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NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

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IMPLEMENTATION OF SEVERE ACCIDENT MANAGEMENT MEASURES

SUMMARY AND CONCLUSIONS
of a Workshop organised in Villigen, Switzerland
in collaboration with KKB, KKL, PSI and EDF/SEPTEN

10-13 September 2001

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ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Pursuant to Article 1 of the Convention signed in Paris on 14^{th} December 1960, and which came into force on 30^{th} September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

- to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
- to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and
- to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The original Member countries of the OECD are Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became Members subsequently through accession at the dates indicated hereafter : Japan (28th April 1964), Finland (28th January 1969), Australia (7th June 1971), New Zealand (29th May 1973), Mexico (18th May 1994), the Czech Republic (21st December 1995), Hungary (7th May 1996), Poland (22nd November 1996), the Republic of Korea (12th December 1996) and the Slovak Republic (14th December 2000). The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention).

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1st February 1958 under the name of the OEEC European Nuclear Energy Agency. NEA membership today consists of all European Member countries of OECD as well as Australia, Canada, Japan, the Republic of Korea, Mexico and the United States. The Commission of the European Communities takes part in the work of the Agency.

The mission of the NEA is:

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

Specific areas of competence of the NEA include safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency (IAEA), with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

C S N I

The NEA Committee on the Safety of Nuclear Installations (CSNI) is an international committee made up of senior scientists and engineers, with broad responsibilities for safety technology and research programmes, and representatives from regulatory authorities. It was set up in 1973 to develop and co-ordinate the activities of the NEA concerning the technical aspects of the design, construction and operation of nuclear installations insofar as they affect the safety of such installations. The Committee's purpose is to foster international co-operation in nuclear safety amongst the OECD Member countries. CSNI's main tasks are to exchange technical information and to promote collaboration between research, development, engineering and regulation organisations; to review the state of knowledge on selected topics of nuclear safety technology and safety assessments, including operating experience; to initiate and conduct programmes to overcome discrepancies, develop improvements and reach consensus on technical issues; to promote co-ordination of work, including the establishment of joint undertakings.

WORKING GROUP ON THE ANALYSIS AND MANAGEMENT OF ACCIDENTS (GAMA)

The Working Group on the Analysis and Management of Accidents is mainly composed of technical specialists in the areas of coolant system thermal-hydraulics, in-vessel protection, containment protection, and fission product retention. Its general functions include the exchange of information on national and international activities in these areas, the exchange of detailed technical information, and the discussion of progress achieved in respect of specific technical issues. Severe accident management is one of the important tasks of the group.

WORKSHOP ON THE IMPLEMENTATION OF SEVERE ACCIDENT MANAGEMENT MEASURES

organised in collaboration with KKB, KKL, PSI and EDF/SEPTEN

Villigen (Switzerland), 10-13 September 2001

SUMMARY AND CONCLUSIONS

INTRODUCTION

The OECD/NEA Workshop on the Implementation of Severe Accident Management (SAM) Measures was held in Würenlingen, Switzerland, September 10 – 13, 2001. It was hosted by the PSI (Paul Scherrer Institut), by two Swiss Utilities (Kernkraftwerk Beznau and Kernkraftwerk Leibstadt), and by Electricité de France. Eighty specialists from fourteen OECD Member countries attended the meeting, as well as specialists from three non-Member economies and the European Commission; a list of participants is reproduced in Appendix 1. The absence of representatives from U.S. plants was regretted since it was known that a comprehensive implementation programme for Severe Accident Management has come to completion by the end of 1998.[1] Thirty-three papers were presented in four sessions, preceded by a brief Introductory Session (two invited papers) and followed by a General Discussion. The programme of the Workshop is reproduced in Appendix 2.

The reason for the meeting was that the CSNI felt it timely to “follow-up” on the past activities in the area of severe accident management implementation and to take stock of the progress made since the Rome Meeting on Severe Accident Management Programme Development held in September 1991 [CSNI reports NEA/CSNI/R(1991)16 and (1992)6], the Niantic Specialist Meeting on Severe Accident Management Implementation held in June 1995 [NEA/CSNI/R(1995)5 and 16], and the Winnipeg Workshop on the Implementation of Hydrogen Mitigation Techniques held in May 1996 [NEA/CSNI/R(1996)8 and 9].

Other relevant CSNI-sponsored meetings were held over the last decade:

- A third Workshop on Iodine Chemistry in Reactor Safety was held in Tokai-mura, Japan in September 1991 [NEA/CSNI/R(1991)15 and (1992)5].
- A second CSNI Specialist Meeting on Molten Core Debris-Concrete Interactions was organised in Karlsruhe, Germany in April 1992 [NEA/CSNI/R(1992)10 and (1993)5].

[1] A US utility representative intended to participate but was prevented at the last minute.

