DS 483: Draft 09042015
09 April 2015

IAEA SAFETY STANDARDS
for protecting people and the environment

STEP 7: Approval by the relevant review Committees for submission to Member States for comments

Accident Management Programmes for Nuclear Power Plants

DRAFT SPECIFIC SAFETY GUIDE XXX (DS483)

IAEA
INTERNATIONAL ATOMIC ENERGY AGENCY

FOREWORD
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EDITORIAL NOTE

An appendix, when included, is considered to form an integral part of the standard and to have the same status as the main text. Annexes, footnotes and bibliographies, if included, are used to provide additional information or practical examples that might be helpful to the user.
The safety standards use the form 'shall' in making statements about requirements, responsibilities and obligations. Use of the form 'should' denotes recommendations of a desired option.

Contents

1. INTRODUCTION

BACKGROUND

1.1 Design basis accidents are defined as 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 authorized limits [1].

1.2 Design Extension Conditions comprise accident conditions more severe than a design basis accident. A design extension condition may or may not involve nuclear fuel degradation. Accident conditions more severe than a design basis accident and involving significant fuel degradation are termed severe accidents [5].

1.3 Consideration of design extension conditions in the design of nuclear power plants[1] is an essential component of the defence-in-depth approach used in nuclear safety [2-4]. The probability of occurrence of a design extension condition is very low, but it may lead to significant consequences resulting from degradation of the nuclear fuel.

1.4 Accident management is the taking of a set of actions during the evolution of accident conditions with the objective of preventing progression into a severe accident, mitigating the consequences of a severe accident, and achieving a long-term safe stable state [6].

1.5 Depending on plant status, accident management actions are prioritized as follows:

- Before the onset of fuel damage, priority is given to preventing the escalation of the event into a severe accident (preventive domain of accident management). In this domain, actions are implemented for stopping accident progression before the onset of fuel damage, or, delaying the time at which significant fuel degradation happens.When plant conditions indicate that fuel damage has occurred or is imminent (mitigatory domain of accident management), priority is given to mitigating the consequences of severe accidents through[2]:
  - preventing the uncontrolled loss of containment integrity,

[1] 'Plant' includes multi-unit sites

[2] The second aspect of accident management (to mitigate the consequences of a severe accident) is also termed severe accident management. Accident management is essential to ensure effective defence in depth at the fourth level [2,3]. The aim of the fourth level of defines-in-depth is to ensure that radioactive releases are kept as low as practicable. The protection of the containment function is most important for achieving this aim. Limiting external releases has the potential for minimizing detrimental consequences on the public, the environment and society beyond the site boundary.

- performing any other actions having the potential for limiting fission product releases to the environment and avoiding releases of radionuclides causing long-term off-site contamination,

• Characteristics of preventive and mitigatory domains of accident management are summarized in Table 1.

1.6 Effective implementation of accident management is done through an accident management programme. This programme encompasses plans and actions undertaken to ensure that the plant and the personnel with responsibilities for accident management are adequately prepared to take effective on-site actions to prevent or mitigate the consequences of a severe accident. The accident management programme needs to be well integrated with the emergency preparedness and response programme in terms of human resources, equipment, strategy and procedures.

1.7 The accident management programme needs to consider all modes of operation, all possible conditions, including combinations of events that could cause failure of fuel cooling and ultimately significant releases. Such conditions should include those that could exist in areas where spent fuel is stored. An effective accident management programme requires that plants establish the necessary infrastructure to respond effectively to severe accident conditions, mitigate fuel damage, and stabilize the units if fuel damage does occur. This infrastructure should include equipment and supporting procedures necessary to respond to events that may affect multiple units and last for extended periods, and personnel having adequate skills for using such equipment and implementing supporting procedures.

OBJECTIVE

1.8 This Safety Guide presents recommendations for the development and implementation of an accident management programme for meeting the requirements for accident management that are established in relevant IAEA Safety Requirements for design [5], commissioning and operation [6], safety assessment [7] and emergency preparedness and response [8].

SCOPE

1.9 This Safety Guide provides recommendations for the development and implementation of an accident management programme during all modes of operation for both reactor and spent fuel pool to prevent and/or to mitigate the consequences of severe accidents[3].

1.10 Although the recommendations of this Safety Guide have been developed primarily for use for both existing and new light water reactors, they are anticipated to be valid for other types of nuclear reactors and possibly other fuel cycle facilities (including storage).

1.11 This Safety Guide is intended primarily for use by operating organizations of nuclear power plants, licensees and their support organizations. It may also be used by national regulatory bodies as a reference document for preparation of their relevant safety requirements.

STRUCTURE

1.12 This Safety Guide consists of three main sections and three annexes. Section 2 presents the general, high level recommendations for an accident management programme. More detailed, specific recommendations for the process of development and implementation of an accident management programme are provided in Section 3. Recommendations for the use of severe accident management guidelines are described in Section 4. Annexes I, II and III provide descriptions of specific SAMG implementation approaches in different countries (France, Germany and the United States of America).

[3] More details can be found in references [10-15]

Table 1: Characteristics of the preventive and mitigatory domains of accident management

Subject/Attribute	Preventive domain	Mitigatory domain
Aim	Prevention of fuel damage, through fulfilment of a set of safety functions of primary importance ('critical safety functions')	Limitation of release of radioactive material into the environment through actions comprising termination of core/fuel melt progression, maintenance of reactor pressure vessel integrity, maintenance of containment integrity, preventing containment by-pass and control of releases
Establishment of priorities	Establishment of priorities among the various 'critical safety functions'	Establishment of priorities between mitigatory measures, with the highest priority to mitigation of significant ongoing releases and immediate threats to fission product barriers
Responsibilities (authorisation of actions)	Control room staff, or emergency director if deemed appropriate	Emergency director (or equivalent)
Role of emergency response organization	Technical Support Centre available for advice to control room, or decision making for complex tasks, if deemed appropriate	Technical Support Centre responsible for evaluation/recommendation of actions
Procedures/ guidelines	Use of procedures for preventive accident management measures (EOPs) by the control room	Use of guidance documents (SAMGs) by Technical Support Centre or other designated staff
Use of equipment	Use of all systems still available, use of design margins admissible; possible use design extension margins upon advice, or decision, by the Technical Support Centre Measures beyond the defined operational range of the systems require advice, or instructions, by the Technical Support Centre	Use of all systems still available, also beyond their design limits, with preference given to safety features for design extension conditions, if available

Verification of effectiveness	The effectiveness of the accident management measures can be verified with reasonable accuracy	The effectiveness of the accident management measures can be verified in a limited way Positive and negative consequences of proposed actions to be considered in advance and monitored throughout and after implementation of measures

2. GENERAL GUIDANCE FOR THE ACCIDENT MANAGEMENT PROGRAMME

REQUIREMENTS

2.1 Paragraph 2.10 in Reference [5] establishes the following requirements on severe accidents and accident management in the design of nuclear power plants:

"Measures are required to be taken to ensure that the radiological consequences of an accident would be mitigated. Such measures include the provision of safety features and safety systems, the establishment of accident management procedures by the operating organisation and, possibly, the establishment of off-site intervention measures by the appropriate authorities, supported as necessary by the operating organisation, to mitigate exposures if an accident has occurred.

2.2 Requirement 19 on accident management in the operation of nuclear power plants in reference [6] establishes:

"The operating organization shall establish, and shall periodically review and as necessary revise an accident management programme". More detailed requirements are provided in paragraph 5.7 and in several paragraphs associated with Requirement 19.

2.3 Reference [7] requires use of the defence in depth philosophy to specify adequate provisions to mitigate the consequences of accidents that exceed design limits and in paragraph 5.6 in reference [7] requires that the results of the safety assessment shall be used as an input for on-site and off-site emergency response and accident management.

2.4 Paragraph 4.7 in reference [10] dealing with minimization of consequences of any nuclear or radiological emergency on peoples' health, property and the environment requires that the transition from normal to emergency operations shall be clearly defined and be effectively made without jeopardizing safety. The responsibilities of emergency staff who would be on the site in an emergency shall be designated as part of the transition. It is also required to ensure that the transition to emergency response and the performance of initial response actions do not impair the ability of the operational staff (such as the control room staff) to follow the procedures necessary for safe operations and for taking accident management actions. Hence the need to properly integrate accident management procedures/guidelines and emergency preparedness and response (EPR) should be considered at the development stage.

CONCEPT OF ACCIDENT MANAGEMENT

2.5 An accident management programme should be developed and implemented for all plants irrespective of the core damage frequency and fission product release frequency calculated for the plant, including new plants equipped with dedicated systems for mitigation of severe accidents.

2.6 Accident management guidance should be developed and maintained consistent with the plant design and its current configuration.

2.7 Accident management guidance should assist plant personnel to prioritize, monitor, and execute actions in the working conditions that may exist during accidents including those resulting from extreme external events.

2.8 A structured top down approach should be used to develop the accident management guidance. This approach should begin with the objectives and strategies followed by measures to implement the strategies and finally result in procedures and guidelines, and should cover both the preventive and the mitigatory domains. Figure 1 illustrates the top down approach to accident management.

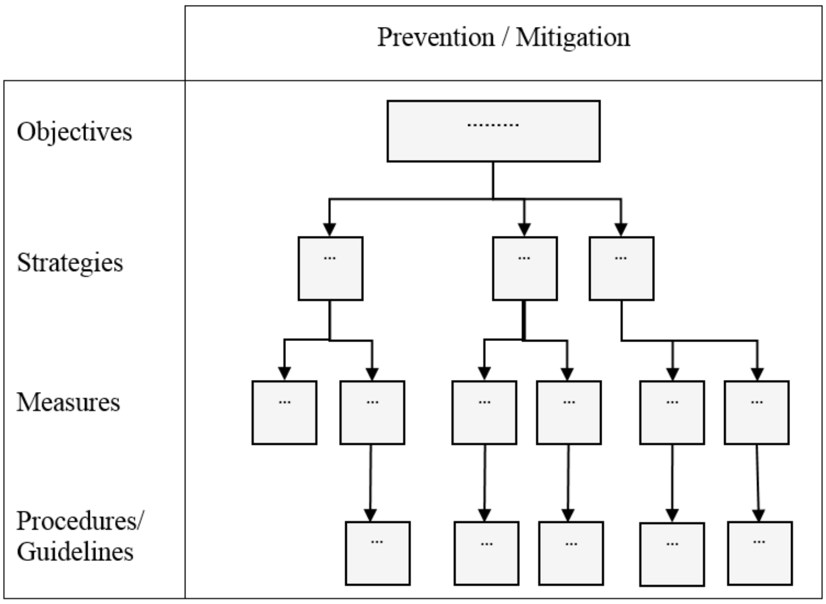

Figure 1 Top down approach to accident management[4]

2.9 Multiple strategies should be developed to achieve the accident management objectives,

[4] Strategies are global orientations contemplated for reaching objectives. For example, a strategy for maintaining containment /Confinementintegrity in PWRs is to fill the Steam Generators with water for preventing Steam Generator Tube Ruptures resulting from tube thermal creep. Measures are more detailed recommendations indicating how SGs could be filled (e.g. through using the normal feedwater system, the emergency feedwater system, the plant the plant fire-fighting system, or any other mean that could exist after re-alignment of other water systems). Procedures and guidelines are documents provided for practical implementation of measures: they could include methods or information helpful for making decisions and should provide recommendations for practical implementation of such decisions.

including:

- Preventing severe fuel damage;
- Terminating the progress of fuel damage once it has started;
- Maintaining the integrity of the containment and preventing containment by-pass;
- Minimizing releases of radioactive material, including releases from any source of radioactive material outside containment[5]; and
- Achieving a long term safe stable state.

2.10 From the strategies, suitable and effective measures for accident management should be derived, corresponding to available plant hardware provisions. Such measures may include plant modifications, where these are deemed important for managing accident conditions including severe accidents. Personnel actions initiated either in the control room or local actions could be an important part of these measures. During an accident such measures would include recovery of failed equipment and use of portable and mobile equipment[6], stored on-site or off-site.

2.11 The teams responsible for execution of accident management strategies should be adequately staffed and qualified.

2.12 Appropriate guidance, in the form of procedures and guidelines, should be developed from the strategies for the personnel responsible for executing the measures for accident management.

