

IAEA-TECDOC-1440

***Overview of training methodology
for accident management
at nuclear power plants***



IAEA

International Atomic Energy Agency

April 2005

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The originating Section of this publication in the IAEA was:

Safety Assessment Section
International Atomic Energy Agency
Wagramer Strasse 5
P.O. Box 100
A-1400 Vienna, Austria

OVERVIEW OF TRAINING METHODOLOGY FOR ACCIDENT MANAGEMENT
AT NUCLEAR POWER PLANTS

IAEA, VIENNA, 2005
IAEA-TECDOC-1440
ISBN 92-0-101805-3
ISSN 1011-4289

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Printed by the IAEA in Austria
April 2005

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.

There are various IAEA activities aimed at assisting countries in the area of accident management (AM). Several publications have been developed that provide guidance and support in establishing AM at NPPs. These publications include *Safety of Nuclear Power Plants: Design*, IAEA Safety Standards Series No. NS-R-1 (2000) and *Implementation of Accident Management Programmes in Nuclear Power Plants*, Safety Report Series No. 32 (2004). Separate technical reports 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 accident management programmes (RAMPs) is offered to Member States; its purpose is to perform an objective assessment of the status at various phases of AMP implementation in 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 Implementation of Accident Management Programmes in Nuclear Power Plants plays a special role among the IAEA Safety Reports Series. 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 also underlines the importance of training for the successful implementation of an AMP. This present publication provides an overview of training methodology for AM. It discusses in greater detail the tools and support material that are applicable to the training of the staff involved in AM. Examples of such tools are also provided. This publication is mainly intended to facilitate the work to be performed by NPP operators, utilities and their technical support organizations in the area of the training required for AM.

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EDITORIAL NOTE

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1. INTRODUCTION

1.1. BACKGROUND

The control and management of normal operation and upset conditions require well-defined operator instructions and a high level of performance of NPP personnel. An essential element of reaching and maintaining this high level of performance is personnel training. Training takes place on various levels and in various forms.

The concept of defence in depth is an essential element of nuclear safety. One of the levels of defence in depth requires that also beyond design basis accidents and severe accidents should be managed, although they were not explicitly addressed in the original design of the currently operating NPPs [1, 2]. The defence in depth is physically achieved by means of four successive barriers preventing the release of radioactive material (fuel matrix, cladding, primary coolant boundary, and containment). 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). If these first three levels fail to ensure structural integrity of the core, additional efforts are made at Level 4 of defence in depth in order to further reduce the risks. The objective at the fourth level is to ensure that both the likelihood of a severe accident (i.e. accident leading to significant fuel damage) and the magnitude of radioactive releases following a severe accident, are kept as low as reasonably achievable. The term AM refers to the overall range of capabilities of an NPP and its personnel both to prevent and mitigate the accident situations, which 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 mitigation of severe accidents. Finally, Level 5 includes off-site emergency response measures, with an objective to mitigate radiological consequences of significant releases of radioactive material.

The definition of AM as used in the IAEA Safety Report [3] states that “Accident management is the taking of a 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. Severe accident management (SAM) is a subset of AM 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. AMP comprises plans and actions undertaken to ensure that the plant and its personnel with responsibilities for AM 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 SAM in OECD/NEA publications, for example in Refs [4, 5].

As specified above, AM comprises one of the key components of defence in depth. The AM provisions should take place regardless of all provisions within the design basis being adequate. The approaches to AM and SAM in particular vary in Member States. Some countries focus on actions to define procedures and SAM guidelines, which are based on utilizing the existing capabilities of the plant once a predetermined safety level has been achieved. In some countries, it is required that the plant modifications including hardware, instrumentation and control (I&C) and procedural changes be taken to improve significantly the plant capability of managing severe accidents without large releases to the environment.

Regardless of the approach, most countries have already implemented or plan to implement an AMP that includes development of the procedures or SAM guidelines or both. In addition, it is a part of the AMP to define the training programme for plant personnel who will be involved in SAM actions during an emergency. The main means for training are the classroom training, drills and exercises as well as the applicable simulator training, if available.

In most countries, SAM skills are not a formal request of the operator licensing. Consequently, the requirements for training are normally only set by the utility or the plant licensee. The first requirement is that the SAM training should not burden the control room operators excessively, since possibilities to increase the overall training time are limited. The SAM training cannot substitute the regular training programmes. The second requirement is that, nevertheless, the training should be efficient enough to ensure for the AM personnel sufficient skills to perform well during emergency situations when AM actions and their subset of SAM actions are needed. Therefore, it is particularly important to develop good training methods and to provide good and illustrative training material and support tools in order to ensure a high efficiency of training.

The IAEA Safety Report [3] also underlines the importance of training as a necessary condition for the successful implementation of an AMP. There is also an IAEA publication [6] that provides guidance for conducting the review of AMPs as an IAEA Safety Service. These two publications provide quite general statements on training related matters. The purpose of the current publication is to carry out a more detailed discussion of various items related to AM training. In particular, the aim is to describe different tools and support material that is available and their application to training. There is another special IAEA publication [7], devoted to the use of simulation techniques in AM training.

There have been several OECD/CSNI specialists' meetings presenting the status of and discussing the available Operator Aids for Severe Accident Management, see Refs [8, 9, 10]. The material available from these meetings also provided valuable insights to the SAM training and to the supporting tools.

1.2. OBJECTIVE AND SCOPE

The main objective of this publication is to describe available material and technical support tools that can be used to support training of the personnel involved in the AM, and to highlight the current status of their application. The focus is on those operator aids that can help the plant personnel to take correct actions during an emergency to prevent and mitigate consequences of a severe accident.

The second objective is to describe the available material for the training courses of those people who are responsible of the AMP development and implementation of an individual plant. The third objective is to collect a compact set of information on various aspects of AM training into a single publication. In this context, the AM personnel includes both the plant staff responsible for taking the decision and actions concerning preventive and mitigative AM and the persons involved in the management of off-site releases.

Thus, the scope of this publication is on the training of personnel directly involved in the decisions and execution of the SAM actions during progression of an accident. The integration of training into the AMP development and implementation is summarized. The technical AM support tools and material are defined as operator aids involving severe accident

guidelines, various computational aids and computerized tools. The operator aids make also an essential part of the training tools. The simulators to be applied for the AM training have been developed or are under development by various organizations in order to support the training on different levels. The plant-specific AMP involves application plans and implementation of these tools.

The report concentrates on existing means, but an outlook on future prospects is also provided. Both preventive and mitigative AM measures, different training levels and different target personnel groups are taken into account.

The report pertains to light-water reactors and pressurized heavy-water reactors, but it can be used for power reactors of other types in the applicable parts.

The report is intended for use by those specialists who are responsible for planning, developing, executing and supervising the training of personnel involved in AM at NPPs.

1.3. STRUCTURE OF THE PUBLICATION

The available information on the training of personnel involved in AM is provided in this publication. In particular, the aim is to have a detailed overview of the training material and technical support for AM training. The report consists of six sections, and there are also eight annexes. The introduction provides background, objective and structure of the report. Section 2 summarizes development and implementation of an AMP of the NPP and describes in particular the training related items. The section deals with two separate areas of AM related training that are (1) training courses for developers, implementers and reviewers of the AMP and (2) training of the AM personnel having responsibility during the accident situations. Section 2 goes on and introduces the development of training material for the courses on the AMP. Such information may also serve as a useful starting point for the planning of the knowledge-oriented training after implementation of the AMP. The further sections make a clear distinction between these two areas. The objectives and orientation of AM training are the topics of Section 3. The training of staff to take correct actions includes various phases to improve knowledge, skills and efficiency of various AM personnel groups. Section 4 is devoted to procedural and documentary material that makes one of the essential building stones for the AM personnel training.

Finally, Section 5 summarizes the available AM support tools and prospects of further development. Description aims at specifying computational aids, computerized tools and AM simulator. The role of a SAM manual in training is discussed.

Concluding remarks are collected in Section 6 in order to summarize the status of the supporting means for AM training.

Annex I proposes contents for an AM training seminar that can be applied as an introductory course on severe accidents and AM for those who are responsible to develop the plant-specific AMP. Other Annexes list various computational aids that have been already applied in various plants (Annex II), organizational charts of emergency response organization (ERO) and work charts for emergency planning (Annex III). Annex IV gives an overview of SAM manuals developed by some utilities and compares their content and application. An example of a chart for checking instrumentation availability is introduced in Annex V and work charts for AM actions performance in Annex VI. Annex VII includes examples of the computerized tools developed to support execution of AM. Annex VIII provides examples of tabletop scenarios. The examples are presented in the format used in the source documents.

2. ACCIDENT MANAGEMENT PROGRAMME AND TRAINING

2.1. DEVELOPMENT OF ACCIDENT MANAGEMENT PROGRAMME

There are a wide variety of potential severe accident scenarios and sequence classes for each individual plant. The sequences start from different initiating events (precursors of a severe accident) that may lead directly or through additional failures to severe core degradation. The potential plant states include operation at power, the plant heat-up and cool-down, and shutdown conditions. Once started, the core degradation may further proceed to melting of the reactor core, to a melt-through of the pressure vessel and to a multitude of physical phenomena potentially challenging containment integrity. The further the accident progresses into the severe accident regime, the more difficult it becomes to manage the accident by the Emergency Operating Procedures (EOP). Therefore, many utilities tend to develop or have already developed Severe Accident Management Guidelines (SAMG) with a structure that is more appropriate for such situations.

In order to create the basis for managing core degradation situations, an understanding of plant-specific severe accident conditions should be created. Developing the AMP is the responsibility of the plant licensee that is the plant owner or the plant operator, or both. The IAEA has developed a Safety Report on Implementation of Accident Management Programmes in Nuclear Power Plants that provides guidance for the planning, development and implementation of the AMP [3]. There are various alternative ways to incorporate AM into plant operations. 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. It is possible to incorporate preventive AM into existing procedures, to develop new procedures and guidelines for preventive AM and mitigative SAM, or to develop AM guidance manuals. The 'procedures' refer to a set of detailed reports, which prescribe specific actions in specified conditions, while the 'guidelines' and 'guidance manual' refer to a general description of actions that could be effective in managing a particular situation.

The personnel involved in the AM within the ERO are composed of different groups. Typically, as mentioned in Ref. [3], such groups are (1) control room operators, (2) a possible permanent or on-call safety engineer, (3) the part of the onsite technical support staff in charge of SAM guidance (often also called Accident Assessment Team, or Accident Management Team, AMT), (4) other parts of the technical support staff, such as an operating support staff, radiation protection staff, etc., and (5) off-site emergency operations staff of the plant licensee. The off-site organization includes one or more crisis teams where also the safety authority is involved.

Some examples of the on-site ERO are presented in Annex III ¹. The implementation of the AMP should take into account that the availability of the technical expertise of the different groups may vary significantly among the utilities. The organizational aspects of the AM implementation include a definition of the roles and responsibilities of the personnel involved. The major functions for executing SAM guidance are the evaluators, decision makers and implementers, as described in Ref. [3]. The tasks of these different personnel groups may vary according to the phase of the AM. The implementation also varies among the

¹ It should be noted that, in practice, many different organization forms exist, although many of the main functions are common to all approaches.

utilities, since the AM organization has to be integrated into the overall utility and plant organization and into the emergency organization.

When entering the domain of core damage, the progress and phenomena become more complex. It might not be so obvious what actions the operator has to take to terminate the accident progression or mitigate its consequences. In an actual case, the personnel responsible for the plant operation under emergency conditions have to make a number of critical decisions. These decisions include the confirmation that a severe accident has occurred, and they concern typically such issues as adding water to a degraded core, depressurization of the reactor cooling system and many containment related issues (e.g. using of sprays, flooding, filtered venting and hydrogen management, etc.).

The timing of these decisions depends on the individual plant design. Timing also may define the organizational level on which the decision should be taken. In the initial phase when the on-call safety engineers or technical support centre (TSC) are not yet available, the plant operators should be able to make the appropriate decisions. In the later phase when TSC staff are available, they can assist in or — where this is so organized — take over the decision making. The decisions are called critical in the sense that the implementation of the decision can also include adverse effects. In such a case, the guidance usually requires the TSC to consider these potentially negative consequences in advance as well as the consequences of not performing the actions. Balancing these positive and negative consequences, and the consequence of not performing the actions, can be a difficult task and, hence, should be trained for appropriately.

