provisions for radiation protection like this in the regulatory framework a **commendable practice**.

Protection against radiation in the main control room or the central location from which accident management will be co-ordinated and monitored (such as a TSC or on-site emergency control centre), as well as important access routes to and from the plant, needs to be evaluated. Decontamination means and facilities and those for the reception and treatment in a local hospital of workers suspected of being contaminated or having contaminated wounds, or of having been exposed to doses near or in excess of the thresholds for deterministic effects should be considered. If a local hospital is not available, special emergency transport to an appropriate medical facility should be provided, by air if necessary.

During a major radiological event, there may be a need for emergency responders to exceed occupational limits. The regulatory requirements for radiation exposure of emergency responders during the accident differ from country to country.

The International Commission on Radiological Protection (ICRP) recommends reference levels of 500 to 1000 mSv to avoid the occurrence of severe deterministic injuries for rescue workers involved in an emergency exposure situation. Furthermore, the ICRP continues to recommend no dose restrictions for lifesaving efforts by informed volunteers if the benefit to others outweighs the rescuer's risk (ICRP Publication 103, Table 8) [20].

As another point of reference, the IAEA Basic Safety Standards envisage three situations where it would be justified for the dose limits to be exceeded:

- for the purpose of saving life or preventing serious injury;
- if undertaking actions intended to avert a large collective dose; or
- if undertaking actions to prevent the development of catastrophic conditions.

Generic criteria applicable in emergency situations for acute doses at which protective and other actions are expected to be undertaken under any circumstances to avoid or to minimise severe deterministic effects are described in the IAEA Safety Standards, GSR Part 3 [21].

As a **commendable practice**, regulatory bodies should establish provisions concerning dose limits for on-site NPP staff and off-site emergency responders in emergency situations. An automatic external radiation measuring network should be installed around to the NPP site to provide the operator and the emergency response organisation with real-time data on environmental radiation levels.

In many countries there are requirements to ensure the monitoring of cumulative dose to emergency workers at the facility and off-site, as well as regarding arrangements for controlling and recording the doses received in an accident situation. It is also essential that emergency workers have full knowledge of the associated risks prior to initiating emergency action and that medical evaluation of emergency workers takes place after such exposure.

Personnel that may be involved in work in high dose-rate contaminated environments should have specialised education on radiation protection and work procedures related to these conditions. Education and training, including training in radiation protection, of all persons involved in emergency response and exercising of emergency plans and emergency procedures should be provided, as described in subsection 4.3 of this report.

Lessons learnt from the Fukushima Daiichi NPP accident highlight some specific areas for attention and **commendable practices** related to radiation protection for responders:

- The reinforcement of radiation monitoring under accident conditions on the site and in surrounding areas to support emergency work should be considered. Enhancing the reliability of monitoring posts and reinforcing monitoring cars may be valuable;
- Consider conducting a specific inventory of radiation monitoring and protective equipment (personal dosimetry, protection equipment, contamination control portals, etc.) in order to establish whether additional equipment is required;
- Provisions should be made for moving workers to well protected on-site/off-site areas to enhance their readiness and availability to perform duties under the IAM plan;

- Updated radiation maps to assist in selection of protective measures. Special consideration could be given to tracking the effects of removing contaminated materials from the site, which could constitute significant new radiation sources;
- Shielding and blocking of high dose rate areas;
- Consider use of robots to perform tasks in high radiation areas.

4.6.2. Protection from extreme environmental conditions

In addition to radiological hazards, a severe weather or other natural event may entail adverse environmental conditions that should be faced by responders. These conditions may be the direct result of the natural events or in combination with the disruption of normal plant processes.

Major weather events have the potential to result in extreme temperature conditions. For example, frigid temperatures accompanying a severe snow or ice storm can impede actions of responders. These events can also create accessibility challenges through route blockage and slipping hazards. The NPP operator should plan accordingly by having appropriate exposure clothing and snow/ice removal equipment available if these types of weather events are possible. In addition, tornado or tropical weather events can be accompanied by high temperature and humidity. Disruption of normal air conditioning during these events or requirements to perform heavy work outdoors can present heat stress related hazards for responders. In anticipation of these conditions, utilities should consider mitigating strategies, such as ice vests or “cool down” areas, to protect personnel.

In addition to climate issues, a widespread flooding or tsunami event can create hazards to personnel. In addition to the obvious hazard created by inundating waters, standing water left in the aftermath can pose access challenges and a hazard to workers. Means of dewatering and the availability of water rescue equipment may become important considerations in protecting responders in these situations.

Earthquakes (and their aftershocks) also present a significant potential hazard to response personnel. In addition to damage to normal roads and walkways used for access, they have the potential to collapse or weaken structures that can threaten the safety of workers. Seismically induced fires present yet another personnel hazard from these events. The scope of planning should consider these aspects when developing personnel protective requirements and measures.

4.6.3. Protection from other industrial or accident-generated hazards

A severe accident or widespread event may involve or create additional hazards to those associated with radiation or the natural-based hazards discussed above. In particular, disruption of on-site systems or the off-site infrastructure may present special challenges to emergency response personnel.

Accidents involving release of energy from plant systems are likely to create significant high temperature and humidity hazards. Availability of steam suits, ice vests, and breathing air apparatus may be important considerations in determining protective equipment needs.

Severe events involving high winds, missiles or seismic activity have the potential to breach plant systems or infrastructure. If these elements contain hazardous materials, such as water treatment chemicals or flammable or toxic gases, special consideration should be given to protect responders from releases.

