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SUMMARY AND CONCLUSIONS

SPECIALIST MEETING ON SELECTED CONTAINMENT SEVERE ACCIDENT MANAGEMENT STRATEGIES

(Stockholm, 13-15 June 1994)

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The Convention establishing the Organisation for Economic Co-operation and Development (OECD) was signed on 14th December 1960.

Pursuant to Article 1 of the Convention, the 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 current Signatories of the Convention are Australia, Austria, Belgium, Canada, Denmark, Finland, France, the Federal Republic of Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention).

NEA

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, Republic of Korea, Mexico and the United States. The Commission of the European Communities takes part in the work of the Agency.

The primary objectives of NEA are to promote co-operation among the governments of its participating countries in furthering the development of nuclear power as a safe, environmentally acceptable and economic energy source.

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

CSNI

The NEA Committee on the Safety of Nuclear Installations (CSNI) is an international committee made up of scientists and engineers. It was set up in 1973 to develop and coordinate the activities of the OECD Nuclear Energy Agency 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.

FOREWORD

The CSNI Specialist Meeting on Selected Containment Severe Accident Management Strategies held in Stockholm, Sweden in June 1994 was organised by the Task Group on Containment Aspects of Severe Accident Management (CAM) of CSNI's Principal Working Group on the Confinement of Accidental Radioactive Releases (PWG4) in collaboration with the Swedish Nuclear Power Inspectorate (SKI).

The Summary and the Conclusions of the Specialist Meeting are attached. The Session Summaries were prepared by the Session Chairmen, the Conclusions by the Programme Committee of the Specialist Meeting (a list of members is given in an Appendix).

The Conclusions have been endorsed by PWG4 and CAM at meetings held in September and October 1994, respectively. CSNI has approved publication of the document in the series of CSNI Reports at a meeting organised in November 1994.

SUMMARY AND CONCLUSIONS OF THE SPECIALIST MEETING

First CSNI Specialist Meeting on Selected Containment Severe Accident Management Strategies

The first specialist meeting on Selected Containment Severe Accident Management Strategies was held in Stockholm, Sweden, 13-15 June 1994. It was hosted by Statens kärnkraftinspektion (SKI). About 50 experts from 13 countries and one international organisation attended the meeting. Twenty papers were presented in four sessions, half of them dealing with accident management strategies implementation status, half of them with research aspects. It should be noted that about one third of the experts were from utilities; discussions were therefore very much oriented to practical issues. It also shows that this is a mature subject with direct impact on utilities.

The specialist meeting focused on accident management strategies in relation to

- Feasibility (including timing, time windows, criteria for action)
- Effectiveness (including its evaluation, e.g. through PSA techniques)
- Positive/Negative aspects
- Long-term impact

Since the TMI accident the research concerning severe accidents have substantially expanded and developed in three phases:

- Severe accident phenomena research
- Implementation of mitigating measures
- Development of accident management (AM)

Research is still ongoing, although it is now more focused on specific topics, considered to be key contributors to loss of containment integrity. Actually some papers treated some unresolved research issues. Containment severe accident management programmes are in place in most OECD member countries, but implementation of mitigating measures and AM development have been performed differently. Some countries, which started early with implementation of mitigating measures, sought for robust solutions as the data base and PSA analysis were incomplete. Other countries have waited for a more complete picture concerning phenomena and have completed PSA analysis. This has led to an optimisation of mitigating measures and AM development.

Status of AM in response to various containment threats

From this meeting, the status from AM point of view for various threats to containment integrity is as follows:

Late overpressurization: This threat to the containment can be reasonably treated with filtered venting devices.

Mark I liner melt-through: This issue appears to have been resolved. Assuming that the vessel melt-through occurs with low pressure in the reactor coolant system, drywell flooding before vessel breach will probably prevent this containment failure mode.

Hydrogen combustion: This issue is on its way to resolution. Several possible solutions were presented and are being evaluated. Actually, installation of passive catalytic recombiners have been decided in principle by the Belgian utility and recommended by the German Reactor Safety Commission.