The personnel involved have to be trained in all aspects related to the decisions to be made. The training needs and methods have been specified in the Safety Report [3]. Many utilities have chosen to develop severe accident management guidelines, and, to develop in parallel, documentation that serves as background information for training and education. This background information is mostly derived from the technical basis that was used to develop the guidelines. Other utilities have adopted a practice to collect the guidance in a single SAM manual. This manual contains also all information that is deemed necessary for the operators and the technical support staff concerning severe accident progression and phenomena. The manual is an important part of the training material.

2.2. ROLE OF TRAINING IN AMP DEVELOPMENT AND IMPLEMENTATION

The Safety Report [3] addresses the training needs during the AM programme development and implementation phases. Accordingly, the important task of the development phase is to identify the training needs in time and to allow the preparation of the training programme to be carried out during the implementation phase. The training plan defines all staff members who need training as well as the level, scope and form of training for various groups.

During the implementation phase all personnel and groups that are required to provide a response during an accident should be clearly identified and their training needs well defined. Training of the personnel involved can be done both by classroom training and exercises and drills. Classroom courses can be used for the basic familiarization with the AM guidance. The drills and exercises, possibly applying simulators with severe accident modelling capabilities when available, provide efficient means for training. The emphasis is on the correct execution

of the EOPs in the phase before extensive core damage, the transition from the EOP domain to the SAM guidelines domain, and the proper execution of the SAM guidelines and other guidelines for the TSC. In addition to training the correct execution of the SAM guidance by the control room personnel and the TSC, the overall Emergency Preparedness Plan (EPP) should also be trained at regular intervals.

Drills should be performed in a way that all team members are trained at the similar level, i.e. too much emphasis on certain team members (e.g. the decision maker) should be avoided. The realism of the training may be improved significantly if the phase before extensive core damage and the transition from the EOPs to SAM is executed on a plant simulator.

An appropriate team that assesses the performance should observe the exercises and drills. The teams involved should also deliver a self-assessment and critique of their performance. Assessments are documented and filed, and the lessons learned are incorporated in the procedures, the guidelines and in the training itself.

In Ref. [3] the individuals and groups of the ERO that require training have been identified and the training levels defined. They include the control room staff and supervisors, the SAM guideline users and the emergency director. All of them need training of a different scope. There are also other interfacing personnel groups, the training of which is to be defined according to the plant-specific situation. Such personnel groups are those persons in the ERO and technical support staff who are not directly involved in the implementation of SAM guidelines as well as members of the off-site technical support centres.

In practice, there is considerable overlap between the different functions. The training needs of the different members of the organization can be evaluated separately. The level and contents of the classroom courses of severe accidents and the AM needs, means and practices in general could be different for these groups. As well the plant-specific training should be tailored according to the chosen approach to severe accident management and the function of the staff receiving it. Utility or vendor staff will normally provide plant-specific staff training.

The training should take place with regular intervals that are compatible with the overall operator and technical staff training programme of the plant. In any case, the training must take place at a frequency which will allow the responsible staff to be well informed and prepared.

2.3. REVIEW OF ACCIDENT MANAGEMENT PROGRAMME AND TRAINING SEMINAR ON ACCIDENT MANAGEMENT

The IAEA has prepared guidelines for conducting a review of the AMP as a standard Safety Service RAMP [6]. The preferable timing of the AMP review would be prior to the implementation and it can be done on different levels and phases. The publication [6] also provides some information on the related training aspects.

The plant licensee can start AMP development with a training seminar on accident management that would acquaint personnel who are to develop and implement the AMP with the various aspects related to severe accidents and to the AMP. The purpose of the seminar is to provide a background and description of AMPs to the team responsible for developing and implementing a programme at a particular plant. This will provide a sound basis for the subsequent project planning and implementation.

The seminar will provide an overview of AMPs, including understanding the objectives, scope and definition of AM, reviewing the different approaches available, and describing the tasks involved in developing and implementing a AM programme.

The seminar is intended primarily for the members of a team responsible for the selection, development and implementation of an AMP at a specific plant. It would be given before the AM programme development begins. Attendance would be expected from:

- NPP staff responsible for the development of the plant specific AM programme;
- NPP management;
- Regulatory body representatives responsible for review/overseeing development process; and
- Engineering support organizations including technical support companies, research institutes and vendor organizations.

The seminar will be of a one-week duration, and will consist of lectures, discussion and exercise sessions. The seminar syllabus is shown in Annex I. It consists of seven modules:

- Introduction;
- Plant behaviour during accidents;
- Severe accident phenomenology;
- Principles of AM;
- Approaches and their features;
- AMP development phases and tasks;
- A workshop/exercise session to illustrate practically the use of AM guidelines.

The seminar will run for five days, each day consisting of six hours of lectures and/or exercises, plus one hour dedicated to a discussion of the concepts raised during the day. The exercises will use actual examples of accident management guidelines to illustrate their practical usage in a simulated tabletop scenario.

The training programme suggested for all AM personnel is addressed also in the RAMP guidelines [6]. Regarding the training, the items to be checked by the review team concern among others the timing for the training preparation in relation to AMP implementation, correct focus and training levels according to the personnel group, and in particular, use of the self-assessment and feedback from the lessons learnt during training.

The guidance publication itself, Ref. [6] can also be considered as sufficient material for the training of the reviewers.

3. OBJECTIVES AND ORIENTATION OF AM TRAINING

The main incentive for AM personnel training is to ensure that the ERO is capable of taking effective actions during accident conditions. For successful operation, it is necessary that AM personnel be acquainted with expected plant behaviour and consequences. The development and implementation of the AMP have resulted in procedures and guidelines that offer plenty of actions available for the staff. During the emergency it is important that the entire organization be capable of playing together in order to manage the situation. The training is given for various personnel groups according to their function during accident progression.

Three high-level objectives can be set to the AM training as discussed at the SAMOA-2 meeting, Ref. [8]. The first objective refers to educating the personnel in the knowledge of various severe accident phenomena that are instrumental for understanding the severe accident progression during various sequences. The second objective relates to training the AM personnel in skills to take actions during a severe accident situation. The third level is to improve the efficiency of the ERO by training the interplay and cooperation of all organizations involved. Accordingly, the three high-level objectives can be defined as:

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

3.1. PERSONNEL ORIENTATION

As defined in connection to AMP development and implementation, there are various personnel groups involved: the control room operators, shift supervisors, on-call or permanent safety engineers, members of the TSC and the other relevant members of the on-site and off-site emergency organization. These groups have different AM training needs according to their function and responsibilities. In addition to the utility AM personnel, it is normal that the regulatory bodies have also technical staff to create their own group of experts during an emergency situation.

The classroom training periods are useful for all the groups involved, although the content of the classroom training may vary according to the group. In many cases, it is important to balance the AM training, particularly for the control room operators, whose annual training shall stay focused on performance-based responsibilities. Therefore, it is beneficial to find efficient and illustrative means for introducing the various aspects associated with severe accidents and AM. There are various simulation and demonstration tools that can be utilized to obtain a higher efficiency of the training that was discussed in a special publication of AM training simulation [7].

Training that improves the skills is needed for the personnel directly involved in the decisions and execution concerning the application of EOPs and SAMGs.

It is important that all the different AM personnel groups be involved in the drills and exercises since these offer the means to train and check the overall performance and efficiency of the AM as well as the interface to the other components of ERO.

Operations personnel training programme in AM domain shall cover knowledge-oriented topics on accident phenomenology to the extent necessary to support skill-oriented

training that is typically linked to the use of full-scope simulators. In the SAM domain it is important that operations personnel are trained in the transition from the EOPs to SAMGs, especially on the aspects of the transfer of responsibilities between the main control room (MCR) and TSC. Practical simulator exercises of this nature given to the all shift crews can be done in such a way that the instructors play a role in the TSC functions. It has to be recognized that large-scale exercises that involve the full TSC complex would not normally be available during training of the shift crews.

Training of the TSC personnel can also benefit from the use of the full-scope simulator as it adds realism in performance, especially in timing of events and effectiveness of the TSC decisions implemented on the simulator.

3.2. CONTENT ORIENTATION

3.2.1. Knowledge-oriented training

The first and basic part of improving the knowledge consists of classroom training. The lessons are aimed at teaching the personnel what would happen in cases of accidents progressing into core melt scenarios. The elements of theoretical lessons are a description of successive steps of core degradation and melting and an explanation of the most significant phenomena and their consequences on plant behaviour, and justification of recommended AM actions. An essential part is the definition and discussion of potential adverse effects as well as consequences of a partial or complete failure of AM actions on accident progression.

As complementary for the classroom training, it is useful to apply computer model based simulation aids or simulators for training in knowledge. The main features for such a simulator would be the consistency with models implemented in current training simulators for the phase from accident initiation to the onset of core melt and the use of state-of-the-art knowledge for modelling the severe accident phenomena. The plant changes and backfits would be implemented in modelling and the computer graphics would be most efficient to support classroom training and help personnel to understand accident progression. The modelling and simulation of system recovery as well as simulation of partial success of AM actions (e.g. possibility for interruption and showing the influence of full or partial success of water injection) would be needed to improve the correspondence to the actual situation. The simulator would need a fast running computational model, allowing discussion of specific issues in parallel with accident progression in the model.

3.2.2. Skill-oriented training

The main goal of skill-oriented AM training is to teach the personnel how to react in case an accident progresses into a core melt scenario. There are important items to be addressed specifically, such as the status of monitoring (instrumentation readings). The operator skills would be improved by exercising the execution of SAMGs and related measures. Consistent use of operator aids, if any, would be considered depending on utility objectives. It is crucial to analyse the operator response in such cases in order to properly understand respective human factor issues.

3.2.3. Efficiency-oriented training

The main goal of improving and testing the efficiency of the AM is to test behaviour of the whole organization. For a slowly progressing accident situation, many operators and technical support personnel would be involved in performing the job. The main tools to train

the efficiency are emergency drills and exercises. The issue to be analysed in the development phase is how to keep consistency of AM throughout the accident. The drills are an efficient tool for training the AM personnel e.g. to train the communication among the personnel involved in AM and to judge the plant status when shifts change, potential consequences for AM and potential divergence of the action, and finally, how to keep track of the whole scenario.

When implementing the plant-specific AMP, the training is done in parallel with the introduction of SAMGs.

3.3. FUNCTION ORIENTED TRAINING PROGRAMME

As described in Ref. [3], personnel assigned to work with SAMG are categorized into the positions decision maker, evaluator and implementer. This personnel has the following tasks and training needs:

1. Decision maker:

The decision maker is designated to assess and select the strategies to be implemented. He is in charge of making decisions in the use and implementation of SAM guidance. The function 'decision maker' can be placed in the accident management team or at a higher management level, up to the site emergency director. The decision maker should maintain a high-level perspective of all the SAMGs.

2. Evaluator:

The evaluator is responsible for assessing plant symptoms in order to determine the plant damage condition(s) of interest and potential strategies that may be utilized to mitigate an event. This function is assigned to members of the TSC accident management team tasked with the following activities:

- Diagnosing conditions that require entry into specific SAMG and transitions within SAM;
- Evaluating the positive and negative impacts of actions directed in SAMG;
- Responding to severe accident challenges;
- Interpreting the response of plant parameters following SAMG strategy implementation;
- Assessing the effectiveness of implemented strategies and determining whether additional mitigation is needed; and
- Using position-specific guidelines and work charts.

For example, TSC positions trained as evaluators are the operations liaison, reactor engineer, safety analysis engineer, and safety parameter display system (SPDS) operator.

3. Implementer:

The implementer is responsible for performing those steps necessary to accomplish the objectives of the strategies (e.g., hands-on control of valves, breakers, controllers, and special equipment). The normal ERO positions of the implementer are control room licensed operators.

Methodology for development of training

The learning objectives and related training materials could be developed using a systematic approach to training (SAT). This model consists of the following elements: analysis, design, development, implementation and evaluation.

The analysis phase of SAT consists of reviewing the various reports associated with SAM and determined those actions performed by the three basic job classifications: decision maker, evaluator, and implementer.

The design phase of SAT identifies the learning objectives of severe AM training for the three functions. The objectives are derived from an analysis of the various source reports pertaining to severe accident management principles and can be displayed in a matrix.

The development phase of SAT consists of the development of evaluation mechanisms (written exam questions, table-top scenarios, performance evaluations, etc.), utility specific training material (lesson plans, table-top scenario guides, etc.), and the application of the training prioritization criteria.

The implementation and evaluation phase of SAT includes the implementation of the training programmes and the evaluation of their effectiveness. These consist of conducting the actual training, obtaining ongoing feedback and evaluating the training programmes for future changes.

Evaluation of training

The assessment of performance during drills should be based on the process used to identify SAMG actions to be performed; thereby ensuring evaluations are made in a systematic method based on the best available information at the time.