2.13 When developing guidance on accident management, consideration should be given to the full design capabilities of the plant, using safety and non-safety systems, and including the possible use of some systems beyond their originally intended function and anticipated operating conditions and possibly outside their design basis. Specific consideration should also be given to maintaining conditions needed for continued operation of equipment ultimately necessary to prevent large or early radioactive releases [7]

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[5] For example, from the spent fuel pool

[6] Portable and mobile equipment is equipment that is not permanently connected to a plant is is stored in an on-site or an off-site facility

[7] For example, at Fukushima Daiichi units 2, 3 and 4, partial depressurizitation of the containment allowed operation of the RCIC (Reactor Core Isolation Cooling) system over a longer period than would have been anticipated under fully depressurized conditions.

MAIN PRINCIPLES

2.14 Accident management guidance, including guidance for management of severe accidents, should be developed for all physically identifiable challenge mechanisms to minimize the impact on public health and safety, for which the development of such guidance is practicable. Accident management guidance should be developed irrespective of the probability of occurrence of the challenges.

2.15 Accident management should also consider that in case of extreme external events[8], there may be extensive infrastructure damage, so that offsite resources are not readily available, including human resources and/or communication, electrical power, compressed air, water and fuel.

2.16 Accident management guidance should be an integral part of the overall emergency arrangements defined in the plant's Emergency Plan[9]. This should include lines of responsibility and accountability for implementing response actions during execution of accident management guidance to maintain or restore safety functions throughout the duration of the accident.

2.17 The utility should have full responsibility for implementation of the accident management guidance and take steps to ensure that roles of the different members of the emergency response organization involved in accident management have been clearly defined and coordinated.

2.18 Adequate staffing and working conditions should be ensured for managing accidents, including those resulting from extreme external events. Plans for defining staffing needs should take into account situations where several units on the same site have been affected simultaneously and some plant personnel have been temporarily or permanently incapacitated. Contingency plans should be prepared to provide alternate personnel to fill the corresponding positions in case of unavailability of staff.

2.19 Plant conditions at which the transition is to be made from the preventive to the mitigatory domain should be specified and should be based on defined and documented

[8] Such as earthquakes or extreme meteorological conditions

[9] Emergency plan: A description of the objectives, policy and concept of operations for the response to an emergency and of the structure, authorities and responsibilities for a systematic, coordinated and effective response. The emergency plan serves as the basis for the development of other plans, procedures and checklists.

criteria.

2.20 The accident management programme should be reviewed, periodically and in response to major lessons learned, to reflect changes in plant configuration, new results from the relevant research, and operating experience. Revisions should be made to the accident management programme where appropriate

2.21 Accident management should consider that some rare events[10] may result in similar challenges to all units on the site.

2.22 The approach in accident management should be, as far as feasible, based on either directly measurable plant parameters or information derived from simple calculations[11].

2.23 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 accidents in order to be able to execute the accident management guidance correctly.

2.24 Accident management should consider the loss of indication of key plant parameters.

2.25 Development of accident management guidance should be based on best estimate analysis of the physical response of the plant. In the accident management guidance consideration should be given to uncertainties in knowledge about the timing and magnitude of phenomena that might occur in the progression of the accident. Hence, mitigatory actions should be initiated at parameter levels and at a time that gives sufficient confidence that the protection intended by carrying out the action will be achieved[12].

2.26 In the severe accident management guidance consideration should be given to any specific challenges posed by shutdown plant configurations and large scale maintenance[13]. The potential damage of fuel both in the reactor vessel and in the spent fuel pool, and dry storage if appropriate, should also be considered in the accident management guidance. As large scale maintenance is frequently carried out during planned shutdown states, a high priority of accident management guidance should be the safety of the workforce.

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[10] For example, an extreme external event

[11] This is often a called ‘symptom-based approach’. The simple calculations are often called computational aids

[12] For example, venting the containment, when physically possible, might be initiated at moderate containment pressure to accomodate pressure increases resulting from the generation of non-condensibles or from combustible gases burns or recombination to give further confidence that containment structural integrity will not be lost

[13] Such as an open containment equipment hatch

2.27 The accident management programme should cover all external events relevant for the site considered, taking into account dependencies between events [14], and all modes of operation. It should also consider that external events could result in significant damage to the infrastructure on-site or off-site.

EQUIPMENT UPGRADES

2.28 Design features important for the prevention or mitigation of severe accidents should be identified and evaluated. Accordingly, existing equipment and/or instrumentation should be upgraded or new equipment and/or instrumentation should be added, if necessary or beneficial[15] for improving accident management programme to provide an efficient means of reducing risks in an appreciable way or to an acceptable level.

2.29 When adding or upgrading equipment or instrumentation is contemplated, related design requirements should be such that there is reasonable assurance [16] (preferably demonstrated by equipment qualification or at least by assessment of the survivability) that this equipment or instrumentation will operate as intended under the environmental conditions present when it is used[17]. The equipment should be designed against accident conditions/loads for severe accidents and extreme external hazards, commensurate with the function that is to be fulfilled, provide adequate margin to failure when it is expected to operate, installed in areas that are not likely to collapse and create un-repairable damage to the component, and independent, as far as practicable, from other existing systems during the accident conditions[18].

2.30 Where existing equipment or instrumentation is upgraded or otherwise to be used outside its previously considered design basis range, the accident management guidance for the use of such equipment should be updated accordingly. Operating procedures or guidelines should be developed for use of the upgraded equipment or instrumentation.

2.31 The installation of new equipment or the upgrading of existing equipment to operate under harsh environmental conditions does not eliminate the need for the development of the

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[14] For example, a seismic event could result in a dam failure upstream a river site, or in a tsunami for some sea sites

[15] Equipment may not be necessary, in the strict sense of the word, but can be very useful for implementing the accident management. For example, passive autocatalytic recombiners remove uncertainties on hydrogen burns.

[16] Reasanoble assurance can be obtained through evaluting whether, based on available information coming from different sources there exist a quantifiable positive margin to equipment failure.

[17] Environmental conditions include pressure, temperature, radiative ambiance as well as damage to surrounding structures or buildings

[18] Accident conditions include severe accidents and effects of extreme external hazards

accident management guidance for the situation when some of this equipment malfunctions.

2.32 New equipment, either fixed, or portable[19] that is stored onsite or offsite, should be protected from external events that cause the challenge. For portable equipment, the ability to move the equipment from its storage location to the location where it fulfils its accident management function and to perform the necessary connections in the time frame needed should be demonstrated. Impact of the new or modified equipment on the staffing needs as well as expectations for maintenance and testing should be addressed.

FORMS OF ACCIDENT MANAGEMENT GUIDANCE

Preventive domain

2.33 In the preventive domain, the guidance should consist of descriptive steps, as the plant status is known from the available instrumentation and the consequences of actions can be predetermined by appropriate analysis. The guidance for the preventive domain, therefore, should take the form of procedures, usually called emergency operating procedures (EOPs), which are prescriptive in nature. EOPs should cover both design basis accidents and design extension conditions, but are typically limited to actions taken prior to fuel damage. Further details on EOPs may be found in Refs [10, 11].

Mitigatory domain

2.34 In the mitigatory domain, large uncertainties may exist both in the plant status, availability of the protective systems and in the timing and outcome of actions. Consequently, the guidance for the mitigatory domain should not be prescriptive in nature but rather should include a range of potential mitigatory actions and should allow for additional evaluation and alternative actions. Such guidance is usually called severe accident management guidelines (SAMGs).

2.35 The guidance should contain a description of both the positive and negative potential consequences of proposed actions, including quantitative data where available and relevant, and should contain sufficient information for the plant staff to reach an adequate decision on the actions to take during the evolution of the accident.

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[19] Portable equipment is contemplated in particular to address situations where extreme external events accidents have occurred and incapacitated essential equipment needed to fulfill essential safety functions. Examples of justification and use of portable equipment can be found in United States of America developed extended damage mitigation guidelines (EDMGs) and Flexible Coping Strategies (FLEX) approaches

2.36 The guidance for the mitigatory domain should be presented in the appropriate form, including guidelines, procedures, manuals or handbooks. The term guideline here is used to describe a set of instructions that describe the tasks to be executed in the plant, but which are still less strict and prescriptive than the procedures found in the EOPs, i.e. used in the preventive domain. Manuals or handbooks typically contain a more general description of the tasks to be executed and their justification.

2.37 Severe Accident Management guidelines should be designed with the appropriate level of detail and in a format that facilitates their effective use under stressful conditions. The usability of the guidelines (step-by-step instructions or flexible decisions) should be considered in the development process and be clear to the user.

2.38 The overall form of the guidelines and the selected level of detail should be tested in drills and exercises. Based on the outcome of such drills and exercises, it should be judged whether the form is appropriate and whether additional detail should be included in the guidance. Drills and exercises should provide for identification of areas for improvement.

2.39 Guidelines or procedures should be developed for all groups participating in accident management such as control room operators, technical support group, and decision makers in accordance with their respective roles.

Both preventive and mitigatory domains

2.40 For extreme external events that result in normal accident management capabilities being unavailable such as loss of the command and control structure, support procedures may be developed to provide guidance on using instrumentation and equipment to cope with these conditions[20]. In this case, command and control is re-established and clearly identified, and the guidance includes conditions for use of these support procedures.

2.41 The procedures and guidelines developed for accident management should be supported by appropriate background documentation[21]. This documentation should describe and explain the rationale of the various parts of the guidelines, and should include an explanation of each individual step in the guidance, if considered necessary. The background documentation does not replace the guidelines themselves. It should be available to all staff involved in evaluation

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[20] For example, use of portable equipment as described in NEI 12-06,"Diverse and Flexible Coping Strategies (FLEX) Implementation Guide"

[21] This documentation is sometimes refered to as the Technical Basis Document

and decision making.

2.42 If procedures, guidelines and supporting background documentation are stored in electronic form, hardcopy backups should be available in all evaluation and decision making locations, such as main control room, supplementary control room and technical support centre[22], so that they can be used in case of station blackout.

ROLES AND RESPONSIBILITIES

2.43 The decision making authority should be clearly defined and established at an appropriate level, commensurate with the complexity of the task and the potential consequences of decisions taken. In the preventive domain, the control room supervisor or a dedicated safety engineer or other designated official should be able to fulfil this responsibility. In the mitigatory domain, decisions should be made by a person having a broader perspective of accident management activities and understanding comprehensive implications of the decisions. Major decisions which could have significant adverse effects on public safety or the environment should be made with the full knowledge of the person entrusted with legal responsibility for the plant, where reasonably practicable.

2.44 The accident management guidance[23] should be compatible with the assignment of responsibilities and should be consistent with the other functions considered in the overall emergency response arrangements[24].

2.45 The roles assigned to the members of the emergency response organization may be different in the preventive and mitigatory domains, and, where this is the case, transitions of responsibility and authority should be clearly defined.

2.46 A specialized team or group of teams (referred to in the following as the technical support centre) should be available to provide technical support by performing evaluations and recommending recovery actions to a decision making authority, both in the preventive and mitigatory domains. The technical support centre should have the capability, based on their knowledge of plant status to recommend mitigatory actions as deemed most appropriate for the situation. This should be done only after evaluating potential negative consequences, and the possibility and consequences of using erroneous information. If the technical support

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[22] Hardcopies should also be made available in all locations used as backups in case of extreme external events accidents

[23] For example, if it has been decided to separate decision making from evaluation, guidance should be available for both functions.

[24] On-site and off-site if appropriate

centre is composed of multiple teams, the role of each team should be specified.

2.47 Appropriate levels of training should be provided to members of the emergency response organization; the training should be commensurate with their responsibilities in the preventive and mitigatory domains.

3. DEVELOPMENT AND IMPLEMENTATION OF AN ACCIDENT MANAGEMENT PROGRAMME

GENERAL REMARKS

3.1 Five main steps should be executed to set up an accident management programme:

(1) Mechanisms that can challenge critical safety functions or boundaries to fission product release should be identified;

(2) Plant vulnerabilities should be identified, considering the challenging mechanisms;

(3) Plant capabilities under challenges to critical safety functions and fission product barriers should be identified, including capabilities to mitigate such challenges, both in terms of available equipment and personnel;

(4) Suitable accident management strategies and measures should be developed, including the use of fixed and onsite and offsite portable equipment [25] to cope with the vulnerabilities identified; and

(5) Procedures and guidelines to execute the strategies and measures should be developed.

3.2 The preventive accident management procedures/guidelines should address the full spectrum of events i.e. all events considered on the basis of credible initiating events, and possible complications during the evolution of the event that could be caused by additional hardware failures, human errors and/or extreme external events.

3.3 For determination of the full spectrum of events[26], useful guidance can be obtained from the probabilistic safety assessment (PSA) level 1 (if available), from expert judgment or similar studies from other plants, and operating experience from the plant and other plants.

[25] Instrumentation is considered part of equipment

[26] External events PSA, if available, can be useful in providing insights to the full spectrum of events to be considered.