- A first Specialist Meeting on Instrumentation to Manage Severe Accidents was held in Cologne, Germany in March 1992 [NEA/CSNI/R(1992)11 and (1993)3].
- A Specialist Meeting on Fuel-Coolant Interactions was organised in Santa Barbara, California, USA in January 1993 [NEA/CSNI/R(1993)8].
- A first Specialist Meeting on Operator Aids for Severe Accident Management and Training (SAMOA-1) was held at the OECD Halden Reactor Project, Norway in June 1993 [NEA/CSNI/R(1993)9 and (1994)13].
- A Workshop on Large Molten Pool Heat Transfer was organised in Grenoble, France in March 1994 [NEA/CSNI/R(1994)11 and 31].
- A Specialist Meeting on Selected Containment Severe Accident Management Strategies was held in Stockholm, Sweden in June 1994 [NEA/CSNI/R(1994)33 and (1995)3].
- A fourth Workshop on the Chemistry of Iodine in Reactor Safety was organised in Würenlingen, Switzerland in June 1996 [NEA/CSNI/R(1996)6 and 7].
- A Specialist Meeting on Fuel-Coolant Interactions was held in Tokai-mura, Japan in May 1997 [NEA/CSNI/R(1997)26 and 30].
- A second Specialist Meeting on Operator Aids for Severe Accident Management (SAMOA-2) was organised in Lyon, France in September 1997 [NEA/CSNI/R(1997)10 and 27].
- A Workshop on In-Vessel Core Debris Retention and Coolability was held in Garching, Germany in March 1998 [NEA/CSNI/R(1998)18 and 21].
- A third Specialist Meeting on Nuclear Aerosols in Reactor Safety was organised in Cologne, Germany in June 1998 [NEA/CSNI/R(1998)4 and (1999)5].
- A Workshop on Iodine Aspects of Severe Accident Management was held in Vantaa, Finland in May 1999 [NEA/CSNI/R(1999)7 and (2000)12].
- A Workshop on Ex-Vessel Debris Coolability was organised in Karlsruhe, Germany in November 1999 [NEA/CSNI/R(2000)14].
- A Workshop on Operator Training for Severe Accidents and Instrumentation Capabilities under Severe Accident Conditions was held in Lyon, France in March 2001 [NEA/CSNI/R(2001)7].

The objectives of the meeting were:

1) to exchange information on activities in the area of SAM implementation and on the rationale for such actions,
2) to monitor progress made,
3) to identify cases of agreement or disagreement,
4) to discuss future orientations of work,
5) to make recommendations to the CSNI.

SESSIONS

Session summaries prepared by the Chairpersons and discussed by the whole writing group are given in Annex. During the first session**, *"SAM Programmes Implementation"***, papers from one regulator and several utilities and national research institutes were presented to outline the status of implementation of SAM programmes in countries like Switzerland, Russia, Spain, Finland, Belgium and Korea. Also, the contribution of SAM to the safety of Japanese plants (in terms of core damage frequency) was quantified in a paper. One paper gave an overview on the situation regarding SAM implementation in Europe.

The second session, ***"SAM Approach"***, provided background and bases for Severe Accident Management in countries like Sweden, Japan, Germany and Switzerland**,** as well as for hardware features in advanced light water reactor designs, such as the European Pressurised Reactor (EPR), regarding Severe Accident Management.

The third session, ***"SAM Mitigation Measures"***, was about hardware measures, in particular those oriented towards hydrogen mitigation where fundamentally different approaches have been taken in Scandinavian countries, France, Germany and Korea. Three papers addressed specific contributions from research to provide a broader basis for the assumptions made in certain computer codes used for the assessment of plant risk arising from beyond-design accident sequences.

The fourth session, ***"Implementation of SAM Measures on VVER-1000 Reactors"***, was about the status of work on Severe Accident Management implementation in VVER reactors of existing design and in a new plant currently under construction.

GENERAL CONCLUSIONS

The overall picture is that Severe Accident Management has been implemented in various ways in many plants, but not yet in all plants. A systematic approach, which is based upon a clearly defined decision-making process, is one of the features implemented in many cases. Available means are determined and priorities are set. This approach is made up of strategies intended to become an optimum approach to prevent or mitigate the consequences of beyond-design basis accidents. It is based upon a prepared information package about plant-specific behaviour to be expected in beyond-design scenarios.

The approaches followed in the different countries do not fit one single pattern. Harmonisation, to the extent it is desirable, does not seem feasible at this stage. As a rule, the responsibility of the plant owner for the safety of his plant remains untouched. Also, safety goals may vary between countries.

Actual differences between SAM programmes at different plants exist also in terms of:

- status of progress of work on specific programmes,
- the extent to which hardware solutions are part of the SAM approach at a plant,

- the extent to which the decision-making process at a specific plant is left in the hands of the operators in the main control room or becomes the responsibility of a specific Technical Support Centre.

In many plants, hardware modifications have been implemented in the frame of the SAM strategy, while in many others SAM programmes, implementation mostly took the form of new or improved procedures and guidelines. From the presentations and discussions at the meeting, it appears that this difference in approach does not necessarily result in differences in safety levels, but reflects differences in regulatory requirements in different countries, and/or differences in the options adopted by utilities.

In some countries, specific approaches were developed years ago and have remained essentially unchanged until today.

