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Application of simulation techniques for accident management training in nuclear power plants

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FOREWORD

Many IAEA Member States operating nuclear power plants (NPPs) are at present developing accident management programmes (AMPs) for the prevention and mitigation of severe accidents. However, the level of implementation varies significantly between NPPs. The exchange of experience and best practices can considerably contribute to the quality, and facilitate the implementation of AMPs at the plants.

Various IAEA activities assist countries in the area of accident management. Several publications have been developed which provide guidance and support in establishing accident management at NPPs. These publications include Safety of Nuclear Power Plants: Design Requirements, and the Safety Report on Development and Implementation of Accident Management Programmes in Nuclear Power Plants. Separate technical documents are being prepared on methodology for severe accident analysis, the development and review of emergency operating procedures, and on training and technical support for AMPs. The safety service for review of AMPs is offered to Member States; its purpose is to perform an objective assessment of the status at various phases of AMP implementation in the light of international experience and practices. Various technical meetings and workshops are also organized to provide a forum for presentations and discussions and to share experience in the development and implementation of AMPs at individual NPPs.

The Safety Report on Development and Implementation of Accident Management Programmes in Nuclear Power Plants has a special role among the IAEA's guidance documents. It provides a description of the elements that should be addressed by the team responsible for preparation, development and implementation of a plant specific AMP at an NPP and is the basis for all other related IAEA publications. The Safety Report underlines the importance of training for the successful implementation of an AMP. The use of simulators with severe accident modelling capabilities is also mentioned as an effective means for training.

The applicability of simulators in the area of accident management, or simulation in a more general sense, is discussed in greater detail in the present report. It describes various approaches from graphical interfaces into severe accident analysis codes up to full scope simulators. Specific issues related to the use of simulation techniques for different training levels and different groups of personnel are discussed. An overview of existing simulators and the status of their application in a number of countries is provided.

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CONTENTS

1. INTRODUCTION

1.1. Background

The defence in depth concept in nuclear safety [1, 2] requires that, although highly unlikely, beyond design basis and severe accident conditions should also be considered, in spite of the fact that they were not explicitly addressed in the original design of currently operating nuclear power plants (NPPs). Defence in depth is physically achieved by means of four successive barriers (fuel matrix, cladding, primary coolant boundary, and containment) that prevent the release of radioactive material. These barriers are protected by a set of design measures at three levels, including prevention of abnormal operation and failures (level 1), control of abnormal operation and detection of failures (level 2) and control of accidents within the design basis (level 3). Should these first three levels fail to ensure the structural integrity of the core, additional efforts are made at the fourth level of defence in depth in order to further reduce the risks. The objective at level 4 is to ensure that both the likelihood of an accident entailing significant core damage (severe accident) and the magnitude of radioactive releases following a severe accident are kept as low as reasonably achievable. The term ‘accident management’ refers to the overall range of capabilities of a NPP and its personnel to both prevent and mitigate accident situations that could lead to severe fuel damage in the reactor core. These capabilities include the optimized use of design margins as well as complementary measures for the prevention of accident progression, its monitoring, and the mitigation of severe accidents. Finally, level 5 includes off-site emergency response measures, the objective of which is to mitigate the radiological consequences of significant releases of radioactive material.

In the IAEA Safety Report on Development and Implementation of Accident Management Programmes in Nuclear Power Plants [3] accident management is defined as: “the taking set of actions during the evolution of a beyond design basis accident (1) to prevent the escalation of the event into a severe accident, (2) to mitigate the consequences of a severe accident, and (3) to achieve a long term safe stable state.” Similarly, severe accident management is “a subset of accident management measures with the objective to: (1) terminate the core damage once it has started, (2) maintain the capability of the containment as long as is possible, (3) minimize on-site and off-site releases, and (4) return the plant to a controlled safe state.” An accident management programme (AMP) “comprises plans and actions undertaken to ensure that the plant and its personnel with responsibilities for accident management are adequately prepared to take effective on-site actions to prevent or to mitigate the consequences of a severe accident.” The IAEA definitions are in line with the definitions of severe accident management in OECD/NEA documents as given, for example, in Ref. [4].

As stated above, accident management constitutes one of the key components of defence in depth. Provisions for accident management should be made even if all provisions within the design basis are adequate.

The approaches particularly to accident management and severe accident management vary in the Member States. Some countries focus on actions aimed at defining procedures and severe accident management guidelines (SAMGs) that are based on utilizing the existing capabilities of the plant once a predetermined safety level has been achieved. Some countries require that plant modifications, including those to hardware and to instrumentation and control (I&C), as well as procedural changes should be made to significantly improve the plant's capability to manage severe accidents without large releases to the environment occurring.

Regardless of the approach used, most countries have already implemented or plan to implement an AMP that includes development of the procedures or SAMGs or both. Furthermore, the definition of the training programme for the plant personnel who will be involved in the severe accident management actions during an emergency is an integral part of the AMP. The main means for training are classroom training, drills and exercises as well as the respective simulator training, if available.

Reference [3] also underlines the importance of training as necessary condition for the successful implementation of an AMP. The use of simulators with severe accident modelling capabilities is also mentioned as an effective means for training. The applicability of simulators, or simulation in a more general sense, is discussed in further detail in the present report.

The use of simulators for training NPP personnel was already addressed in earlier IAEA publications, e.g. in Ref. [5], but without reference to specific accident management training issues. Available national standards, mainly the American National Standard ANSI/ANS-3.5-1993 on Nuclear Power Plant Simulators for Use in Operator Training and Examination [6], were taken into consideration when preparing this report. The IAEA Advisory Group Meeting on Implementation of Severe Accident/Accident Management Simulation in NPP Support Staff Training (Software, Hardware), held in Vienna, 4–8 September 2000, also provided valuable input for the report.

1.2. Scope and objectives

This report describes simulation techniques used in the training of personnel involved in accident management of NPPs. This concerns both the plant personnel and the persons involved in the management of off-site releases. The report pertains to light water reactors (LWRs) and pressurized heavy water reactors (PHWRs), but it can equally be applied to power reactors of other types.

The report is intended for use by experts responsible for planning, developing, executing or supervising the training of personnel involved in the implementation of AMPs in NPPs.

It concentrates on existing techniques, but future prospects are also discussed. Various simulation techniques are considered, from incorporating graphical interfaces into existing severe accident codes to full-scope replica simulators. Both preventive and mitigative accident management measures, different training levels and different target personnel groups are taken into account.

1.3. Structure

Based on the available information compiled worldwide, present views on the applicability of simulation techniques for the training of personnel involved in accident management are provided in this report. Apart from the introduction, this report consists of four sections and three appendices. In Section 2, specific aspects of accident management are summarized. Basic approaches in the development of an AMP and the importance for its successful implementation of various well trained groups of staff are described. The influence of effective accident management on risk reduction is emphasized. The objectives of and requirements for accident management training and for the use of simulators, in particular, are given in Section 3. Simulation requirements for training in both the preventive and the mitigative domain, for different training levels and different personnel groups as well as requirements concerning the simulator type are briefly specified. Various issues related to the application of simulators in training are discussed in Section 4. The present capabilities and limitations of various categories of simulators and examples of the simulators' software basis are described. Specific aspects of the methodology used for verification and validation of severe accident simulators are given. Differences in the use of simulators for various purposes and different target groups are summarized. The prospects for further development in simulator training are presented. The main conclusions with respect to the applicability, capabilities and limitations of simulation for accident management training are given in Section 5.

Appendix I gives an overview of different types of existing simulators. The status of the application of simulators in accident management training and a more general description of the approach to accident management training in selected countries is presented in Appendix II.

2. SPECIFIC ASPECTS OF ACCIDENT MANAGEMENT

2.1. Development of an AMP

For each individual plant, there are a wide variety of severe accident scenarios and sequence classes. The sequences start with different initiating events or precursors that may lead directly or through additional failures to core degradation. The range of the initial plant states includes power operation, the plant heat-up and cool-down phase and shutdown conditions. Once started, core degradation may proceed further, leading to melting of the reactor core, to melt-through of the pressure vessel and to a multitude of physical phenomena potentially challenging the containment integrity. The further the accident progresses into the severe accident domain, the more difficult it becomes to manage by means of the emergency operating procedures (EOPs), which usually do not include severe accidents. Therefore, the utilities tend to develop SAMGs with a structure that is more appropriate for such situations.

Developing an AMP is the responsibility of the plant licensee, i.e. the plant owner and operator. There are various alternative ways of incorporating accident management in plant operations [7]. The selection of the best way in each individual case is influenced by the organizational structure and the available technical expertise of the utility as well as by the extent of the problem solving required to accomplish specific strategies. The various aspects involved are discussed in Ref. [3]. The principal ways are to: (1) develop severe accident guidelines (SAGs), (2) develop a severe accident guidance document, or (3) incorporate severe accident elements in existing procedures. The term 'procedures' refers to a set of detailed documents that prescribe specific actions in specified conditions, while 'guidelines' refers to a general description of actions that could be effective in managing a particular situation.

The personnel involved in the emergency response organization (ERO) for accident management is composed of different groups, as described in Ref. [3]. Typically, these are: (1) control room (CR) operators, (2) a possible permanent or on-call safety engineer, (3) an on-site technical support centre (TSC), (4) an on-site operations support centre, and (5) off-site emergency operations staff. The implementation of the AMP should take into account that the availability of the technical expertise in these groups may vary significantly among the utilities. The organizational aspects of accident management implementation include the definition of the roles and responsibilities of the personnel involved. The tasks of the different personnel groups may vary according to the particular phase of the accident management. The implementation also varies among the utilities since the accident management organization must be integrated in the overall utility and plant organization and in the existing ERO.