The selection of events should be sufficiently comprehensive to provide a basis for guidance for the plant personnel in any identified situation.

3.4 The determination of the full spectrum of events should include extreme external events[27] in which onsite capabilities may be lost and on- and off-site area damage may occur.

3.5 The actions used in preventive accident management should be included in EOPs, and, in case of extreme external events, further detailed by special procedures designed for this purpose[28].

3.6 The accident management in the mitigatory domain addresses challenges caused by significant reactor fuel damage (in the core or spent fuel pool); i.e. it deals with the severe accidents. Severe Accident Management guidance should address the full spectrum of challenges to fission product barriers, including those arising from multiple hardware failures, human errors and/or extreme external events, and possible physical phenomena that may occur during the evolution of a severe accident[29]. In this process, even highly improbable failures, abnormal functioning of equipment and human errors should be considered.

3.7 For determination of the full spectrum of challenge mechanisms, useful guidance can be obtained from the probabilistic safety assessment (PSA) Level 2 (if available), or similar studies from other plants, expert judgment and insights from research on severe accidents. However, identification of potential challenge mechanisms should be comprehensive to provide a basis for guidance for the plant personnel in any situation, even if the evolution of the accident would constitute a very unlikely path within the PSA Level 2 or is not identified in the PSA Level 2 at all.

3.8 External events, including extreme external events, with adequate consideration of dependencies, should be part of the full spectrum of challenges to safety functions and fission product barriers.

3.9 The development of an accident management programme should consider the following:

- Available hardware provisions for execution of accident management strategies;
- The means of obtaining information on the plant status, and the role of instrumentation therein, including the case in which all normal instrumentation and control power is

[27] More details can be found in Ref [20]

[28] For example, Extended Damage Mitigation Guidelines (EDMGs) in the United States of America

[29] For example,steam explosions, direct containment heating and hydrogen burns

unavailable;

- Specification of lines of decision making, responsibility and authority in the teams that will be in charge of the execution of the accident management measures;
- Integration of the accident management programme within the emergency arrangements for the plant;
- Verification and validation of procedures and guidelines;
- Education and training, drills and exercises and evaluation of personal skills;
- Supporting analysis for the development of the accident management programme;
- A administrative control and management system for all tasks in the accident management programme; and
- A systematic approach to periodic evaluation and updating of the guidance and training with incorporation of new information and research insights on severe accident phenomena.

3.10 Accident management programmes may be developed first on a generic basis, by a plant vendor or other organization, and may then be used by a plant utility for development of a plant specific accident management programme. When adapting a generic accident management programme to plant specific conditions, care should be taken that the transition from a generic approach to a plant specific one is handled appropriately, including searching for additional vulnerabilities and strategies to mitigate these. On the other hand, any deviations from plant operating requirements and generic accident management guidance should receive a rigorous review that considers the basis and benefits of the original approach and the potential unintended consequences of deviating from this approach.

3.11 To ensure the success of the development of the accident management programme, a development team of experts with sufficient scope and level of expertise should be assembled, with full support from the upper management of the operating organization.

3.12 The development team should contain staff responsible for the development and implementation of the accident management programme in the plant, including personnel from the training department, operations staff, maintenance staff, radiation protection staff, instrumentation and controls staff, engineering staff, persons responsible for EPR planning and external experts as appropriate[30]. If use of a generic programme has been selected, experts familiar with this programme should be part of the development team.

[30] Examples of the composition of a core development team are presented in Ref. [13].

3.13 The staff who will be working in the control room or technical support centre or any other organizational unit responsible for evaluation, decision-making, and implementation in the course of an accident should be involved at an early stage of development of an accident management programme, as this provides valuable training for future tasks and feedback.

3.14 Consideration should be given to the way in which plant personnel will be made available to participate in the development activities of the accident management programme in relation to their normal duties. Sufficient time should be allocated to plant personnel in the development team in relation to their other obligations.

3.15 Accident management programme controls should be established to ensure that accident management guidelines are not adversely impacted during plant changes, including plant modifications, procedure and training programme changes.

3.16 After the accident management guidance has been completed, it should be assessed whether all important challenges to fission product boundaries have been addressed, including those resulting from extreme external events.

IDENTIFICATION OF PLANT VULNERABILITIES

3.17 A safety assessment should be performed to identify and consider all credible challenges resulting from individual events or combinations of events that could cause failure of barriers against release of fission products. For external events, the safety assessment should consider identified margins to events in which the consequences can significantly worsen for small changes in the event magnitude.[31]

3.18 Guidance for plant damage assessment should be part of an accident management programme and instructions should be provided to address challenges to physical barriers and safety functions before any significant fission product release. Of particular importance is the assessment of site and building structural damage in case of extreme external event.

3.19 The vulnerabilities of the plant to challenging conditions should be identified. It should be investigated how specific accidents will challenge critical safety functions, and, if these are lost and not restored in due time, how the integrity of fission product barriers including fuel

[31] Also it called "cliff-edge effect". According to the IAEA Glossary: "In a nuclear power plant, an instance of severely abnormal plant behaviour caused by an abrupt transition from one plant status to another following a small *deviation* in a plant parameter, and thus a sudden large variation in plant conditions in response to a small variation in an input.

will be challenged. The possibility of being left with portable equipment only for mitigating some challenges should be contemplated. Vulnerabilities resulting from the failure of command and control due to loss of control room or impairment of the capability to set up the Emergency Response Organization should also be addressed[32].

3.20 The vulnerabilities to extreme external events that can impact the use of accident mitigation features, both permanently installed as well as portable, should be identified. It should be investigated how specific external events can interfere with the use of accident mitigation features.

3.21 The behaviour of the plant during severe accidents, including those caused by extreme external events, should be well understood with identification of the phenomena that may occur together with their expected timing. The severity of these phenomena should be assessed. In the severe accident domain, analysis results should be collected and set out in a report that could serve as the technical basis[33] for severe accident management.

3.22 The information regarding the plant behaviour in accident conditions should be obtained using appropriate analysis. Other inputs should also be used, such as the results of research on severe accidents, operational experience including insights from other plants and engineering judgment. Consideration should be given to uncertainties in the severe accident knowledge base and the assumptions made in models and analysis.

IDENTIFICATION OF PLANT CAPABILITIES

3.23 All plant capabilities available to fulfil and support plant safety functions should be identified and characterized. This should include safety systems, as well as use of non-dedicated systems, unconventional line-ups and temporary connections for portable equipment located on-site or brought in from off-site. When unconventional line-ups or temporary connections are contemplated, consideration should be given to the availability of equipment necessary for easy use of these capabilities.

3.24 Accident management should be robust, which can be assured by the following:

- It should promote consistent implementation by all staff during an accident;

[32] Vulnerabilities could be created by loss of communication with the control room, physical damage to the control room (e.g. fire) or staff injuries or even death

[33] An example of a generic technical basis that is widely used in Member States is provided in Electric Power Research Institute (EPRI) report on *Severe Accident Management Guidance Technical Basis Report*, Volumes 1 and 2, TR-101869-V1 and TR-101869-V2, EPRI, Palo Alto, CA (1992).

- It should emphasize the use of components and systems that are not likely to fail in their expected operating regimes including accident conditions;
- It should implement all feasible measures that will either maintain or increase the margin to failure or gain time prior to the failure of safety functions or fission product barriers;
- the possibility of adding components, including portable equipment, should be investigated in the event that existing plant systems are unable to preserve critical safety functions or limit challenges to fission product barriers;
- Specific consideration should be paid to accidents developing when the facility is in a shutdown state, as the containment barrier could be functionally lost and restoration difficult in some cases.

3.25 The capabilities of plant personnel to contribute to unconventional measures to mitigate accident challenges, including the behaviour and reliability of personnel under adverse environmental conditions, should also be considered[34]. Where necessary, protective means should be provided and training should be implemented for the execution of such tasks. It should be noted that work that poses risks to the health or the life of plant personnel is voluntary in nature and can never be demanded of the individual; the guidance should be developed accordingly.

3.26 The capabilities of the plant personnel to deploy mitigating equipment in possible harsh environments should include the implications of:

- working in high temperature/pressure areas,
- working in poorly lit or dark areas,
- working in areas ventilated using portable ventilation systems,
- working in high radiation areas,
- wearing portable breathing gear, and
- use of portable instrumentation or portable power supply.

DEVELOPMENT OF ACCIDENT MANAGEMENT STRATEGIES

3.27 On the basis of the vulnerability assessment and identified plant capabilities as well as the understanding of accident phenomena, accident management strategies should be developed for each individual challenge or plant vulnerability, in both the preventive and mitigatory domains.

[34] Including performance when using protective clothing and breathing devices

3.28 In the preventive domain, strategies should be developed to preserve critical safety functions that are important to prevent fuel damage or prevent radioactivity release. These include achieving and maintaining sub-criticality, fuel cooling, coolant inventory and containment integrity. [35]

3.29 In the mitigatory domain, strategies should be developed with the objectives of:

- Terminating the progress of fuel degradation;
- Maintaining the integrity of the containment and preventing containment bypass;
- Minimizing releases of radioactive material; and
- Achieving a long term safe stable state.

Strategies may be derived from 'candidate high level actions', examples of which are given in Appendix II of Ref [12][36] .

3.30 The implementation of specific mitigatory strategies should be triggered when certain parameters reach their threshold values. These parameters should be selected to be indicative of challenges to fission product barriers.

3.31 A systematic evaluation of the possible strategies should be conducted to confirm feasibility and effectiveness, to determine potential negative impacts, and develop prioritisation, using appropriate methods. Adverse conditions that may affect the execution of the strategy during evolution of the accident should be considered.

3.32 The strategies (including those for using portable equipment, and including the technical background), should be documented and maintained. Changes to the documentation should contain a record of previous strategies and the basis for changes.

3.33 Particular consideration should be given to strategies that have both positive and negative impacts in order to provide the basis for a decision as to which strategies constitute a proper response under a given plant damage condition[37].

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[35] An example of a preventive strategy is 'feed and bleed'. Another example is the use of portable equipment for a prolonged station blackout caused by an extreme external event.

[36] Examples of mitigatory strategies are: filling the secondary side of the steam generator to prevent creep rupture of the steam generator tubes; depressurizing the reactor circuit to prevent high pressure reactor vessel failure and direct containment heating; flooding the reactor cavity to prevent or delay vessel failure and subsequent basemat failure; mitigating the hydrogen concentration, depressurizing the containment to prevent its failure by excess pressure or to prevent basemat failure under elevated containment pressure.

[37] An example is withholding water from the reactor cavity to extend the time to overpressure failure of the containment; this has the negative impact of assured possible core concrete interactions that may be irreversible. A further example is flooding the cavity, with the negative impact of possible occurrence of an ex-vessel steam explosion.

3.34 Strategies should be prioritized taking into account plant status and the existing and anticipated challenges. The basis for the selection of priorities in accident management strategies should be documented. When prioritizing, special attention should be paid to the following:

- Timeframes and severity of challenges to the barriers against releases of radioactive material;
- Availability of support functions[38] as well as possibility of their restoration;
- Plant initial operating mode, as accidents can develop in operating modes where one or more fission product barriers could already be lost at the beginning of the accident[39];
- Adequacy of a strategy in the given domain; some strategies can be adequate in the preventive domain, but not as relevant in the mitigatory domain due to changing priorities[40];
- The difficulty of developing several strategies in parallel; and
- Long-term implications or concerns of implementing the strategies.

3.35 For strategies that rely on portable equipment following an extended loss of all AC power, steps should be taken to ensure that personnel can install and operate such equipment within the time frame necessary to avoid loss of critical safety functions. Support items such as fuel should be available.

3.36 If strategies are considered that need to be implemented within a certain time window, the possibly large uncertainties should be taken into account in identifying such a window. However, care should be exercised in order not to discard potentially useful strategies.

3.37 A systematic identification of the plant control and logic interlocks that need to be defeated or reset for the successful implementation of accident management strategies should be performed. It should also be verified that the potential negative effects of such actions have been adequately characterized and documented.

3.38 The definition and selection of strategies applicable in the mitigatory domain should consider the potential usefulness of maintaining strategies initiated in the preventive domain[41].

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[38] For example, AC power, DC power, cooling water

[39] At shutdown, the Reactor Coolant system and containment might be open. Priority could be given to restoring containment integrity before anything happens on the fuel.

[40] For example, cooling the fuel could be first priority when the fuel is undamaged and containment intact, while restoring containment integrity or limiting fission product releases could be first priority when the containment is open (e.g. at shutdown) or has been damaged (e.g. cracks resulting from verey severe mechanical loadings)

[41] For example, sub-criticality of the core geometry or corium debris configuration should be maintained, and a path should be

Limitations that could arise from harsh environmental and radiological conditions should be taken into account.