In many countries, the development and implementation of a SAM programme has been a requirement of the safety authorities, but not necessarily translated into rules and regulations. It is finally the duty of the safety authority to review the work of the utilities.

Progress made since the Niantic meeting includes:

- In general, the extent of implementation of the SAM programme is remarkable. This was shown in session 1.
- Basic work for identification of features to address severe accident management issues in reactors in Eastern Europe is well under way.
- Hardware modifications in addition to software development -- In many plants, in particular in Finland, Germany and Sweden, hardware modifications have been implemented in the frame of the SAM strategy, while in many others the implementation of SAM mostly took only the form of new or improved procedures and guidelines.
- Since the Winnipeg Workshop, the extent of implementation of hydrogen mitigation measures, mainly passive autocatalytic recombiners (PARs), has significantly increased in many countries, in particular in some Western European countries.
- The role and significance of plant-specific probabilistic safety analyses (PSA) were stressed. Some utilities have used PSAs in an attempt to develop and further improve plant-specific accident management procedures.
- Operational states covered by SAMG -- The implemented SAMGs cover only accidents initiated under full-power operation conditions. Past PRA studies have identified Low Power and Shutdown (LPSD) states as significant risk contributors. This topic was not extensively covered during the meeting as only one presentation was devoted to how SAM approaches could be developed to address LPSD state challenges. Progress in this area was thus difficult to assess. Nevertheless, the Westinghouse presentation showed that the WOG SAMGs do not have to be completely rewritten to cover accidents starting in shutdown states, but a few important modifications and additions are needed.
- Duration of the process -- Overall, it can be concluded that a long time is needed between the decision to implement a SAM programme and the end of actual implementation, i.e. including the training programme. The duration of the process was reported to be between 4 and 10 years, depending on the approach selected for the SAM programme.

Once implemented, the Severe Accident Management Guidelines (SAMGs) should be considered as a living product. They should be periodically reviewed and updated, and improved if necessary, as new knowledge becomes available and new assessment methods are developed. This should be part of the safety culture at a plant. It also allows smooth knowledge transfer to newcomers.

It is just recalled briefly here that the details of operator training for severe accident management and instrumentation capabilities under severe accident conditions were discussed during a Workshop held in Lyon in March 2001.

The role of research with respect to SAM was discussed. Although further R&D results are not expected to modify SAM strategies significantly in the future, they could nevertheless reduce some remaining important uncertainties and give more confidence in the robustness of guidelines, either existing or to be developed. Examples of areas where further R&D results could increase confidence are ex-vessel debris coolability and fuel/coolant interactions.

It was pointed out that ageing materials might exhibit smaller margins with respect to limiting design conditions. It was stressed that component reliability and initiating event frequencies could be influenced by ageing phenomena.

In many countries, electricity market liberalisation (deregulation) is known to put financial pressure on the utilities. Concern was expressed that utilities would avoid implementing safety improvements that are not strictly required by the regulator. However, this was not the case for the utilities that reported their work at the meeting.

The benefit of conducting a SAM implementation programme is not only achieving the goals of the exercise but also acquiring important knowledge and experience in related areas. Many utilities reported that the process had important beneficial by-products. Examples are: improved communications between different parts of the organisation, and between different organisations; making the plant personnel more aware of the plant PSA thereby increasing their knowledge of the relative importance of safety features; improved PSA by taking into account the experience and insights of plant personnel; independent safety review of the plant, bringing improvements to operational practices, to the periodic testing programme, and to accident and incident procedures; improved training programme; last but not least in providing a good way for knowledge transfer to the young.

The subject of severe accident management is part of a string of actions that are taken by utilities and national authorities in order to be able to respond appropriately to a severe accident at a nuclear power plant. Such actions involve a large number of steps, such as preventive actions, installation of hardware, development and implementation of software, development and implementation of severe accident management strategies and programmes (including guidelines), training of all personnel - in the plant and outside the plant - who would be called upon to deal with a severe accident, severe accident management, emergency centres, mitigation of consequences, emergency preparedness, and emergency response plans. Several international organisations, including the NEA and the International Atomic Energy Agency, have responsibilities and are active in this area; they have published a large number of documents. The NEA organises periodic international emergency exercises. The Chairman of the Workshop summarized during the meeting a document that the IAEA intends to publish in 2002, “Preparedness and Response for a Nuclear or Radiological Emergency”.

RECOMMENDATIONS

- Severe accident management programme development is a living process. Severe accident management strategies and associated procedures or guidance should be reviewed periodically. New knowledge, gained from experience or from research, should be integrated regularly. Severe accident management leaves no room to complacency or negligence. It should be part of the safety culture at a plant.
- Appropriate training for severe accident management should be provided regularly, at every level.
- Significant uncertainties remain regarding the feasibility of ex-vessel debris coolability. Efforts should be made to assess the effectiveness of ex-vessel debris cooling and to increase confidence in related accident management strategies and procedures.
- Effort should be made to clarify strategies developed to address Low Power and Shutdown states, both from a procedural standpoint and an implementation time frame perspective.
- Another meeting to exchange information and experience on the implementation of severe accident management measures should be held in a not too distant future (say, two or three years, if enough new information is available by that time), preferably in the USA or Japan in order to encourage participation from the utilities of these countries.