In addition to on-site hazards, a widespread event such as an earthquake, tsunami or flood, can affect facilities in the vicinity of the NPP. In particular, industrial facilities such as refineries, chemical plants, or natural gas plants, can pose significant hazards if the materials they contain are released. If prevailing winds carry these products to the NPP, they can represent a similar, if not more severe, level of hazard to personnel as previously discussed for on-site sources.

One of the lessons learnt from the Fukushima-Daiichi NPP accident is that combined hazard maps can be effective in managing protection from the full range of hazards. For example, radiation maps can be augmented to show the location of debris and other accident, industrial or naturally generated hazards that could complicate the response and pose personnel protection challenges.

4.6.4. Use of monitoring and communication systems

Protection of responders relies on the ability to monitor conditions and communicate appropriate information and instructions to enable responders to safely execute their duties.

Additional discussion of equipment used to monitor plant conditions and provide command and control communications is contained in subsection 3.5 of this report.

4.7. Compilation of commendable practices

The commendable practices contained in this section of the report are summarised below:

- Evaluation of staffing needs to ensure an adequate number of personnel are available to respond to a major event. Staffing needs should consider long duration complex disasters and simultaneous multi-unit events. Augment site staffing as appropriate using inter-utility mutual aid agreements and vendor/contractor support networks;
- Use training needs analyses to identify gaps with regard to training for implementation of the IAM plan. Implement principles of the systems approach to training to develop appropriate training for each class of emergency responder;
- Use plant reference simulator to the extent possible in conducting training for beyond design basis accidents. Continue training using desktop computer or table top exercises when limits of simulation are reached;
- Develop a training plan for each emergency team member based upon the individual's role in the IAM response and use a qualification card or training notebook to track progress. Include an appropriate level of training for off-site responders, such as fire brigades, medical personnel and subcontractors;
- Use a combination of periodic drills and exercises to test the full range of emergency response capabilities. Enhance realism by including off-hours drills, reduced availability of responders, long duration and multi-unit accident scenarios and the actual connection/installation of mobile equipment on the appropriate locations;
- Include co-ordination with other response organisations as part of drill/exercise scenarios, to include local, state and national government counterparts, news media, and neighbouring countries;
- Conduct inspections or reviews of drill/exercise performance for lessons learnt and use feedback to continually improve response performance;
- Strengthen infrastructure to enhance readiness of the initial and sustained responses, to include diverse means of communication for personnel recall and event command and control, as well as hardened or alternate command and control centres;
- Evaluate and obtain needed resources (food, water, shelter, sanitation, and medical care) to support a sustained response. Support systems may be in the form of modular units with dedicated functions;
- Pre-plan emergency exposure limits for saving life and equipment. Ensure availability of radiation protection equipment for responders, including stable iodine, as well as monitoring devices and shielding.

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GLOSSARY*

Accidents	Design basis accidents or beyond design basis accidents.
Accident Management	The taking of a set of actions during the evolution of a beyond design basis accident: to prevent the escalation of the event into a severe accident; to mitigate the consequences of a severe accident; to achieve a long-term safe stable state.
Arrangements	The set of infrastructural elements necessary to provide the capability for performing a specified function or task. These elements may include authorities and responsibilities, organisation, co-ordination, personnel, plans, procedures, facilities, equipment or training. [From IAEA Safety Glossary]
BDBA	Beyond Design Basis Accidents. Accident conditions more severe than a design basis accident.
DBA	Design Basis Accidents. Accident conditions against which a facility is designed according to established design criteria, and for which the damage to the fuel and the release of radioactive material are kept within authorised limits.
Severe Accident	Accident conditions more severe than a design-basis accident and typically involving significant fuel degradation.

* For the purpose of this report.

LIST OF ACRONYMS AND ABBREVIATIONS

AC - Alternating current
AGR - Advance gas-cooled reactor
AOP - Abnormal operating procedure
ARI - Alternate rod insertion
ATWS - Anticipated transient without scram
BDBA - Beyond design basis accident
BWR - Boiling water reactor
BHWR - Boiling heavy water reactor
CANDU - CANada Deuterium Uranium (reactor)
CNRA - Committee on Nuclear Regulatory Activities (NEA)
CRPPH - Committee on Radiation Protection and Public Health (NEA)
CSNI - Committee on Safety of Nuclear Installations (NEA)
DBA - Design basis accident
DC - Direct current
DG - Diesel generator
DiD - Defence-in-depth
EEGD - Emergency equipment guideline document
ELAP - Extended loss of AC power
EOP - Emergency operating procedure
EU - European Union
FSAR - Final safety analyses report
HFE - Human factors engineering
IAEA - International Atomic Energy Agency
IAM - Integrated accident management
I&C - Instrumentation and control
ICRP - International Commission on Radiological Protection
LWR - Light water reactor
MCC - Motor control centre
MCR - Main control room
NEA - Nuclear Energy Agency
NPP - Nuclear power plant
PAR - Passive autocatalytic recombiner

PPE - Personal protective equipment
PSA - Probabilistic safety assessment
PWR - Pressurised water reactor
RL - Reference level
RPV - Reactor vessel
RCS - Reactor coolant system
SAM - Severe accident management
SAMG - Severe accident management guideline
SBO - Station blackout
SFP - Spent fuel pool
SSC - Systems, structures and components
STC - Standing Technical Committee
TGAM - Task Group on Accident Management (CNRA)
TSC - Technical support centre
VTR - Video transmitter
WGAMA - Working Group on Analysis and Management of Accidents (CSNI)
WENRA - Western European Nuclear Regulators' Association
UHS - Ultimate heat sink