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EC cost-shared research activities on severe accidents under the framework programme 1994-1998

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ABSTRACT

Nowadays in many countries of the European Union (EU) the ultimate goal of nuclear reactor safety experts is to render "practically" unnecessary extensive evacuation precautions for populations in the site vicinity. This means essentially developing safety systems and procedures to respond to the challenge of the hypothetical severe accidents, which are beyond-design-basis events, assuming that the accident prevention measures have failed. In this report the strategy and the main achievements of the EC research programmes on severe accident analysis and some applications to plant assessments are discussed in broad lines.

INTRODUCTION / EC RESEARCH ON NUCLEAR FISSION SAFETY

The subject of severe accidents in light water reactors (LWRs) is usually just so complex to understand and the investigations are so expensive that international research efforts are needed to come to firm conclusions. At the European Commission (EC), two programmes were focused on the understanding of the physics of beyond-design-basis accidents and on the development of accident management measures for LWRs of both the present and the future generation, namely: the Reinforced Concerted Action 1990-1994 and the current EURATOM Framework Programme 1994-1998 on nuclear fission safety.

Throughout the two above mentioned EC research programmes, many aspects of severe accident analysis were addressed, starting from early accident progression in the primary coolant system and going up to severe damage to the containment integrity, assuming that the safety systems are not working satisfactorily. Special emphasis was put on the applications of the findings to the development of measures for the mitigation of the consequences of severe accidents. The EC research programmes are organized in multipartners projects, each under the responsibility of a coordinator nominated amongst the contractors. A total of 35 contracting organisations are involved, coming from 11 EU member states. Some examples of research activities are given in this report, in particular in the areas of in- and ex-vessel molten corium behaviour and containment integrity, with emphasis on the thermo-mechanical loading aspects. Materials ageing effects and applications to accident management measures are also discussed.

On the basis of the EURATOM Treaty and in concertation with the main actors of the reactor safety research, the European Commission embarked in 1991 on a major "research and education programme" devoted to severe accidents analysis for existing as well as future light water reactors and aimed to be executed in close connection with existing national projects of the member states. That was the Reinforced Concerted Action, terminated in 1994, consisting of 8 major projects of which the final report has been produced [1].

Similarly, on the same bases as above, under the EURATOM Framework Programme 1994-1998, the EU embarked recently on a "Framework programme of Community activities in the field of research and training for the European Atomic Energy Community (1994-98) ", following the Council Decision of 26 April 1994 about nuclear fission safety.

The research activities of the EC on nuclear fission safety are carried out usually through two channels: either (1) "indirectly" through shared-cost and concerted actions, involving the member states of the European Union, under the responsibility of scientific officers of Directorate General XII "Science, Research and Development" (EC headquarters /Brussels), or (2) "directly" through research programmes executed by the EC scientists of the Joint Research Centre (JRC) in one of their establishments specialized in nuclear reactor safety (like Ispra in Italy, Karlsruhe in Germany, Geel in Belgium or Petten in the Netherlands). In the case of "indirect" activities, the task of the EC consists in proposing a scientific workprogramme for integrated research projects executed by various organisations and in providing part of the financial support needed to bring the research to a success.

DEFINITION OF SEVERE ACCIDENTS

A severe accident is defined nowadays as a highly hypothetical beyond-design-basis event that results in catastrophic fuel rod failures, severe core degradation and fission product releases into the reactor vessel, the containment and the environment.

Before the TMI-2 accident (1979), reactor safety studies were mainly focused on design basis accidents. Since TMI-2, and especially since the Chernobyl accident (1986), it is clear that one of the key objectives to get public acceptance is that any accident will be controlled within the reactor containment, with no off-site consequences. Therefore in many countries with NPPs, procedures and engineered systems to cope with severe accidents are nowadays under discussion in the design and licensing procedures.

It is worth reminding the definition of the design basis: it comprises basic specifications which ensure the capability of the plant to undergo a specific range of operational events, accidents, and external hazards within strictly limited radiological protection requirements. The design basis usually includes the specification of challenging events ("design basis accidents" or DBAs), and requires particular methods of analysis. In the traditional defence-in-depth strategy, the third level of safety is determined by analytically evaluating the effects of these "design basis accidents", as they might arise from the simultaneous failure of various components of the plant and of some of the safety systems.