ANNEX

SESSION SUMMARIES

Session 1

SAM Programmes Implementation

Session Chairpersons:

W. Aeberli (KKB)
B. De Boeck (AVN)
R. Martínez (Tecnatom)
G.M. Schoen (HSK)

Twelve papers were presented during Session 1.

During this session, the implementation of severe accident programmes in several countries and/or nuclear power plants was presented. This broad spectrum of overviews allowed to have a detailed picture of the status in those countries and to measure the progress achieved since the Niantic meeting. In particular, it appeared that, even though a number of countries have completed their implementation programme, there are still many countries that are either in the implementation phase or in an improving and optimisation phase.

In ***Switzerland***, the Federal Nuclear Safety Inspectorate (HSK) has completed its policy on SAMG and the utilities are expected to complete implementation by the end of 2003. The basic elements of the HSK policy consist of high-level qualitative objectives. The utilities are given the necessary flexibility to devise solutions meeting those objectives.

The following items were discussed after the presentation:

- Some participants expressed surprise that a safety authority considers cost/benefit aspects in its decisions regarding SAM-related backfitting at plants, as regulations in their countries do not include such a requirement. They asked how the benefits of possible backfits were measured. The speaker explained that in Switzerland extensive backfits had already been implemented (as described in the paper). The benefit of additional backfits can be analyzed with the help of PSA. Furthermore, the benefit of backfits (e.g., measurement instrumentation) can also be assessed or demonstrated using the experience gained with SAM exercises.
- The difference between the terms ‘guidance’ and ‘guideline’. Guidance seems to be appropriate. The authority provides goals and objectives, but actual implementation is the plant’s responsibility. The authority will monitor the implementation.

In ***Russia***, a requirement for beyond design basis accident management was introduced in the regulations in 1997, but the implementation of the programme is still far from complete. First experience with the programme is being fed back into the process. One of the lessons learned concerns the need to optimise the balance between probabilistic and deterministic methods.

The following items were discussed after the presentation:

- In the categorisation scheme to be worked out, the time-wise evolution of specific accidents has not been considered. The approach, so far, has been purely qualitative.
- An attempt will be made to find a correlation between signals provided by the instrumentation and the action steps to be done subsequently. Some additional instrumentation has been added to improve the available information about the plant status in specific situations.
- Some degree of skepticism was shown about the accuracy practicable in the presented approach of identifying the degree of core damage.

In ***Japan***, the utilities were required in 1992 to submit implementation plans for accident management. Those plans were reviewed by the MITI in 1994 and it is now expected that the implementation phase for all PWRs and BWRs will be completed in 2002. In the past years, the effectiveness of the measures being implemented has been assessed by means of PSA in order to quantify the expected reduction in core damage frequency and in containment failure frequency.

The following items were discussed after the presentation:

- Although the factors of CDF reduction are impressive, they might need some qualification as no information about the consideration of scenarios due to external initiating events is available.
- The strategies considered in the evaluation are basically those which were developed for U.S. reactors; some additional strategies are considered, such as natural convection containment vessel cooling. All related hardware backfits will be implemented by the end of February 2002.

In the next three papers, three ***Spanish*** utilities described the implementation process of SAM in their plants:

- In Garoña, the implementation was finished at the end of 2000. The generic guidance of the BWROG was used and applied in a plant specific way. No hardware modifications were implemented. A very useful set of lessons learned during the implementation process constituted an important feedback to the plant.
- Trillo is a Siemens-KWU PWR. In accordance with CSN (Spanish Regulatory Body) requirements, the German rules and regulations are applicable. For SAM, this meant the RSK recommendations were analyzed for their applicability to Trillo. In particular it was decided to install PARs. The PSA showed that filtered containment venting was not needed. The end of the implementation is foreseen in 2002 and will have to be approved by the CSN.
- Ascó, Vandellós and Almaraz are Westinghouse PWRs. The technical basis for SAM was the WOG generic guidance. Translating the generic guidance into plant specific SAMGs was seen as an important process. The SAMGs were validated by specific exercises. Training is an important part of the implementation. Interesting lessons had been learned during the programme development and implementation. The implementation had been completed recently (December 2000-February 2001). For some plants, possible improvement studies had been identified.

The following items were discussed after the presentation:

- The plant simulators are being used for validation, but only within the simulation scope (EOP domain), which does usually not cover core damage.
- Periodic retraining of the plant personnel for SAM will be performed once a year.
- Revisions to the Owners' Group generic guidance are not implemented systematically.
- Clarifications were asked concerning the basis of the dimensioning of the PAR system for Trillo. It was answered that analyses performed by Siemens supported this feature.
- A question was asked about the difficulty of applying the rules and regulations of the country of origin of the plant, which sometimes means taking apparently contradictory measures for different plants in the same country. It was answered that, in some cases, it was indeed not an easy situation, but that it was manageable, taking into account the particular technical aspects of the plants.