The personnel responsible for the plant operation under emergency conditions must make a number of critical decisions. These decisions typically concern such issues as:

- off-site and on-site emergency preparedness recommendations,
- effectiveness of in-plant mitigation measures, and
- prioritization of actions to recover inoperable equipment and systems.

Further critical decisions regard:

- adding water to a degraded core,
- depressurization of the reactor coolant system,
- preventing steam generator tube creep rupture, and
- containment related decisions, e.g. use of sprays, flooding, filtered venting and hydrogen management.

The timing of these decisions is plant specific. The timing also determines the organizational level at which the decision should be taken. In the initial phase, the plant operators should be able to take them. In a later phase, when the on-call safety engineers or the TSC are available, they can assist or take over in the decision making. The decisions are considered critical in the sense that the implementation of a decision can also include adverse effects. In such a case, the potential negative consequences have to be properly assessed before an action is carried out. In the decision making process, awareness of these possible consequences is necessary in order to balance the actions to be taken.

The personnel involved have to be trained in all aspects related to the decisions to be taken. The training needs and methods are specified in Ref. [3]. Many utilities have adopted the practice of developing SAGs supported by a separate document containing the necessary technical background information. Others have chosen an approach integrating these two elements in a single background information document, often referred to as the SAM Handbook. This background material should contain all information that is deemed necessary for the operators and the technical support staff with respect to severe accident progression and phenomena and the procedures and guidelines applied for accident management. This document itself is an important part of the training material.

The AMP implementation report [3] discusses the application of classroom training and exercises and emergency drills, but it does not specify in detail the needs and methods for simulator training. For the preventive phase of accident management, the full-scope replica simulators are an efficient means of training since they normally include the necessary range of phenomena.

The operator aids to be used during a severe accident have been developed in many countries; they range from graphs and simple hand calculation tools to more sophisticated computational tools. They are described in more detail in Ref. [3]. Two specialists meetings have been organized by the OECD where such tools were reviewed, including the development and application stage of simulators used for training [8, 9].

2.2. Influence of accident management on risk

When planning the accident management approach and strategies, one must take into account possible adverse effects to avoid any unwanted impact on the plant safety. The potential adverse effects are closely related to the critical decisions.

A precondition for the development of a consistent accident management approach is that the severe accident phenomenology and progression as well as the consequences of accident management actions be sufficiently understood for the individual plant. If this knowledge has been duly incorporated into the accident management guidance and accident management personnel training, successful management during the accident is far more probable. The accident management approach should be simple and robust as well as easily understandable to the accident management personnel.

There have been some attempts to quantify the influence of accident management on core damage frequency or fission product (FP) releases, with varying results (see Ref. [10]). A possible reason for only few available quantifications is that the state of the probabilistic safety assessment (PSA) methodologies applied has often not been adequately defined to account for the recovery actions, particularly when complex human behaviour is involved. The modelling of the decision making process is a difficult task, and it is further complicated by the balancing of positive and negative consequences. Many decisions within the severe accident management framework depend on the outcome of actions, the consequences of which cannot be predicted, such as the time up to restoration of power in a station blackout sequence, the time to recover safety injection after it has failed, or deliberations to use a last remaining water source for the containment spray system, RPV injection, or containment flooding.

An effort to develop a quantitative evaluation of the severe accident management methodologies (i.e. a comparison of the efficiency of preventive and mitigative accident management actions) has been made in an EU research programme. The study compared the traditional and advanced PSA methodologies and the risk oriented accident analysis methodology (ROAAM) in evaluating the efficiency of individual accident management and severe accident management measures [11]. The conclusion of the project was that ROAAM is a method for dealing with mitigative severe accident management issues, especially when a high level of residual risk cannot be tolerated. PSA is an obvious choice in the preventive regime, where the recovery of systems involving operator actions is often the key safety issue.

In addition to a consistent and comprehensive approach to accident management and to the implementation of this approach to a given plant, a key factor for ensuring its effectiveness is to train the personnel involved, whereby training should include the use of calculational aids where these are provided as a tool to assist the personnel in decision making during the accident.

3. OBJECTIVES AND REQUIREMENTS

3.1. Objectives of accident management training

The incentive for accident management personnel training is to ensure that the accident management organization is capable of taking effective actions in accident conditions. For successful accident management, it is necessary that the accident management personnel be acquainted with expected plant behaviour and consequences. The development and implementation of an AMP has made a variety of actions available to the staff. During an emergency it is important that the entire organization is capable of acting in unison in order to manage the situation.

The objectives of accident management training were discussed at the SAMOA-2 meeting [12]. Accordingly, the three high level objectives are:

- **Knowledge oriented training** (teaching severe accident phenomena and progression);
- **Skill oriented training** (training staff in skills that permit them to take action in case of a severe accident situation); and
- **Efficiency oriented training** (training in the interplay of all involved organizations).

Knowledge can be improved by teaching personnel about the processes that cause accidents to progress into core melt scenarios, including:

- describing the successive steps of core degradation and melting;
- explaining the most significant phenomena and their consequences on plant behaviour; and
- justificating recommended accident management actions, and explaining the potential adverse effects and consequences (accident progression) of their partial or total failure.

Apart from classroom training, it is useful to apply computer model based simulation aids for knowledge oriented training. The main features of such a model and the training would be:

- consistency with models implemented in current training simulators for the phase from accident initiation to the onset of core melt;
- use of state-of-the-art knowledge for modelling severe accident phenomena;
- implemented modelling of plant changes and backfits;
- computer graphics to support classroom training and help personnel understand accident progression;
- simulation of system recovery;
- simulation of partial success of accident management actions (e.g. possibility for interruption and demonstrating the influence of full or partial success of water injection); and
- a fast running model, permitting discussion of specific issues in parallel with the modelled accident progression.

The main goal of skill oriented accident management training is to teach personnel how to react in case an accident progresses into a core melt scenario. Specific items that should be addressed are:

- monitoring instrumentation readings;
- practising the execution of SAMG and related measures;

- consistent use of operator aids, if any, or testing operator conclusions regarding the plant status with or without guidelines could be considered depending on the objectives of the utility; and
- analysing operator response in such cases to understand better the respective human factor issues.

The main goal of testing the efficiency of accident management is to test the behaviour of the respective organization as a whole. For a slowly progressing accident situation, many operators and technical support personnel would be involved in managing the accident. Issues to be analysed could be:

- ensuring the consistency of accident management;
- judgement of plant status when shifts change, potential consequences for accident management;
- communication among the personnel involved in accident management;
- potential divergence of action; and
- keeping track of the entire scenario.

When implementing a plant specific AMP, it is important that training programmes do not lag behind. Thus training should be carried out in parallel to the introduction of SAMG. When proceeding to the implementation of the training, the above considerations should be borne in mind, in particular with regard to the application of simulators.

3.2. Objectives of the use of simulators

The general objectives of using simulators for accident management training are the same as for other simulator applications for operator and personnel training. Simulators are now widely applied in the preventive accident management domain, but less so, to date, in the mitigative accident management domain because of the specific accident management features and current status of AMP implementation. The complexity of severe accident phenomenology makes the respective software development a very demanding task.

An essential element of AMP implementation is that the personnel involved in the execution of accident management actions are trained in an appropriate and effective manner. Accident management training can take place at three levels that are consistent with the knowledge, skill and efficiency oriented objectives. The first level employs classroom training, which familiarizes the personnel with the severe accident phenomenology, the accident management approach, the structure of the procedures and guidelines and the organizational matters. The second level of training concerns the use of the procedures and SAMG. At the third level, emergency drills are organized that may focus on the level of accident management implementation or may include the overall emergency organization.

The use of simulators for accident management training at the three levels varies according to the particular training level and the phase of accident progression being considered. The severe accident simulation capability can be utilized first in the classroom training by demonstrating the progress of severe accidents for a given plant. While the classroom training is already an important step, it is evident that the second level of training, namely the implementation of the procedures and guidelines, would benefit directly from training on simulators, provided that these are available for severe accident regimes. On the other hand, many of the existing full-scope training simulators can be utilized for training in preventive accident management actions before core melt starts. In the case of the third level, the SAM simulator could provide a useful and efficient tool for the on-line construction of the framework for the drill.

3.3. Basic requirements to be met by the accident management training tools and simulators

Various standards, such as presented in Ref. [6], have been established with respect to the functional requirements for full-scope simulators used for operator training and for the examinations that NPP operators are required to take. Since full-scope replica simulators are often an efficient means of training during the preventive phase of accident management, the respective requirements can be applied.

The first basic requirement that a severe accident management training simulator should fulfil is the ability to simulate severe accident progression to the degree deemed necessary for the training to be effective. It should be noted that it is not necessary (and currently not even possible) for the simulator to be capable of predicting fully the associated severe accident phenomena. It is, however, essential that it be able to follow the expected accident progression and allow operator intervention during that progression. It would be advantageous if the instructor also had the possibility of intervening in the progression. Thus, even though the accuracy of simulation in the severe accident management domain is certainly limited, it can be adequate to provide the crucial information needed during the training.

3.3.1. Requirements for training in preventive and mitigative actions

The requirements for training simulation in the preventive domain of accident management are, to a large extent, the same as for training operators to cope with a design basis accident (DBA). Thus, simulators with advanced thermal-hydraulic modelling are required. The range of application extends as far as the beginning of core degradation. The main phenomenology is related to the secondary side bleed and feed and primary bleed and feed actions. When primary circuit depressurization leads to successful injection, primary bleed and feed ensures sufficient core cooling and terminates the accident progression. If the feed function is not successful, core heat-up will occur. The transfer from preventive accident management to mitigative severe accident management actions is normally connected to the onset of core damage, which is detected on account of the elevated core exit temperature.