3.39 Strategies should be preferred which avoid or minimise the accumulation of large amounts of potentially contaminated water, including leakage from a failed containment. Strategies for storing and remediating accumulated contaminated water should be considered in an appropriate manner.

DEVELOPMENT OF PROCEDURES AND GUIDELINES

3.40 The strategies and measures discussed in the previous section should be converted to procedures for the preventive domain (EOPs) and guidelines for the mitigatory domain (SAMGs). Procedures and guidelines should contain the necessary information and instructions for the responsible personnel, including the use of equipment, equipment limitations and cautions and benefits.

3.41 Procedures and guidelines should be written in a user friendly way so that they can be readily executed under high stress conditions, and should contain sufficient detail to ensure the focus is on the necessary actions[42]. The procedures and guidelines should be written in a predefined format. Instructions to implementers should be clear and unambiguous, using consistent language and the use of specific terms in accordance with established rules, preferably in a writer's guide.

3.42 Human factor aspects should be considered in the development of the accident management programme. This should include consideration of adherence to:

- procedures and guidelines[43], and
- the command and control structure.

3.43 Where accident conditions require immediate attention and short term actions, there may be no time available for the deliberation of all possible consequences of the actions. In

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provided from the core or corium debris decay heat to an ultimate heat sink, where possible.

[42] For example, where primary injection is recommended, it should be identified whether this should be initiated from dedicated sources (borated water) or alternate sources (possibly non-borated water such as fire extinguishing water). Also the available line-ups to achieve the injection should be identified and guidance should be put in place to configure unconventional line-ups, where these are needed. It should be known how long sources will be available, and what needs to be done to either replace or to restore them once they are depleted.

[43] This can result, for example in identifying the need for knowledge based versus rule based procedures and guidelines

such cases, the guidance should be developed accordingly[44], by directly identifying the recommended action.

3.44 The procedures and guidelines should contain as a minimum the following elements:

- Objectives and strategies;
- Potential negative consequences of the actions;
- Initiation criteria;
- The time window within which the actions are to be applied (if relevant);
- The possible duration of actions;
- The equipment and resources (e.g. AC and DC power, water) required;
- Consideration of environmental condition in the location where actions would be carried out;
- Consideration of required personnel resources;
- Cautions and limitations;
- Local actions sheets (if relevant);
- Transition criteria and exit/termination condition; and
- Assessment and monitoring of plant response.

3.45 The set of procedures and guidelines should include relevant plant parameters that should be monitored and they should be referenced or linked to the criteria for initiation, throttling or termination of the various procedures and guidelines. Specific attention should be paid to situations where instrumentation is lost or incorrect due to a loss of power or harsh environment. Guidance should be provided for making adequately informed decisions in such cases.

3.46 In the preventive domain, it may be possible to diagnose the accident on the basis of an appropriate procedure and plant alarms. Guidance should be put in place for situations where such a diagnosis cannot be obtained or, when it has been obtained, it later has been found to be incorrect or has changed due to the evolution of the accident[45]. Alternatively, the guidance can be fully linked to the observed physical state of the plant and so further diagnosis of the accident sequence is not necessary. Nevertheless, it may be appropriate to apply the diagnostic procedure at regular intervals to make it possible to return to the procedure

[44] For example, an immediate challenge to a fission product barrier, where ‘immediate’ means that there is no time or limited time for evaluation prior to decision making. Other examples are ´immediate actions`, to obtain a stable plant condition and work from there. Also such actions may be relevant before the TSC is available and operators must take action.

[45] The diagnostic procedure should be applied at regular intervals in the evolution of the accident to evaluate the appropriateness of the diagnosis.

specifically developed for the observed accident sequence. The guidance should be aimed at monitoring and preserving or restoring critical safety functions on the basis of the selected strategies.

3.47 Although in the mitigatory domain it should not be necessary to identify the accident sequence or to follow a pre-analysed accident scenario in order to use the SAMGs correctly, the control room operators and technical support staff should be able to identify the challenges to fission product barriers and plant damage conditions, based on the monitoring of plant parameters. However, a potential misdiagnosis of the plant conditions should not preclude execution of the guidelines.

3.48 The guidelines should be developed in such a way that the potential for an erroneous diagnosis of plant status is minimized. The use of redundant and diverse instrumentation and signals is recommended.

3.49 Possible positive and negative consequences of proposed strategies should be specified in the guidelines as a basis for selection of strategies during the evolution of the accident.

3.50 Priorities should also be defined among the various procedures and guidelines, in accordance with the priority of the underlying strategies. Conflicts in priorities, if any, should be resolved. The priorities may change in the course of the accident and, hence, the procedures and guidelines should contain a recommendation that selection of priorities be reviewed on an ongoing basis. The selection of actions should be changed accordingly.

3.51 Procedures and guideline sets that are implemented during accident management conditions should be integrated with each other to establish a comprehensive strategy for accident management.

3.52 A transition point from the preventive domain to the mitigatory domain should be set with careful consideration of timing and magnitude of subsequent challenges to fission product barriers. Specific and measurable parameter values should be defined for the transition from the preventive domain to the mitigatory domain. When the transition point is specified on the basis of conditional criteria (i.e. if certain planned actions in the EOPs are unsuccessful), the time necessary to confirm that the transition point has been reached should be taken into account[46].

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[46] For example, fuel temperature rise and amount of fuel degradation as a consequence of anticipated time needed for

3.53 The possibility of transition from EOPs to SAMGs before the technical support centre is operable should be considered in the development of procedures and guidelines[47]. Any mitigatory guidance provided to control room operators in this case should be presented in a way that makes prompt and easy execution possible and, therefore should be presented in a format operators are able to work with and already trained for.

3.54 Proper transition from procedures to guidelines should be provided for, where appropriate. Functions and actions from the procedures that have been identified as relevant in the mitigatory domain should be retained in the guidelines.

3.55 Where EOPs are not exited but are executed in parallel with the SAMGs, their applicability and validity in the mitigatory domain should be demonstrated. In that case, a hierarchy between EOP and SAMG actions should be established, in order to address conflict.

3.56 In addition to entry conditions to the SAMGs, exit conditions/criteria to long term provisions should be specified[48]. Safe stable state should be clearly defined and provisions to maintain the long term stable state should be specified.

3.57 Procedures and guidelines should be based on directly measurable plant parameters. Where measurements are not available, parameters should be estimated by means of simple computations and/or pre-calculated graphs. Use of parameters that could be obtained after carrying out complex calculations during the accident should only be contemplated if there is ample time for such calculations and there is reasonable assurance that the likelihood of error is reasonably low[49].

3.58 The guidelines should be written in such a way that there is a possibility to deviate from an anticipated path where this might be necessary or beneficial[50].

3.59 It should be noted that various equipment may start automatically or change configulation upon certain parameters reaching pre-defined values ('set points')[51]. Such automatic starts have usually been designed for events in the preventive domain. These

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identification of the transition point.

[47] This situation can occur in cases where an event rapidly develops into a severe accident, or where the TSC cannot be activated within the time assumed in the guidance.

[48] An example is given in Appendix VII of Ref. [13].

[49] When calculations and verifications can be carried out by proficient engineers using reliable, adequately qualified, computational tools.

[50] Such flexibility may be necessary due to the uncertainty in the status of the plant and in the effectiveness and/or outcome of actions, and in order to cover unexpected events and complications.

[51] For example, like containment isolation devices

automatic actions may be counterproductive in the mitigatory domain. Hence, all automatic actions should be reviewed for their impact in the mitigatory domain and, where appropriate, equipment should be inhibited from automatic start. Manual start of the equipment concerned should then be considered in the guidance.

3.60 Procedures and guidelines should contain guidance for situations where the preferred accident management equipment may not be available[52]. Alternate methods for achieving the same purpose should be explored and, if available, included in the guidance.

3.61 Guidance should be developed to diagnose equipment failure and to identify methods to restore such failed equipment to service. The guidance should include recommendations on the priorities for restoration actions. In this context the following should be considered:

- The importance of the failed equipment for accident management;
- Possibilities to restore the equipment;
- Possibility for unconventional system line-ups;
- Possibility to connect portable equipment;
- The likelihood of successful recovery if several pieces of equipment are out of service;
- Dependence on a number of failed support systems; and
- Doses to personnel involved in restoration/connection of the equipment.

3.62 Recovery of failed equipment and/or, recovery from erroneous operator actions should be factored into accident management guidance. The time to recover failed equipment or to implement/connect portable equipment may be outside the time window to prevent core damage. If this is the case, an earlier transition to the mitigatory domain can be decided.

3.63 Relevant management levels in the operating organization of the plant, as well as outside organizations responsible for the protection of the public and environment should be made aware of the potential need for transition to the mitigatory domain.

3.64 When containment venting is possible, the accident management programme should provide guidance on its use to prevent uncontrolled loss of containment integrity and to avoid releases of radionuclides causing long-term off-site contamination. Guidance should be provided for performing venting under conditions such as loss of power and high radiation levels and high temperatures in areas where vent valves are located (if local access is

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[52] For example, because of equipment failure or equipment lockout. Note: equipment failure includes instrumentation failure. Example: assume normal AC and DC power supplies and air systems not available.

required).

3.65 The development of accident management guidance should take into account the habitability, operability and accessibility of the control room or the Technical Support Centre. Accessibility of other relevant areas, such as areas for local actions should also be assessed. It should be investigated whether expected dose rates and other environmental conditions[53] may give rise to a need for restrictions for personnel access to such areas.

3.66 Pre-calculated graphs or simple formulae should be developed, where appropriate, to avoid or limit the need for complex calculations during the accident. These are often called 'computational aids' and should be included in the documentation of the guidelines[54]. Computer based aids should consider the limited battery life of self-contained computers (laptops) and the potential for loss of AC power.

3.67 Rules of usage should be developed for the application of the guidance. Questions to be addressed should include at least the following:

- If executing EOPs and a guideline entry point is reached, should actions in the EOP then be stopped or continued if not in conflict with the applicable guideline?
- If a guideline is in execution, but the point of entry for another one is also reached, should that other guideline be executed in parallel?
- Should one delay the consideration to initiate another guideline while parameters that called upon the first one are changing value?

3.68 Adequate background material should be prepared to support development of accident management guidelines. The background material should fulfil the following roles:

- It should be a self-contained source of reference for:
  - The technical basis for strategies and deviations from generic strategies, if any;
  - A detailed description of instrumentation needs;
  - Results of supporting analysis;
  - The basis and detailed description of steps in procedures and guidelines; and
  - The basis for specification of set-points used in the guidelines.
- It should provide a demonstration of compliance with the relevant quality assurance requirements; and
- It should provide basic material for training courses for accident management staff.

[53] Adequate lightning, temperature, chemical conditions if appropriate…

[54] Examples are provided in Appendix III of Ref. [13] or by the TSGs developed by the BWR Owners Group.

Multi-unit Sites

3.69 In the case of sites where several units are in operation at the same site (multi-unit sites), the continued use of a unit that has not been affected should be taken into account in the accident management guidance. Special care should be used to identify impact on any equipment or systems that might be shared between units[55], in particular from the point of view of adequate capacity of the shared systems. There should be pre-defined criteria to decide whether or not the neighbouring units have to be shut down.

3.70 For multi-unit sites, the guidelines should address the possibility that more than one, or all units, may be affected, including the possibility that damage propagates from one unit to other(s), or is caused by actions taken at one unit.

HARDWARE PROVISIONS FOR ACCIDENT MANAGEMENT

3.71 Plant hardware provisions should be assessed to evaluate whether they are likely to meet accident management objectives. For some plants, it may be concluded that modifications in hardware provisions are needed to:

- reduce or delay challenges to safety functions; and
- reduce challenges that could lead to potential failure of fission product barriers.[56]

In that case, modifications of the plant should be considered accordingly.

3.72 Additional hardware provisions, including portable on- and off-site equipment, should be considered where the existing[57] equipment is not anticipated to remain functional in the long-term[58] or could be disabled in case of station black-out. In estimating the long-term availability of components the feasibility of performing maintenance or repairs should be evaluated and taken into account.

3.73 Changes in design should be evaluated where challenges to fission product barriers cannot be reduced to an acceptable level, or to reduce uncertainties in the analytical prediction of such challenges.

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[55] For example, a cross-tie of heat removal systems from an unaffected unit may be useful for heat removal from the affected unit but this may require that the unaffected unit will remain at a certain predefined power level.

[56] An example is a reactor with a small containment which is vulnerable to hydrogen explosions. Inertisation may then be needed.