The ***Finnish*** presentation summarized the comprehensive SAM strategy that has been developed and progressively implemented at Loviisa since more than 10 years. The overall approach includes hardware modifications for core damage prevention and mitigation, new I&C qualified for SA conditions, new guidelines, a revision to the emergency preparedness organization, and a training programme for which a SA simulator is being developed. The most innovative hardware modifications include the provision to cool the molten core debris inside the vessel by cavity flooding and long-term containment cooling by external spray. The hydrogen management strategy resulted in a new approach with three components: capability to open the ice condenser doors for mixing purposes, installation of PARs, keeping the igniters in the lower containment compartments.

The following items were discussed after the presentation:

- There was a question about the way to handle station blackout events. It was answered that an independent electrical source was installed for SAM purposes.
- The strategy to cool the molten core does not take a failure of the in-vessel cooling into account. Significant efforts have been made to take all uncertainties into account; in-vessel cooling by cavity flooding has been shown to work very reliably.
- The question was asked why the glow plugs are still maintained. The answer was that they are needed to cope with fast hydrogen production. The estimated containment failure pressure is indeed rather low.

The ***Belgian*** paper provided an overview on the severe accident approach in this country. Several measures that could be implemented to reduce the risk associated with beyond-design-basis accidents were examined. Plant-specific severe accident analyses were performed with the MELCOR code. Taking into account the installation of catalytic recombiners the probability of containment failure by hydrogen combustion before or at vessel failure is negligible. A comparative study clearly established the advantages of passive autocatalytic recombiners (PAR) compared to other systems like ignitors or containment inertisation. Flooding the reactor vessel cavity is under consideration as a severe accident management measure to mitigate the consequences of core/concrete-interactions. Negative effects like pressure rise, thermal shock of the reactor pressure vessel, reduced amount of water in the sump for recirculation etc. had been considered. The conclusion had been that for some units it could be possible to find a way to inject water but for some others not. The overall approach is to implement plant-specific WOG SAMGs for the Tihange NPP, while for the Doel NPP the already existing severe accident procedures are being extended and updated by corresponding guidelines.

The following items were discussed after the presentation:

- The reliability of computation of the H_2 production and risk coming from H_2 was discussed. It was mentioned that local H_2 concentration could be a problem.
- The size of the total catalytic surface is large enough to hold the average hydrogen concentration below 5% (with 20% safety margin on installed catalytic surface). It was questioned why 5% and not 4% of hydrogen concentration was used as a design criterion. It was answered that the design allows for combustible mixtures, but tries to avoid fast deflagration.
- It was emphasized that the qualification of the instrumentation is important.
- The fact that in Doel, the operators in the main control room are more strongly involved in the SAM compared to what is foreseen in the SAMG-WOG was noted.

The status of regulatory activities related to the accident management programme in ***Korea*** was presented. Based on the regulatory requirement, the accident management programme will be implemented in all Korean NPP's between June 2001 and December 2008. KINS is reviewing the adequacy of the Korea Standard Nuclear Plant Severe Accident Management Guidance and is developing an Accident Management Program Review Guideline (AMPRG). The AMPRG consists of: the review of the SAR (Safety Analysis Report), general requirements of the accident management programme, the review of materials submitted by the licensee, and the review of the plant strategies during accident conditions.

The following items were discussed:

- The approach is basically the Westinghouse approach with some formal differences.
- The definition of a stable condition/state for finishing the severe accident management. (The termination conditions are given in the Diagnostic Flow Chart).
- Some of the presented criteria (e.g. core exit temperature) are given with an excessive precision on the values. The precision of these values was questioned. It was explained that these values had resulted from the conversion from a system with different units.
- In Korea there are different plant concepts, for example CANDU NPPs. The licensee will decide whether the SAMG developed by the Westinghouse Owners' Group will be used as a basis.

The status of implementation of SAMG at the Borssele NPP in ***The Netherlands*** was presented. The general considerations and task definition for the implementation of the SAM programme in Borssele, the time schedule and basic criteria to adapt the Westinghouse approach to a Siemens design plant were described. Furthermore, the basic considerations about responsibilities, and the equilibrium between two different reactor concepts were described. Priorities on the scenario surveillance and expectations in the near future were also presented.

The following items were discussed:

- There was some confusion regarding the time schedule and the total time of the project. It was explained that the reason for this are differences with the original time planning.
- It was concluded that it is impossible to separate effects like stress concepts, mechanical analysis, and other criteria in some scenarios.

- The initial assumptions (e.g. station blackout) were discussed.
- It was considered necessary to have clear prioritization criteria.

SAMIME is a ***European Commission*** (EC) Concerted Action on Severe Accident Management Implementation and Expertise in Europe. An overview of the EC project was given. Different countries and companies were involved in obtaining updating on guidelines and a reasonable consensus degree about different items related to SA management. It was emphasized that first the technical insights of severe accidents should be considered. Based on this knowledge, strategies can be developed which are then the basis of the plant-specific guidelines. Different steps and phases have been identified: status review, SAM guidance, useful tools, research and development activities, compilation of results.