Elements of a systematic evaluation of severe accident strategies should include the following:

- Diagnosis of plant conditions to determine the applicable strategies to be evaluated;
- Verification of plant conditions and use of alternate indications;
- Communication with the control room to determine available equipment;
- Identification of positive and negative impacts of the strategy;
- Identification of limitations and long term concerns; and
- Follow-up to verify expected plant responses.

Post-drill debriefings will provide participants the opportunity to receive direct feedback from drill facilitators. Debriefings also allow the participants to provide direct input into the self-assessment process. During these debriefings, feedback forms should be made available to the participants giving them the opportunity to provide additional comments that may be factored into the assessment.

Input from drill controllers and the drill debriefings should be utilized to identify weaknesses and opportunities to improve performance. Comments that require further evaluation, training, or revisions to SAM documentation should be documented and tracked.

The level and intensity of the function-oriented training is presented in Table I.

TABLE I. EMPHASIS ON VARIOUS TYPES OF TRAINING FOR THE FUNCTIONAL STAFF GROUPS

	Decision makers	Evaluators	Implementers
Knowledge-oriented training	**	****	*
Skill-oriented training	*	***	***
Efficiency-oriented training	***	*	*

The scale of emphasis is from '*' (meaning that only the basics needs to be trained) to '****' (meaning that the main emphasis should be here).

4. ACCIDENT MANAGEMENT TRAINING BY MEANS OF APPLYING THE PROCEDURES, GUIDELINES AND MANUALS

Such sources of background information as the technical basis reports and the SAM manuals provide valuable material for knowledge-oriented training.

The entire range of procedural and guidance reports of preventive and mitigative AM such as the EOPs, AM guidelines, SAM guidelines and SAM manuals have been written to advise the operator in controlling and managing severe accidents. These publications represent the most important material for AM personnel training in improving their skills and efficiency.

4.1. USE OF TECHNICAL PUBLICATIONS FOR TRAINING

Many technical publications are produced during the development phase of the AM programme. A part of this documentation can also be used as material for the classroom training phase of various personnel groups. An important departure point for the development of SAM guidelines is the technical basis publication.

As an example, the development of SAMG and SAMG training material in the USA is described. The work started by the collection of the relevant severe accident insights by EPRI in the so-called Technical Basis Report (TBR), Ref. [11]. In this report the major phenomenological issues were defined and examined with respect to the anticipated severe accident behaviour based on the knowledge of the individual phenomena at that time. This information was then used to assess the influence of possible high-level countermeasures that could be taken to recover from a severe accident, the so-called Candidate High Level Actions (CHLAs) on the various plant damage states. The Owners' Groups used the EPRI TBR plus other insights such as the plants individual plant examinations (IPEs) to develop generic SAM guidelines for the different plant types. As a final step, the utilities prepared the plant-specific procedures based on these publications. The Owners' Groups developed from the TBR and the other insights the training documentation, which provided the necessary information for those responsible for executing the SAM guidelines. INPO also provided training material.

It is worthy to note that final implementation of SAM guidelines in the USA is licensee-specific depending on different plant design features, available technical support and operational practices of the utility. These features have also an impact on AM training. Nevertheless, the overall approach offers a possibility to use similar technical background material for training in the knowledge of severe accidents and execution of SAM guidelines.

4.2. EOPS AND SAM GUIDELINES AS TRAINING TOOLS

The procedural and guidance publications in themselves make an essential part of the AM training material.

When AM personnel are trained by means of exercises and drills, the teams of control room personnel and the TSC play a severe accident scenario. The emphasis is on the correct execution of the EOPs prior to core damage, the transition from the EOP domain to the SAM guidelines domain, and the proper execution of the SAM guidelines and guidelines for the

TSC (where these latter ones exist). Where a shift of responsibility occurs, e.g. from control room to the TSC on hitting an exit condition in the EOPs, this is to be trained explicitly.

In order to provide more frequent possibilities for AM personnel training, tabletop drills may turn out to be useful. The tabletop drills are efficient for training correct execution and transitions, but the full drills are still necessary for training of the aspects of the overall emergency plan.

The training should be done on the basis of an appropriate template that consists of a scenario plus all the branching needed to play the scenario in the actual drill. In developing this template, it is important to consider that a wide spectrum of SAM guidelines should be trained in parallel. The templates should also be flexible in the sense that not being able to predict different actions by the TSC and control room in sufficient detail, a range of possible responses should be considered. The template does not cover normally the whole core damage scenario due to its length in time, and therefore the jumps in the scenario are necessary in most cases. The templates are usually developed based on the integrated severe accident code calculations. When the plant simulators are available with the severe accident modelling capability, the use of such simulators can replace the pre-defined scenario with the pre-defined branching.

The templates, procedures and guidelines form the necessary framework for the exercises and drills. It is clear that AM personnel are supposed to follow this frame. Nevertheless, the success of the drill or exercise is assessed according to how well the teams have worked together, have followed their working procedures, and have established the proper level of communication, evaluation and decision making. Various examples of templates and objectives of using tabletop scenarios in training have been given in Annex VIII.

After the development of SAM guidelines, much attention is given to their validation before they are formally introduced. This validation is usually done at the final stage of the initial training. It is usually an extensive activity, which may take several weeks and involves all utility personnel assigned to the various TSC functions, often including the plant manager. It is executed in a large drill, where a broad spectrum of SAM guidelines is addressed. The validation is followed by a critique, where the lessons learned are drawn and fed back into the guidelines.

Later on, refresher training is organized at various intervals of two years or longer.

4.3. USAGE OF SAM MANUAL FOR TRAINING

The approach to writing a SAM manual as the support publication for the implementation of SAM actions has been adopted by some utilities. The contents and title of the SAM manual may vary, but essentially the publication contains various basic information on severe accidents and introduces the approach taken to manage severe accidents. Annex IV provides two examples of concrete applications in Sweden and in Finland.

Because of its information content on the physical phenomena, plant conditions etc. the SAM manual can be widely utilized for the knowledge-oriented training of all the personnel groups involved.

The main users of the SAM manual during the emergency depend on the actual organization and on the assignment of the responsibilities within the ERO. The applicability during an accident also depends on the structure and degree of detail of the manual. The users are normally within the TSC: at least some of the TSC personnel would be assigned to follow the SAM manual in more detail.

The feedback on the usability of the SAM manual for the skill-oriented training can be obtained from the drills and exercises. Accordingly, there is a need to upgrade the SAM manual at regular intervals.

4.4. USE OF GUIDELINES AND WORK CHARTS FOR TECHNICAL SUPPORT AND OTHER ERO ASPECTS AS TRAINING TOOLS

The execution of EOPs and — even more — of SAM guidance and other activities of the ERO can be a complex task for which a number of NPPs have developed specific guidelines and work charts. Typical functions to be executed by the TSC and described in the guidelines are:

- To evaluate the operability and reliability of instrumentation used to determine the values of EOP/SAMG control parameters (symptoms) and to develop a best estimate value for each parameter, taking into consideration any harsh environmental conditions that may damage I&C;
- To forecast the future values of EOP/SAMG control parameters, specify the current state of the plant with respect to certain conditions, and prepare alternate EOP/SAMG limit curves as appropriate;
- To evaluate the operability and reliability of plant systems, structures and components, both in short term and on a longer time interval, which may be used to perform functions specified in the EOPs/SAMGs; and
- To determine the priority with which systems should be restored to service, to optimize repairs by noting system interdependencies and to select restorative actions where chances are best taking note of the radiation levels at various locations, and to identify timing for actions directed by the EOPs/SAMGs.

Such guidelines should be used in classroom training as well as during a drill/exercise. An example of comprehensive guidelines is shown in Ref. [16]. An example of a chart to evaluate availability of the plant I&C and its environmental limitations is presented in Table V.1.

Apart from the guidelines for the TSC, all of the AM personnel shall be thoroughly familiar with applicable procedures and guidelines within their area of responsibility. Responsibilities and actions to be taken by individuals on strategic AM positions may be defined in different EPP documents. Therefore, AM position-specific quick reference summary work charts for performance of AM actions may be a very useful tool for training as well as for the execution of actions during a real event. An example of such a work chart in table form is presented in Annex VI. Such a work chart provides a summarized overview, i.e. applicable procedure or guideline identification, high level actions to be performed, and interfaces between personnel.

5. TECHNICAL SUPPORT TOOLS FOR AM TRAINING

Most technical support tools for AM training are the same as the tools for supporting AM personnel in the successful execution of SAM guidance during an accident. There are various operator aids that have been developed to support the AM personnel to follow and predict the accident progression, and thus to help in making decisions and taking corrective action. The operator aids have been developed in many countries and they range from the presentation and illustration equipment to the computational tools such as graphs and simple hand calculation tools up to more sophisticated computerized tools. In this section the operator aids are divided into presentation equipment, computational aids and computerized tools. The distinction between the latter two is made mainly on the level of sophistication. The fourth subsection then discusses the use of simulators with severe accident modelling capability for the SAM training.

As already mentioned, two specialists' meetings have been organized by OECD to discuss and review such tools [8, 9]. The use of operator aids has also been summarized within Euratom research project SAMIME, Ref. [12].

5.1. OPERATOR AIDS

The NPPs are equipped with extensive control and monitoring capabilities that are available during a severe accident to a various degree depending on accident progression. The information available in an NPP was not originally designed up to severe accident conditions and its presentation is not necessarily optimal for use during such conditions. Therefore, various ways of presentation and illustration aids have been developed to support the control room operators and the TSC to follow the accident's progression.

Many plants have already installed an operator support system that supports the use of symptom-based EOPs. Depending on application, the system can have different names such as the Safety Parameter Display System (SPDS), the critical function monitoring system (CFMS) or simply the operator support system. These display systems have capabilities to be helpful throughout a severe accident on the condition that the input from the plant instrumentation and computer system is available and reliable. When using this system during AM training, the availability and reliability in severe accident situation should be taken into consideration.

It is essential for the TSC to record accident progression. Wallboards and charts can be a very efficient means to record and monitor the plant damage states, trends of the parameters and the actions taken. Even a better solution can be to load such information into an internal computer network. In this case the information would be directly accessible by all the personnel involved in AM. There should be a person assigned to this task. The use of such arrangements and equipment should also be trained for properly.

In the case that dedicated equipment and instrumentation have been installed for SAM purposes, the control panels would be modified and there can be a separate control panel outside the main control room. The clear graphics and system mimics are good practice in these systems to help monitoring.

The instrument qualification tables and system dependency matrices as well as other process and instrumentation documentation will be needed during an accident. The

presentation of this information in an easily accessible form will be beneficial. The next chapter discusses the use of computer presentation for such information.

In order to ensure the good performance of AM personnel during an accident situation, many tools have been developed recently in the form of pre-calculations or based on using separate computer capacity. These tools are called computational aids and they should be accounted for in the development of the AMP for the plant. They can provide estimates of parameters which affect AM decisions, such as reactor coolant system (RCS) integrity and containment leak rates, remaining time to key events (e.g. to core uncover, reactor vessel failure and containment failure) and core and containment conditions. They should also provide a basis for assessing the effectiveness of strategies under consideration or in progress during an accident.

The computational aids can be in the form of a parameter graphs, diagrams, a set of formulae, a compilation or a table of plant-specific information, or small computer programmes. The aids are typically plant-specific and they are developed in line with development of the AMP. For example, a U.S. utility operating various plant designs has developed a set of calculational tools in the form of the computer programmes that provide critical engineering information calculations on timing of critical milestones, critical plant data and plant response to severe accidents, Ref. [13]. A list of computational aids and two examples of computational aids are presented in Annex II.

5.2. COMPUTERIZED TOOLS

Significant progress has been made in the development of on-line diagnostics and simulation capabilities that could enable TSCs or other accident response centres (e.g., national emergency response centres), and in particular off-site emergency management teams to supplement their technical basis for decision-making. Such tools are referred to as computerized tools.

The functions of the computerized tools include accident tracking, on-line symptom-based diagnostics, and fast-running accident simulation capabilities to enable better assessment of trends, and determination of the potential implications of severe AM alternatives, well before such actions may become necessary. In addition, as these computerized tools and advanced simulation methods become more developed, they can be used in extending and supporting the execution of SAM guidelines in areas such as parameter trends, equipment availability, and trade-off analysis of alternative SAM actions.

The predictive simulator is, in principle, interactive; i.e. severe AM actions can be tested to study their effect in advance. The input for the predictive calculations is taken from the actual plant data. The speed of calculations can be much higher than the real time. The predictions are used e.g. for determining the timing of deliberate release (venting).