Severe accidents can be initiated by the failure of engineered systems developed for current LWR plants to address the main safety functions such as: reactor trip, the emergency core cooling system (ECCS) aimed at providing adequate cooling of the reactor core in the event of a LOCA, systems for the post-accident radioactivity or/and heat removal, or other containment integrity systems.

RESEARCH NEEDS FOR UNDERSTANDING SEVERE ACCIDENTS

The safety record for western commercial reactors and more generally for water-moderated reactors is excellent. However, if one looks to all types of reactors, two main categories of nuclear reactor accidents, with potential developments into a severe accident with large escapes of radioactive materials, can be identified, each illustrated by one of the two major accidents to date, those of Chernobyl and TMI-2:

Reactivity insertion accidents (RIA)

In a LWR, such accidents, characterised by a runaway chain reaction, are highly improbable, due to negative feedbacks and shutdown mechanisms. They are less unlikely in other types of reactors, given sufficient design flaws. The Chernobyl accident, which occurred in 1986 in Ukraine in a graphite-moderated boiling water reactor of very peculiar Soviet design, started as a reactivity accident, and terminated in large energy releases and steam explosions involving severe core degradation and contamination of the environment.

Loss-of-coolant-accidents (LOCA)

If the coolant flow is disrupted, then even if the chain reaction is promptly stopped, there remains a large heat output due to the radioactive decay of the reactor fuel. Unless this heat is removed by an appropriate cooling system, the temperature of the fuel will rise and the core eventually will melt. The TMI-2 accident, which occurred in 1979 in a western LWR (Three Miles Island, Pennsylvania, U.S.A.) but without large escape of radioactive material from the containment, was actually a LOCA with substantial core melting.

Regarding research needs, it can be said that prevention measures are usually rather design specific and may be considered to be adequate for the current generation of NPPs, such that only a limited amount of additional research is needed. On the contrary, measures for the mitigation of consequences of severe accidents are an area with many uncertainties, undoubtedly deserving international research programmes on generic aspects.

Regarding mitigation measures for severe accidents, it is generally believed that the qualitative aspects and the major possible problems are relatively well identified. What is needed actually is a drastic improvement in the quantification of the risk assessment and in the predictive capability of numerical models which should lead to a reduction in the above mentioned uncertainties.

Some risk relevant questions like the potential for steam explosions (in- and ex-vessel) and the critical threshold for deflagration-to-detonation in hydrogen issues are still a matter of debate amongst the safety experts involved in the EC research programmes. Regarding in-vessel steam explosions, there seems to be a broad consensus among the designers, that they would not lead to reactor pressure vessel (RPV) rupture, and therefore would not challenge the containment, mainly because a low pressure melt scenario is postulated as a consequence of early depressurization. Actually mainly ex-vessel steam explosions seem to be a possible matter of concern to the containment integrity. Regarding the hydrogen risk in the containment, some of the Community research efforts are converging towards simple design rules of the λ/D type where λ is the detonation cell size for the air-steam-hydrogen mixture and D designates the characteristic length of the reacting mixture.

Another item of discussion in the current EC research programmes is the reduction of the containment by-pass risk, e.g. through steam generators in the PWRs, through pressure suppression pools in the BWRs or through penetrations in both types of reactors.

Obviously there are many other open issues in the area of severe accidents. They cannot all be listed in this report. It is worth recalling that the first published detailed study of LWR accident possibilities and consequences, for accidents going beyond the plant design basis and including core melting, was carried out in 1973-1975 in the WASH-1400 report.

STEAM EXPLOSIONS AND HYDROGEN BURNS DURING CORE MELTDOWN

Only after TMI-2, the use of probabilistic methodology for risk assessment and in particular operational safety were given the attention they deserved. The PSA approach, introduced earlier in the WASH-1400 report, contributed certainly to the drafting of new research programmes about complex transients and accident mitigation techniques. It made it possible to identify potential weak links in the systems components and open areas in the physics of severe accidents and therefore to set up research priorities, like steam explosions and hydrogen combustion, as well as accident management support.

In the course of a core meltdown there might be conditions which may have the potential to result in a steam explosion that could rupture the reactor vessel or the containment building. The term "steam explosion" refers to a phenomenon in which the fuel is in finely divided form and intimately mixed with water so that its thermal energy is efficiently and rapidly deposited in the water, creating a large amount of steam in a short time. These conditions refer to the ex-vessel steam explosion scenario, where the core is supposed to melt through the bottom of the reactor vessel and to fall into water in the bottom of the containment building. This mode of containment failure is examined in some of the EC research programmes, together with the prediction of its probability of occurrence.