The physical phenomenology becomes far more complicated when extensive core degradation takes place and, in particular, in the later phases, when the severe accident progresses to core melt, core relocation, to possible in-vessel retention or reactor vessel melt-through and, finally, to severe accident containment phenomenology. Severe accident scenarios may vary greatly. There are also many bifurcation points, where further progression depends on the outcome of, for example, an energetic phenomenon that could lead to a direct challenge to the containment integrity. The simulation of mitigative action thus requires extremely complex software.

3.3.2. Requirements for the different training levels

The requirements are different for the various levels of training. The first level is usually classroom training, which focuses on expanding the knowledge base. In this case, it is important to dispose of effective means for teaching the severe accident progression and phenomena of a particular plant as well as the role and structure of the procedures and guidelines for accident management purposes. Here simulators can be applied to demonstrate the progression of severe accidents. It is important for such a demonstration simulator to be able to: (1) predict reliably the severe accident progression of the plant in question, (2) provide a clear graphical representation of the complex physical situation and (3) provide a clearer understanding of the associated phenomena.

At the second level of training, which deals with the use of procedures and guidelines, it is important that the simulator provide information equivalent to that which would be available on-site during an emergency. It is also important that the simulator offer the possibility for the personnel to intervene with all actions foreseeable in accident management and that it respond correctly to these interventions. Often the accident progresses only very slowly. Also in these cases, it should be possible to use the simulator in such a way as to allow training that covers such long term periods. The training must also include the use of available computational aids (CAs) and computerized operator support.

At the drill level, one can use the existing on-site full-scope training simulators in the full EOP domain including such actions as bleed and feed. When the transition to the severe accident management domain occurs, this, at present, exceeds the application range of full-scope simulators as regards the physical modelling. A dedicated severe accident management simulator could take over at that moment. Naturally, it is feasible here to use the same simulator as for the second level training, if available. At this level, it might be useful to have FP models available that include the capability to calculate the releases to the environment and the radiation levels on-site. The simulator should be capable of running at least in real time.

3.3.3. Requirements for different personnel groups

The training needs vary according to the different personnel groups, consisting of: the CR operators, the shift supervisors, the on-call or permanent safety engineers on the shift, the TSC and the other relevant members of the on-site and off-site ERO. In addition to the utility personnel, it is usual for the regulatory bodies also to have technical staff to create their own group of experts.

The simulators can be considered crucial in the training of the operators, shift supervisors and safety engineers in the use of the procedures and guidelines. In many cases, the TSC will also benefit from the use of a simulator for training purposes.

Simulation for classroom training is useful for all the groups involved. All of the groups are also involved in the drill level of training and could also benefit from the simulator applications there.

3.3.4. Requirements concerning the simulator type

Full-scope simulators can be applied effectively for training in preventive accident management actions. To this end, the thermal-hydraulic software must be sufficiently advanced for reliable event calculations. In many plants, there may be a need for certain accident management measures before the emergency organization is fully operational. It is therefore of value to be able to train the operators in these actions in a situation in which the support organization is not yet available.

Generally, there is no immediate need for a full-scope replica training simulator for training in accident management actions to be taken in the longer term. The operators, safety engineers and TSC can be trained separately and together by using, for example, a workstation based simulator with sufficient graphical presentations. However, a full-scope replica training simulator can still be a useful tool, at least for short term action.

4. APPLICATION OF SIMULATORS TO TRAINING

4.1. Present simulator capabilities

A wide variety of simulators are currently available that are capable of modelling plant behaviour under:

- the full spectrum of operating conditions;
- operational transient conditions;
- DBA conditions, including the full spectrum of loss of coolant accident (LOCA) and steam line breaks as well as quite complex reactivity initiated transients; and
- beyond DBA conditions that do not involve extensive core degradation.

Simulators are divided into engineering simulators and training simulators. Engineering simulators are used for design purposes and, in particular, for justification of the design. They have proved to be efficient for validation of the control systems for the entire plant. Engineering simulators are also useful for validation of plant specific SAMG. The rapid development, in recent years, of plant analyzers that connect advanced thermal-hydraulic modelling to a detailed plant description in a compact manner now enables plant analyzers to be applied flexibly to engineering studies. Here, however, the focus is only on the application and use of the training simulators.

As discussed in Ref. [13], the operator training cycle can be divided into the following phases: (1) instruction in the basic principles, (2) training related to specific functions, (3) training covering the full operating range, and (4) detailed accident training for the application of EOPs. The training needs for the various phases have to be identified and the training tools adapted accordingly.

Simulators can be applied in different phases of the training programmes. A classification of the simulators was proposed in Ref. [13] based on their area of application, namely:

- basic principle simulators,
- partial-scope simulators,
- full-scope simulators.

Full-scope simulators, which are full replicas of the CR equipment, are currently a standard tool for various phases of operator training in most countries and utilities. The trend has been to also incorporate more advanced software for transient and accident simulations in the simulators.

Partial scope simulators describe only a limited part of the process. They can be used in training at the system operation level.

Basic principle simulators include the physical models, but there is no real operator interface. For example, the first simulators for severe accident management purposes normally included an integrated severe accident analysis code coupled with a graphical simulator interface for visualization.

An overview and a short description of the different simulator types presented according to their complexity and application is provided in Appendix I.

From the functional viewpoint, it is interesting to note that so-called multifunctional simulators that combine functions for different applications have been developed in recent years. They have an advanced software package combined with an efficient computer. The user interface is based on advanced graphical designs that make them useful for operator training. The multifunctional simulators that have been developed and implemented are discussed in Refs [14, 15].

The development of simulator software progressed very fast in the accident simulation area, in particular with respect to advanced thermal-hydraulic modelling. The difference in the accuracy of the modelling between training simulators, on the one hand, and plant analyzers, on the other, is vanishing. Many simulators have been developed that either apply existing advanced thermal-hydraulic system codes such as CATHARE, used in SIPA and SCAR [16], RELAP5 in NPA [17], ATHLET in ATLAS [18], and TRAC in the simulator at Tecnatom, Spain [19], or have a dedicated code package equivalent to the advanced codes like, for example, APROS [15]. Some simulators are being extended to cover shutdown states including mid-loop operation conditions as, for example, in the case of the French plan for SCAR [16] and the Belgian application to the Doel training simulator [20]. Perhaps the most ambitious effort underway at present is the Japanese IMPACT Super Simulation Project that aims at combining mechanistic modules with high speed computing with parallel processing computers [21].

An overview of current practices in the use of simulators in eleven OECD countries is presented in Ref. [22]. This report also addresses various studies on specific themes such as diagnostics and decision making in teamwork and the role of stress and fidelity. The report concentrates on the preventive accident management domain, but the role of simulator training in severe accidents is also briefly addressed.

Many efforts have been made to extend the simulation capabilities to severe accident conditions. These developments, subdivided according to the approach chosen, are described below.

Severe accident code with a graphical interface

The first applications combined a graphical interface with an integrated severe accident code. Examples of such simulators are:

- MELSIM, developed under IAEA programmes and based on MELCOR [23];
- MAAP-GRAAPH [24];
- SCDAPSIM [23];
- MELCOR with NPA graphical interface for Krško NPP [25];
- BWR simulator for education and accident management, developed by the Japan Electric Power Company (TEPCO), Japan [26].

Severe accident code as a basis for simulator development

Another approach is to take an integrated code as a basis for simulator development. The difference to the above is not necessarily very pronounced. Examples of such developments are:

- SUBA, a Hungarian severe accident simulator for Paks NPP combining MELCOR for severe accidents and HERMET for the bubbler condenser containment [27]; and
- TSG, a Spanish simulator for Garoña NPP based on the MAAP code [28].

Severe accident code coupled with an analysis simulator

There have been efforts to introduce severe accident codes in an existing simulator environment, as has been done through the inclusion of the COCOSYS containment code and the MELCOR severe accident code in ATLAS [18].

Severe accident models specific to the existing simulation environment

For Ringhals 2, 3 and 4, the MAAP models were integrated with the full-scope simulator back in the late 1980s or early 1990s using MAAP 3b.

Simulator development that aims solely at severe accident management training of personnel has been started for the APROS simulation environment. The severe accident analysing capability is closely coupled to the plant's severe accident management programme and, in the first stage, the simulator will simulate in simple terms the key phenomena and their effect on the plant response [29]. Thus the simulator will calculate the predefined accident progression, which is based on an understanding of the plant's behaviour under severe accident conditions gained through the extensive development of the severe accident management approach.

Integrated severe accident code in the full-scope training simulator

One application of a full-scope simulator exists that is also capable of handling severe accidents. This is a CAE SIMEX simulator that uses MAAP4 and which is installed at Krško NPP, Slovenia [26].

Simulators to predict the evolution of an accident and the source term

A number of simulating tools exist that are able to follow the evolution of an accident, to predict major events (such as core uncovery and containment pressure rise) and, finally, the source term. These simulators mainly serve crisis teams to initiate the appropriate timely protection measures in the environment. Examples are:

- ADAM, which is in use at the Swiss Federal Nuclear Safety Inspectorate (HSK), Switzerland [30];
- MARS, which is applied by the Consejo de Seguridad Nuclear (CSN), Spain [31];
- CRISALIDE/TOUTEC, which is used by the Electricité de France (EDF) national crisis team [32].