Annex VII provides a short description of some computerized tools and advanced simulation systems. It is noted that the current users of the computerized tools are nuclear regulatory authorities and to a lesser extent, the TSCs and other utility organizations.

Determining the availability of systems and equipment that could be used for executing the SAM actions takes time during an emergency. In some cases the SAM guidelines include a series of tables, which summarize the data pertinent to the use of pre-identified equipment and systems. The system dependencies are important for some actions, but it may be laborious to work them out from the documentation available. The experience shows that in practice the

AM personnel often consult the paper copies of the plant process and instrumentation (P&I) drawings and equipment and system manuals. Further development of computerized database for the instrumentation availability, system dependencies and other important P&I information could assist AM personnel in making these determinations.

Parameter trends are very important for AM personnel for many reasons. First, it can be the primary tool for predicting such important timings as time to steam generator dry-out, to containment challenges and to hydrogen burn. Second, it can be the method for monitoring the plant behaviour after strategy implementation. Third, it permits the taking of actions prior to reaching actual setpoints. Use of computerized tools, particularly in the case of access to the process computer, can assure that trending is based on relevant data and that relevant parameters are trended.

There are also other cases, where further development of computational aids would be useful. The status of equipment repair and predicted time of availability is not easily tracked by AM personnel during an accident. Recovery of unavailable equipment is one of the prime SAMG strategies. During the accident progression the priority for the equipment repair may change. Again, a computerized database that can maintain the current repair status would be useful for the AM personnel.

The computer-based system to predict the onsite radiation levels is very useful to give information for the AM personnel on the accessibility of the equipment. Such a tool can be developed based on the projected fission product releases from the primary circuit and from the containment. The same system can be further applied as the interface between the AM personnel and the team responsible for the off-site dose predictions. Such a system has been developed for the Loviisa SAM usage and is currently under testing phase [14].

The computerized tools could also play an important role in extending and supporting the execution of the SAM guidelines for such items as parameter trends, equipment availability, and recording of timing.

The main users of the computerized tools in accident progression are foreseen to be the emergency teams. For the final application during the emergency, the training is connected to the emergency drills. Current trends indicate that the TSC with sufficient expertise could also benefit from the use of computerized tools.

5.3. USE OF SIMULATORS

There is a specific IAEA publication on the application of the simulation methods for the AM personnel training [7]. In the present section, the outcome of that report is highlighted. It has been recognized in Ref. [7] that the simulators and simulation in general provide an efficient tool for AM training.

The current state of severe accident modelling has made it possible to develop many different approaches to the simulation that can be used to support the AM training in the utilities. The various techniques include introduction of graphical interfaces into existing severe accident codes, installing a severe accident code to an existing simulation environment, and developing specific models tailored for the SAM purposes of the given plant. The current state of the art in the computer technology is sufficient for simulation of severe accidents on full-scope replica simulators. Such simulators may be very valuable tools to support preparation and performance of larger-scale emergency exercises and drills but should be cautiously used for training of operators. As the uncertainties in severe accident simulation are

unavoidable, training scenarios shall sufficiently vary to eliminate the development of such an impression that the plant behaviour during severe accident conditions would necessarily follow a specific pattern.

Simulators contribute to the training of the people, having this large variety of tasks and responsibilities. Hence, for AM the emphasis is not primarily only on the full-scope replica, but on any simulator that can provide useful functions. An example is the development of appropriate templates, as a major drawback in drills usually is the need to pre-calculate various scenarios and to anticipate operator interaction, together with cuts and interruptions in the scenario. The use of an interactive simulator would largely overcome these problems.

The severe accident simulating methods have turned out to be an effective tool for classroom training to explain and display the phenomena and progression of severe accidents. In these cases, the simulation method can be a sophisticated severe accident analysis code that has been equipped with illustrative graphical interface.

An important aspect for simulators would be the training of the communication of SAM between the MCR and the TSC. In general, SAM domain simulators are useful as long as meaningful countermeasures are possible to be simulated. Where these cease to exist, pre-calculated scenarios presented on paper would largely be sufficient.

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

The use of simulation in the SAM space is limited due to uncertainties and limits in the scope of simulation, but such incompleteness is acceptable as long as it is well understood by the trainees, what is the range of the impacts on the outcome. The incompleteness should be covered by some other means of training.

The simulator can be used to verify SAM guidelines if the models used are sufficiently accurate, and to validate these if the simulator is sufficiently close to the control room lay-out. At present, simulators hardly include low power and shutdown states, although the risk from these operational states is considerable. This area should be further developed.

Finally, some developments exist in expanding full-scope simulators into the severe accident regime. This development should be followed and the lessons learnt should be fed back into simulator application.

5.4. INSTRUMENTATION AVAILABILITY

The availability of measurement information for AM personnel is of crucial importance during an emergency situation to guide the decisions and actions and to monitor the accident progression and efficiency of performed measures. Different approaches exist to ensure the needed information. Some utilities and plants have chosen the approach to install and qualify dedicated instrumentation for those measurements that are needed for performing the proper preventive and mitigative SAM actions and monitor their success. Such an approach has been presented for the Finnish NPPs in Ref. [15]. Another approach that is widely adopted is to take efforts to estimate the reliability of information obtained from the existing measurements and instrumentation and to use information from different sources to support the decisions during the SAMG execution.

Not depending on the chosen approach, the training should address the issue of instrumentation availability and reliability. The operator has to know on what he can rely during the situation when he is supposed to take SAM actions.

In case the dedicated instrumentation has been installed for the critical SAM functions, the situation can be governed easily by emphasizing the use of the dedicated information.

Checking the validity of the instrumentation readings is an important task when the used measurements are not qualified to severe accident conditions. Many efforts have been taken in various countries to study the instrumentation availability and reliability. The results are often very plant specific and the resulting documentation is extensive. The obtained material has to be processed for the use of AM personnel. The usefulness of the plant-specific information can be improved by applying modern computer-based processing. The readings should be checked both from the perspective of the expected response during a severe accident and a comparison to other instrumentation. Computerized tools would be useful to alert the user when the accident has progressed to a point where certain instruments may not longer be valid and when the instrument readings deviate from those of the corresponding measurements.

6. CONCLUSIONS

Many utilities have already implemented or plan to implement AMPs in their NPPs, which include development of the SAM guidelines as an essential element. Along with it is a part of the AMP to define the training programme for plant personnel who will be involved in SAM actions during an emergency. In most countries, SAM skills are not a formal regulatory requirement for operator licensing. Consequently, requirements for training are normally only set by the utility. The training programme should be efficient to provide sufficient training without bringing an unnecessary burden on the operators' training programme. Consequently, efficient training methods are essential. Illustrative training material and support tools can be very helpful in achieving these objectives in order to ensure high efficiency of training.

The high-level objectives of the AM training are improving the knowledge of the all responsible staff on the all aspects of severe accidents and their management, improving the skills of the plant personnel involved in the AM and improving the efficiency of the ERO. The training contents, methods and tools depend on the objective and also on the target group to be trained. The classroom training can improve the knowledge, the tabletop and simulator exercises can improve the SAM skills and the drills and exercise can improve the overall response of the ERO.

The EOPs for the preventive AM and the SAM guidelines for the mitigative SAM are the essential part of the training material when improving the skills and efficiency. The background material such as the technical basis reports and the SAM manuals provide valuable material for the knowledge-oriented training.

The operator aids that have been developed for supporting personnel are used as technical support tools for AM training. The operator aids range from presentation and display means to computational aids such as graphs and simple hand calculation tools up to more sophisticated computerized tools.

The computational aids are plant-specific and are developed in line with development of the AMP. Parameter trending is crucial for AM personnel since it can be the primary predictive tool for important timings and it permits the taking of actions prior to reaching an actual set-point. Significant progress has been made in the development of on-line diagnostics and simulation capabilities that could enable the TSC and other accident response centres (e.g. national emergency response centres, etc.) and in particular off-site emergency management teams to supplement their technical bases for decision-making.

The current state of severe accident modelling has made it possible to develop many different approaches to the simulation that can be used to support the AM training. The techniques include introduction of graphical interfaces into existing severe accident codes, installing a severe accident code to an existing simulation environment, developing specific models tailored for the SAM purposes of the given plant and equipping a full-scope simulator with severe accident models. An important aspect for simulators would be the training of the communication between the main control room and the TSC. The simulator is also an effective tool to detect and improve weak elements of human behaviour in SAM, as it provides the appropriate physical environment. The severe accident simulators have limitations due to uncertainties and insufficient modelling. However, for simulators to become effective training tools, they should enable the simulation of the expected range of uncertainties.

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DEFINITIONS

The definitions that follow are provided solely for the purposes of this publication.

accident management	The taking of a set of actions during the evolution of an event sequence to a beyond design basis accident: <ul style="list-style-type: none">— to prevent the escalation of the event into a severe accident;— to mitigate the consequences of a severe accident;— and 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.
computational aid	Pre-calculated analyses, nomographs or user friendly computer software available for plant staff use during a severe accident: 1) to support plant staff guidance, 2) to predict accident phenomena and timing, and 3) to evaluate the effectiveness of candidate specific strategies.
computerized tool	Severe accident simulating tool that can be used by the technical support centre and by the crisis management teams during the accident to track and predict the accident progression.
core damage	Substantial loss of the core geometry with major release of radioactive material, leading to conditions beyond the criteria established for design basis accidents, typically due to excessive overheating by the core.
core degradation	A process that leads to core damage.
design basis accident (DBA)	Accident conditions against which a 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.

emergency response organization (ERO)

The organization responsible for the execution of the emergency plan of the plant.

individual plant examination (IPE)

A study to determine a quantitative understanding of the overall probabilities of core damage and fission product releases, ordered from plants in the USA by the U.S. Nuclear Regulatory Commission in the Generic Letter 88-20.

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.

operator aid

Severe accident guidelines, presentation means, displays, computational aids and computerized tools that can be used during the accident to process and utilize available information in order to support execution of the severe accident management. Note that here the term 'operator' may include persons other than 'control room operators'.

preventive accident management measures (preventive measures)

Accident management measures which prevent or delay core degradation.

severe accident

Accident conditions more severe 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 release of radioactive material to the environment.

severe accident management (SAM)	<p>A subset of accident management measures that:</p> <ul style="list-style-type: none"> — 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, — return the plant to a controlled safe state.
Severe Accident Management Guidelines (SAMGs)	A set of guidelines 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 part of the NPP during various operational states and malfunctions. The simulators are typically equipped with an advanced user interface (graphical or hardware interface) suitable for interactive operation and particularly suitable for training purposes.
severe accident management manual	The report containing the plant-specific information on severe accidents and strategies to manage them. During an accident, the manual can be used as guidance by the emergency response organization.
technical support centre (TSC)	The part of the emergency response organization with the task of providing technical support and/or being responsible for the decisions concerning the execution of the SAM action.
accident template	A predefined accident scenario, consisting of an initiating event plus additional failures, that will call for safety functions to be fulfilled and which is to be used in a drill.