Direct Containment Heating: A reasonable solution adopted by most countries is depressurization of the primary system before vessel melt-through. It should also be pointed out that severe accident research has found that the probability of this event leading to containment impairment has been overestimated for most containment designs.

Leak tightness of the containment (short-term and long-term): The significance of this subject may be underestimated. It is imperative to detect and control leaks. Management related actions should be taken. However, if this is planned beforehand a reasonable solution can be found.

Coolability of core melt debris in the containment: There seems to be no immediate solution, which will cool the core melt, agreed upon by all experts. Preliminary core catcher work presented at the meeting was not encouraging, at least not for the geometry considered. However, it is agreed that in cavities with an area larger than about 30 m^2, it could be advantageous in most cases to use water. However, it has not been shown conclusively that the melt will be cooled. But radioactive aerosols generated from core-concrete interaction will be scrubbed by the overlying water pool.

A widely discussed topic is the question of adding water before or after vessel melt-through. From coolability point of view, adding water into the reactor cavity prior to vessel melt-through, is advantageous, as the initial heat transfer from the melt to the water is very high if the melt falls into water. On the other hand steam explosions have to be considered.

Another possibility is to cool the melt in the vessel, either with water inside or outside the vessel. In-vessel core Debris Cooling through Cavity Flooding (IDCCF) was discussed only briefly as the subject had been examined at the OECD Workshop on Large Molten Pool Heat Transfer held in March 1994. The value and the interest of the OECD RASPLAV Project were emphasised.

Steam explosions: This still seems to be an open issue. Main issue is today ex-vessel steam explosions in deep pools, which the melt can fall into after vessel melt-through. There is no way to guarantee that ex-vessel steam explosions can be suppressed but containment loadings can be limited by specific geometrical features of the containment. Careful attention should be paid to local steam explosions.

Conclusions

1 For plants with significant risk contribution from hydrogen combustion, this can be alleviated or even eliminated with currently available technique. A careful selection between available techniques may be needed.

2 Although direct containment heating leading to containment impairment may be less significant than previously thought, it is recommended that depressurization of the primary system is included in operator procedures either with secondary feed-and-bleed or primary

feed-and-bleed.

3 More emphasis on leak detection, control and management is recommended. The use of expert systems can be of great help to operators, especially during crisis situations. Severe accident source term evaluation remains a topic of great interest.

4 Further research is recommended for unresolved issues as melt coolability and ex-vessel steam explosions. On the latter point it is emphasised that small scale experiments performed with thermite may not give results representative of real reactor conditions. Strong interest was expressed in the results of the Japanese ALPHA Programme, in particular the experiments on the limitation of energetic interactions.

5 As it is impossible to cool the core melt ex-vessel in some plant geometries it should be emphasised that it is always advantageous to cool the melt in the vessel with water inside or outside the vessel. This type of research should be pursued.

6 Long term aspects of accident management have to be considered at an early stage. This is particularly true for containment aspects of long term accident management.

7 Consideration needs to be given to the question: ”How and when do we know we have done enough?”

SESSION 1

CONTAINMENT ACCIDENT MANAGEMENT STRATEGIES - GENERAL ASPECTS

Session Summary by J. Rohde, GRS (Chairman)

Seven presentations were given in this session. While six of them were concentrated on the general aspects of severe accident management strategies, selected for different reactor concepts in specific countries and containment designs to minimise the potential activity release from the containment, one paper tried to explain the physical boundary conditions preventing vessel melt-through in the TMI-event and what can be learned from it for accident management.

Most of the presentations, summarising the actual status of the implementation of containment related severe accident strategies were given from representatives of the utilities, for PWR and BWR plants.

In the first paper the French approach was described, explaining in detail the interrelation of procedures on French plants, but also the responsibilities of the control room operators, the safety engineers and the crisis team. The strategic options proposed to the team in charge of the situation regarding the safeguarding of the containment are determined pragmatically in the Severe Accident Intervention Guide, which includes the emergency procedures for containment monitoring and filtered containment venting (U2 and U5 procedures).

In parallel with the operating procedures, a guide devoted to the overall monitoring of the containment has been developed for the use by the crisis team.