Computerized accident management support tools

Some simulators have the capability of providing an operator aid during an accident. Functions include a tracking capability using on-line data, from which the initiating event and the plant damage state can be derived, and a predictive capability, from which the evolution of the accident and, finally, also the source term can be predicted. Such a simulator is, in principle, interactive, i.e. severe accident management actions can be implemented to study their effect in advance. Due to the large measure of uncertainty in the severe accident codes, however, practical applications are still very limited. Examples are:

- CAMS, for which an application is being studied at Cofrentes, Spain [33];
- KAMP, under development in the Republic of Korea [34].

Further use of computerized accident management support is discussed in Section 4.4.

4.2. Methodology for verification and validation of simulators

Simulators should perform in such a manner that no notable differences exist between the response of the simulator and that of the actual plant, both in steady state and in a transient. This is assured by means of the verification and validation process described below.

The purpose of the verification process is to verify that the NPP processes have been modelled in conformity with the design specification, which, among other things, describes how the physical phenomena should be modelled and how the plants' systems and layout should be represented.

The aim of the validation process is to establish whether the simulator's response to normal operation, transients and accidents indeed matches the observed and expected behaviour of the actual plant.

An example of these processes and the respective requirements is given in Ref. [6], where these processes are referred to as 'testing and validation'. In this example, the steady state parameters of the simulator should remain within a few percent of the actual plant value in the case of malfunctions, where it is required that simulator response is in line with the expected plant behaviour, including similar alarms and automatic actions. More stringent requirements could however be applied.

The validation of simulators can be achieved by comparison with available plant data for the full operating range and, in particular, by comparison with actual plant transients to the extent possible.

For the thermal-hydraulic software, one method is to try to follow directly the same validation principles against experimental data used for the system codes. The reactor kinetics models should be validated against the plant behaviour to the extent possible. Validation of thermal-hydraulic models may also be performed based on a comparison with advanced thermal-hydraulic system codes with respect to the transients and accidents that are within the DBA domain.

The validation of severe accident simulators can prove to be considerably more complicated. There are different reasons for the complexity:

- the models may not be capable of treating the crucial phenomena correctly, also because they may have been developed for different applications, e.g. for PSA. whereby the simulated accident progression may proceed in a totally different manner (as was discussed in Section 2);
- severe accident phenomena are versatile and complex and the applied models require time consuming computations;
- operator interventions should be possible; and
- in case of a bifurcation, the code should be able to select a path according to the training objectives.

Hence, one should seek the most practical ways to perform the validation.

The requirements and strategy for the validation depend on the approach chosen for training simulation. In the case of the application of the predictive function of simulators, the means of validation might be nearly the same as for that employed for integrated severe accident codes.

In the case of the tracking function of the simulator, the validation can be performed in comparison to plant data, as far as available, and to the integrated code calculations.

In the case of the specific severe accident management training simulator that simulates the predefined progressions of an accident, the validation is already an essential element of the development. The further validation must be carried out in direct connection with the accident management procedures and SAMG validation, since these applications cannot be clearly separated.

Specific requirements concerning the recovery actions and the system responses should be incorporated in the simulator. The validation of such actions is also an essential task.

4.3. Development and use of simulators for training

The requirements for the training simulators were discussed in detail in Section 2.3 according to the following:

- training within preventive and mitigative domain,
- different training levels,
- different personnel groups, and
- different simulator types.

The use of simulators should be considered based on these requirements as well as on the discussion concerning the objectives of:

- knowledge-oriented training,
- skill-oriented training, and
- efficiency-oriented training.

4.3.1. Use of simulators for training of preventive and mitigative actions

Simulators that are equipped with advanced thermal-hydraulic system code modelling are already capable of being used for training of the accident progression and the procedures that aim at preventive accident management actions. Normally these tools can be used until core degradation starts. Their application has been discussed in Ref. [35], for, example, for the main actions such as the secondary side bleed and feed and primary bleed and feed. It is important to note that the primary circuit depressurization can be included in such simulators.

As discussed in Section 3.3.1, requirements for simulation in the severe accident phases that are important for mitigation purposes become very demanding. The simulators that will be used should be able to describe the severe accident and containment phenomena to the extent that is of interest for mitigation.

In the severe core damage region, the use of predictive simulators may become problematic since their validation is difficult. Hence instructors and trainees should be aware of the limitations and uncertainties of the simulator used and handle these appropriately where they could influence the training or drill. This is even more important since computed values are often accepted unquestioningly without any concern for the way in which they have been computed, specifically in a high stress environment.

A major problem in severe accident management training is the development of suitable templates that can be used in drills and exercises. Usually, these are precalculated scenarios, where the results are presented to the drill team and updated at regular intervals (every 5–10 minutes). Where suitable simulators exist, it may not be necessary to perform the tedious task of preparing the templates. The use of simulators would also eliminate the discrete points of time at which the plant data is updated. These usually become points on which the drill team focuses attention, which is a major drawback in using precalculated scenarios.

Instead of a predictive simulator, another possibility is to adopt the approach of simulating the accident progression in a predefined manner that is based on the knowledge gained of the plant specific severe accident behaviour. In this case, the AMP developer uses all the background information available to choose the scenarios that are deemed manageable and to follow these scenarios.

The overall approach to severe accident management may require the effort of screening out the sequences that cannot be managed, i.e. to apply design and procedural means to transfer all unmanageable sequences to the residual risk category in the sense that all unmanageable sequences can be considered as physically unreasonable. This approach allows the user to concentrate on the known sequences. The simulator can then be developed in such a manner as to have the capability to follow only those sequences.

4.3.2. Use of simulators for different training levels

Simulation techniques that combine an integrated severe accident code with graphical representation are available and can be used for classroom training and demonstration purposes. An example of this type of technique in Germany is given in Ref. [36]. The IAEA has sponsored the development of such severe accident simulation tools [23].

Simulation techniques that are capable of responding to various operator actions are suitable for training at the second level. Operators can perform the actions on the simulator that are indicated in the SAGs and observe the response of the system. Examples of simulators currently under development are the full-scope training simulator with added severe accident management capabilities at Krško NPP, Slovenia, and the APROS-based simulator for Loviisa NPP, Finland. An example of a simulator with a Windows platform is the Japanese Boiling Water Reactor (BWR) severe accident management simulator developed by TEPCO.

For training the organization of overall emergency planning, simulators are in use that concentrate on the evolution of the accident with respect to the integrity of the FP barriers and the potential source term. Examples are the CRISALIDE/TOUTEC system used in France, and ADAM used in Switzerland.

4.3.3. Use of simulators for training different personnel groups

The use of simulators is an efficient tool for all personnel directly involved in accident management during an emergency. In the case of drills and exercises, the entire team can benefit from the visually efficient simulation.

In addition to the on-site personnel, there may be technical staff involved in the support of the utility level, and the regulatory body may also have various needs related to its emergency centre.

Calculational aids and computerized accident management support systems have been developed for on-line support. Naturally, the training should involve these systems if they are applied within the severe accident management regime. In many cases, these support systems can themselves be used as training tools.

A simulator exposes the user to the same type of physical environment that he or she would experience during an actual event and is therefore a very suitable tool for detecting weak points his or her actions. The more realistic the simulator, the more effective this function is.

The greater the extent to which the handling of quantitative plant information lies within the responsibility of the personnel involved, the more important the role of the simulator probably is. Hence, those who actually decide on and implement countermeasures, namely CR operators and the supporting technical staff (who are often the staff of the TSC), benefit most from the simulator. An important aspect here is the training of communication between the main CR and the TSC. Where no meaningful countermeasures are possible anymore, the simulator loses its importance and precalculated information on paper probably is sufficient.

The ERO as a whole has many other responsibilities. It consists of a number of teams with different types of expertise and with various tasks, ranging from maintenance, repair and other forms of operational support to assessing off-site consequences and recommending off-site actions (the tasks of the ERO are described in more detail in Ref. [3]). The staff are trained in their responsibilities by means of drills and exercises, whereby the emphasis is on communication and teamwork rather than on information provided by a simulator except in the case of dose prediction, where a simulator could also play a role.

The various applications of simulators were discussed extensively at the SAMOA meetings [8, 9]. In France, for example, simulators have been developed and applied by EDF, on the one hand, and by the Institut de Protection et de Sûreté Nucléaire (IPSN), the regulator support organization, on the other. The Spanish regulator, CSN, applies a MARS-based system in its own emergency room that is capable of being used for all Spanish plants [37].

4.4. Further developments in simulator training

4.4.1. Low power and shutdown modes

Risk from low power and shutdown states can be significant compared to that from full power operation. Hence, appropriate procedures and guidelines should be available to cover these states. So far, however, these exist only to a very limited extent. Also, their application at NPPs is very limited. The development with respect to simulators for this area is therefore also very weak (so far it is being carried out only at Doel NPP in Belgium). It is nevertheless anticipated that further development will take place.

4.4.2. Improvement in the use of severe accident codes

The severe accident codes that have been discussed above still have a number of limitations and uncertainties. With regard to the issue of uncertainties, the several weaknesses of current severe accident simulation codes exist in terms of their suitability for SAMG predictions, as indicated in Ref. [38]. They are based on input data, models and assumptions suited for determining vulnerabilities and sources terms, derived from probabilistic safety analysis (PSA). In this regard, many of the models are based on empirical correlations that are biased toward finding vulnerabilities or maximizing realistic FP source terms. While many of the models and assumptions can be adjusted through user input, multiple runs are required to determine the uncertainties. The simulation codes do not have the capability to display the impact of uncertainties in an easily understood manner.