ABBREVIATIONS

AC	Alternate Current
ADAM	Accident Diagnostic and Management
AFW	Auxiliary Feedwater
AM	Accident Management
AMP	Accident Management Programme
AMT	Accident Management Team
ATWT	Anticipated Transient Without Trip
BDBA	Beyond Design Basis Accident
BWR	Boiling Water Reactor
CAMS	Computerized Accident Management Support
CCW	Component Cooling Water
CDE	Committed Dose Equivalent
CETC	Core Exit Thermocouples
CFMS	Critical Function Monitoring System
CHLA	Candidate High Level Action
CR	Control Room
CRDM	Control Rod Drive Mechanism
CSNI	Committee on the Safety of Nuclear Installations
CTMT	Containment
DBA	Design Basis Accident
DC	Direct Current
DFC	Decision Flow Chart
DG	Diesel Generator
ECC	Emergency Crisis Centre
ECCS	Emergency Core Cooling System
ED	Emergency Director
EIP	Emergency Implementing Procedure
ENS	Emergency Notification
EOF	Emergency Operations Facility
EOP	Emergency Operating Procedure
EPG	Emergency Procedure Guideline
EPP	Emergency Preparedness Plan
ESF	Engineered Safety Features
ESFAS	Engineered Safety Features Actuation System
HHSI	High Head Safety Injection
HP	Health Physics
HPN	Health Physics Notification
I&C	Instrumentation and Control
IPE	Individual Plant Examination
IS LOCA	Interfacing System LOCA
LB	Large Break
LHSI	Low Head Safety Injection
LOCA	Loss of Coolant Accident
LOSP	Loss of Station Power
MCR	Main Control Room
MOV	Motor Operated Valve
NEK	Nuklearna Elektrarna Krško (Krško NPP)
NPP	Nuclear Power Plant

ODEF	Offsite Decontamination Facility
ORAA	Off-site Relocation and Assembly Area
ORAL	Off-site Radiological and Analytical Laboratory
OSC	Operational Support Centre
P&I	Process and Instrumentation
PRT	Pressurizer Relief Tank
PSA	Probabilistic Safety Assessment
PTS	Pressurized Thermal Shock
PZR	Pressurizer
RAMP	Review of Accident Management Programme
RCP	Reactor Coolant Pump
RCS	Reactor Coolant System
RHR	Residual Heat Removal
RPV	Reactor Pressure Vessel
RWST	Refuelling Water Storage Tank
SACRG	Severe Accident Control Room Guideline
SAEG	Severe Accident Exit Guideline
SAG	Severe Accident Guideline
SAM	Severe Accident Management
SAMG	Severe Accident Management Guideline
SAT	Systematic Approach to Training
SBO	Station Black-out
SCG	Severe Challenge Guideline
SG	Steam Generator
SGFP	Steam Generator Feedwater Pump
SI	Safety Injection
SPDS	Safety Parameter Display System
STM	Source Term Module
SW	Sump Water
TBR	Technical Basis Report
TDAFW	Turbine Driven Auxiliary Feedwater (pump)
TEDE	Total Effective Dose Equivalent
TSC	Technical Support Centre
TSD	Technical Support Document
WCC	Work Control Centre
WWER	Water cooled, water moderated power reactor (Russian design)

ANNEX I

SYLLABUS FOR TYPICAL IAEA SEMINAR ON ACCIDENT MANAGEMENT PROGRAMME DEVELOPMENT

#	Module Title	Topics covered	Time
Day 1:			
1	INTRODUCTION	Seminar overview Plant design basis and safety analysis report Overview of design basis accident analysis Introduction to thermal hydraulics PSA and its role Tools for accident analysis <ul style="list-style-type: none"> • DBA • severe accident • simulation tools Accident management concepts - prevention and mitigation Overview of AM programme components Emergency plan / preparedness	3 hr
2	PLANT BEHAVIOUR DURING ACCIDENTS	Design basis events Beyond design basis events Severe accidents Analysis methodologies and tools Plant response to DBA and BDBA	3 hr
Day 2:			
3	SEVERE ACCIDENT PHENOMENOLOGY	Severe accident phenomena and their importance in accident management In-vessel phase phenomena: <ul style="list-style-type: none"> • behaviour up to core uncover • core melt progression • hydrogen generation • natural circulation - creep failure phenomena • reactor vessel failure • fission product behaviour in core and primary system Ex-vessel phase phenomena: <ul style="list-style-type: none"> • high pressure melt ejection • debris dispersal and direct containment heating • vessel thrust • steam explosions • debris coolability • core-concrete attack • hydrogen behaviour in containment • containment fragility and failure modes • fission product transport, deposition, release Plant response to severe accidents	6 hr

#	Module Title	Topics covered	Time
4	PRINCIPLES OF ACCIDENT MANAGEMENT	Objectives and background of AM Preventive and mitigative measures Analysis requirements for AM development	3 hr
5	WORKSHOP / EXERCISE MANAGEMENT	A practical table top exercise using actual Severe Accident Management Guidelines to illustrate their principles of usage.	3 hr
Day 4:			
6	APPROACHES TO ACCIDENT MANAGEMENT AND THEIR FEATURES	Approaches to prevention and mitigation <ul style="list-style-type: none"> • guidelines vs. procedures • symptom based approaches • coverage • entry and exit criteria Preventive AM strategies Emergency Operating Procedures Mitigative AM strategies Severe Accident Management Guidelines Information needs and decision support tools <ul style="list-style-type: none"> • instrumentation • computational aids AM organization and responsibilities Techniques for verification and validation	6 hr
Day 5:			
7	ACCIDENT MANAGEMENT PROGRAMME DEVELOPMENT PHASES AND TASKS	Preparatory phase <ul style="list-style-type: none"> • team • selection and definition of programme • review of safety analyses • preliminary analysis needs Development phase <ul style="list-style-type: none"> • strategy development • procedures and guidelines development • instrumentation and equipment requirements and capabilities • integration in emergency response plan • verification and validation aspects • training needs • programme review • regulatory aspects Implementation phase <ul style="list-style-type: none"> • training • staffing and qualification • maintenance 	6 hr

ANNEX II

EXAMPLES OF TYPICAL COMPUTATIONAL AIDS

Number	Title	Explanation
1	RCS INVENTORY DEPLETION AND CORE UNCOVERY	Guidance on time available to core uncovery for different types of events
2	CORE HEAT REMOVAL	
2a	MINIMUM FLOWRATE REQUIRED FOR CORE QUENCH AND REFLOOD	Injected coolant flow vs. RCS pressure showing achievable flow and flow required to quench and reflood overheated core
2b	LONG TERM COOLING REQUIREMENTS	Required coolant flow vs. time after shutdown needed for decay heat removal by boiling
3	RCS PRESSURIZATION	
3a	RCS PRESSURIZATION — RCP RESTART	The amount of RCS pressurization to be expected following the core reflood due to main circulation pump restart
3b	RCS PRESSURIZATION — REFLOODING SCENARIOS	The amount of RCS pressurization to be expected following the core reflood due to coolant injection
4	RCS VENTING AND DEPRESSURIZATION	Coolant outflow rate for different RCS vent paths
5	HYDROGEN GENERATION	
5a	HYDROGEN GENERATION FROM IN-VESSEL CORE MATERIAL METAL-WATER REACTIONS	Magnitude of hydrogen sources from in-vessel oxidation
5b	HYDROGEN GENERATION FROM EX-VESSEL CORE MATERIAL METAL-WATER REACTIONS	Magnitude of hydrogen sources from ex-vessel core material oxidation
5c	HYDROGEN GENERATION FROM CONTAINMENT MATERIAL METAL-WATER REACTIONS	Magnitude of hydrogen sources from containment material oxidation
6	CORE MELT PROGRESSION	Amount of core melt vs. time
7	CONTAINMENT CHALLENGE DUE TO HYDROGEN COMBUSTION	Containment pressure vs. hydrogen concentration showing flammable, non-flammable and severe challenge (=flammable with risk of containment damage) regions
9	CONTAINMENT VENTING	Containment pressure vs. vent (gas) flow for all the containment vent paths

Minimum Injection Flow Rate Required to Quench Molten Core (4000 deg. F)

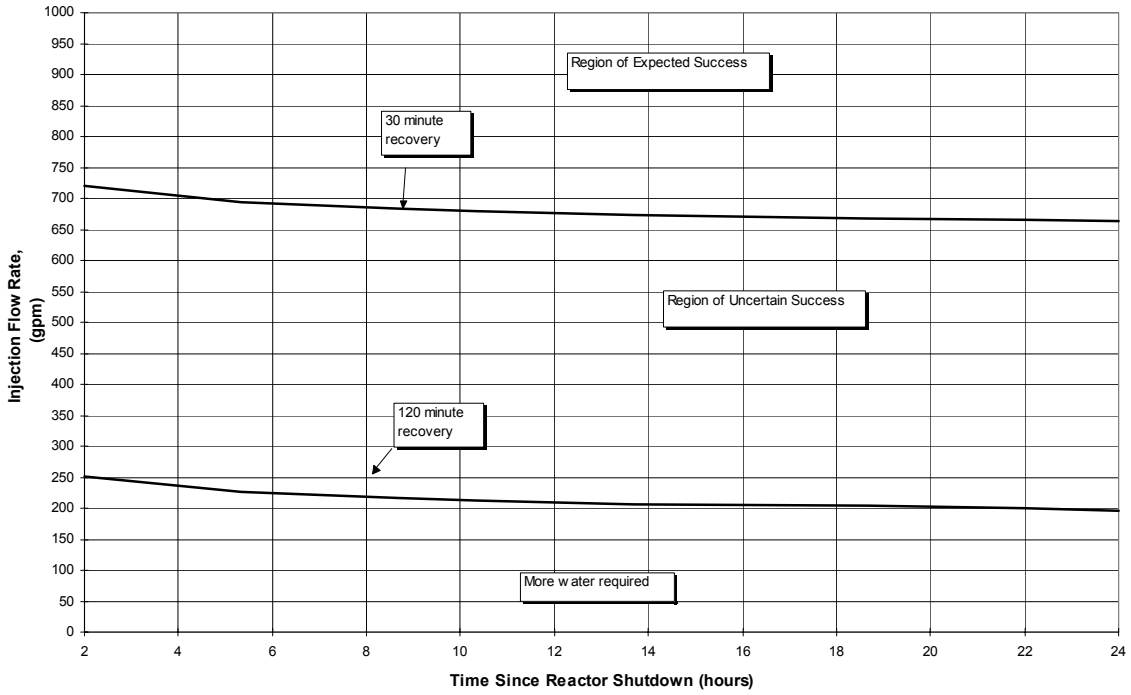


FIG. II.1 Minimum injection flow rate required to quench molten core (4000 deg. F).

Example 2b

Minimum Flowrate Required to Remove Decay Heat

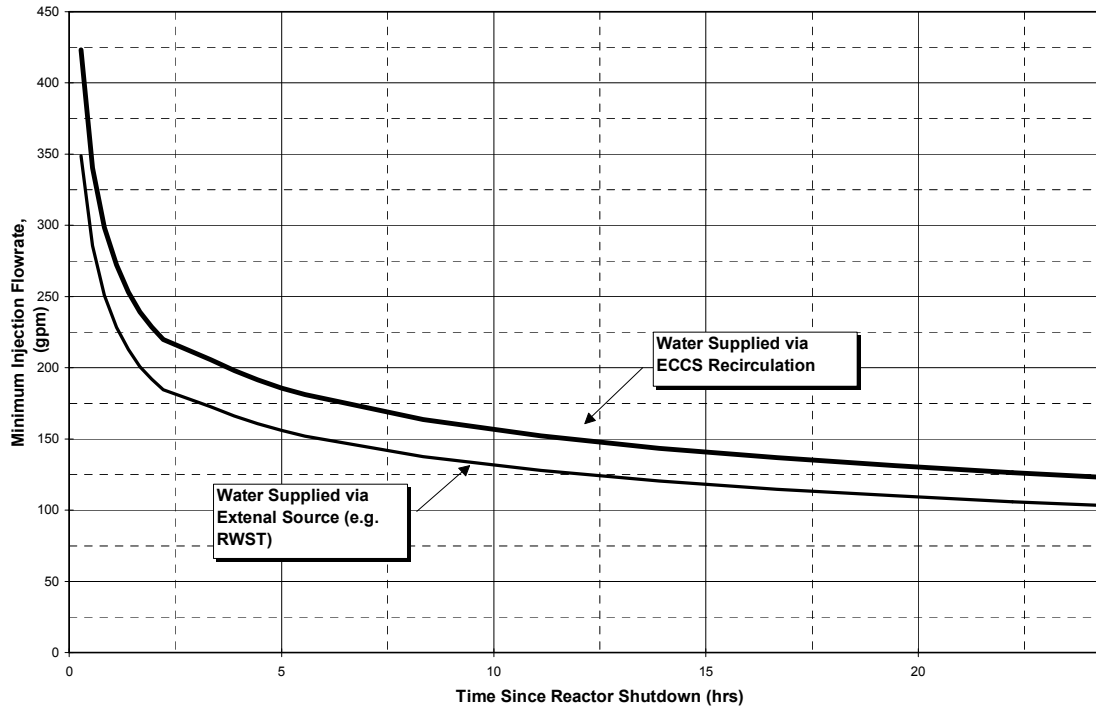


FIG. II.2 Minimum flow rate required to remove decay heat.