First principles were given, how to include the knowledge base, gained by developing severe accident strategies for existing plants, into the design of future reactor concepts, specially for the EPR.

The next two papers described the provisions taken to cope with severe accidents in Swedish PWR´s and BWR´s.

Mainly the implementations such as filtered venting and external water sources at all Swedish PWR´s by 1988 were described together with the development of the related Emergency Operating Procedures. In the following time period the accident management system has been further improved and special attention was drawn on the long term aspects of a severe accident management. A new knowledge based handbook was written to support the plant leader and the members of the technical support centre including the specific issues of the Beyond Emergency Response Guidelines /BERG/ and the management of the long term severe accident situation. Both the BERG and the knowledge based handbook are updated periodically. The similar approach was described in the following paper for Swedish BWR´s. Additional information was given, concerning the interrelations between the management on the unit and the accident management centre.

In support of the ongoing periodic safety reviews in Switzerland an independent PSA was made, mainly concentrating on risk implications of severe accident management strategies. The method used and some main findings were presented. It was mentioned that in terms of release frequencies the effects of severe accident management strategies showed a shift from filtered vented accidents to accidents with an intact containment. In some cases, the increased availability of the engineered safety features induced an increase in the frequency of the late containment failure. However, the consequences of these accidents which are already small in the base case analysis, are largely reduced by other mitigative effects. It was stated in general that large detrimental effects are not apparent by the adoption of any of the severe accident strategies which have been considered in the investigation.

The next two presentations gave an overview on first thoughts given by Japanese utilities for PWR and BWR plants severe accident management. Concerning BWR's different reactor concepts and containment designs were investigated like containments of type MARK I, II and the ALWR.

The basic philosophy of Japanese BWR's utilities in developing strategies is to fully utilise the existing plant resources due to the findings of PSA-work which has been carried out in the last years. Only minor plant modifications seem to be necessary. Special attention was drawn on the availability of instrumentation and information's needed to control the accident progression, development of guidelines and the training of the operators are in the planning status together with clarifying the organisation and the responsibilities in case of a severe accident.

Joint studies were done by Japanese PWR owners to fulfil the recommendations given by the Japanese NSC in May 1992 to develop severe accident strategies. Special strategies have been selected for further plant specific investigations on the basis of PSA work.

Severe accident strategies needs the preparation of specific procedures and limited plant modifications. This work will be performed in the near future.

The last paper gave some new interpretations of the situation in the lower head of the TMI reactor pressure vessel, after the relocation of molten materials into the lower plenum. Special emphasis was drawn to interpret the heat transfer mechanisms and the vessel wall situation together with the debris behaviour leading to a rapid cooling down, keeping the integrity of the vessel.

The author draws two main conclusions in case of an accident:

- water should be added to the RPV, regardless of the accident state to make use of the inherent in-vessel cooling mechanism, explained above and

- submerging the core debris with water in the RPV is sufficient to protect the vessel integrity and to cool down the debris.

In this session different approaches were presented from the different countries in developing severe accident management strategies:

- well organised strategic planning for the use of existing plant capabilities, if necessary with minor plant modifications;

- systematic plant modifications to enlarge the grace period of the containment before actions have to be taken. Special attention was drawn to keep the actions as simple and robust as possible as all detailed analysis was not finalised;

- based on detailed PSA work and extended experimental programs, the development of accident strategies against identified major threats to the containment integrity.

Some combinations of these three major approaches were demonstrated in the presentations.

Different technical aspects of the strategies selected were discussed but also more general questions were raised which could not be answered such as:

* what is the better way, manual actions or automatic systems

or

* how do we know that we have done enough?

In general it was agreed that some open questions still exist, mainly in connection with the short term strategic planning of actions, the long term accident management, and the duties and the training of teams being involved in the management of severe accidents.

SESSION 2a

HYDROGEN MANAGEMENT TECHNIQUES

Session Summary by J. Duco, ISPN (Chairman)

The first paper, presented by GRS (FRG), deals with the use of catalytic recombiners as a passive mitigation technique, aimed at preventing hydrogen concentrations in the containment reaching a level threatening its integrity.