As an example, the simulation code generally uses a point estimate of the steam production from fuel coolant interactions. The assessment of fuel coolant interaction steam production rates in the Electric Power Research Institute's severe accident management report [39], indicates that the experimental data shows at least an order of magnitude's variation in the steaming rate with no apparent second level correlation to other test parameters. Next, the amount of fuel leaving the reactor vessel to participate in the initial fuel coolant interactions is determined by a predefined vessel failure mode which may (or may not) maximize the molten fuel available. Finally, the containment failure pressure used in most severe accident simulation codes is the 50th percentile failure pressure. In PSA, it has been shown that for large dry containment PWRs, vessel failure and subsequent fuel coolant interactions are not expected to challenge the containment pressure capability. Therefore, the models are valid for PSA analyses. However, if these same models are used to predict the peak containment pressure at reactor vessel failure, they may display an inaccuracy of as much as 50%.

Hence, in the further development of the codes for use in severe accident simulators these biases and uncertainties should be treated with due attention. In line with the future progress of computing power, codes should be rendered capable of running so fast as to permit a sufficient number of sensitivity runs to establish the sensitivity of the models to parameter changes where the uncertainties of such parameters are important for accident management. The ability to consider combined uncertainties in severe accident models as they impact on the accident progression and consequences, as well as the capability to run real time calculations would contribute to resolving one of the major limitations of severe accident codes as a predictive tool.

4.4.3. Computerized accident management support

In future, simulators may also play a role as computerized accident management support. Computerized support could enhance SAMGs in a number of areas such as, for example:

- trends of parameters (now often ignored);
- the status and availability of systems/components, such as power supply, logic actuation, I&C design information and signal validation, and the physical situation at the plant;
- proceeding in accordance with set points to initiate the execution of actions specified in the SAGs up to date;
- keeping track of the projected times of availability of equipment and status of system repair;
- use of small interactive calculational models to replace or update calculational aids; and
- storage and retrieval of documents.

Reference [38] provides a more detailed picture of the use of computerized support in accident management.

Computerized accident management support could therefore be helpful in recognizing the root cause of an accident (i.e. identifying which essential safety function was lost and how), in identifying the minimum capability for accident stabilization and, ultimately, in preventing catastrophic containment failure. It could be used to study beforehand the effect of countermeasures.

Caution should however been exercised in using computer codes for plant damage identification, for the prediction of accident progression and for assessing the effect of countermeasures. The uncertainties in severe accident codes (e.g. MAAP4), discussed above, and the lack of information during an accident could, in fact, result in a strongly biased understanding of the plant status and of bifurcations in plant behaviour, when attempting to forecast the evolution of an accident. Such codes should not be used for predicting accident progression or for recommending strategies unless these concerns have been eliminated.

From the human behaviour point of view, it must be stressed that predictions by computer codes tend to be taken at face value without intense scrutiny or investigation of the applicability of the code models to the situation in question. Under conditions of great stress, this tendency becomes a rule.

4.4.4. Full-scope simulators in the severe accident domain

Although partial-scope simulators can provide all necessary quantitative information during an exercise or drill in the severe accident domain, they cannot provide the realistic environment of a full-scope simulator. Where such a simulator is used in the preventive part of accident management, an interruption necessarily occurs when the transition to the mitigative domain is made. The actions that are taken by the operators upon entering the SAMG domain are no longer executed under realistic conditions, and the information that flows back to them as well as to the TSC is in a totally different form, namely information on personal computers (PC) monitors and/or in writing. This will also affect the way the TSC and the main control room (MCR) communicate with each other. From the human behaviour standpoint, therefore, development of full-scope simulators in the severe accident domain would be an improvement.

Apart from the human element, the full-scope simulator, which is also capable of operating under severe accident conditions, provides similar functions to those of the partial-scope simulators described above (Section 4.3). However, it does so more realistically, as, for example, in the development of templates for the drills, where it removes the somewhat arbitrary cuts and interruptions previously still needed to switch to other parts of the scenario. Further realism is also achieved due to the fact that less interaction on the part of the drill team leader is necessary since the simulator is capable of responding to a larger number of operator actions, i.e. also to those actions that were not foreseen during the preparation of the drill. The simulator will also more clearly and realistically display the negative consequences of actions, specifically where these have not been properly considered. This also lessens the requirement/workload on the severe accident expert who is normally available to adjust the pre-analysed plant parameters as unanticipated actions are taken.

Nevertheless, even for training with full-scope simulators, discontinuity in simulating accident progression is required. There is a limited amount of time available in comparison to the severe accident sequence time. There is a lot of dead time in some scenarios used to assess late accident strategies (e.g. core concrete interactions, containment venting, etc.). Often the exercise is integrated with other exercise requirements where the sequence must be delayed (or paused) to allow non-SAMG activities to be completed before moving to another phase (e.g. off-site radiological protection actions).

So far, the only application of such a simulator that exists is at Krško NPP in Slovenia. It is anticipated that, on account of the characteristics described above, further development will follow.

4.4.5. Virtual reality

There are developments underway to use virtual reality (VR) in operator training. VR techniques can be applied in accident management as a tool for improving communication between the management and the rescue team in emergency situations. A VR model of an emergency scene can be visualized by a projector and a large screen for the easy audit and inspection by a large number of people simultaneously. The VR model can easily be changed to reflect the current emergency situation. Another possibility is to connect the VR model to a simulator or prediction system. As in the case of conventional full-scope simulators, trainees can improve their skills and understanding of a system through actual practice.

Unlike a conventional simulator, a virtual environment can be modified relatively cheaply and the equipment used can be applied to a diverse variety of applications. Also, members of the rescue team not familiar with the scene of the severe accident can be briefed by using the VR model prior to entering the area. Route planning could be done for work in high risk environments.

5. CONCLUSIONS

Most NPPs have implemented AMPs or are in the process of doing so. An essential part of AMP implementation is the training of the personnel directly involved in applying the procedures and guidelines related to accident management. It has been recognized that the simulators, and simulation in general, provide an efficient tool for such training. The training should consider various aspects such as preventive and mitigative measures, the training level and the personnel group to be trained.

The current state of severe accident modelling has made it possible to develop many different approaches to simulation that can be used to support accident management training in the utilities. The various techniques include the introduction of graphical interfaces into existing severe accident codes, installing a severe accident code in an existing simulation environment, and developing specific models tailored for the severe accident management purposes of the given plant. One application exists up to now, at Krško NPP, in which a full-scope replica simulator is equipped with severe accident models.

The training of personnel for accident management differs largely from training for normal operation and anticipated transients. During an accident, specifically one that evolves into a severe accident, an emergency organization is set up that includes many more parties in addition to the CR operators and the shift supervisors, both on- and off-site. It usually includes a TSC, which plays a major role in establishing the further actions to be taken with regard to the plant. The instructions available are not as unambiguous, exact or clearly structured as in the EOP domain; rather, they have the character of guidelines as relevant information may be missing and because both positive and negative consequences must be considered, which cannot be done beforehand. Another difficult item is to account for possible bifurcation points, where the accident progression may follow different paths, depending on the outcome of energetic events.

Simulators contribute to the training of personnel with complex tasks and responsibilities. Hence, for accident management the primary emphasis is not only on the full-scope replica but also on any simulator that can provide useful functions. An example is the development of appropriate templates since a major drawback in drills usually is the need to calculate various scenarios in advance and to anticipate operator interaction, together with cuts and/or interruptions in the scenario. The use of an interactive simulator would largely overcome these problems.

Another important aspect related to simulators would be training in the communication of severe accident management between the MCR and the TSC. In general, severe accident management domain simulators are useful as long as meaningful countermeasures are possible. Where these cease to exist, precalculated scenarios presented in the form of templates would largely be sufficient.

The simulator is an effective tool to detect and improve weak elements of human behaviour in severe accident management since it provides the appropriate physical environment. The more realistic the simulator, the better these elements are taken into account.

The simulator in severe accident management space has limitations, due to uncertainties and insufficient modelling, but such incompleteness is acceptable as long as it is well understood by the trainees. The incompleteness should be covered by some other means of training or education.

The simulator can be used to verify SAMGs if the models used are sufficiently accurate, and to validate these if the simulator sufficiently closely represents the CR layout.

The simulator in the severe accident management domain is also very useful for educational purposes, where precalculated scenarios are mostly sufficient. Such approaches can be based on mechanistic severe accident codes.

At present, simulators hardly include low power and shutdown states, although the risk from these operational states is still considerable. This area should be developed further.

Another development is computerized operator support. Such support may alleviate the many manual tasks that need to be executed at present and may provide additional information. Examples of possible applications are tracking of I&C qualification, signal validation, evaluation of data trends and their extrapolation, adaptation of relevant set points to changed plant conditions, optimization of CAs, automation of procedures and guidelines, indication of available success paths, projected times of equipment availability and status of equipment repair.

Another development is the predictive simulator, used as accident management support, which is capable of demonstrating a physical picture of the plant damage state and its evolvement. Here large uncertainties still exist, which makes this task very difficult.

Finally, developments exist to expand the capacity of the full-scope simulator with respect to the severe accident regime. This development should be followed and the lessons learned used as feedback for future simulator applications.

Appendix I

OVERVIEW OF EXISTING SIMULATOR TYPES: EXAMPLES

Specialists meetings on simulators and plant analyzers offer good overviews of the existing simulators [40, 41]. In this appendix, a short presentation will be given for selected simulators presenting different capabilities and one or more examples.

The existing simulators can be divided according to their complexity and application purpose, for example, into the following groups:

- Compact simulators,
- Plant analyzers,
- Full-scope training simulators,
- Multifunctional simulators,
- Severe accident simulators, and
- Accident management support tools (e.g. MARS and CAMS).

It should be noted that there is no formally systematized terminology.