The following items were discussed:

- The reliability and uncertainties of a level 2 PSA, and in particular how to quantify SAMG based operator actions, were discussed. The presenter emphasized that the use of PSA for SAMG development had been discussed during the SAMIME project.
- The importance of the transition criteria from EOPs to SAMGs was stressed. Differences in the SAM approach may be a reason to select different transition criteria.

GENERAL DISCUSSION ON SESSION 1

- It was noted that the field of SAM development, implementation and improvement is still very active, six years after the Niantic meeting.
- In most countries, the development and implementation of a SAM programme has been a requirement from the safety authorities, but not necessarily translated in rules and regulations. There is agreement that the role of the regulator is to set high level objectives, without being too prescriptive concerning the way to meet the objectives. The utilities should then develop solutions that not only meet the objectives, but that are also technically, financially and practically feasible. It is finally the duty of the regulator to review the work of the utilities.
- It was noted that a PSA can be a useful tool in the frame of SAM. It can help to define some aspects of the SAMGs and to validate them, to quantify safety benefits of SAMG, and can help in defining the SAM training programme.

Session 2

SAM Approach

Session Chairpersons:

M. Auglaire (Tractebel)
H. Eitschberger (KKL)
S. Guieu (EDF)
S. Güntay (PSI)

Six papers were presented during Session 2, devoted to severe accident management development.

The first paper presented the ***German*** approach to SAM with focus on the interaction between the different public and utility organisations in the case of an accident. A beyond-design-basis-accident operating manual is being developed, for use at the plants. Samples of flow charts were presented to show the generic approach of guidance in an accident.

The following items were discussed after the presentation:

- The question “when to alarm the population?” could not be finally answered.
- The majority of the procedures concentrate on preventive measures.
- The development of more detailed plant specific procedures and handbooks is still to be required.
- Time to reach pressure for FCVS opening is in the same range as the time needed for basemat meltthrough.
- Filtration of MCR air is needed before and during containment venting.

An overview of the implementation of SAM in ***Sweden*** presented in the second paper showed a comprehensive and detailed approach for PWRs and BWRs. Especially the implementation of a knowledge-based handbook seems to close gaps between predefined actions and possible challenges during an accident.

The following items were highlighted during the discussions after the presentation:

- SBO is the basic event used for containment venting design.
- External spray uses an independent diesel generator.
- A list of future investigations of phenomena like steam explosion, core melt coolability, long term effects etc. shows the desire to overcome present uncertainties.

In the third paper presented, the importance of the use in ***Switzerland*** of PSA methods and deterministic models for development of SAMGs was demonstrated. The Leibstadt NPP uses the code MELCOR 1.8.4: they built a complete model with all safety systems, integrated controls and consideration of accident management actions. The insights gained already helped improving existing EOPs and will support verification and training of severe accident management guidance. This approach is encouraged by the Swiss authority.

In response to the request of the regulatory authority for nuclear power in ***Japan*** to upgrade the safety of the installations regarding AM measures, JAPC had introduced backfitting modifications to prevent and mitigate severe accidents in BWR and PWR. The basis for hardware modifications came from the results of Probabilistic Safety Assessment. In addition to these hardware modifications, emergency procedures defining the organisation have been developed together with training programmes.

Westinghouse Electric Europe presented an overview of the Westinghouse SAMG package, describing the chosen approach as well as the overall organisation of the SAMG-WOG procedures. The existing SAMG-WOG package is only applicable for nominal (power) conditions. However, several PSA studies performed have shown that core damage frequency during shutdown and low power operation can be of the same order of magnitude as for full power operation. Based on this conclusion, Westinghouse developed the Shutdown Severe Accident Management Guidance (SSAMG) which gives guidance for both control room and TSC personnel. These shutdown SAMGs will be an extension of the existing SAMG package.

The extensive R&D efforts made since TMI-2 on phenomena to be expected in a severe accident enable today the design of new NPPs achieving the overall goal of reliable confinement of fission products in case of severe accidents. A paper presented by ***Framatome ANP*** showed that mitigation measures related to hydrogen control, long-term reduction of containment pressure, and melt retention have been introduced in the design of the new European Pressurized Water Reactor (EPR) as well as in the new Boiling Water Reactor (SWR1000).

The following items were discussed after the presentations:

- New designs profit significantly from R&D developments and new techniques to solve different problems in facing severe accidents in existing NPPs. So they are designed with H_2 mitigation, long-term containment cooling, ex-vessel debris stabilization and proper instrumentation covering a wide range in order to monitor the effectiveness of mitigative actions, even in a harsh environment.
- Nevertheless, one designer expressed the view that the need for future R&D programmes can be limited to confirmatory experiments for SAM implemented on existing plants.
- The opportunities for introducing mitigation measures - new hardware and software implementation or modification of existing ones - in current LWRs are limited because of their design.

Session 3

SAM Mitigation Measures

Session Chairpersons:

G. Koroll (AECL)
P. Lundström (Fortum)
J. Oliveri (IPSN)
J. Rohde (GRS)

Session 3 comprised 10 papers on selected aspects of SAM Mitigation Measures, covering a range of topics including analysis of the effectiveness of SAM Measures, hardware descriptions and R&D on SA phenomena relevant to SAM.