After reminding the principles of functioning, and the operating constraints linked to the environmental conditions in a reactor containment during a severe accident, the device itself is described as a thin, strongly adherent coating of porous metallic palladium or platinum on a stainless steel plate. The current status of the three varieties of recombiners developed in the FRG by GRS, Siemens and NIS Ingenieur GmbH is shortly described, as well as typical experimental results obtained in particular in the Battelle Model Containment in Frankfurt and in the HDR facility.

Future activities encompass additional, confirmatory testing of industrial catalytic modules, with particular attention to the two following points:

a) their energy dissipation capability, even in hydrogen-rich atmospheres, to make sure they cannot exceed a temperature of approximately 600 °C (overheated support structures could then initiate mixture ignition) and

b) their resistance to poisoning and aging in a reactor containment environment.

The location of catalytic devices in new plants will be based on calculations of the hydrogen concentrations in the reactor containment for typical accident scenarios; their capacity has been specified in the FRG so as to recombine within 24 hours the hydrogen amount corresponding to 100% of zirconium oxidation; the combination of catalytic recombiners with other hydrogen mitigating measures may provide an additional efficiency to rapidly decrease the concentration in the early stages of a release; in-service inspection plans have also to be considered to make sure the long-term efficiency of the recombining devices is maintained.

Catalytic recombiners have demonstrated the capacity of reducing the hydrogen concentration under steam-inerted conditions and at very low hydrogen concentrations. In addition, they enhance containment atmosphere mixing by heat generation during operation, which may offer some flexibility regarding their location in the containment. No negative effect has been identified, as long as they are appropriately designed and fabricated to avoid excessive heat-up when functioning, adequately installed in the reactor containment and periodically inspected and tested.

In May 1994, the German Reactor Safety Commission recommended the installation of catalytic recombiners to protect the containment of PWR plants during beyond design events; this could be supplemented in the future by the consideration of igniters for the case of rapid, large hydrogen releases; nevertheless, the safety of such igniters is not currently established under all severe accident conditions.

The second paper addresses the issue of hydrogen management in CANDU reactors and was presented by AECL Research (Canada). In single-unit CANDU reactors, the assumptions made regarding the amount of hydrogen generated, as well as the natural and engineered mixing mechanisms inherent to the system, are expected to keep hydrogen concentration to non-flammable concentrations in the containment. Multi-unit CANDU stations similarly have engineered mixing systems, expected to appropriately homogenize hydrogen concentration in the containment, and are equipped with ignition systems (glow-plugs, automatically actuated), the number and distribution of which may be optimized by further accident analyses and research. As, in addition, one peculiarity of the multi-unit stations is to allow for combustion venting to large adjacent volumes, research is oriented to deflagration behavior in stratified mixtures and complex geometries like room chains; flame accelerations and deflagration to detonation transitions are investigated, as well as standing flames. Catalytic recombining systems adapted to CANDU severe accident environmental conditions have also been studied and a high capacity hydrogen removal appears to be readily achievable.

The third paper, presented by Belgatom, describes calculations of the active surface area of catalytic recombiners that could prevent hydrogen concentrations high enough for jeopardizing containment integrity if combustion takes place. A post-processor, named CARE, has been developed at Belgatom, which determines for a single volume the instantaneous gas concentrations from thermal-hydraulic conditions and gas production rates calculated with MARCH3; CARE also calculates the containment gas concentrations for given active surface area and recombination rate of the catalytic device, and, ultimately, assesses the containment pressure resulting from an isochoric, adiabatic combustion. Attention is paid to a "SEY" sequence (a small break LOCA, with an early core melt and the availability of the containment cooling system), which corresponds to a high, rapid release rate of hydrogen, on the Doel 3 and Tihange 2 power plants, differing mainly from each other by the containment volume and the concrete composition of the basemat. Conservative calculations show that a 250 m^2 catalyst area should be sufficient for preventing containment failure; it is worth to be observed that such catalytic devices improve containment atmosphere homogenization. The Belgian utility has made the principle decision to install such catalytic recombiners in all units and will make a detailed plant-specific proposal to the regulatory body.