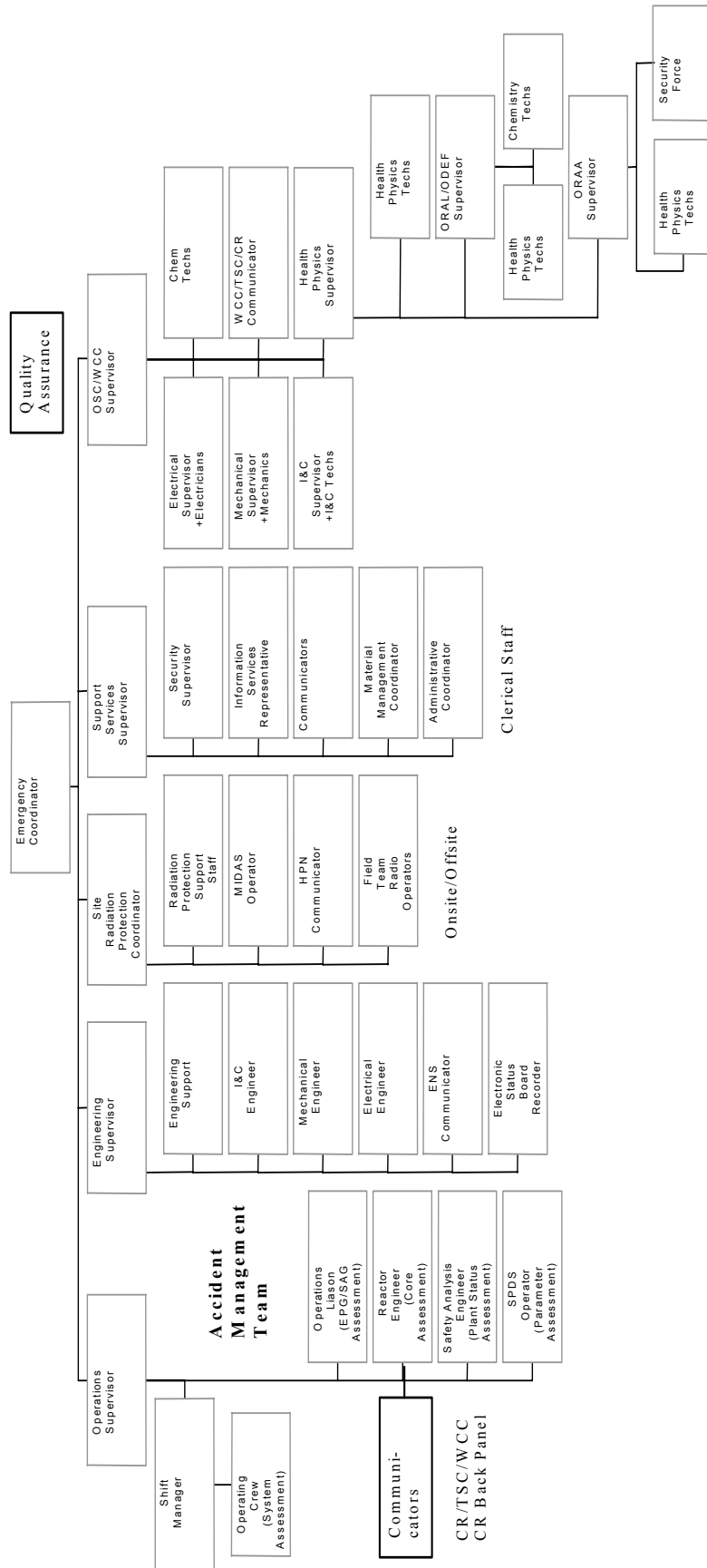


FIG. III.2. Emergency response organisation scheme of a typical NPP in USA.

Emergency Control Center of Forsmarks NPP

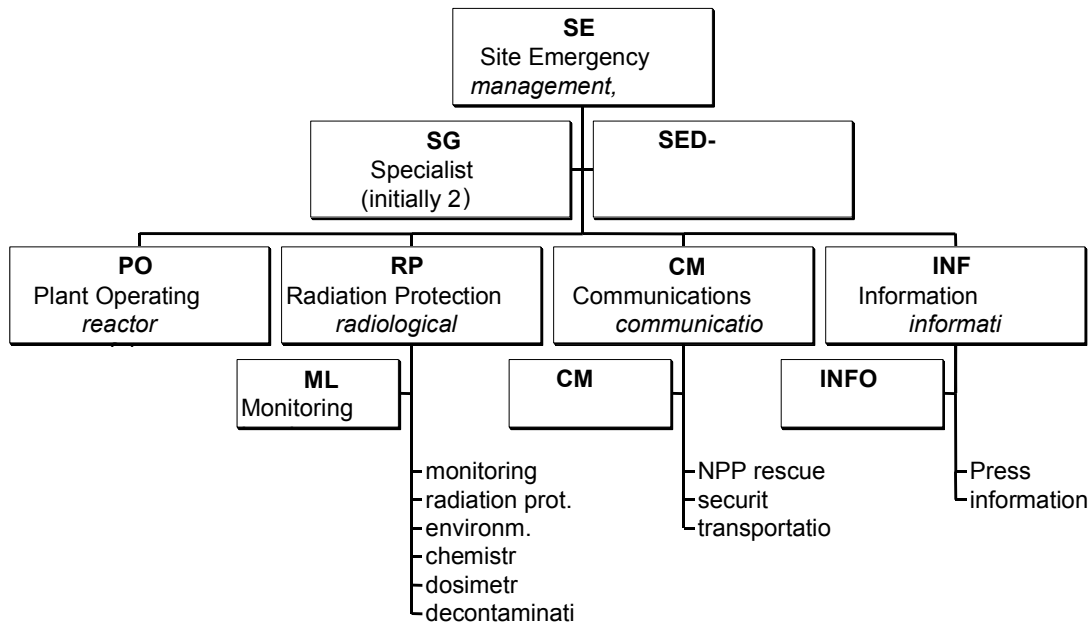


FIG. III.3. Emergency Control Center of Forsmark NPP.

Emergency organization of Forsmarks NPP

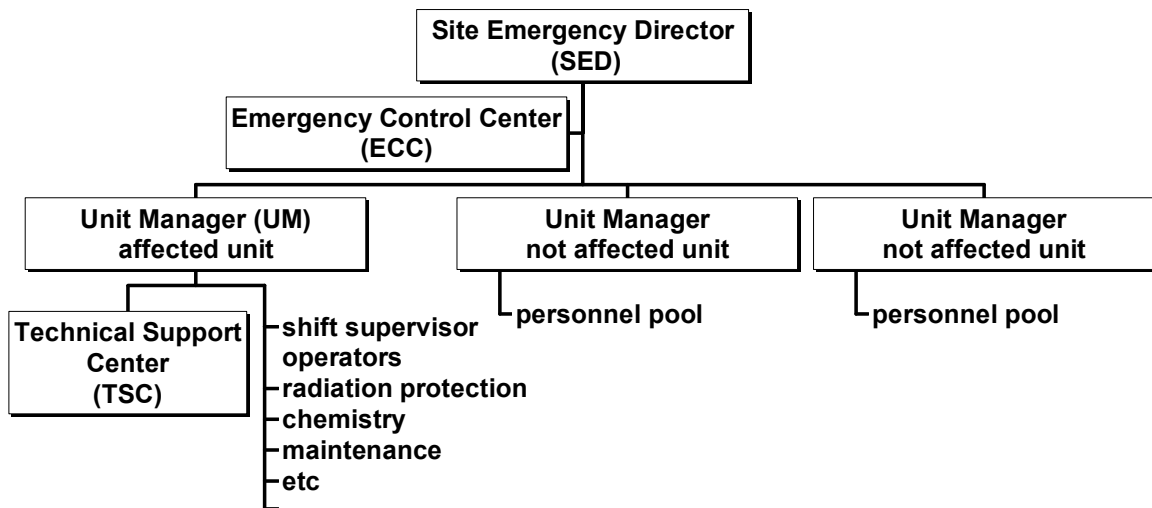


FIG. III.4. Emergency organization of Forsmark NPP.

ANNEX IV

EXAMPLES OF THE SEVERE ACCIDENT MANAGEMENT MANUALS

Nordic utilities, in particular, have adopted the practice to develop a SAM manual to support the personnel, who will make the critical SAM decisions. The objectives of the manual are twofold: first they aim at acquainting the AM personnel with all aspects of the severe accidents and their management, and secondly they have been written in such a way that they can support AM personnel also during the course of the severe accident. The SAM manuals can be utilized for the classroom training of the AM personnel in addition to the other technical basis documentation.

This Annex gives two examples of the SAM manuals developed for two NPPs: Forsmark NPP with BWR in Sweden and Loviisa NPP with WWER in Finland. There are some differences in the structure of these manuals, but the content as a whole is similar.

1. FORSMARK NPP

The structure of procedures and guidance reports in the Forsmark plant has been discussed in Ref. [IV.1]. During the accidents, there are specific EOPs used by the control room personnel. If the accident progresses beyond the validity of these EOPs, the accident management measures are guided by the knowledge of the emergency team. The main applicable tools for this phase are the Technical Support Document (TSD) at the unit level and the Manual for Severe Accident Management in the Emergency Crisis Centre (ECC). The manual contains the most important results and conclusions from the severe accident analyses performed. It also contains strategies for handling various accident situations and addresses important items relevant to AM. The manual is intended to be used by the TSC staff within the ECC.

The first version of the manual was developed at the beginning of the 1990's. Ref. [IV.1] discusses the upgrading of the manual. The aspects that have been emphasized are the strategies presented in the user friendly format. In the manual it was also reflected that certain short-term AM actions are of importance in the long-term perspective.

The main part of the manual is subdivided into four sections. The first section explains the use of the manual and the second one gives an overview of the current understanding of the severe accidents. The strategies for short-term measures in the Forsmark plant are then described in the third section subdivided into eight subsections. The strategies for long-term measures are described in the fourth section similarly subdivided into eight subsections. The remaining sections of the manual deal with various issues relevant for the ECC.

Contents of the Forsmark SAM Manual is as follows:

1. User's manual
2. Severe accidents — a general description
3. Short-term measures
4. Long-term measures
5. Instrumentation
6. Radiological environment after the accident
7. Safety measures for the personnel
8. AC power
9. Communication

10. Mobile equipment
11. Operation of non-damaged unit
12. Process parameters.

2. LOVIISA NPP

The first version of the manual is in use since May 2000. The publication with the title ‘SAM Manual: Training and Background Material for Severe Accident Management’ is applicable both for the TSC as well as for the off-site support during the accident. Clear structure increases its user friendliness.

After an introduction, there are seven sections in the publication devoted each to a separate severe accident safety function, which were defined specifically for Loviisa SAM. The safety functions are based on the requirement to ensure the containment integrity with a high confidence during severe accidents. Some of the safety functions (ensuring the containment integrity, primary circuit depressurization, in-vessel retention of the molten core, hydrogen management and containment overpressure protection with external sprays) have required significant plant modifications. The approach and its relation to the Finnish regulatory requirements have been explained in more detail in Ref. [IV.2].

The remaining sections of the Loviisa manual describe the recovery actions, which are bringing the plant to a long-term safe state, radiation protection and accidents during shutdown. In addition, there is an appendix describing the SAM instrumentation.

The contents of the Loviisa SAM Manual are:

1. Introduction
2. Ensuring the containment integrity and minimization of the releases
3. Depressurization of the primary circuit
4. Cooling the core or the core debris
5. Hydrogen management
6. Monitoring of the subcriticality
7. Prevention of the containment over-pressurization during a severe accident
8. Securing the fuel pool cooling
9. Recovery actions
10. Bringing the plant to the long-term safe state
11. Radiation protection issues
12. Accidents starting during shutdown conditions

Appendix 1: The instrumentation related to the SAM safety functions.

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ANNEX V

**CHARTS FOR FOLLOWING INSTRUMENTATION AVAILABILITY AND
SYSTEM DEPENDENCIES**

TABLE V.1. RPV PRESSURE INSTRUMENT DATA TABLE FOR BWRs

Instrument Identification	Readout	Range (psig)	Power Supply	Other Limitations and Adjustments Condensing Chamber (CC) or Heated Leg (LE)	Sensor Transmitter Location	Environmental Limitations	
						Temp.	Water Level
						Limit (°F)	Limit (ft)
PRIMARY							
PR-4599A PT-4599A	1C09 (SPDS B129)	0-1500	1Y11	LE 4531	RB-786-NE (1C56)	120	
PR-4599A PT-4599A	1C09 (SPDS B130)		1Y21	LE 4532	RB-757-NW (1C55)	104	
PI-4563 PT-4563	1C09 (SPDS B127)	0-1200	1Y23	CC 4561	RB-786-NE (1C56)	120	
PI-4564 PT-4564	1C09 (SPDS B128)		1D11	CC 4562	RB-757-NW (1C55)	104	
PI-4565 PT-4565	1C05		1D21	CC 4561	RB-786-NE (1C56A)	120	
PR-4542 PT-4542	1C05 (SPDS A-B405)	0-1100	1Y	LE 4532	RB-757-NW (1C55)	104	
PI-4590A PT-4590A	1C03	0-250	1Y11	LE 4531	RB-786-NE (1C56A)	120	
PI-4590B PT-4590B			1Y21	LE 4532	RB-757-NW (1C55)	104	
PI-4599A PT-4599A		0-1500	1Y11	LE 4531	RB-786-NE (1C56A)	120	
PI-4599B PT-4599B			1Y21	LE 4532	RB-757-NW (1C55)	104	

ANNEX VI

WORK CHARTS FOR AM ACTION PERFORMANCE

This is an excerpt of a work chart for AM actions performance that is used by NPP Krško in Slovenia. Inside NPP Krško ERO such work charts are developed for Emergency Director position and Shift Engineer position. Work charts are developed consistently with plant Emergency Preparedness Plan (EPP) documentation, i.e. Emergency Implementing Procedures (EIPs) and SAMGs.