Compact simulators

Compact simulators have been applied ever since the beginning of simulator development. They are equipped with soft panels, which helps to reduce the cost of hardware since there is no need for a large room or CR hardware panels. The scope of simulation is also often limited only to the most crucial systems from the safety point of view. Compact simulators have been applied successfully for initial training of the basic principles and phenomenology. In the past, they have also been very valuable for design engineers when considering design alternatives. The fast development of computers makes it possible to include very sophisticated modelling in a compact environment. Multifunctional simulators and plant analyzers will therefore probably take the place of compact simulators in nuclear design and training applications.

Example: Tihange simulator (now not longer in use).

Plant analyzers

Plant analyzers combine advanced thermal-hydraulic and core modeling so as to permit an extensive modelling of the plant systems. The plant analyzers can be based on the widely applied advanced thermal-hydraulic system codes (ATHLET, CATHARE, TRAC and RELAP5) or they can have the advanced thermal-hydraulics and reactor kinetics specifically developed for this purpose (APROS). Since the simulator software for physical modelling has been developing rapidly over the recent years, the difference between plant analyzers and simulators is becoming narrower.

Examples: RELAP5-NPA, ATLAS, CATHARE-SIMU, TRAC-PWR Parallel Plant Analyzer.

Full-scope training simulators (FSS)

It is common practice to have a full-scope training simulator for a specific plant or for a group of similar plants; this is widely used for operator training in the full range of plant operating conditions and for training EOPs. These simulators normally include the full replica of the CR. The software development has been fast, and in many cases the simulators are even fully capable of simulating most of the postulated accident domain.

Examples: Many exist from various vendors.

Multifunctional simulators

Multifunctional simulators have been developed in order to obtain cost-effective solutions to the wide scope of specific simulation needs for training purposes. A typical feature of these simulators is that the quality of the physical models is at least the same as for the full-scope simulators, but there is little control panel hardware. These simulators can be applied for different purposes including engineering, validation of operating procedures and operator training for the full range of operating conditions.

Example: APROS. This simulator has now been extended to the severe accident domain.

Severe accident simulators

A group of simulators with the capability of simulating plant conditions beyond initial core degradation up to the full severe accident phenomenology may be referred to as severe accident or SAM simulators. Such simulators can be specific developments, varying from the existing integrated severe accident codes with a graphical interface up to full-scope or multifunctional simulators that include the severe accident analysing capability. Developments are progressing fast now, although considerable difficulties have been encountered owing to the very complex phenomenology of severe accidents.

Examples:

- ATLAS, based on the ATHLET code;
- MAAP-GRAAPH, based on the MAAP4 code;
- MELSIM and SCDAPSIM, based on MELCOR and SCDAP; and
- Krško Full-scope Simulator (MAAP4 based).

Accident management support tools

Computerized tools for supporting accident management during an accident can function both as tracking and predictive simulators. The tracking simulators monitor the plant status and provide the accident management personnel with calculated information also of those parameters that are not directly monitored by the plant systems. The predictive simulator has to be a fast-running tool since the idea is to use it to predict on-line the paths of the accident progression and for planning mitigation strategies. Ultimately, it will also provide source term information.

Examples:

- MARS: the MAAP Accident Response System (MARS) is an accident management software package that assists in the interpretation and understanding of the nuclear plant status before and during severe accident conditions. MARS uses available plant data to initialize MAAP. For training purposes the plant data may be simulated by a CR simulator or by a MAAP signal generator.
- ADAM, a similar system, but with simplified software.

- CAMS, which is under development by the OECD Halden Reactor Project (status as of October 2000).
- KAMP which is under development by the Korean Institute of Nuclear Safety (KINS) (status as of October 2000).

Appendix II

STATUS OF APPLICATION OF SIMULATORS TO ACCIDENT MANAGEMENT TRAINING IN A NUMBER OF COUNTRIES

The following material is based on a questionnaire on the current state of application in those countries represented at the IAEA Advisory Group Meeting on Implementation of Severe Accident/Accident Management Simulation in NPP Support Staff Training held in Vienna from 4 to 8 September 2000. More detailed information may be found in the working material of that meeting.

The following questions were asked:

- How is the training of accident management procedures and guidelines organized in the NPPs of your organization/country?
- What is the extent of application of simulators for accident management training?
- What kinds of simulators are applied for such training?
- What are the future prospects of developing or applying simulators for accident management training?

Responses were obtained from Belgium, the Czech Republic, Finland, Germany, Japan, the Netherlands, the Russian Federation, Slovakia and Slovenia.

Belgium

Tihange site: Present situation

The EOPs are used in the case of an accident up to and including a beyond design basis accident (BDBA) without significant core damage detection. When significant core damage is detected the EOPs are replaced by SAMGs. These are based on the SAMGs of the Westinghouse Owners Group (WOG). The EOPs are trained in the full-scope simulator, which is a replica of the CR. Each holder of an operator licence (RO and SRO) has to spend two weeks of training in the simulator. severe accident management training consists of two parts: explanation of severe accident phenomena and explanation of the SAMGs. For the SAMGs, the complete training of the engineers of the support staff lasts three to four days. For CR operators, the complete training lasts two days.

The full-scope simulator is validated with RELAP5 calculations.

To support the explanation and help operators understand severe accident evolution (including parameter evolution), the training is largely based on computer tools, consisting of an interactive graphic display system (ATLAS software) that provides a visual presentation of the computational results of the MELCOR severe accident code. Two kinds of views, built with ATLAS as a user-interface, exist: (1) schematic diagrams representing the primary circuit, the reactor vessel, the cavity, the containment and the combustion diagram for hydrogen, and (2) synoptic diagrams representing the instrumentation readings in the TSC. The explanation of the SAMGs is a classroom exercise without the use of a simulator.

Tihange site: Future prospects

The next step in the development of operator training sessions will be the organization of validation exercises for the severe accident management procedures through the use during the course of selected scenarios displayed on computers. It will also be possible to take into account the operator actions by interrupting the scenario at certain points in time (freeze) and show the influence of these actions on source term release and severe accident evolution, displaying the potential consequences of partial or total failure of severe accident management.

Moreover, the representation (ATLAS) of the instrumentation of the TSC will be extended. Some of the CR instrumentation will also be represented in synoptic diagrams. These developments will be used to train the SAMGs and the communication between the CR and the TSC. In addition, the synoptic diagrams will be used during the Emergency Plan Exercise.

It should be noted that the above applies only to the Tihange site since accident management is still under development at the Doel site.

Czech Republic

Present situation

Temelin NPP finalized the first version of EOPs in 1996, based on the WOG methodology. In June 2000, Revision 1A of the EOPs was completed, including verification and validation on the full-scope replica simulator. The training and drills for the EOPs are done on the full-scope replica simulator and they include prevention of severe accidents, e.g. bleed and feed, ATWS, etc. The events where the core is overheated and core degradation starts are beyond the scope of the simulation in the full-scope replica simulator. Training and drill of the severe accidents with significant core damage is not performed because the SAMGs are not available at this time.

Dukovany NPP carries out training and drills of EOPs for BDBAs on a multifunctional simulator, and a training programme for EOPs in a full-scope replica simulator is being carried out. The training and drills include prevention of a severe accident within the framework of the EOPs. The capability of both the multifunctional simulator and the full-scope simulator does not cover simulation of core damage.

SAMGs are not available for Dukovany NPP yet.

Training in connection with severe accidents is now carried out only in the form of presentations by the Nuclear Research Institute Řež, Czech Republic, and Westinghouse. The NPP is supposed to connect the MCR of the full-scope simulator with the TSC for training of the communication part of severe accident management between the MCR and TSC.

Future prospects

It has been decided to develop SAMGs using the WOG methodology for Temelin NPP. The project started at the end of the year 2000. A study of severe accident analysis and sequences is in progress. These analyses are performed with MELCOR at the Nuclear Research Institute Řež. A simulator for the visualization of the precalculated data from

MELCOR is available at the Nuclear Research Institute Řež. Apart from classroom training, this simulator is expected to be used for education and training of the SAMGs (severe accident mitigation).

A common project between Dukovany NPP, Bohunice and Mochovce is under way. It is assumed that the project will be completed in 2003. Development, training and drill of the SAMGs will be based on the WOG methodology. Should a simulator for severe accidents become available, then the learning, training and drill should include the simulator in future.

Finland

Olkiluoto BWR: Present situation

The utility is responsible for the training: lecturers and instructors are appointed from among the utility personnel. For operator trainees, lectures are held on accident management including both the DBA and BDBA domain up to severe accidents. The lectures consist of: (1) general theory and (2) plant specific part. In the plant specific part, the EOPs and the Emergency Preparedness Plan (EPP) and the use of the Safety Parameter Display System (SPDS) are presented. The SPDS has a mode for each EOP except severe accident. The severe accident monitoring is based on dedicated severe accident monitoring. The simulator runs follow the lectures. The full-scope simulator will be used for all EOPs, DBA, transients and minor malfunctions. For severe accidents, the PC based severe accident simulator is used. Similar training is arranged regularly for the licensed operators. Also, the ERO has similar training but without simulator runs.

Olkiluoto BWR: Future prospects

The current environment and extent of simulation is considered acceptable. The full-scope simulator has recently been modernized with new RELAP based thermal-hydraulic software, and system modifications from the modernization programme of Olkiluoto Units 1 and 2 have been included in the simulator. The PC based severe accident simulator is being updated for new computer operating systems. The operator, Teollisuuden Voima Oy, has a common project together with Swedish utilities, where the accident management scheme, and particularly the severe accident management procedures, are reviewed against current knowledge. The review may result in new accident management procedures, which would be included in the training.