The fourth paper, presented by Paul Scherrer Institute in Switzerland is related to the prevention of ignition in the LWR containment atmosphere by carbon dioxide inertization during the early stages of a severe accident. The author claims that large quantities (100 tons) of carbon dioxide can be stored under pressure (20 bar) on a nuclear plant site and delivered into the containment without energy supply during the short time window between the onset of a severe accident and the mass release of hydrogen due to zirconium oxidation. The paper describes an experimental program, carried out in a 34 liter, heated autoclave, to determine the ignition limits of four-component gas mixtures constituted of hydrogen, air, steam and carbon dioxide, under conditions typical of the early stages of a severe accident. Starting from a base load of one bar air pressure at 35 °C, hydrogen, carbon dioxide and water (in the wet gas mixture tests only) were added; for representativity, pressures and temperatures were varied between 1.6-5.0 bar and 35-160 °C, respectively. The author concludes that carbon dioxide inertization, reducing oxygen concentration to 6.4% in volume (30.5 vol. % air), should prevent ignition under the range of boundary conditions considered, and that an incomplete inertization, expected to result into a mild combustion, does not appear as a reliable option.

The fifth paper, presented by TNO Environmental and Energy Technology (the Netherlands), describes the decision analysis approach used to handle the complex issue of the best appropriate hydrogen mitigation technique to be chosen for the Borssele Nuclear Power Plant. The approach comprises nine steps. The first four steps (problem identification, definition of alternatives, selection criteria, definition of value ranges for the criteria) are basically desk work carried out on TNO premises. Step five consists in giving scores to each alternative in regard of each criterion: this task was achieved by thirty-two mitigation technique experts, nuclear safety experts, and nuclear technology experts, convened to a one-and-a-half-day workshop. Although the solicitation process of experts might always raise the issue of subjectivity of the advises, the procedure is generally deemed appropriate for the present case. After the valuation of the scores, the next critical step is to assign weighting factors to the criteria, which is the matter of a second workshop to be organized with the advisers of the Dutch Nuclear Safety Inspectorate. A calculation will ensue, in order to obtain the total score of each alternative, followed by a sensitivity analysis to have an insight on the stability of the best alternative(s) when scores and weighting factors are slightly altered.

In summary, various candidates exist for hydrogen management in a reactor containment during a severe accident, for the case the containment failure cannot be excluded as a result of hydrogen combustion. Some of these potential solutions have been extensively studied with significant success; one of them, the installation of passive catalytic recombiners in the containment, has recently been decided in principle by the Belgian utility and recommended by the German Reactor Safety Commission. Research efforts should be pursued to optimize the various possible solutions, which could combine several mitigation principles, for the different types of reactors currently existing or to be installed in the future.

SESSION 2b

OTHER CONTAINMENT ACCIDENT MANAGEMENT STRATEGIES

Session Summary by W. Frid, SKI (Chairman)

The session contained five papers. Three of the papers addressed accident management and phenomenological aspects of ex-vessel melt-water interactions, one paper discussed the strategy adopted in the VVER-440 Loviisa plant in Finland to prevent slow, long-term overpressurization of the ice-condenser containment, and in one paper the critical review of the potential strategies to control iodine in the containment was presented.

The external spray cooling of the Loviisa containment was described in a paper presented by IVO International Ltd (Finland). The external containment spray plays an important role in the overall severe accident management strategy at the Loviisa plant. The paper presented the thermal-hydraulic basis of the external spray design, including calculations and experiments, the design principles of the system, as well as some operational aspects of the system. The presentation clearly demonstrated an obvious but important fact that accident mitigation strategies are plant specific and that combination of systematic experimental and analytical approach is necessary to resolve complex severe accident problems.

Initially, filtered venting of the containment was considered as a measure to keep the containment pressure under control. However, accident analyses for the Loviisa conditions showed that venting had several disadvantages for the Loviisa plant design, the main drawback being the poor subpressure performance of the Loviisa thin steel shell containment. Accident studies showed that spraying of the outer surface on the containment dome in order to condense steam was an attractive alternative to venting. It has to be stressed that specific features of the Loviisa plant, such as the steel shell containment and a relatively low steaming rate, make the external spray cooling feasible.