Legend

Step/Location/Procedure

- Procedure step number which describes the action
- Abbreviations (MCR, TSC, EOF) show which location is responsible for performing an action. If more than one are listed it means that responsibility for performance of corresponding action transfers with the operability status of emergency organization (e.g. MCR-TSC-EOF means that responsibility for the action transfers from MCR to TSC and then to EOF).
- Procedure number in which describes the actions.

Action

- Determines activities to be performed in order to cope with the condition.

Emergency Director

- Describes main actions to be taken by emergency director

Other Personnel Involved

- Shows other personnel involved which is responsible to perform their actions to support to high level action described in “Action” section. TSC position responsible for performance of such action is shown in parenthesis () and EOF responsible position is shown in brackets [].

Action not taken IF

- In this column emergency class level(s) and/or other conditions are listed to indicate when performance of particular action is not applicable.

Performed (Date, Time, Signature)

- Emergency director fills in the data and signs when the action comes in effect.

TABLE VI.1. EXAMPLE OF A WORK CHART FOR AM ACTIONS AT KRSKO NPP

ACTIONS DURING EMERGENCY (Emergency Director)					
IMMEDIATE ACTIONS (if necessary)					
Step Location Procedure	Action	Emergency Director	Other Personnel Involved	Action not taken IF	Performed (Date, Time, Signature)
6.5.2 MCR-TSC EIP-17.041	Evacuation of limited plant area or building	<ol style="list-style-type: none"> Commands evacuation and determines: <ul style="list-style-type: none"> Area to be evacuated; Assembly point for evacuees; Special measures to be carried out. Informs shift engineer to announce evacuation over plant paging system. Informs security shift supervisor to coordinate evacuation.. Informs HP technician (if necessary) to perform necessary radiation protection measures. Follows-up on conduct of evacuation with security shift supervisor. Declares conditions for disbanding the assembly point. Declares normal conditions in affected (evacuated) area. 	<p>Shift Engineer</p> <ul style="list-style-type: none"> Announces evacuation over plant paging system <p>Security Shift Supervisor</p> <ul style="list-style-type: none"> Co-ordinates the conduct of evacuation Co-ordinates security personnel activities during evacuation Prepares the list of evacuees and provides it to Emergency Director <p>HP Technician</p> <ul style="list-style-type: none"> Performs radiological survey and decontamination of evacuees; Determines radiological conditions in affected area 	/	

TABLE VI.1. EXAMPLE OF A WORK CHART FOR AM ACTIONS AT KRSKO NPP (Continuation)

ACTIONS DURING EMERGENCY (Emergency Director)						
INITIAL ACTIONS						
Step Location Procedure	Action	Emergency Director	Other Personnel Involved	Action not taken IF	Performed (Date, Time, Signature)	
6.6.1 MCR EIP-17.020	Inform Shift Engineer to report to MCR	1. Calls Shift Engineer and informs him to report to MCR.	/	/		
6.6.2 MCR-TSC- EOF EIP-17.001	Emergency class determination	1. Use procedure EIP-17.001 and determine class of emergency. 2. Prepare and sign declaration of class of emergency.	Shift Engineer (TSC Data Communicator) <ul style="list-style-type: none"> Performs assessment of plant status to determine action level categories and corresponding class of emergency in accordance with procedure EIP-17.001. Provides support to emergency director in classification or reclassification of emergency. (Technical Support Coordinator) <ul style="list-style-type: none"> Co-ordinates support to Emergency Director for performance of classification/reclassification. 	/		

TABLE VI.1. EXAMPLE OF A WORK CHART FOR AM ACTIONS AT KRSKO NPP (Continuation)

6.6.6	Follow data about radiological conditions and assess radiological status around the plant	<ol style="list-style-type: none"> 1. Based on radiological conditions performs assessment of actual or potential radiological releases to the environment. 2. Follows situation on radioactive releases dispersion. 	<p>Shift Engineer (Off-site Monitoring Team Co-ordinator)</p> <ul style="list-style-type: none"> • Follows meteorological conditions and dispersion of radioactive releases; • Calculates dose rates in the environment using EIS application or manually; • Informs emergency director about radiological status. <p>(Radiation Protection Co-ordinator)</p> <ul style="list-style-type: none"> • Follows radiological consequences in environment; • Informs emergency director about the status. 	/	
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TABLE VI.1. EXAMPLE OF A WORK CHART FOR AM ACTIONS AT KRSKO NPP (Continuation)

6.6.18	Evaluation of conditions and action determination based on SAMGs.	1. Makes decisions and issues written order to implement actions based on evaluation per SAMGs.	<p>Shift Engineer (SAMG Evaluation Team in TSC)</p> <ul style="list-style-type: none"> Analyse the situation and recommend actions to emergency director based on SAMG. <p>(OSC Teams Foremen)</p> <ul style="list-style-type: none"> Evaluate suggested actions and provide support to emergency director with relevant information for decision making related to implementation. <p>(Technical Support Co-ordinator in TSC)</p> <ul style="list-style-type: none"> Co-ordinates status evaluation in accordance with SAMGs; Based on evaluation per SAMGS recommends actions to emergency director 	UNUSUAL EVENT ALERT SITE EMERGENCY	
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TABLE VI.1. EXAMPLE OF A WORK CHART FOR AM ACTIONS AT KRSKO NPP (Continuation)

ACTIONS DURING EMERGENCY (Emergency Director)					
SUBSEQUENT ACTIONS					
Step Location Procedure	Action	Emergency Director	Other Personnel Involved	Action not taken IF	Performed (Date, Time, Signature)
6.7.1 TSC EIP-17.022	Activation of TSC and transfer of responsibilities from MCR to TSC.	<ol style="list-style-type: none"> 1. In accordance with procedure EIP-17.022 Technical support centre – activation, perform actions to activate TSC. 2. Co-ordinate transfer responsibilities for implementation of actions from MCR to TSC. 	TPC Personnel <ul style="list-style-type: none"> • Take actions to activate TSC in accordance with procedure EIP-17.022 and assume responsibilities for continuation of actions that were before co-ordinated from MCR. 	UNUSUAL EVENT	

ANNEX VII

EXAMPLES OF COMPUTERIZED TOOLS

In several countries there is ongoing research, development and implementation of various computerized tools and expert systems for accident management and source term predictions to be used by control room operators, TSCs at the site and national emergency teams. A few examples of such systems are presented here.

EDF

Electricité de France (EDF) has developed a set of tools and simplified models, named TOUTEC and CRISALIDE, which are aimed to be used by the French Utility National Crisis Team in order to perform the task of diagnosis and prognosis during an emergency situation [VII.1]. The method is based on the diagnosis of the state of the safety barriers and on the prognosis of their behaviour.

At a first level, the software TOUTEC is intended to complement the handbook of crisis team members with simplified calculation models and predefined relationships. The main items are the calculation of the primary circuit break size and the evaluation of hydrogen burning. The set of models named CRISALIDE is devoted to evaluate the following critical parameters: delay before core uncovering, containment pressure behaviour and source term. With these models, it is possible to take into account combinations of boundary conditions according to safety and auxiliary systems availability and operator's actions. The CRISALIDE models and man-machine interface TOUMEC are running under WINDOWS environment on a personal computer.

IPSN

The Institute for Nuclear Safety and Protection (IPSN, at present IRSN) in France has developed a methodology to evaluate the plant status and to estimate the evolution of the accident in French PWRs [VII.2]. Two systems are used: SESAME for the evaluation of the plant status and potential releases and CONRAD for radiological consequences calculations. The diagnosis of the status of a PWR during an accident is based on the analysis of plant-specific data. The information transmitted from the plant is used by the expert team to assess the status of different safety functions and barriers. The specific tools of the SESAM system are used to quantify parameters such as break size or potential fission product release within or outside the plant. The prognosis of the evolution of safety functions and barriers is based on the assessment of the current and future availability of the safety systems and on extrapolations to forecast the evolution of the accident (time to core uncovering and core degradation, fission product releases prognosis, etc).

CAMS

The objective of CAMS (Computerized Accident Management Support) is to provide support in accident states and normal plant states [VII.3]. This support is offered in identification of the plant state, in assessment of the future development of the accident, and in planning accident mitigation strategies. The CAMS system is being developed as a research activity at the OECD Halden Reactor Project in Norway. The first CAMS prototype was completed in 1995.

CAMS consist of a data acquisition module, a signal-validation module, a tracking simulator, a predictive simulator, a state-identification module, a probabilistic safety assessment module, and a man-machine interface module. The work of these modules is coordinated by a module called the system manager. The data acquisition module operates as an interface between CAMS and the monitored process. In addition, there are the strategy generator and the critical function monitor. However, these two modules have not been integrated into the present version of the CAMS prototype.

The tracking simulator module gives an estimation of the values that are not directly measured, calculates the initial values that are needed for the predictive simulator, and gives support in the validation of the signals by calculating values of certain parameters. The predictive simulator module predicts the evolution of the state of the plant, being faster than the real process. Finally, the plant state identification module gives information about the state of the plant, the state of the systems (their availability), and the state of the critical safety functions (heat sinks, core cooling, reactivity control, and containment integrity).

The purpose of the PSA module is to provide on-line accident prevention and mitigation strategies for a nuclear power plant. The module contains plant specific PSA data, comprising event trees, failure probabilities, etc. The core damage frequency is re-calculated based on the current state of the plant and the pre-calculated PSA Level 1.

ADAM

The WINDOWS-based ADAM (Accident Diagnostic and Management) system has been developed by Energy Research, Inc. in USA for analysis of selected plant data, following accidents, to arrive at symptom-based diagnostics of potential nuclear power plant accidents [VII.4]. It operates in two modes:

1. On-line accident diagnostics/monitoring mode.

In this mode, selected plant parameters (as measured by plant sensors), arriving into ADAM at a pre-specified frequency, are used to assess the margins to core damage, containment failure, vent actuation, and hydrogen combustion (through appropriate alarms). In addition, the state of reactor, containment, and auxiliary building (if applicable), are assessed using a symptom-based diagnostics logic that is developed on a plant-specific basis.

2. Accident management and simulation mode.

In this mode, ADAM can be used to simulate various operational and severe accident scenarios to determine the potential impact of the available severe accident management strategies (or Emergency Operating Procedures) on the evolution of the accident in progress. Alternatively, ADAM can also be used as an accident analysis tool. The simulation code can also be used to generate data for the diagnostic mode to assist in the visual display of the accident. The plant initial conditions and information about the type of the accident is user-specified.

STM

The STM (Source Term Module) software, developed by NNC in the UK, employs Bayesian analysis techniques, in particular belief network analysis to calculate the conditional probabilities and the potential magnitude of a release of activity into the environment [VII.5]. STM had been designed to provide a rapid indication of the most likely source terms, prior to a release occurring, using plant data which will be available to the plant operator whilst

following emergency procedures to control the critical safety functions. The module is stand-alone and PC based and does not require expert knowledge of severe accidents or fission product behaviour. It has been developed using PSA Level 1 and Level 2 results for PWR Sizewell B plant in the UK. Source term categories are defined for the 3 release points (primary circuit/containment, secondary circuit and the auxiliary circuits) with information provided on the quantity and timing of the release.

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- [VII.5] ROJAS-PALMA, C., SOHIER, A., SMEDLEY, CH., GRINDON, E., CLARK, D., DUTTON, M., 'On and Off-site Source Term Estimation during Nuclear Emergencies', 7th Topical Meeting on Emergency Preparedness and Response, California, USA, September 1999.