[57] For example, decay heat. removal

[58] In estimating the long term availability of components, the limited possibility – or impossibility – of maintenance should be taken into account (for example the long term running of highly contaminated residual het removal pump without the possibility of maintenance for a long period.

3.74 Equipment upgrades aimed at enhancing preventive features of the plant should be considered as tasks with high priority. [59] For existing plants, providing portable on- or off-site equipment (reasonably protected against external events) may be the preferred option to enhance the preventive plant capabilities.

3.75 Equipment upgrades aimed at preserving the containment function, or minimizing releases when the containment function has been lost or by-passed should be considered as a high priority for both the preventive and mitigatory domains. In particular, equipment upgrades which increase capability or margin to failure for the following functions should be taken into account:

- Monitoring key containment parameters such as temperature, pressure, radiation level, hydrogen concentration, and water level;
- Containment isolation in a severe accident, including bypass prevention;
- Ensuring the leak-tightness of the containment, including preservation of the functionality of isolation devices, penetrations, personnel locks, etc., for a reasonable time after a severe accident;
- Establishing or restoring the containment heat sink to manage pressure and temperature in the containment;
- Control of combustible gases, fission products and other materials released during severe accidents;
- Prevention and mitigation of dominant challenges:
    - containment overpressure and underpressure,
    - high-pressure core-melt scenarios;
    - reactor vessel melt-through; and
    - basemat melt-through by molten corium.
- Monitoring and control of containment leakages.

3.76 Measures allowing control of fission product releases should be evaluated.

3.77 There should be multiple diverse accident management strategies and measures for mitigating challenges to containment integrity[60]. For portable equipment, multiple hook-up

[59] Examples are qualification of pressurizer valves for feed and bleed operation and additional redundancies on important safety systems (AC and DC power, available cooling water).

[60] Such measures can include special design provisions, or alternate use of equipment designed for other tasks

points to facilitate their use during extreme external events[61] should be considered, taking into account benefits versus potential negative implications[62] .

3.78 Appropriate provisions should be available to remove the decay heat from the corium debris to an ultimate heat sink.

3.79 When containment venting is contemplated or directed, the accident management strategies should provide guidance for the following:

- Situations when all AC and DC power is lost and the instrument air system is not available.
- Situations involving high radiation areas and high temperatures in areas where vent valves are located (if local access is required).
- An alternate means of venting the containment if rupture disks are installed that could inhibit venting when required. The preferred option should be to vent using a pathway that is likely to provide some reduction of fission product release[63].
- The potential negative consequences[64] of containment venting should be assessed during the decision making process.

3.80 If equipment and systems used to cope with design basis accidents are supplemented by additional equipment to mitigate severe accidents, the latter equipment should preferably be independent.

3.81 For dedicated or upgraded equipment, its capability to perform the required actions in accident conditions including severe accidents and effects of extreme external hazards should be demonstrated.

3.82 When the strategies rely on portable equipment, the equipment qualification, configuration and layout should be assessed whether they are likely to meet accident management objectives. Steps should be taken to ensure that personnel can install and operate the portable or mobile equipment within the timeframes necessary to prevent loss of fission product barriers.

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[61] For example: connection points at different elevations may be considered to address flooding concerns.

[62] Such as creating a potential for containment bypass.

[63] For example, filtered path or through a scrubber

[64] For example, loss of water inventory

3.83 Accident management strategies should be developed for situations when DC power is lost during a long-term loss of all AC power.

3.84 Portable equipment needed for accident management should be staged and protected so that it could be ready for use within a predefined time-frame.

3.85 There should be inspection, maintenance and testing procedures available for all equipment to be used in accident management.

Multi-unit Sites

3.86 For multi-unit sites, concurrent accidents affecting multiple units and potential interactions between units should be considered in the accident management programme.

3.87 Effectiveness for multiple usages of equipment or response centres (e.g. control room and/or technical support centre) that are shared by different units, the impact of accidents occurring simultaneously at several units on the accident management programme should be evaluated and decision on the need for modifications made accordingly

3.88 If structures, systems, and components (SSCs) important to safety are shared between two or more nuclear power reactors, it should be demonstrated that all the safety recommendations and considerations should be met for each reactor. In the event of a design extension conditions involving a reactor that shares SSCs with other reactors, it should be demonstrated that an orderly shutdown of reactors and safe shutdown are achievable in the other reactor(s). The reliability of the shared SSCs should be commensurate with the safety functions being performed, and due consideration should be given to the possibility that an event could give rise to the need to shut down two or more reactors simultaneously.

INSTRUMENTATION AND CONTROL

3.89 Essential instrumentation needed for monitoring core, containment and spent fuel conditions should be identified. To the extent practicable these monitoring functions should be maintained throughout an extended loss of AC power event. A plant-specific assessment should be performed to identify equipment, materials and actions to restore power to the minimum essential components in the event installed DC batteries are depleted.

3.90 Guidance should be provided to validate important instrumentation outputs (i.e., those used for symptom based diagnosis of potential challenges to fission product barriers or for confirmation of the effectiveness of implemented strategies). All important instrumentation readings should be verified with other independent information[65][66]. This should also be practiced in drills and exercises.

3.91 It should be confirmed that information needed for decision making during execution of accident management strategies can be obtained from the instrumentation in the plant. Such information should be available in all places where the evaluation and decision making is to be made. Where instruments can give information on the accident progression in an indirect way, such possibilities should be investigated and included in the guidance.

3.92 The uncertainty of readings of instruments essential for accident management should be assessed. In many cases, important instrument indication that permits trending may be more important than the accuracy of the indicated values.

3.93 The survivability of instrumentation essential for accident management should be considered. Nevertheless, instrumentation may continue to operate well beyond their design range with decreasing accuracy. The following should be taken into account:

- Use of instrumentation that is designed for the expected environmental conditions following an accident should be the preferred method to obtain the necessary information
- Alternate instrumentation should be identified if the preferred instrumentation becomes unavailable or not reliable.
- Where such instrumentation is not available, additional means (such as computational aids), or alternate strategies should be developed[67].

3.94 The time needed for obtaining adequate information from plant parameters important for accident management should be taken into account when developing guidelines.

3.95 The effect of environmental conditions on the instrument reading should be estimated with taking into consideration of a local environmental condition which can deviate from global conditions because instrumentation that is qualified under global conditions may not function properly under local conditions. The expected failure mode and resultant instrument

[65] Instruments may continue to provide information, such as trends, even if the readings are not accurate.

[66] E.g. sometimes, a degree of malfunction of thermocouples depends on temperature, humidity, salt deposition and other environmental factors. Availability of them can be evaluated by checking trends of neighboring signals and response to changes in cooling conditions such as the injection rate.

[67] Adequate information on additional means can be found in Safety Report Series No 32, Implementation for Accident Management Programme for Nuclear power Plants.

indication (e.g. off-scale high, off-scale low, floating) for instrumentation failures in severe accident conditions beyond the design basis should be identified.

3.96 All available information and background documentation on key instrumentation needed to support accident management decision making should be available to appropriate members of the emergency response teams.

PERSONNEL STAFFING AND NEEDS

3.97 Adequate staffing levels and personnel qualifications should be established for implementation of accident management measures taking into account the possibility that multiple units can be affected simultaneously and taking into account the requirements for emergency response. Staffing should be capable of sustaining an adequate response until relief arrives when the plant is isolated for some time.

3.98 A nominative list of persons that will be part of the accident management should be established. This list should account for accidents developing over a long period so that adequate shift manning is maintained.

3.99 Shift turnover documents[68] should be prepared. During turnovers the new shifts should be provided the accident-related information as well as other information deemed appropriate to maintain continuity in strategies for managing the accident[69].

3.100 Contingency plans should be developed for situations where accident management staff have been incapacitated or when outside support may be delayed.

3.101 The possibility of the site being isolated, in particular as a result of an extreme external event, should be evaluated and adequate supplies of non-perishable goods[70] should be maintained. Periodic review of supply adequacy should be done.

3.102 A highly reliable communication network between the different locations of the emergency response organization (ERO) should be used. Guidance should be put in place for measures to be taken if off-site communication fails and only the part of the emergency

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[68]Information useful for the turnover document may be (but not limited to) severe accident related information such as: the severe accident sequence development, the procedures and guidelines in used at the time of the transition from the preventive to the mitigative domain, the emergency teams involved in the mitigation, possible instrumentation inaccuracies and the recovery actions undertaken for unavailable systems.

[69] For example, severe accident sequence development, procedures and guidelines in use at the time of the transition from the preventive to the mitigative domain,emergency response teams or actions performed for recovering unavailable systems.

[70] For example, food and amenities

response organization located at the plant site remains functional in case of failure of the primary communications systems and period.

3.103 Acceptable working conditions should be provided to plant and external support personnel in situations where the site is partially or totally isolated from continuous offsite support.

3.104 Plans should be established for relocating personnel as well as communication and coordination functions to alternate locations, should primary emergency response facilities be rendered inoperable during an event.

3.105 Plans should be developed to address family/personal needs of personnel who are unable to leave the site.

3.106 Contingency plans, training, and guidance should be developed to help personnel cope with the emotional stress affecting personnel performance during a natural disaster or nuclear accident.

INTERFACES WITH EMERGENCY PREPAREDNESS, RESPONSIBILITIES AND LINES OF AUTHORIZATION

Interfaces with emergency preparedness

3.107 Arrangements for local response should be coordinated with the site, corporate and national level concerning functions, responsibilities, authorities, allocation of resources and priorities. The emergency response organization could include elements as depicted in Fig. 2.

3.108 The site emergency plan should define the overall emergency response organization of a nuclear power plant. The responsibilities defined in the accident management programme should be described in this emergency plan with clearly defined interfaces in order to ensure a consistent and coordinated response to severe accident conditions [71]. A review of the emergency plan and accident management programme should be performed with respect to the actions that should be taken according to the emergency response plan and accident management strategy, to ensure that conflicts do not exist[72].

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[71] Such interfaces include for example: information needs and transfer, interactions between on- and off-site actions, activation criteria (including contingencies in case of personnel inability to access the site), and potential conflicting demands for limited resources.

[72] For example, conflict of priority for using protable equipment for security purposes and accident management purposes.

3.109 Ref. [8] in part requires that the transition from normal plant operation to accident conditions during an emergency be clearly defined and be effectively made without jeopardizing safety. The responsibilities of everyone required to be on the site in an emergency should be designated as part of the transition. It is also required to ensure that the transition to emergency response and the performance of initial response actions do not impair the ability of the operational staff (such as the control room staff) to follow the procedures necessary for safe operations and for taking accident management actions.

3.110 Use of the SAMGs must interface with the organizational structure and actions defined in the emergency plan to ensure a consistent and coordinated response to severe accident conditions. Therefore, as part of the plant specific SAMG implementation, both the emergency plan and accident management strategy should be reviewed with respect to the SAMG actions and emergency response plan, to ensure that conflicts need to be resolved. This review might recommend changes to the emergency plan to eliminate such conflicts.

Responsibilities and lines of authorization

3.111 The person having authority for deciding implementation of actions and strategies in different phases of an accident should be identified. Decision makers and selected members of the emergency response team that deals with coping with the consequences of extreme events should be trained to lead under extreme conditions and demonstrate their leadership abilities during exercises or drills.

3.112 Responsibilities and authorities for implementation of certain accident management action with a potentially significant impact[73] should be established in the entire emergency response organization. The emergency director (or other person with clearly assigned decision-making authority) should have the authority to take any necessary actions to mitigate the event including venting containment or injecting low quality water into the reactor without the need for external authorization[74].

3.113 Contingency plans should be prepared for the case where a certain authority level is incapacitated[75]. Such contingency plans should identify an alternative authority and decision-makers.

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[73] For example, containment venting or use of un-borated water for injection to a PWR core and/or spent fuel pool (SFP)

[74] If local regulations require external authorization for such actions, steps should be taken to gain concurrence in advance on criteria for which these actions may be carried out

[75] Incapacitation could be the result of site isolation

3.114 When off-site support to accident management is contemplated, responsibilities, priorities and contingencies should be addressed in a way that minimizes the possibility of negative interaction between activities performed by on-site and off-site teams. And accident management should be implemented to ensure that all teams have a common situational awareness.

3.115 Impact of external events should be considered in the allocation of responsibilities, period when placing the decision making authority for accident management at both on-site and off-site locations.