Discussion of the paper was concentrated around some technical details of the system and some aspects of the experiments. One important issue which was briefly addressed during discussion was selection and relevance of accident scenarios used in the process of designing the system. This aspect of the problem was only very briefly addressed in this interesting paper.

The second paper was presented by the Forsmark power plant in Sweden. It discussed the basis for installing a core-catcher in Forsmark 1 and 2. It was an interesting presentation since it demonstrated the kind of problems we are facing (in this particular case the regular yearly maintenance at the plant) with regard to the efforts aimed at mitigating the consequences of postulated ex-vessel melt-water-structures interactions. The long-term coolability of core material in the flooded lower drywell is one of the crucial issues in the accident management strategy. During the initial phase of the project it was concluded that uncertainties concerning basic phenomena and accident scenarios which would govern the design and function of the core-catcher were too large to allow design specifications. The main uncertainties were connected with the following issues: breakup of the melt stream in a deep pool of subcooled water, the mode of reactor vessel failure (local or global) and, finally, the likelihood and consequences (in terms of generation of small particles and dynamic loads) of steam explosions.

The paper concluded that it is important to learn more about the severe accident scenarios and phenomena before modifications are introduced in the plant. It is especially important as the installation of the core-catcher would interfere with regular yearly maintenance activities at the plant. Another conclusion was that emergency procedures must be developed in parallel to the new knowledge that is generated by ongoing research activities. The work in Forsmark is now focusing on the evaluation of alternative accident management strategies.

During the discussion of the paper, the problem of maintenance activities in the lower drywell in the presence of a core-catcher was addressed. It was acknowledged that, to make the investigated core-catcher an acceptable solution, the maintenance personnel must understand and accept the safety benefits of this device.

The next two papers addressed ex-vessel coolability and steam explosions. The JAERI paper entitled "Accident management measures on steam explosion and debris coolability for Light Water Reactors" described experiments performed in the ALPHA facility in Japan. The main objective of the experiments had been to assess the effectiveness of possible accident management measures on steam explosions and the core debris coolability in the containment. This is potentially important considering that virtually all melt-water interaction studies focus on improving our understanding of the physics of steam explosions rather than looking for practical ways of preventing or mitigating energetic melt-water interactions. Two series of experiments have been conducted at JAERI, namely spontaneously triggered steam explosions using up to 20 kg of melt (which was dropped into water) generated by the thermite reaction between iron oxide and aluminum and melt coolability experiments in which water was poured onto the melt.

In melt-drop, steam explosion experiments the effects of melt mass, ambient pressure, water temperature and melt dispersing conditions were investigated. In general, spontaneous steam explosions occurred in all experiments when the melt was dropped into a pool of subcooled water at the atmospheric pressure without the use of a dispersion device. However, steam explosions did not occur when the ambient pressure was increased from 0.1 to 1.6 MPa, which by large is in agreement with the theory. Concerning the effect of the dispersing device, it was concluded that it may reduce the probability of steam explosions. Further investigations are apparently needed in this area.

In melt coolability experiments the heat transfer between the melt and overlying water was examined. It was concluded that adding water to the containment is, in general, an effective accident management strategy, with appropriate conditions. Thus, low water subcooling and high ambient pressure would decrease the probability of steam explosions. Unfortunately, these conditions are seldom satisfied in the containment. The dispersion device could also be a possible accident mitigation measure. During discussion of the paper two issues were addressed, namely how representative of the real reactor conditions is thermite melt, and the possible mitigating effect of moderately elevated containment pressure (0.2 to 0.3 MPa). It was proposed to perform experiments in the ALPHA facility at these pressure levels.