Analyses of the effectiveness of the SAM Measure of RCS injection for the Maanshan PWR (***Chinese Taipei***) were presented by INER. The speaker described MAAP4 analyses of SBO sequences with and without operator intervention. The operator intervention involved RCS injection in form of bleed-and-feed cooling (base case), with sensitivity studies on effects of the number of PORVs (power operated relief valves) and CCPs (centrifugal charging pumps). The case of 2 CCP plus 1 PORV was found to provide more injection flow (and less hydrogen mass generated) than the case of 2 PORV plus 1 CCP.

The next paper was devoted to the implementation of PAR systems in ***German*** LWRs. The presentation described the major regulatory developments; from the German Risk Study of 1988 to the recommendation of RSK in 1998 to implement PARs; the technological development and qualification of PARs; the reference analyses done at GRS and the current status of implementation (near completion at the time of presentation) in German LWRs. The speaker described the basis used for calculation of the hydrogen source and the particular features of the reference calculation of hydrogen distributions, showing that PARs effectively control the hydrogen threat and that any deflagrations that may arise in the containment will be in an environment of diminished hydrogen mass (due to action of PARs) and through a negative concentration gradient in direction of containment boundary, which opposes flame acceleration effects.

Hardware available from ***Framatome ANP*** for hydrogen control (PARs) and filtered venting (venturi scrubber) for severe accident application in LWR reactors was described in the following paper.

An EDF paper described the systematic assessment of hydrogen control alternatives which had led to a decision to implement PARs in ***French*** NPPs and the official launch of the industrial process in 2001 March to complete installation in French NPPs by 2007. Ignitors were ruled out because of the complexity of analysis for combustion sequences and inability to function under steam-inerted situations. Inerting schemes were ruled out because of cost, complexity and safety hazard (hypoxia) during normal operation. The PAR validation process was described and insights on implementation aspects were given. With respect to the potential for PARs-initiated deflagration, it is viewed that the reduction of hydrogen concentration by PARs would be beneficial at all times with respect to possible combustion threats (relative to no PARs), given that ignition from a random source could not be ruled out in any case. In response to a question from the Swedish delegate on the technical basis for the EDF implementation of PARs, the author cited the defence-in-depth principle and an interest in conforming with German and Belgian approaches. The IPSN participant stated that mitigation was required by the safety authorities in order to avoid combustion pressure higher than the pressure leading to loss of containment leak-tightness under assumption of hydrogen generation resulting from 100% Zr oxidation of active cladding.

Severe Accident hydrogen control in the ***Korean*** KSNP (1000 MWe-class PWR) was described in a paper presented by KINS. The KSNP hydrogen analyses assume 100% fuel clad oxidation, resulting in 11.8% average hydrogen concentration in containment (MAAP 4.0.1 calculation). Hydrogen control is effected by ignitors installed at 20 locations in the cavity, drain tank and SG compartment. Hydrogen distribution analyses, using CONTAIN and 3D GOTHIC, show that ignitor locations are adequate from the viewpoint of local hydrogen concentrations.

A TVO paper presented the provisions installed for Severe Accident Management in Olkiluoto 1 and 2 BWRs in ***Finland***. The measures implemented were: containment overpressure protection, containment filtered venting, lower drywell flooding from wetwell, containment penetration shielding in lower drywell, containment water filling from external source, containment instrumentation for severe accident control, and emergency operating procedure for severe accidents.

A second EDF paper described prevention of delayed containment failure with sand bed filters (coupled with a metallic pre-filter in the containment) at ***French*** nuclear power plants according to the U5 operating procedure. A general overview of the R&D test programmes for the sand bed filters was also given. The presentation stressed the importance of maintaining the containment function as long as possible. Investigation was performed on the consequences of opening the venting system for containment pressure values higher than the containment design pressure.

Framatome ANP presented the containment in-situ PASS and emission monitoring system, which has been installed and is operational at 11 nuclear power plants in ***Germany***. The new system is based on the principle of in-situ sampling and rules out significant sample measurement errors caused by aerosol and iodine deposition in sampling lines. The system can be used for monitoring of the containment atmosphere activities in severe accidents. It was suggested that the in-situ PASS system could be used for optimization of the venting strategy.

Accident management aspects of the ***European Commission*** SGTR project were presented in the following paper. The goal of the SGTR project is to provide a database for fission product retention in steam generator tube rupture sequences and a model, which can be applied to estimate the effectiveness of different accident management strategies in these kinds of accidents. Work is done both for vertical and horizontal (VVER) steam generators. The experimental part of the project includes experiments with the ARTIST (PSI) and Horizon (Fortum) facilities.

The final paper presented the new developments within the ARTIST (Aerosol trapping in a steam generator) project. An experimental project to be performed in the ARTIST facility is planned at the Paul Scherrer Institute in ***Switzerland***. The project will study phenomena at the separate effect and integral levels, and also address accident management issues. The project is an international consortium with participants from several countries.