ANNEX VIII

EXAMPLE OF TABLETOP SCENARIOS AND OBJECTIVES

1. OBJECTIVES

1. Given access to the SAMG documentation and given the information and data specified in this scenario, the EVALUATOR shall be able to use the guidance provided in the SAMG to perform the evaluations required by that process so that the DECISION MAKER will be able to make process based decisions.
2. Apply the entry criterion and exit conditions for applicable guidelines.
 - Recognize the criteria for entering applicable guidelines.
 - Prior to exiting a guideline, ensure that any applicable exit conditions are met and that a process to follow long term concerns is implemented.
3. Determine which strategies are available and applicable under current plant conditions.
4. Identify any negative impacts potentially associated with the available strategies and evaluate action to mitigate negative impacts.
5. Decide whether to implement a strategy and which mitigative action, if any, to take.
6. Specify instructions for the control room pertaining to strategy implementation and mitigative action.
 - Preferred line-up;
 - Limitations.
7. Verify implementation of instructions pertaining to strategies and mitigative actions.
8. Monitor negative impacts and decide whether to take additional mitigative action.
9. Check the effectiveness of an implemented strategy and determine whether additional strategies should be attempted.
10. Evaluate data and interpret instrumentation readings given that severe accident conditions exist.
11. Use computational aids as needed.
12. Actively participate in the scenario critique process.
13. Utilize effective communication techniques to coordinate emergency information/actions with the Control Room IMPLEMENTORS and other ERO staff.

2. TURNOVER INFORMATION — UNIT 2 SHIFT SUPERVISOR TO ON-CALL ED

- An ALERT was declared 1 hour ago due to a .07g seismic event. Both units remained at 100%.
- All off-site notifications have been made for the Alert.
- A Site Area Emergency was declared 20 minute ago following an after shock that resulted in a LB LOCA, an LOSP, and a loss of .1 Unit 1 AC Power.
- Suspected SU XFMER and Diesel Generator damage.
- All offsite notifications have been made for the SAE.
- Unit 2 is tripped and stable in accordance with the procedure ESP-0.1; 2B DG is supplying all needed Unit 2 loads.
- Unit 1 is currently under the procedure FRP-C.1 with CETCs 1300 degrees F and continuing to rise.
- Following the aftershock, the procedure ECP-0.0 was entered due to no Unit 1 Diesel Generators initially being available
 - B train has been restored; A train is still de-energized.
 - DG 1-2A failed to start due to damage to its fuel supply system.
 - DG 1C failed to start because it had previously been tagged out for slow start maintenance and is currently not available.
 - The 1B DG did automatically start following the LOSP but DG08 did not automatically close due to a suspected B1G sequencer failure; B train loads were manually shed and the 1G and 1L buses were manually energized by closing DG08 and DG02.
 - Switchhouse does not know how long the grid will be unavailable; the procedure FNP has priority for power restoration.
 - A Reentry team is working to return the 1C and 1-2A DGs to service.
- Following the reenergization of the B train, ECP-0.0 was exited
- Procedural transition has been through the procedures ECP-0.0, FRP-P. 1, FRP-Z. 1, EEP-0, FRP-C.2, to FRP-C1. Currently at FRP-C.1 step 22 preparing to transition to SACRG-1.
- Adverse CTMT conditions exist.
- SG levels are being maintained by the TDAFW pump.
- The 1A CCW pump, 1C Charging pump, and the 1D and 1E SW pumps have been started manually from the Control Room. Charging flow indicated on FI-943 is erratic.

3. DESCRIPTION OF THE SCENARIO 1A

TRANSIENT SAMG1R1 .WK4/SEQB03/TRE271H

Big picture

A transient occurs due to flooding of the cable spreading room. All ECCS injection is unavailable because of ESFAS actuation failure. AFW fails, and all fan coolers and containment spray do not operate. Seal cooling is provided to the RCPs, so a consequential seal LOCA does not occur. The containment is isolated.

Narrative summary

While operating at 100% power a break in the pre-action fire sprinkler system piping occurs in the Cable Spreading Room. Flooding begins because the fire protection piping has been left pressurized due to an earlier fire protection system problem. The unisolated flood is conservatively postulated to cause a short-to-ground of the power supplies to both trains of protection and control panels and termination cabinets in the room. This results in an automatic reactor trip/turbine trip at time 0. Due to the flooding no other protective actions or equipment operate. The short-to-ground of the DC power supply in the cabinets causes a trip of the cabinet DC power supply breakers which effectively generates a close signal for solenoids resulting in a loss of air to air operated components, including CTMT isolation dampers. Containment is effectively isolated and no release occurs. CTMT fan coolers and containment spray are also affected by the flooding and will not function. The flooding results in loss of AFW. The operators are expected to attempt to start AFW from the Hot Shutdown panels. Alternate alignment of condensate, and feed and bleed are unsuccessful and the SGs boil dry at approximately 25 minutes (actual time is 60 minutes). The loss of decay heat removal capability results in increasing core temperatures. PZR relief to the PRT results in PRT rupture disc failure at 35 minutes. Core uncover occurs in approximately 40 minutes (actual time is 100 minutes) followed by the onset of core melt (>1200F) at 50 minutes (actual time is 112 minutes). CETC failure occurs at 65 minutes (actual time is 180 minutes) with the last reading at 2594 °F. Vessel failure occurs at approximately 85 minutes (actual time is 185 minutes) from the start of the transient resulting in high pressure melt ejection.

The core damage frequency for this accident which was run as part of the IPE back-end analysis is $5.406e-6 \text{ yr}^{-1}$. Maximum CTMT pressure (with no successful operator actions) is 88 psig (52 psig for the time period of this scenario data) and CTMT failure occurs > 48 hours from the start of the transient with a maximum cavity concrete ablation of 6 ft.

4. DESCRIPTION OF THE SCENARIO IB

SBO-SAMG5R1/SEQB47/BOE24IH

Big picture

A single-unit LOSS OF ALL AC results in seal LOCAs on all 3 pumps with no RCS makeup available. The turbine-driven AFW pump provides decay heat removal until power is recovered at 75 minutes. Containment spray (both trains) is assumed to initiate when power is recovered, but neither train of SW or CCW is restored. ECCS injection and the containment fan coolers therefore do not operate. Spray recirculation is conservatively assumed to fail. The containment is isolated.

Narrative summary

While operating at 100% power a single-unit LOSP with loss of 4160 V buses F and G with failures of the associated bus DGs results in LOSS OF ALL AC (SBO). An automatic reactor/turbine trip occurs at time 0 due to complete loss of forced RCS flow. The SBO DG is initially unavailable. Due to loss of seal injection and CCW cooling to the RCP seals a seal LOCA of 480 gpm/pump (modelled as a 0.00375 ft² break in each of three intermediate legs) occurs at 5 minutes resulting in an SI actuation signal generation. The containment is isolated due to the SI but due to no electrical power available to the ESF pumps PZR level continues to decrease until empty at approximately 10 minutes. The turbine-driven AFW pump starts upon loss of all AC and provides SG makeup to allow for decay heat removal until power is recovered. The continued loss of RCS inventory without makeup results in increasing core temperatures. Core uncover occurs in approximately 30 minutes (actual time is 96 minutes) followed by the onset of core melt (>1200⁰F) at 45 minutes (actual time is 112 minutes). The SBO DG becomes available at 50 minutes however the failure of the 1A CCW pump and the B train SW pumps prevent operation of HHSI and LHSI. CETC failure occurs at 60 minutes (actual time is 210 minutes). Vessel failure occurs at approximately 110 minutes (actual time is 252 minutes) from the start of the transient resulting in high pressure melt ejection. Note that spray recirculation is conservatively assumed to fail at 115 minutes (actual time is 260 minutes).

The core damage frequency for this accident which was run as part of the IPE back-end analysis is 5.035e-7 yr⁻¹. Maximum CTMT pressure (with no successful operator actions) is 25 psig and CTMT failure occurs >48 hours from the start of the transient with a maximum cavity concrete ablation of 5.8 ft.

5. DESCRIPTION OF THE SCENARIO 2A

TRANSIENT- SAMG7R1.WK4//RVE211L

Big picture

An ATWT results in core damage, high RCS pressure and RPV rupture. The RPV rupture is modelled as a 4 ft² break in the vessel wall. (Note that this sequence bounds those cases where pressurized thermal shock (PTS) could be postulated to fail the RPV. Since this is a break beyond the capability of the ECCS, ECCS operation is not credited, but all three accumulators do inject. One CTMT fan cooler and one train of spray operate. Spray recirculation is assumed to be unsuccessful. Note that this sequence leads to substantial basemat ablation which could be mitigated by continued vessel injection/recirculation. The containment is isolated.

Turnover

A TSC/EOF table top drill is being conducted in the TSC as part of the EPP training programme. Both units are at 100% power.

Narrative summary

Unit 1 experiences a fault on the 1F 4160V bus resulting in a Main Turbine trip and loss of both SGFPs. The Steam Dumps do not operate. The Reactor does not trip automatically and can not be tripped from the Control Room. Continued power operation without the main feed system results in the 1B and 1C SGs boiling dry (1A RCP trips due to the electrical fault and therefore the 1A SG is not steaming). At 4.5 minutes core temperatures exceed 1200F and transition to the SAMGs occurs. At 5 minutes, RCS pressure is 2550 PSIG when the reactor is tripped locally by securing the operating CRDM set. At approximately 5.5 minutes the reactor pressure vessel is believed to fail due to the high pressure and corium relocation to the bottom reactor pressure vessel head. CETC indication fails at this time also. CTMT pressure reaches 50 PSIG during the transient. The Control Room Crew will proceed thru step 18 of SACRG-1 prior to the TSC reporting that they are staffed and monitoring the SAMGs. Success paths will include manual alignment of HHSI flow from the 1C Charging Pump, SG refill, CTMT flooding, manual operation of CTMT spray and fans. The TSC is expected to utilize SAG1, 3,4,6, and 8 as well as SAEG-1. No release occurs.

The core damage frequency for the RPV failure accident which was run as part of the IPE back-end analysis is $9.97e-8 \text{ yr}^{-1}$. Maximum CTMT pressure for the RPV failure without the ATWT (with no successful operator actions) is 32 psig and CTMT failure occurs >45 hours from the start of the transient with a maximum cavity concrete ablation of 7 ft.

6. DESCRIPTION OF THE SCENARIO 2B

LBLOCA- SAMG3R1/LLE27IL

Big picture

A seismic event causes a large LOCA to occur with failure of both trains of ESF to automatically initiate an SI signal. A subsequent LOSP with diesel/sequencer failures results in multiple failures of ESF equipment including all fan coolers and CTMT Spray. The LB LOCA is modelled as a 3 ft² break in the cold leg. ECCS injection using one charging pump will occur and all three accumulators will inject. The containment is isolated. The containment is predicted to fail at 37 hours because of over-pressurization.

Turnover

An ALERT has been declared due to a .07g seismic event which occurred 2 hours ago. DG 1C is tagged out of service for slow start investigation/maintenance. The TSC and EOF are staffed and operational. Both Units are at 100% power.

Narrative summary

An aftershock results in a LB LOCA and a Unit 1 LOSP due to SU XFMR damage. DG 1C had previously been tagged out for slow start maintenance and the 1-2A DG fails due to loss of its fuel supply system resulting in loss of all A train components. The 1B DG is running following the LOSP but due to damage to the B1G sequencer no loads were shed and the DG has not re-energized the 1G 4160V bus. The crew will reenergize the B train using ECP.0.0 and subsequently will transition thru FRP-P.1 and FRP-Z. 1 into EEP-0. The 1A CCW pump and 1C Charging pump will be restarted by the crew; no other B train components can be started from the Control Room. The 1B RHR pump can be made available once control power fuses are replaced. The lengthy time of core uncover results in increasing CETC temperatures and subsequent transition to FRP-C.2 and C. 1. Instrument air is available from Unit 2 and SG depressurization is allowed per FRP-C. 1. Despite FRP-C. 1 actions, CETC's continue to rise resulting in entry into SACRG1 at 18 minutes. At step 8 the TSC assumes responsibility for SAMG implementation and the crew transitions to SACRG2. The TSC continues DFC usage and implementation of SAG 3,4,6, and 8. CETCs fail at 28 minutes. Due to CTMT spray and fan coolers remaining unavailable CTMT pressure rises to greater than 92 psig at 50 minutes and the TSC transitions into SCG2 where venting is the only success path. At 65 minutes the crews will be informed that time has elapsed and that a negative 5 psig now exists in the CTMT resulting in TSC transition into SCG4.

The core damage frequency for this accident which was run as part of the IPE back-end analysis is $3.9\text{e-}6 \text{ yr}^{-1}$. Maximum CTMT pressure (with no successful operator actions) is 105 psig and CTMT failure occurs >36.8 hours from the start of the transient with a maximum cavity concrete ablation of 6.7 ft.

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Consultants Meeting

Vienna, Austria: 11–15 December 2000