3.116 Roles of personnel involved in accident management should be assigned in three categories of functions:

- Evaluation/recommendation (assessment of plant conditions, identification of potential actions, evaluation of the potential impacts of these actions, and recommendation of actions to be taken and, after implementation, assessing the outcome of actions; personnel in charge of these duties are often called 'evaluators');
- Authorization (decision making – approving the recommended action or deciding other appropriate actions for implementation; personnel in charge of these duties are often called 'decision makers');
- Implementation and support of the actions (operation of the equipment as necessary including verification of operation, dose assessment in support of accident management actions, emergency response functions: personnel in charge of these duties are often called 'implementers'). This includes remote operations from the control room, and also local actions by appropriate personnel to recover or connect equipment.

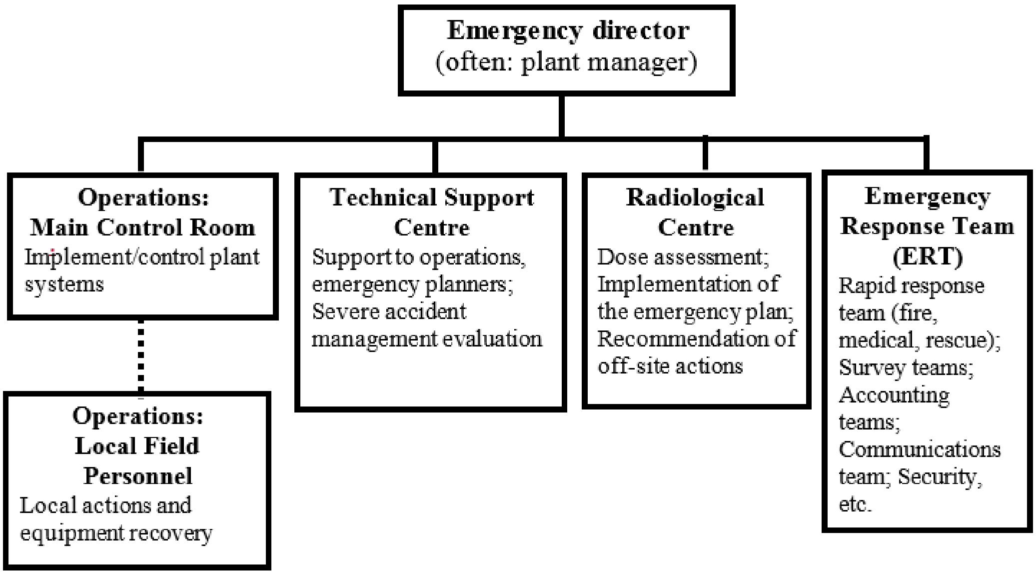

Figure.2 Example layout of the technical elements of the on-site emergency response organization

3.117 In the preventive domain, decision making should be carried out by the control room staff[76]. For some situations,[77] decision making may be placed at another appropriate level of authority.

3.118 The decision making authority in the mitigatory domain should lie with a high level manager, denoted as the emergency director. The emergency director should be granted the authority to decide on the implementation of accident management measures proposed by the technical support centre or based on his own judgment. The emergency director should maintain a broad understanding of the actual status of the plant, plant capabilities and vulnerabilities and key accident management actions, including their off-site effects.

Transfer of responsibility

3.119 The points at which authority for decision-making and implementation of accident management actions is transferred should be clearly established.

3.120 Transfer of responsibilities and decision making authority from the control room staff to an appropriate level of authority should be made if an event is likely to degrade into a

[76] The shift supervisor or shift manager, or a particular dedicated person, e.g. a safety engineer

[77] For example, incapacitation of control room staff

severe accident and decision making becomes highly complex in view of the uncertainties involved.

3.121 In transferring the overall authority for accident management from the control room to the emergency director, the functions that remain in the control room and actions that can be decided upon by the control room staff independently of the emergency director should be specified[78]. As the control room staff is also responsible for the execution of the measures decided upon by the emergency director, consistency, and a hierarchy, between the two groups of actions should be established.

3.122 If transfer of authority to off-site persons is contemplated, it should be verified that such persons have the required background to efficiently exercise such authority. The impact of extreme external events should be considered. In particular, a highly reliable communication network should be provided, and necessary guidance on communication devices and consumables to be taken in case of failure of communication should be established.

3.123 It should be noted that transfer of responsibilities during an accident in itself poses risks. Hence, such transfer should take place at a point in time that minimizes such risks and, thus, is optimal from the viewpoint of accident management. The transfer of responsibility should not create a 'vacuum' in decision making and necessary actions. Hence, formal transfer should not take place until the new decision maker is ready to assume its role. Transfer of responsibilities should be consistent with the emergency plan.

Technical Support Centre

3.124 Criteria for activation of the technical support centre should be unambiguous and clearly specified in plant procedures or on-site emergency plan. Accident management measures should continue to be decided and carried out by the control room staff until the technical support centre is functional. When there are multiple support teams, their responsibilities and interfaces should be defined[79]

3.125 Depending on the situation, the technical support centre may be activated in the preventive domain. The technical support centre should provide technical support to the

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[78] These include activities that control room staff can carry out independently, such as maintaining support conditions (e.g. room cooling, service water) and responding to some alarms; activities that the control rooms staff should not do on their own (e.g. starting up major equipment) should also be specified

[79] Could be the case for large organizations

control room staff, and, where applicable, to other parts of the emergency response organization by performing evaluations and recommending mitigative actions to the decision making authority[80].

3.126 Selected technical support centre personnel should have a detailed knowledge of the procedures and guidelines. They should have prompt access[81] to the information on the plant status and a good understanding of the underlying accident phenomena[82]. The technical support centre should communicate extensively with the control room staff to benefit from their expertise of and insight into the plant capabilities.

3.127 Support from qualified organizations, including the plant vendor or designer, should be sought, as necessary, for the implementation of additional appropriate accident management recommendations[83]. The mechanisms for calling on early support should be established, and the support capabilities should be verified on a periodic basis.

3.128 Rules for information exchange between the various teams of the emergency response organization should be defined. The mechanisms for ensuring the flow of information between the technical support centre and the control room as well as from the technical support centre to other parts of the emergency response organization, including those responsible for the execution of on-site and off-site emergency plans, should be specified. Oral communication between the technical support centre and the control room staff should be done by a member of the technical support centre who is a licensed operator or similarly qualified person. As the occurrence of a severe accident will generate extensive communication between on-site and off-site teams, care should be taken that this communication does not disrupt the management of the accident at the plant.

3.129 If there is to be any involvement of the regulatory body in the decision making[84], it should be defined how this is to be done.

[80] For example, the intention to vent the containment at a certain moment and during a certain time on the basis of plant parameters may not be in line at that moment with proposed actions of the off-site emergency response organization.

[81] They should be able to get any information they need but that is not directly forwarded to them, e.g. through pre-established protocols for contacting the control room

[82] Their knowledge should be of such level that they are capable to understand the threat to important safety functions and fission product barriers also if complications arise or unexpected events occur that bring them outside pre-staged guidelines.

[83] If such support is not already part of the emergency response organization

[84] Some Member States have specific regulations on regulatory body involvement; in other cases involvement of the regulatory body may not be required but may be prudent (e.g. for containment venting).

3.130 Information about the performance of the instrumentation and control and other equipment (possibly already summarized in the guidance for easy reference) should be made available to the technical support centre. Preferably the technical support centre should have direct access to plant information. The availability and use of such information should be considered in the development of guidelines. The plant information in the technical support centre should be recorded and monitored appropriately[85]. Where manual transfer of data is needed, this should preferably be done by a dedicated member of the technical support centre.

3.131 Extended loss of AC power should be considered in providing for communication between the control room and the technical support centre.

3.132 The physical location of the technical support centre should be designed against extreme external events.

Multi-unit Sites

3.133 For multi-unit sites, the site emergency plan should include the necessary interfaces between the various parts of the overall emergency response organization. Unit emergency directors may be assigned to decide on the appropriate actions at that unit. In that case, an overall emergency director should also be assigned to coordinate activities and priorities amongst all affected units on the site. Decision making responsibilities should be clearly defined. In case of different operating organizations at the given site, appropriate agreements should be stablished on coordination of emergency response activities including accident management guidance.

VERIFICATION AND VALIDATION[86] [87]

3.134 Verification and validation processes should assess the technical accuracy and adequacy of the instructions, and the ability of personnel to follow and implement them. The verification process should confirm the compatibility of document instructions with referenced equipment, user-aids and supplies (e.g., portable equipment, posted job aids, strategy evaluation materials, etc.). The validation process should demonstrate that the document provides the instructions necessary to implement the guidance[88].

[85] For example, by electronic data transfer

[86] Definition is from IAEA Safety Glossary (2007)

[87] More detail information in Safety Report Series N.32, “Implementation of Accident Management Programmes in Nuclear Power Plants”.

[88] Text is from NEI-14-01 rev.0, “Emergency Response Procedures and Guidelines for Extreme Events and Severe Accidents”

3.135 All accident management procedures and guidelines should be verified and validated. With adequate periodicity, changes made to guidelines and procedures should be re-evaluated and revalidated to maintain the adequacy of the accident management programme.

3.136 Possible methods for validation of the procedures and guidelines are the use of a full scope simulator (if available), an engineering simulator or other plant analyser tool, or a table top method. The most appropriate method or their combination should be selected, taking into account the role of each target group in emergencies.

3.137 Validation should include an independent, cross-functional safety review of the plant should be performed with the objective of fully understanding all accident management implications. This review should incorporate a plant walk-down[89] for assessing which kind of difficulties could exist for practical implementation of accident management measures, in particular in case of an extreme event, including seismically induced fires and floods[90].

3.138 All equipment used in the accident management programme, including portable and mobile equipment, should be tested, or other reasonable means used, to verify that performance conforms to the requirements. Testing should include the equipment and the assembled sub-system needed to meet the planned performance. Tests should include needed local actions, contingencies, and its proper connection to plant equipment, access to the site, off-site actions, multi-unit events, emergency lighting, etc., and the time needed for these actions. Guidance should be provided for maintenance and periodic testing to assure proper functioning.

3.139 Staff involved in the validation of the procedures and guidelines should be different from those who developed the procedures and guidelines. Developers/Writers of plant specific procedures and guidelines should prepare appropriate validation scenarios and should participate as observers to the validation process[91].

3.140 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

[89] Inspection of local areas in a nuclear power plant where structures, systems, and components are physically located in order to ensure accuracy of procedures and drawings, equipment location, operating status, and environmental effects or system interaction effects on the equipment which could occur during accident conditions

[90] For seismic-PRA and seismic-margin-assessment reviews, the walk-down is explicitly used to confirm preliminary screening and to collect additional information for fragility or margin calculations.

[91] This includes independent review in Sections 6.3-6.of IAEA Safety Standards Series No GS-R-3

the operating organization. The documentation should be stored in order to provide for any future revalidation.

ACCIDENT MANAGEMENT TRAINING, EXERCISES AND DRILLS

3.141 Personnel responsible for performing accident management duties should be trained to acquire the required knowledge, skills, and proficiency to execute their roles. A comprehensive training programme for accident management (AM) should be prepared. Training should include a combination of education (classroom training), exercises and drills, supported by appropriate means, such as desktop training or adequate simulation tools.

3.142 Training needs and objectives should be specified, preferably in the development phase of the accident management programme. The training programme should be put in place prior to the accident management programme being implemented.

3.143 Training should be established and implemented for each on-site group and off-site group involved in accident management. Training should be commensurate with the tasks and responsibilities of the participants, taking into account appropriate technical level needed for each group. In-depth training should be contemplated for people entrusted with critical functions in the accident management program.

3.144 Training, including periodic exercises and drills should be sufficiently realistic[92] and challenging to prepare personnel responsible for accident management duties to cope with and respond to situations expected to occur during an event[93], including accidents occurring simultaneously on more than one unit, from different reactor operating states and in the spent fuel pool. Training should consider unconventional line-ups of the plant equipment, use of portable equipment (such as diesels or pumps) as well as repair of the equipment. Training material should address implementation of strategies under adverse environmental conditions, including those resulting from external hazards, potentially high radiation situations and influence of the anticipated human behaviour under stress.

3.145 Accident management exercises and drills should periodically challenge responders by making unavailable information sources (such as the safety parameter display system), equipment, and facilities that potentially could be damaged in the accident. Drills that

[92] Drills should extend over a time period long enough not to unacceptably distort plant response, and allow to test transmission of information during shift changes

[93] Special drills/exercises should be developed to practice operating shifts and TSC staff changeover and information transfer between different teams (e.g. turnover packages as are developed in several countries)

purposely include sources of inaccurate or miscommunicated information to personnel can be used as a way to exercise their questioning attitude, teamwork, and diagnostic skills. However, caution should be used so that misinformation does not contribute to negative training.