Loviisa WWER: Present situation

The objectives of severe accident management training are to provide for a large group of plant personnel a fundamental understanding of the purpose of the new severe accident management systems and expected severe accident behaviour at Loviisa. Members of the severe accident management support team and other persons with important positions within the ERO have to: (1) understand the reasoning behind each procedure and guideline, and (2) familiarize themselves with the Severe Accident Management Handbook and understand it contents. The severe accident management strategy of the plant includes certain crucial measures for which training has to be provided. General classroom training is provided for a large number of plant personnel. Intensified classroom training based on the Severe Accident Management Handbook is provided for the severe accident management support personnel.

The structure of the Loviisa SAMGs and procedures is directly related to the overall severe accident management strategy. The severe accident management procedures include ensuring subcriticality, core cooling, ensuring containment leak-tightness, hydrogen management in the containment, containment pressure and primary system pressure. The Loviisa specific Severe Accident Management Handbook is meant for the use and training of the severe accident management support team. It includes analyses, background information, experimental results and reasoning behind the procedures and recommendations given. The Severe Accident Management Handbook is built around top level critical severe accident management functions and also includes chapters on recovery actions, severe accident safe state criteria, radiation protection and accidents originating from shutdown states.

Loviisa WWER: Future prospects

There is an ongoing project to develop a new set of EOPs for the Loviisa WWER plant. Fortum, the plant owner and operator, has also started to develop a special-purpose simulator to be applied in the severe accident management training of the Loviisa NPP operators and TSC personnel. The simulator is based on the APROS multifunctional simulator that has been developed in co-operation between Fortum Engineering and the Technical Research Centre of Finland. The objectives of the APROS severe accident simulator as a training tool is to familiarize operators, shift supervisors, safety engineers and the severe accident management support group with the Loviisa specific severe accident management strategy. The development uses extensively the in-house engineering capability and experience. The basic idea is to utilize the predictability of the Loviisa severe accident behaviour that is obtained on account of the well-defined severe accident management strategy.

Germany

Present situation

After the Chernobyl accident, the utilities of German NPPs declared their willingness to take additional measures on a voluntary basis to further minimize the risk posed by their plants beyond the provisions already laid down in their licence. Such accident management measures are actions taken by the operator to cope with the situation when an accident propagates into the beyond design basis area.

From the beginning, the strategy of the German utilities was to limit the number of accident management measures only to those having the potential to significantly reduce the probability of a core melt accident or the consequences of such an event.

The accident management measures are contained in a separate manual, the so-called Beyond-Design-Basis Emergency Manual. At present, this manual contains the following measures:

- filtered venting of the containment;
- filtered CR air supply;
- sampling of the containment atmosphere;
- secondary side bleed and feed;
- primary side bleed and feed; and
- plant recovery after station blackout.

The hydrogen in the accidental containment atmosphere is controlled by passive means and hence does not require any operator action or guidance.

As the issue of the licensing level of accident management measures was taken to court, a final verdict by the National Court classified accident management measures as being, in principal, ‘beyond’ the necessary licensing requirements and were, therefore, to be handled fully within the responsibility of the utilities of existing plants.

The introduction of accident management procedures requires comprehensive training, especially for the CR personnel. The initial psychological barriers within the shift crews were overcome, and accident management measures have become a regular part of practical and theoretical training. In co-operation with the utilities, the Kernkraft-Simulator-Gesellschaft (NPP school) Simulation Centre in Essen and GRS, the training of accident management procedures was tested on a full-scope plant simulator. The crisis teams of both the licensee and the vendor of the plant were also involved.

To determine the exact time span for the manual actions some on-site exercises were also performed. It can therefore be stated that training in accident management procedures, especially those for the prevention of core melt, have become part of regular simulator training and practical on-site retraining. Also, theoretical training on beyond design phenomena and related problems caused by large activity releases have become an integral part of retraining of shift teams and members of the ERO.

Beside the use of plant specific full-scope simulators for education, training in procedures and for emergency exercises, special analysis simulators are used in connection with core melt sequences and relevant severe accident phenomena (particularly for classroom teaching of the shift personnel and members of the crisis team). In addition, parameter displays keep the crisis team informed in the meeting room.

Future prospects

At the present time, further development of severe accident simulators and computerized operator support is not foreseen.

Japan

Present situation

In Japan, full-scope simulators are used for the training of operators for the prevention of core damage. For the purposes of severe accident management training of the TSC staff and operators, an education and training system, which works on personal computers, was developed by Japanese BWR utilities and Hitachi Ltd. The education and training system consists of two sub-systems. One is a computer aided instruction (CAI) education system and the other is an education and training system with a computer simulation. Both systems are designed to execute on the MS-Windows platform of personal computers.

The CAI education system has two functions: a visual education function and a ‘practical question’ function. Trainees can learn about accident management through the visual education function, which incorporates many animations and vocal instructions. With the practical question function trainees can confirm their degree of understanding by answering questions about accident management.

The education and training system with computer simulation uses the MAAP3.0B code. Accident management countermeasure equipment models, radioactive models (e.g. CAMS, SGTS), and monitoring model are incorporated in the system. The simulator can run twenty times faster than real time on a PC with a 233 MHz processor, depending on the sequence. The simulation speed can be chosen to be real time, four times faster than real time and maximum as well as zero (freeze) during the simulation. Plant parameters calculated with the simulator are visualized and are indicated by each monitor connected over the network. Furthermore, core status, such as core damage and reactor pressure vessel (RPV) failure, is indicated in the sketch, which corresponds to the plant condition. Trainees can learn plant behaviour during severe accidents and the use of SAMGs through the input of severe accident management actions during simulation.

The education and training system with computer simulation has three functions. These are sessions for the operation training function, practical question function and group practice function. With the group practice function, the TSC staff and operators can perform emergency exercises where the both groups monitor the same plant information, which is visualized from the results of the executed simulation.

These systems provide plant operators and TSC personnel with an effective education and training tool for accident management. TEPCO, Japan, have used the simulation system for an emergency exercise assuming the occurrence of a hypothetical severe accident, and performed an effective exercise in March 2000.

Netherlands

Present situation

Borssele NPP (a 480 MWe reactor of Siemens design), the Netherlands’ only operating nuclear power, has implemented the WOG EOPs and SAMGs. The EOPs are executed by the MCR operators under their responsibility; SAMGs are under the responsibility of the TSC, but the actions are performed by the MCR only.

Training of the personnel involved is done through classroom training and on the simulator. The simulator is a full-scope replica simulator, which is not located on-site, but at the NPP school in Essen, Germany. This also houses simulators of German NPPs.

SAMGs are also periodically trained in exercises/drills. Templates are developed separately using MAAP4.

The simulator is capable of addressing all events that are within the envelope of the EOPs (including, for example, feed and bleed). It is not capable of simulating events where the core is overheated (i.e. above 1200°C). Because of this, SAMGs are not trained on the simulator.

As mentioned above, the full-scope simulator is used for all events for which EOPs have been developed. For severe accidents, a MAAP-GRAAPH visualizer is available which *inter alia* shows pictures of the primary system and the containment on which the accident progression can be followed.

Future prospects

In future, it is planned to include the simulator in the drills and exercises to train the transition from EOP space to SAMG space, which is a critical point in the WOG SAMGs.

At present, the NPP does not plan to extend the simulator to the severe accident domain.

Russian Federation

Present situation

The main operational documents related to accident management are the “Instruction on liquidation of accidents” and the “Guidance on control of beyond design basis accidents”. The first document requires the operator to verify whether the systems and equipment designed to cope with a certain DBA have been switched on and, if not, to switch them on manually. This document is arranged in the form of a list of the DBA events with the corresponding operator actions. The second document is also based on the list of BDBA events and scenarios; this list is established for each power plant and agreed upon with the safety authority. To cope with BDBAs, the operator is authorized to use any operable equipment even under conditions in which this equipment is not designed to operate. To the same extent, the “Guidance on control of BDBAs” may be considered as analogous to EOPs, i.e. they are prescriptive in nature.

A full scope simulator is used for the regular training of operators within the scope of the two documents above. Until recently, the term ‘severe accident’ did not exist in the safety standards. Instead, the term ‘BDBA’ was used. The latter was defined as an accident whose initiating events exceed the design scope or as a DBA that is accompanied by more than one single failure. In the high level standard OPB-88/97 (issued in 1997), the term ‘severe beyond design accident’ can be found, which may be considered analogous to ‘severe accident’, since it also implies core melt sequences.

Future prospects

Up to now, severe accident simulation has not been included in the simulators used for operator training. At the moment, it is difficult to foresee whether this will be done in the very near future. A programme, however, exists on the development of domestic severe accident codes. One of these codes is being developed on the basis of the software installed in the full-scope plant simulator. Thus, bearing in mind the fast progress in computer capabilities, this new severe accident code may be available soon for use in the plant simulator.

Slovakia

Present situation

There are six units under operation in Slovakia at the present time. The first two units of Bohunice NPP (V-1) are of WWER-440/V230 type and the second two units (V-2) are of V213 type (i.e. with bubbler condenser tower). Mochovce NPP consists of two units of WWER-440/V213 type.

Training of accident management procedures: Preventive EOPs

Within the framework of the ‘Basic Preparation’ of operators, approximately 70 hours of theoretical and practical training are carried out in the area of the EOP application. The theoretical training is performed at the training centre of VÚJE Trnava, Inc., Engineering, Design and Research Organization. It includes a basic explanation of the physical background of each EOP, rules for EOP usage and strategy for each EOP. The practical training for the operators of Bohunice NPP is also performed at the VÚJE training centre. The training centre is equipped with a full-scope simulator for V-2 units and a multifunctional simulator for the V-1 units. The operators of Mochovce NPP obtain practical training directly on the on-site full-scope simulator. The second level consists of periodical training of operators twice a year for a period of one week, where 25–30% of the training time is devoted to the practical use of the EOPs. The third level constitutes requalification training, which is performed in the case of a change of position from operator of the primary (secondary) circuit to shift supervisor.