The second paper on ex-vessel steam explosions, entitled "A study of ex-vessel steam explosions in Swedish BWRs", was presented by ABB Atom. It described computer calculations of premixing and explosion phases of postulated steam explosions in a deep, subcooled water pool. Two computer codes were used for the analysis: PM-ALPHA for premixing calculations and ESPROSE.m for explosion calculations. The purpose of the study was to provide quantitative insights on the steam explosion for ex-vessel situations, mainly pressure distribution in the pool. This information is needed to assess dynamic loads on pedestal structures. A number of cases were calculated in which parameters such as melt flow rate, particle size, water subcooling and melt superheat were varied in order to assess the sensitivity of results to assumed model parameters and accident scenarios. The presented analysis is one of a very few steam explosion studies for deep water pools for ex-vessel situations and probably the most comprehensive one. Calculations revealed a number of potentially important mitigative mechanisms (in moderating loads on nearby structures), such as "explosion venting" and "penetration cutoff". It was noted that structural response was not calculated. The discussion of the paper addressed some aspects of the model and accident scenarios. The opinion was expressed that a parametric study on the magnitude of the applied explosion trigger would be useful in distinguishing between propagating explosion and merely amplification of the trigger.

The last presentation in this session, entitled "Potential strategies to control iodine released into the containment in the case of a severe reactor accident" was given by CIEMAT and CSN (Spain). A comprehensive and critical review, from the accident management point of view, was presented of various "classical" strategies to control iodine released into the containment under severe accident conditions. Also, other potential measures to control iodine in containment based on the current state of knowledge of iodine chemistry were discussed. Discussion of iodine behaviour was structured with regard to boundary conditions (pH, dose rates etc.), global behaviour of iodine in the containment (iodine evolution and speciation), engineered safety features (sprays, suppression pool etc.) and pH control. A rather strong statement was made concerning the effect of pH. Thus it was concluded that pH is a crucial factor for iodine volatility in the containment and, consequently, if pH is controlled during an accident the important uncertainties are limited to the phenomena of iodine-surface interactions or revolatilization. If pH is uncontrolled then the issue of pH evolution becomes very important. Iodine volatility is also strongly affected by radiation. During the discussion, the importance of pH in sumps was emphasized.

In summary, the session provided interesting insights into some phenomena crucial for accident management and containment integrity. Uncertainties with regard to the ex-vessel melt-water interactions in deep, subcooled water pools should be further reduced, which motivates continued research in this area. The influence of chemistry on fission product behaviour, both in short- and long-term, is another issue where it seems desirable to further reduce uncertainties.

SESSION 3

SURVEILLANCE AND PROTECTION OF CONTAINMENT FUNCTION

Session Summary by B. De Boeck, AVN (Chairman)

In this session, three papers were presented that covered the monitoring of the containment leaktightness and the protection of the containment integrity by means of a filtered venting system.

The Swedish Kärnkraftteknik presentation "Selection of scrubber as a filtered venting device" describes the considerations that have led to the choice of the technology for the filtered containment venting systems for all Swedish nuclear power plants. Barsebäck was the first plant in the world being equipped with a containment pressure relief system designed for severe accident conditions. The design basis event was a large LOCA with total black-out and impaired pressure suppression system. No operator actions were assumed for the first 24 hours. Based on the knowledge in severe accident phenomenology available in the early eighties, a large passive condenser consisting of a 10,000 m^3 building filled with gravel stones was selected as a filter.

Considering the increased knowledge about radioactive aerosols behaviour and transport, it was possible in 1986 to reflect on many filter alternatives for the other Swedish plants. Dry and wet filter technologies were considered. The dry filters considered included wire mesh filters, sand bed filters, gravel beds and cyclones. For reasons of efficiency, volume and cost, the wet filter scrubber technology was selected.

The evaluation of the two tenders received led to the choice of the multiple venturi scrubber system (MVSS). The MVSS contains over 800 venturi tubes connected in parallel and submerged in a circular shaped container. When the MVSS is put in operation after a severe accident, gas is forced by the containment pressure to pass through the tubes. The venturi accelerates the gas to high speed (100 m/s), and the consequent underpressure sucks water from the surrounding pool through holes in the tube. Due to the combination of high differential speed and fine sized water droplets, the particles carried by the gas are easily collected on the droplets, and the decontamination factor is high. An analytical and experimental programme has shown that the efficiency was higher than required.

The influence of the choice of the analytical tools on the design of the filter system was discussed. This is still an open question for the definition of any severe accident management strategy. The answer requires either the use of several independent codes, or the implementation of a solution which is not too dependent on the results of analytical calculations.