3.146 The decision makers should be trained for understanding the consequences and uncertainties inherent in their decisions; the implementers should ensure that they understand the actions that they may be asked to take; and the evaluators should ensure that they understand the technical basis upon which they will base their recommendations.

3.147 Exercises and drills should be based on scenarios that require application of a substantial portion of the overall accident management programme in concert with emergency response and in realistic conditions characteristic of those that would be encountered in a severe emergency. Large scale exercises providing an opportunity to observe and evaluate all aspects of accident management should be undertaken.

3.148 Training material should be developed by subject matter experts and qualified trainers. Experts could assist in:

- answering questions that are beyond the capability of professional trainers, and
- operation of field/local equipment, operation under adverse condition[94], including operation of portable equipment.

3.149 Training should be developed using a systematic approach to training[95]. This includes identifying training needs, defining the training objectives, identifying the technical basis for training material, developing training material, specifying the appropriate venue for delivering training and measuring the effectiveness of training to provide feedback to the training process.

3.150 Initial training as well as refresher training should be developed for all groups involved in accident management. The frequency of refresher training should be established based on the difficulty and importance of accident management tasks. Replacement staff must be trained appropriately. A maximum interval for refresher training should be defined; depending on the outcome of exercises and drills held at the plant, a shorter interval may be selected. Changes in the guidance and/or use of the guidance should be reflected in the training programme, consistent with the nature of the changes.

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[94] For example, high radiation, temperature, humidity, on-site damage

[95] Defined in Ref. [16]

3.151 Some of the scenarios used for exercises and drills should go far into the core damage domain and eventually result in failure of reactor pressure vessel (RPV) and containment. Attention should be paid to exercises that enhance the awareness of control room personnel, technical support centre (TSC) members or engineering staff to the need and possible consequences of defeating or resetting control and logic blocks for implementing some successful strategies.

3.152 Results from exercises and drills should be fed back into the training programme and, if applicable, into the procedures and guidelines as well as into organizational aspects of accident management.

3.153 Criteria for evaluating the effectiveness of a drill or an exercise should be established. Such criteria should characterize the ability of the team participating in the drill or exercise to understand and follow the evolution of plant status, to reach sound decisions including in case of unanticipated events and initiate well-founded actions, meet job performance criteria and drill objectives.[96]

UPDATING ACCIDENT MANAGEMENT PROGRAMME

3.154 The need of the accident management programme update should be assessed as new information becomes available which may indicate potential for new accident scenarios, phenomena or challenges to physical barriers or any other significant effect on accident management that had not been fully considered previously.

3.155 The effect of any changes in the plant design including the available portable equipment or the operating organization on the accident management programme should be evaluated. A formal process should be developed for making changes when such changes are deemed necessary.

3.156 Any update of the accident management programme should include revision of background documents including supporting analysis used for their implementation[97].

3.157 When new information is received that challenges the basis of current external event

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[96] Additional guidance for exercises/drills is presented in Safety Report Series No. 32, Implementation of accident management programme in nuclear power plants.

[97] An example is a plant that has based its procedures and guidelines of a reference design or some other generic source of information, where then the originator of the procedures and guidelines on the reference design issues a revision of the accident management programme. Another example is an update of the PSA that identifies new accident sequences or existing sequences with s different weight, that were not a part of the basis of the existing accident management guidance

design assumptions, the capability of installed equipment and accident management procedures and guidelines should be evaluated to determine if safety functions could be compromised. Based on this evaluation, measures for updating the accident management programme commensurate with the impact should be identified.

3.158 New insights from international research on accident phenomena and industry operating experience (including lessons learned from events) should be evaluated on a regular basis and a judgment made on their potential value for accident management by the operating organization/utility[98].

3.159 When modification of the accident management programme is deemed appropriate, the operating organization should be responsible for establishing an action plan aimed at prioritising activities needed for implementation of said modifications.[99] The action plan should identify the timeframe and the organization in charge of practical implementation of the modifications.

SUPPORTING ANALYSIS

3.160 Suitable analysis methods that utilize appropriate safety or risk metrics should be used to aid in decision making regarding upgrades. Consideration should be given to the fact that analysis in the field of severe accident management is usually not conservative but of best estimate analysis[100], and does not in itself create margins.

3.161 Development and implementation of the accident management programme should be supported by appropriate computational analysis showing progression of representative accident scenarios to be addressed by accident management with the results to be used for formulation of the technical basis for development of strategies, procedures and guidelines.

3.162 The analysis should address all significant sources of radioactive material in the plant, in particular the reactor core and spent fuel pools and occurrence of accidents in all relevant normal operational states, not only reactor operation at power but also non-power states, including shutdown states with open reactor or open containment.

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[98] Exchange of information with peers should be used to provide continuous improvement of the accident management guidance. Such an exchange of information could be through, but not limited to, peers observing plant drills, and participation in exercises at other plants, the available IAEA RAMP program, IAEA OSART program, or WANO peer review.

[99] Where a generic accident management programme is used, such processing should involve the vendor of the generic program.

[100] Accident analysis which is free of deliberate pessimism regarding selected acceptance criteria and uses a best estimate code with uncertainty analysis.

3.163 The analysis should be comprehensive enough to address all phenomena (thermal-hydraulic, structural) important for assessment of challenges to integrity of barriers against releases of radioactive materials as well as for assessment of potential radiological consequences of reactor accidents (in term of doses). Multi-unit accidents should be analysed where applicable.

3.164 The analysis should address sufficiently broad set of accident scenarios adequately covering potential evolutions of initiating events into design extension conditions and a comprehensive set of plant damage states. PSA Level 1 and 2 (if available) in combination with engineering judgment should be used for selection of the scenarios.

3.165 The selection of accident sequences should be performed in the following steps:

(1) A suitable categorization approach and a set of plant damage states should be developed. A categorization scheme[101] should result in a list of groups of accident sequences including fuel degradation and melting, reactor vessel failure and containment boundary failure, and the associated severe accident phenomena. The full list of plant damage states should be screened out less important plant damage states in order to identify a limited set, considering contribution to core damage frequency and ensuring that all initiators are represented.

(2) One or more accident sequences for each plant damage state should be chosen, considering the total contribution to core damage frequency, the ability of the chosen sequence to represent other sequences in the same plant damage state, and the amenability of the chosen sequence to preventive accident management measures.

3.166 The analysis should be preferably performed using plant specific data, including plant operational parameters, plant systems configuration and performance characteristics and set-points.

3.167 Use of generic plant analysis, if available, may provide valuable contribution to the analysis, but in such case it should be convincingly demonstrated that the generic analysis is applicable for the specific plant.

3.168 In the analysis of accident scenarios that would lead to core damage and subsequent

[101] Many categorization schemes are possible. Level 2 PSAs contain such categorization schemes

potential challenge to fission products barriers[102] the following aspects should be taken into account:

- Consideration should be given to sequences with no operator action or inappropriate operator actions (errors of omission or errors of commission);
- Further on, the availability and functionality of equipment, including instrumentation, and the habitability of working places under anticipated environmental conditions should be considered; and
- This process should demonstrate that proposed strategies are not sensitive to cliff-edge effects.

3.169 The analysis should provide sufficient input for development of procedures and guidelines, in particular:

- choice of symptoms for diagnosis and monitoring the course of the accidents including confirmation of choice of symptoms for long-term processes,
- identification of the key challenges and vulnerable plant systems and barriers,
- specification of set-points to initiate and to exit individual strategies,
- positive and negative impacts of accident management actions including, demonstration of effectiveness of the actions,
- time windows available for performing the actions,
- prioritisation and optimisation of strategies based on timing and severity of challenges,
- evaluation of capability of systems to perform intended functions; expected trends in the accident progression (projections of the timing),
- conditions for leaving SAM domain,
- recommendations for equipment and instrumentation upgrades, and
- computational aids development.

3.170 The analysis should also provide sufficient information regarding environmental conditions for assessment of the survivability of the plant equipment including instrumentation needed in accident management, as well as for the assessment of the working conditions/habitability of working places for personnel involvements in the execution of the accident management actions.

[102] Note that Selection of sequences that would, without intervention, lead to core damage, is an appropriate way of identifying accident scenarios for subsequent investigation of both preventive actions (taken before core damage) and mitigatory actions (taken after core damage).

3.171 The analysis of accidents should be performed using best estimate computer codes, assumptions and data regarding initial and boundary plant conditions. Appropriate consideration should be given to uncertainties[103] in the determination of the timing and severity of the phenomena.

3.172 Computer codes used for analysis should have the capability of modelling severe accident phenomena with reasonable accuracy in prediction of key physical phenomena and modes and timing of failure of barriers and should be validated to the extent as far as reasonably practicable.

3.173 All code results should be evaluated and interpreted with due consideration given to code limitations and the associated uncertainties[104]. The appropriateness of carrying out sensitivity analyses should be evaluated when computer code results are relied upon for making critical decisions

3.174 The analysis should be performed in accordance with basic rules for safety analysis as specified in the relevant IAEA Safety Requirement [7].

MANAGEMENT SYSTEM

3.175 Development of an accident management programme should be the responsibility of the operating organization and follow the applicable IAEA safety requirements and guidance on this subject [15]. Where these should not be followed due to the uncertainties in the severe accident domain, the intent of the safety requirements should be followed to the extent practicable.

3.176 Operating organization should integrate all the elements of the accident management programme with the exist management system so that processes and activities that may affect safety are established and conducted coherently protection of site personnel and the public, and protection of the environment.

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[103] Uncertainties include uncertainties in understanding the phenomena that occur in the evolution of the accident as well as those associated with SAMG actions

[104] For example, many codes have fixed heat transfer correlations (e.g. critical heat flux on a flat plate) based on an assumed geometry, whereas the actual event may involve geometry changes (e.g. shattering of corium debris), which create varying heat transfer surfaces that will enhance or degrade heat transfer and, hence, influence the actual temperatures attained.

4. EXECUTION OF SAMGs

4.1 In case of an emergency, in particular one taking place in combination with an extreme external event, plant staff should assess the global situation on-site and ensure that their emergency command and control structures are capable of directing responses in accordance with established procedure and guideline sets. If required, contingencies developed to re-establish command and control should be implemented. The assessment of the situation should include:

- Number of affected units;
- Control facilities functionality and habitability;
- Damage to essential structures and buildings;
- Availability of access to essential buildings and equipment; and
- Capability to communicate with offsite organisations.

4.2 Once the control room staff, while executing the EOPs, has reached the point of entry to the SAMG domain or the emergency director has determined that SAMG should be applied, or SAMG entry is reached by some other specified basis, the transition from the EOP domain to the SAMG domain should be made. The control room staff should initiate actions under the SAMGs that apply until responsibility for recommending actions is transferred to another appropriate structure[105]. This occurs when the technical support centre is operable, is informed about the overall situation, has evaluated the plant status and is ready to give its first recommendation or decision on execution of a SAMG. The control room staff should continue to work with actions already initiated in the EOP domain providing they are consistent with the rules of usage of the guidance.

4.3 The technical support centre should reassess plant conditions at regular intervals as the accident progresses, to confirm or adjust the priorities for mitigatory actions. Recommendations should be presented by the technical support centre in written form to the decision maker, who will decide on the course of actions to be taken.

4.4 Decisions on actions to be taken should be given to the control room staff in a form that minimizes misunderstandings. The main control room staff should confirm the actions it is being directed to take and should report back the progress of the actions taken and the impact that these have on the plant. Oral (telephone) communication to the control room staff should

[105] For example, the technical support center for most PWR nuclear power plants

preferably be carried out by a technical support centre staff member who is a licensed operator. A major step prior to recommending or attempting executing an action is to check feasibility of proposed actions.

4.5 The key plant parameters should be displayed in an easily accessible way, e.g. by optical means (displays) or by wall boards. Long term station blackout should not lead to loss of data. Trends should be noted and recorded. Actions taken should also be recorded, as well as other relevant information, such as the EOP or SAMG applicable at the time, emergency alerts for the plant and planned releases of radioactive material. Adequate technical means should be available for this.

4.6 The timing and magnitude of possible future releases as a consequence of severe accident management guideline actions or their failure[106] should be estimated at regular intervals, and should be communicated in a suitable form through proper channels to the organization responsible for further actions[107].

4.7 The work at the technical support centre should be well structured based on a clear task description for each staff member. The technical support centre should convene in sessions at regular times and should leave sufficient time for individual staff members to do their analysis between these regular sessions.