GENERAL DISCUSSION ON SESSION 3

- Accident management during shutdown states was raised as a topic that is not well-developed.
- By-pass sequences continue to be problematic. The ARTIST and SGTR projects are examples of current R&D addressing fission product release/retention in SG systems.
- The papers presented on SAM Mitigation measures showed significant progress in the area of hydrogen (PAR implementation).
- Ignition under conditions of PAR overload continues to be a concern. There was consensus that PARs are only one of the possible sources of ignition. However, PARs do not add a new threat of initiating combustion. Rather, the reduction of hydrogen concentration by PAR action is safety oriented with respect to possible combustion threats.
- Damage to equipment and power cables under hydrogen burn conditions was raised as an issue. Currently, this is viewed as an issue of environmental qualification (EQ) of equipment. The magnitude and duration of thermal loads from combustion are expected to be within existing qualification for most equipment.
- Carbon monoxide from ex-vessel chemical reactions can be a significant addition to energy available for release by combustion. It was generally agreed, from example from tests done in Canada, that PARs can effectively remove CO at the same time as H_2. An OECD paper entitled "Carbon Monoxide-Hydrogen Combustion Characteristics in Severe Accident Containment Conditions" [NEA/CSNI/R(2000)10] was noted, for general information.
- Water injection into the primary circuit is a recognized SAM measure under degraded core conditions. The consequent pressurization, fission product release and hydrogen release peak following quenching processes are not well-quantified. Research is continuing.
- There was general agreement that there is still a significant research need on the topic of melt coolability. Research projects are underway in the area of in-vessel retention of molten corium and with regards to ex-vessel coolability issues. In particular, chemical interactions e.g. in molten pool configurations were mentioned as examples of phenomena that are not well understood at the moment.
- The question was raised whether the processes involved in measures implemented for SAM are adequately modelled by our codes. It was suggested that the desired endpoint for code capability is not so much to reduce uncertainties in all cases but, rather, to produce a clear statement of uncertainty which can be evaluated for adequacy for the particular application. Nonetheless, there was consensus that it is essential for code maintenance to update codes and models with new knowledge, as it becomes available.

Session 4

IMPLEMENTATION OF SAM MEASURES ON VVER-1000 REACTORS

Session Chairman:

J.Rohde (GRS)

Session 4 comprised one paper about the status of implementing EOPs and SAMGs in NPP Temelin 1&2, and three papers about the process of decision-making for the development of strategies on how to cope with severe accidents in Russian VVER1000-type reactors, for existing and future NPPs.

The first three papers described the current status of operating VVERs regarding preventive AM measures, and the planning of a kind of SAMG approach in the mitigation domain.

The last paper described plant specific SAM measures already implemented into the design of a new reactor generation, under construction in China.

At the Temelin plant in the ***Czech Republic***, EOPs and SAMGs are part of the AM programme. EOP analytical work, plant specific EOPs verification and the EOP validation using the Temelin full scope simulator have been done, the implementation is completed. Operator training in the use of these symptom-based EOPs and the process of EOP maintenance is included in the whole programme. SAMG development support by analytical and technical bases, such as the results of a previous PSA Level 2 study, has been nearly completed, while the development of plant specific SAMGs will be finished at end of 2002 and site implementation will follow one year later.

Only some preliminary SAM measures based on hardware changes have been proposed, such as RCS depressurisation to prevent DCH and expanded reactor cavity floor to slow down MCCI.

Russian approaches for SAM strategies were presented in the two papers describing what has been done so far and what should be done. At present no special regulatory document is available in Russia, that could be used for guidance on the development of SAM measures. Existing guidelines were extended from DBA to the preventive part of BDBA, the EOPs domain. At present these guidelines are improved for existing VVERs by the responsible Russian organisations. There were developments, put together from a number of Russian organizations. The background was several TACIS projects and special contracts with Western organisations like ANL, EDF and Westinghouse. The Russian approach concerning a generic SAM strategy development is based mainly on the definition of the IAEA defense-in-depth concept. Actions have been started to develop SAMGs for the existing VVER plants before the end of the year 2003. For this work, the reference plant is the Balakovo NPP, unit 4.

The integration of SAM measures into advanced VVER-1000 designs was illustrated by the presentation on the technical solutions chosen to cope with severe accidents in the Chinese Tianwan NPP, which is under construction and will be the first VVER (and also the first PWR) equipped with a core-catcher. By design, the following radiation safety acceptance criteria for new reactor concepts have to be fulfilled:

- exclusion of off-site emergency measures (such as evacuation)
- reduction of emergency planning zones to 3 to 5 km, and
- limitation of emergency measures to temporary sheltering and food consumption restrictions.

This implies the availability and use for SAM of all safety systems and normal plant operation systems, and specific design features including SAM instrumentation and engineered SAM measures like PAR system, core-catcher and sump water pH control.

The progress made in Russia since the Niantic meeting in 1995 is evident from these presentations. At the time of Niantic, the main efforts were concentrated on meeting the western standards of the DBA approach. Now, similar SAM programmes are seriously discussed, structured and integrated into official procedures.

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