It was also stated that if the internal containment spray is operating, venting may not even be required.

The presentation from IPSN, France, "Containment by-pass and isolation failure detection with the expert system ALIBABA" describes an expert system which is part of the tools available at the emergency technical centre (CTC) to assess the status of barriers (fuel clad, reactor coolant system, containment building) and the related safety functions (subcriticality, primary system coolant inventory, pressure and temperature control, confinement) of a plant undergoing an accident. ALIBABA allows to detect the occurrence of containment isolation faults.

The information available at the CTC includes the indication of the containment isolation valves position, the global activity measurements in the ventilation ducts and at the stack, and the local activity measurements in the auxiliary buildings (measurements above sumps or near pipes). An expert system is valuable to obtain early indication. The knowledge base of ALIBABA includes information on the penetrations (potential leakage sources) and on systems (instrumentation and various equipment).

The assessment consists of four stages. It starts with the checking of the availability of equipment and sensors. It then proceeds to the upstream approach by checking the state of the containment isolation valves. It also performs a downstream search based on the activity measurements. The last step consists of a qualitative balance which is the synthesis of the two former tasks. Each penetration is given a coefficient according to the selection path (valve position, local activity, ventilation duct activity). This allows the identification of the most probable sources of a leakage. When selected, a penetration is shown on the computer screen in its environment.

Examples of use were given during the presentation. ALIBABA has been tested during emergency drills with positive results. It is presently being improved to take into account the experience feedback. The author pointed out that the development of the system benefited from the standardisation of the French nuclear programme.

The Italian ENEL presentation 'Containment leaktightness after severe accident'' discusses some ideas about methods to inform the plant operators of proper containment isolation system performance. First the present knowledge about severe accident source terms in containment is reviewed with the aim to select an appropriate radionuclide release spectrum. The following phases were considered: gap activity release, early in-vessel release, ex-vessel release, and late in-vessel release. Considering the free volume of a typical containment, a table was produced which gives the activity concentration in the containment atmosphere for the various accidental phases. To detect a possible containment leak in accident conditions, it was then necessary to find discriminating elements. From the previous table, radionuclides were identified which could play the role of tracers. The radionuclide spectrum has been referred only to the phases "gap" and "early in-vessel" because, for evolutionary and passive reactors, the accident scenarios associated with "ex-vessel" and 'late in-vessel" phases appear not credible.

In a second step, the containment penetrations of a typical pressurised ALWR and the related isolation system were analysed. All the containment penetrations have been subdivided into five categories according to their characteristics. This allows to define remedy actions in case of leaks.

Finally, a containment monitoring function is foreseen in the workstations available in the control room. One of the several displays that are accessible to the operators to perform the monitoring functions is related to the containment isolation system. This screen is dynamic, in the sense that it provides real time updated information and is capable to accept commands by the operator. The information provided on this screen includes the penetration number, the isolation valve status, the main plant parameters and the system related to the various penetrations. If after an accident, a given penetration leaks, high activity level will result in both the penetration piping and in the room of the faulty penetration system. This occurrence, on the basis of the source spectrum defined in the first step, will generate a tightness failure alarm.

The two last papers were complementary in the sense that the first one presented a tool for the central emergency team, related to existing plants, and the second one, a tool for the operators in the control room, related to future plants. Both papers draw the attention on the very important topic of ensuring the containment leaktightness after an accident. Severe accident management is made more difficult when there is a leak in the containment. It is therefore essential that the containment leaktightness is ensured during normal operation, that it is monitored after an accident has taken place, and that possible corrective actions be defined in advance. If this work is performed before the design of the plant is completed, it can be used to improve the design to lower the probability of isolation failures, to ease the detection of leaks, and to facilitate remedial action.

ANNEX

MEMBERS OF THE PROGRAMME COMMITTEE AND/OR SESSION CHAIRMEN

Dr. Gustaf Löwenhielm (Vattenfall AB, Sweden) - General Chairman

Mr. Benoit De Boeck (AVN, Belgium)

Mr. Jacques Duco (IPSN, France)

Dr. Wiktor Frid (SKI, Sweden)

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