4.8 The technical support centre or any equivalent structure(s) should ensure that external organisations are aware of planned actions with potential impact on the plant surroundings. Through consultations it should be ensured that off-site response organizations are aware of and prepared for planned releases. Alternatively, the releases should be delayed to a later time, if such a shift is compatible with the severe accident management actions foreseen. Final decision making rests with the person of the Emergency Response Organisation responsible for the decision making.

4.9 A mechanism should be put in place to assign priorities in case of a conflict between planned releases and the off-site readiness. In principle, priority should be assigned to the actions that prevent major damage to the fission product barrier still intact.

4.10 Generally, the decision making process includes deliberation of possible actions and

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[106] Such as deliberate releases, or isolation of release paths

[107] Such releases may be determined by consulting the PSA for the plant and inferring the relevant scenarios by interpretation of the plant parameters. Alternatively, fast running computer codes may be applied to analyse perceived scenarios and their most probable future evolution.

alternatives, and takes into account possibilities to restore systems back to service (i.e. repairs), consequences of possible releases, etc. However, in fast developing scenarios, there may be insufficient time to consider all these aspects. Consequently, the process for decision making should take into account the fact that decisions may have to be made in a very short time frame. A basic principle is that the decision making process should always be commensurate with the time frame of the evolution of the accident.

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ANNEX I - Insights on the use of SAMGs in France Plants

In France, SAM guidelines applicable to the EDF nuclear fleet (GIAG in French) have been developed under the form of both flowcharts and text. There are two parameters that are used for entry in GIAG, one characterizing very high core exit temperature, the other high containment activity.

Either criterion can be used for entering GIAG or subsequent performance of a whole set of immediate actions by main control room (MCR) personnel. Upon entering GIAG, EOPs are exited. However, some specific actions that are called upon by EOPs and are beneficial for SAM may remain operational (e.g. containment venting). The possibility of some recommended actions leading to negative consequences is addressed from two different perspectives:

- For immediate actions, the balance between pros and cons has been made during the development of the programme and it is considered that they can be implemented without undue risk,
- On the contrary, delayed actions must be evaluated by the crisis team when the accident is developing, and decisions have to be made after balancing the pros and cons of such actions. For each action that can possibly be contemplated, the pros and cons are provided in GIAG for allowing response teams to make an informed decision.

Upon entering GIAG, Emergency Response teams prioritize actions to be implemented, the first priority being to minimize releases to the environment. In case an action is not successful, GIAG proposes alternatives to specialists in the Technical Support Centres. In case of unconventional development of the situation, Emergency Response teams are also allowed to propose to the Emergency Director, for approval or rejection, actions they think appropriate for dealing with the identified development.

GIAG doesn't contemplate any pre-defined long-term provision nor incorporate exit criteria to long-term measures. Long-term provisions are to be decided by Emergency Response teams

The importance of getting reliable information on capabilities or performing actions, which are helpful for protecting the third barrier, is recognized. Examples of such information or actions are:

- Use of computational aids available for supporting the diagnosis of plant status and informing the decision making process and the plant evolution prognosis;
- Immediate opening of all SRVs (if not opened before)[108] for preventing RPV failure at high pressure and limiting the risk of debris dispersal in the upper parts of the containment (and potential subsequent DCH in case of RPV failure);
- Limiting the risk of RCS re-pressurization above 20 bars, before vessel failure, through specific RCS water injection limitations;
- Limiting the risk of consequential SGTRs that would lead to containment bypass through immediate actions implemented upon entering GIAG:
    - isolating radioactive SGs,
    - filling non-radioactive SGs with water, and
    - depressurizing the RCS, all being,
- Detection of RPV failure using temperature measurement in the reactor pit, with the potential of confirming the information through cross-checking other sources of information;
- Activation of the containment spray system to prevent containment over-pressurization and remove thermal energy from the containment atmosphere[109];
- Use of PARs (Passive Autocatalytic Recombiners) for eliminating Hydrogen from the containment atmosphere; and
- Heating of the pipe situated between the intake of the sand bed filter inside containment and the containment filter for preventing steam condensation in the tube and in the filter[110].

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[108] Dedicated lines in case of EPR (European Pressurized Reactor)

[109] This actuation is required by the ERT when deemed appropriate (essentially for preventing unacceptable de-inertization of the containment atmosphere) also leads to the flooding of the reactor pit.

[110] For limiting the risk of Hydrogen combustion in very specific stuations

ANNEX II - Insights on the use of SAMGs in German Plants

Although emphasis has been put, in Germany, on the prevention of severe accidents, hardware modifications as well as Emergency Operating Procedures (EOPs) have been made or developed after the Chernobyl accident: they include, in particular:

- The installation of filtered containment venting
- The installation of Passive Autocatalytic Recombiners (PARS) on PWR units
- Implementation of Containment Inertization on BWR units

In addition, to keep abreast with the international community, the development of SAMGs has been started in 2010, and full completion is contemplated for the end of 2014.

The Severe Accident Management Manual (SAM-M) for PWRs includes:

- The diagnosis of the plant (damage) state,
- Related strategies for mitigating the consequences of a Severe Accident
- Existing and potential new mitigative EOPs.

SAM-M is managed using clear criteria in the Accident Management Flow Chart (AMFC). There are two entry criteria to SAM for at-power states. For shutdown states, an additional dedicated criterion is used..

Upon entering SAM, all EOPs remain active. In other words, after entering the SAM-M, EOPs in use remain active until a request for their interruption or termination has been issued.

In a severe accident, the plant state must be diagnosed on the basis of the available instrumentation. In currently operating plants, there is no instrumentation that enables diagnosing containment status, or the extent of core damage, in a simple way. Therefore, the data provided by the available post-accident instrumentation are used.

To enable prioritizing measures contemplated for preventing massive core damage and RPV failure, the level of core degradation must be known. Three core degradation states are used for this purpose:

- Core state “A” characterizes a low degradation level (rod-like geometry)
- Core state “B” characterizes ongoing core degradation until RPV failure
- Core state ”C” means the RPV has failed.

Characterization of confinement status or identification of the containment damage state is also made using a selection flowchart. For German PWRs, six representative confinement states have been defined:

- The containment is intact and there is no risk of losing containment integrity;
- Containment integrity is challenged;
- The containment is bypassed to the secondary side of the Steam Generators;
- The containment is bypassed to the reactor building annulus;
- The containment is bypassed to the nuclear auxiliary building or containment isolation failed; and
- The containment has been impaired (leak or rupture).

Based on these plant states, dedicated strategies are implemented to prioritize the performance of adequate mitigative measures. Although parallel implementation of several measures is not excluded, performance of previously implemented more efficient measures (measures with a higher level of priority) must not be jeopardized. It is also recommended In addition, postponing implementation of measures having a lower level of priority until success of previously implemented ones has been recognized is not recommended.

When a high level action has been started, the Emergency Response Team (ERT) goes to the next high level action contemplated in the flow chart without the need for evaluating whether previously implemented actions are successful. To recognize any transition between different plant states, the ERT regularly checks the parameters that define the plant damage states for confirming whether implemented actions work satisfactorily or not. However, judgment on whether such actions work satisfactorily is not based on reaching success criteria. In case of change of plant damage state, implementation of the current strategy must be stopped and the execution of the new strategy starts from the top.

For all candidate high level actions, dedicated information is provided. In particular, the cons of implementing a specific measure are listed to allow the ERT to make an informed decision on what needs to be done. Implementation is recommended only after balancing pros and cons, and having reasonable assurance that pros exceed cons. If this were not the case, the ERT should not advise implementation of the contemplated action.

SAM guidelines neither contemplate implementation of pre-defined long-term provisions nor use any exit criterion for long-term measures.

The importance of getting reliable information on capabilities that are helpful for protecting some of the barriers or performing actions that would also protect such barriers is recognized. Examples of such information or actions allowing maintaining the second barrier or the third barrier are:

- Computational aids used for supporting the diagnosis on plant state , the decision making process and the prognosis on plant evolution, including the determination of the required flow for removing decay heat from the core
- Non-graded depressurization (i.e. in any case, opening of all pressurizer valves) of the Reactor Coolant System for preventing high pressure core melt that could lead to RPV failure and subsequent transfer of core debris to the upper parts of the containment with a potential risk of Direct containment Heating, is a contemplated measure. This however doesn't prevent temporary re-pressurization of the RCS below 20 bars under some specific plant conditions
- Prevention of bypass sequences resulting from consequential SGTRs through isolating in advance dry Steam Generators that would likely be impossible to feed during the accident.
- Mitigation of SGTRs through isolating all failed Steam Generators or injecting water in failed non-isolated Steam Generators.
- Monitoring parameters that allow confirming that the RPV has not failed, minimum grace period provided by deterministic analyzes before RPV failure and trending parameters that could allow characterization of RPV failure are also used. For cases where the differentiation between different core states cannot be done using existing instrumentation only, it should be possible to use alternate means, such as a dedicated post-accident sampling system for monitoring carbon monoxide and carbon dioxide that are indicators of Molten Core Concrete Interaction (MCCI), and, consequently, of RPV failure. This possibility is currently discussed with German utilities.
- Water injection into the Reactor cavity for preventing or limiting basemat attack and scrubbing fission products in case of RPV failure,
- Use of a flammability diagram for evaluating the risk of losing containment integrity in case of flammable mixture, and recommending tripping Containment Heat Removal systems when measurements indicate that the concentration of Hydrogen inside the containment is nearing the flammability limit
- Inertization of the filtered venting system for preventing possible system degradation.

ANNEX III - Insights on the use of SAMGs in US Plants

The main characteristics of the US is that operating plants have been developed by at least four vendors (Westinghouse [W], Babcock & Wilcox [B&W], Combustion Engineering [CE] and General Electric [GE]). The first three vendors are PWR vendors, while GE is the sole vendor of the BWR technology in the US. This has led to the development of four different approaches to SAM, and, though all PWR operators are now members of a unique Owners Group, (Pressurized Water Reactors Owners Group [PWROG]), there is no unique approach for PWRs at this time. However, the PWROG is in the process of developing a generic approach that will be used for all PWR operators as a basis document for their individual SAMGs. The PWR approach will be modelled after the Westinghouse (WH) version of the SAMGs.

Concerning guidelines, they have been developed under the form of text by Westinghouse, while all other three vendors have adopted use flowcharts.

Considering entrance in SAM, once done, WH SAM relies on two logic diagrams, one related to immediate severe challenges to the integrity of fission product barriers and ongoing releases, a second one for following a certain chronology of anticipated challenges to fission product barriers. The other two PWR vendors rely on logic diagrams to establish the EPRI TBR plant damage states.

Once entering the SAM domain, all EOPs are exited, except in the CEOG, where EOPs and SAMGs are executed in parallel. However, in the approach retained by the WOG or the BWROG, some important actions required in EOPs can be repeated, but SAM guidelines have priority upon EOPs. In the B&WOG approach, no re-entrance in EOPs is contemplated. All Owners Groups address the pros and cons of contemplated actions, with a level of detail adapted to their needs. The WOG has adopted tables with the pros and cons of each contemplated action, and possible ways for mitigating the consequences of cons, while the CEOG and the B&WOG have opted for putting cautions in each guide.

For PWRs, priorities for implementing strategies or actions are given in a logic diagram, an answer to a question in a logic diagram being always linked to an earlier question, but implementation of an action doesn't require full completion of previously implemented actions. For BWRs, all guidelines related to core and containment behaviour are executed in parallel. When an action fails, only WOG guidelines provide alternatives.

There are no predefined long-term provisions. As for exit condition, WOG has some based on core exit temperature, primary pressure, containment pressure, hydrogen concentration and releases.

The importance of getting reliable information on capabilities that are helpful for protecting some of the barriers or performing actions that would also protect such barriers is recognized. Examples of such information or actions for protecting the second barrier or the third barrier are:

- All PWRs use computational aids, while the BWROG treats this in its Technical Support Guidelines;
- Graded depressurization is not contemplated, except in the latest version of the BWROG guidelines, that mention slow depressurization for allowing an injection system using a steam turbine (Reactor Core Isolation Cooling System [RCIC]) to run as long as possible through using reactor steam;
- Injection of water in the Steam Generators(number priority for WOG) or the core (other PWRs or BWROG);
- Injection of water in the Reactor Cavity (common to PWRs and BWR;
- Monitoring parameters that allow confirming that the RPV has not failed for CEOG and B&WOG, that use logic diagram to characterize vessel failure (WOG has no such diagrams); and
- Use of a flammability diagram for evaluating the risk of losing containment integrity in case of flammable mixture (all PWR technology Owners Groups) with various degrees of sophistication,. The BWROG, on the contrary, addresses the issue in their Technical Support Guidelines. Hydrogen risk in venting system filters is not addressed as filtering is not contemplated in these systems.

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