Training of accident management guidelines: Mitigative SAMGs

SAMGs are not yet available for Slovak NPP units. The development of SAMGs is a common project between Bohunice, Mochovce (both in Slovakia) and Dukovany (Czech Republic) NPPs.

Decision support system (DSS) for crisis staff

The RTARC 4.5 GIS 2.0 Decision Support System is already available at the Emergency Crisis Centre (ECC) at Mochovce NPP and at Bohunice NPP. The DSS is devoted to the fast evaluation of plant (barriers) status, potential and real source term and the effect of countermeasures, including evaluation of their effectiveness under BDBA and Severe Accident conditions. Two simulators have been developed for training in the use of the RTARC 4.5 GIS Decision Support System: the STP-V213 simulator for simulation of selected critical process parameters (≤18), and the RG-SIM 1.0 simulator for simulation of the environmental data (gamma dose rates) measured by a teledosimetric monitoring system and for simulation of meteorological data. The first one, based on the MAAP4/VVER deterministic code, uses precalculated severe accident scenarios. The basic database consists of seven precalculated scenarios for the Bohunice V-2 units. It is planned to utilize these simulators in the training process and in the preparation of the drills, when the entire emergency plan is trained (i.e. all the personnel involved in accident management during an emergency).

Future prospects

The new full-scope simulator of Bohunice V-2 units was recently installed at the VÚJE training centre. The thermal-hydraulic modelling on this simulator will be based on RELAP5/Mod3.2. The simulator will not have the capability to simulate severe accident conditions. An extension of the Mochovce full-scope simulator to simulate severe accident conditions is not planned in the near future.

The STP-V213 and RG-SIM 1.0 simulators will be improved in two areas: (1) enhancement of the database of the precalculated scenarios and/or creation of the basic databases for Bohunice V-1 and the Mochovce units, and (2) development of a direct (computerized) connection between the two simulators to ensure consistency between source term predicted during the pre-release phase of the accident and the response of the teledosimetric system detectors during the post-release phase.

Slovenia

Present situation

Training for personnel assigned to duties in the ERO at Krško NPP is organized in the form of classroom presentations, drills and exercises. The scope and content of the training is defined for the different groups depending on their role in the ERO. Emergency response training is also conducted for off-site support organizations.

Initial emergency response training is conducted for the individuals upon assignment to the ERO. Refresher and specialized emergency response training is conducted on an annual basis. Training for licensed CR operators is conducted as a part of their regular annual requalification training.

During preparation for the implementation of the WOG SAMGs, classroom training on severe accident phenomenology and SAM philosophy was conducted for various groups. With the implementation of SAMGs, the training on severe accident phenomenology, procedures and guidelines became an integral part of the overall emergency preparedness training. There are no legal requirements for such training, but it is required based on the plant Radiological Emergency Response Plan.

Simulation tools are used in the development of training sequences (scenarios) and also for demonstration of accident phenomenology. Plant response predictions are done primarily with the MAAP 4 and MAAP-GRAPH codes. Larger scale exercises involve training in response to environmental consequences induced by radiation releases. For the off-site dose projections the EIS (Ecological Information System), MAAP-DOSE, RASCAL and INTERAS codes are used.

The training sequences are planned in detail and supporting training materials are prepared in advance. This standard approach requires a substantial amount of up front preparatory work (analysis), lacks realism during execution and is not flexible in terms of ability to adapt the scenario flow path during the drill. With the acquisition of a new full-scope simulator in March 2000, the training on accident management within EOP limits has improved for operations personnel and shift engineers as well as for the TSC. The simulator will also be used to support classroom presentations and individual training.

Future prospects

The simulator will also have the capability to simulate severe accidents up to and including fuel melt, vessel failure, containment failure and FP release. The MAAP4 code, including all higher level executive functions, will be incorporated within an CAE SIMEX environment as part of a standard foreground configuration. MAAP4 will run as part of the simulation code.

The implementation of severe accident simulation on a full-scope simulator will significantly influence accident management training at Krško NPP. Major expected benefits are:

- Support in the preparation of the exercise (less upfront preparatory work on the templates);
- Ability to test the exercise in segments related to predicted plant response prior to execution of the exercise (will eliminate potential conflicts in the equipment status, timing, etc.);

- Increased realism during the execution of the entire exercise;
- Realism of the information available to the evaluators;
- Interactive inclusion/execution of the decisions taken by the decision maker;
- Realistic interactive inclusion of successful actions (e.g. water supply, power supply, equipment restoration);
- Realism in implementing the transfer of responsibility between the main CR and the TSC; and
- Increased quality of the exercise evaluation.

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ABBREVIATIONS

AMG	accident management guidelines
AMP	accident management programme
BDBA	beyond design basis accident
BWR	boiling water reactor
CAE	Canadian vendor of simulators
CAI	computer aided instruction
CSN	Consejo de Seguridad Nuclear
CSNI	Committee on the Safety of Nuclear Installations
DBA	design basis accident
DSS	decision support system
ECC	emergency crisis centre
EDF	Electricité de France
EOPs	emergency operating procedures
EPP	emergency preparedness plan
ERO	emergency response organization
I&C	instrumentation and control
INSAG	International Safety Advisory Group
KSG	Kernkraft-Simulator-Gesellschaft (nuclear power plant school), Essen, Germany
LOCA	loss of coolant accident
LWR	light water reactor
MCR	main control room
NPP	nuclear power plant
NRC	Nuclear Regulatory Commission (USA)
OECD	Organisation for Economic Co-operation and Development
PHWR	pressurized heavy water reactor
PSA	probabilistic safety analysist
PWR	pressurized water reactor
ROAAM	risk oriented accident analysis methodology
RPV	reactor pressure vessel
SAMG	severe accident management guidelines
SPDS	safety parameter display system
TSC	technical support centre
TSG	training simulator for Garoña plant (Spain)
WOG	Westinghouse Owners Group

DEFINITIONS

* *The definitions marked with an asterisk (*) were compiled solely for the purpose of the present report. The list does not represent a consensus or an endorsement by the IAEA.*

accident management	Taking a set of actions during the evolution of a **beyond design basis accident** to: — prevent the escalation of the event into a **severe accident**, — mitigate the consequences of a **severe accident**, — to achieve a long-term safe stable state.
accident management programme*	Comprises plans and actions undertaken to ensure that the plant and its personnel with responsibilities for **accident management** are adequately prepared to take effective on-site actions to prevent or to mitigate the consequences of a **severe accident**.
beyond design basis accident (BDBA)*	Accident conditions more severe than a **design basis accident** falling outside the safety systems design envelope. A BDBA may or may not involve **core degradation**.
computational aid*	Pre-calculated analyses, nomographs or easily used computer software available for the plant staff use during a **severe accident**: (1) to support plant staff guidance, (2) to predict accident progression and timing and (3) to evaluate effectiveness of candidate specific strategies.
core damage*	Substantial loss of the core geometry with major radioactivity release from the core, leading to conditions beyond the criteria established for **design basis accidents**, typically due to excessive core overheating.
core degradation*	A process that leads to the **core damage**.
design basis accident (DBA)	Accident conditions against which the nuclear power plant 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.
emergency operating procedures (EOPs)*	Plant specific **procedures** containing instructions to operating staff for implementing measures to prevent **core degradation**, for both DBA and BDBA.
guideline*	A document written to support activities that can be used to mitigate or stabilize accident conditions.
mitigative accident management measures (mitigative measures)*	**Accident management** measures which mitigate the consequences of an event involving **core degradation** (a **severe accident**).
mitigative accident management*	See **severe accident management**.

Preventive accident management measures (preventive measures*	**Accident management** measures which prevent or delay **core degradation**.
Procedure*	A document written for directing activities to a strict detail. The action described should be accomplished in the sequence written unless noted in the **procedure** body or by the rules for usage of a document.
severe accident*	Accident conditions more serious than a **design basis accident** and involving significant **core degradation**. In practice, the term **severe accident** has come to be synonymous with core melt accident. The severity of an accident depends on the degree of fuel degradation and on the potential loss of the containment integrity and the resultant radioactivity release to the environment.
severe accident management (SAM)*	A subset of **accident management** measures that: — terminate **core damage** once it has started, — maintain the capability of the containment as long as is possible, — minimize on-site and off-site releases, and — return the plant to a controlled safe state.
Severe accident management guidelines (SAMGs)*	A set of **guideline**s containing instructions for actions in the framework of **severe accident management**.
Simulator*	A computer-based assembly of software and hardware, which is capable of presenting the physical behaviour of the whole NPP or a part of it during various operational states and malfunctions. The **simulator**s are typically equipped with an advanced user interface (graphical or hardware interface) suitable for interactive operation and particularly suitable for training purposes.
Template*	A predefined accident scenario, consisting of an initiating event plus additional failures, that will call upon safety functions to be fulfilled and which is to be used in a drill.
validation*	The process of determining whether a product or service is adequate to perform its intended function satisfactorily. The evaluation is performed to determine that the actions specified in the instructions and **guideline**s of AMP can be executed by trained staff to manage emergency events.
Verification*	The process of determining whether the quality or performance of a product or service is as stated, as intended or as required. The evaluation is performed to confirm the correctness of a written **procedure** or **guideline** to ensure that technical and human factor concerns have been properly incorporated.

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