Hydrogen combustion might also occur in the course of a core meltdown if sufficiently hydrogen is produced out of the metal/steam reaction and if air is available. Hydrogen burns occurred during the TMI-2 and the Chernobyl accidents. This is another major area of Community research, especially of interest to the experts of structural analysis of the equipments and the containment building.

MEASURES OF HARM IN REACTOR ACCIDENTS AND RISK ANALYSIS

The most fundamental harm in reactor accidents is that done to individuals. This can be measured in terms of the individual radiation exposures, the total population exposure, the number of prompt fatalities caused by intense exposures, and the number of latent cancers, thyroid nodules and genetic defects caused by lower levels of exposure.

There is also the question of physical damage to the reactor plant and contamination of the surrounding environment, which may force evacuation of large regions as well as relocation and decontamination. Plant damage was clearly the most important direct consequence of the TMI-2 accident, and ground contamination was a major consequence of the Chernobyl accident.

To measure harm in reactor accidents, safety goals for individual fatality risk, as well as quantitative risk goals for accident frequency, have been proposed by the safety authorities and are curently under discussion amongst safety experts in the EC research programmes.

It is difficult to single out any one of these accident consequences as the indicator of reactor safety. In practice, the most significant question may be that of core damage. Therefore, much of the efforts in assessing and reducing reactor risks in the EC reactor safety programme focuses on the issue of core damage. In this report, devoted to the technological aspects of reactor safety and - as opposed to the health and safety aspects, like the radioprotection of man and environment - the emphasis is on the evaluation and prediction of core damage as well as on the development of mitigation measures for accident management.

Nuclear power reactors, with the enormous inventories of fission products and the very high energy density in the core, carry the potential for major accidents involving many people. Fortunately there have been not many such accidents to date - only the TMI-2 accident of 1979 (with serious core damage but no large radioactivity release to the atmosphere) and the Chernobyl accident of 1986. As a result it is not possible to evaluate the risk of this kind of accident as directly as, say, that of a fatale automobile accident where there is abundance of data. Therefore sophisticated methods of accident risk analysis, some of which were developed for the aerospace industry, have to be applied to nuclear power plants.

"Risk" is a common word which may convey different meanings to different people. For the purpose of making comparisons between different types of risk, the risk associated with a specified event is usually defined as the "consequence of the event per unit time" and expressed in "acute fatalities per person-year" in the case of individual or societal risks. The risk can be computed in an very natural way from the frequency of the event and the magnitude of the consequences of the event, that is: Risk (consequences/unit time) = Frequency (events/unit time) x Magnitude (consequences/event).

In the EC research programmes on severe accidents, the emphasis so far has been on the understanding of the physics of severe accidents in order to predict their magnitude and to develop appropriate mitigation measures. This is done using in particular a deterministic approach which is useful in establishing and verifying design criteria for future reactors. A limitation of the approach however is that it does not address the question of likelihoods, in particular the frequency of hypothetical severe accidents.

EC-SPONSORED ACTIVITIES OF INTEREST TO THE SAFETY AUTHORITIES

Amongst nuclear safety authorities in the EU, there is a consensus stipulating that "the safety demonstration for the nuclear power plant of the next generation has to be achieved in a deterministic way, supplemented by probabilistic methods", that is: based on a list of predefined scenarios, classified in categories according to the probability of occurrence. As it has been said earlier, it is recommended to "practically eliminate" accidents with significant off-site radiological consequences, that is : the maximum conceivable release must be such that only limited protective measures in area and time are needed, with "no permanent relocation, no need for emergency evacuation outside the immediate vicinity of the plant, limited sheltering and no long-term restrictions in the consumption of food".

Hence for the regulatory safety authorities, future reactor designs should follow a twofold strategy which goes well beyond the traditional concept of defence-in-depth against DBAs, and which is also part of the strategy of the EC research programmes, namely:

- improve accident management measures of the preventive type with a view to limiting the residual risk by a reduction of the Core Damage Frequency (CDF) target

- develop highly efficient mitigation measures aimed at containing the radioactive substances in the very improbable event of a core meltdown, rendering unnecessary extensive evacuation precautions for populations in the site vicinity.

This twofold strategy is implemented in particular in the European Pressurized Reactor (EPR) by designing the plant with a strong "Deterministic Design Basis" and, beyond this basis, considering "Risk Reduction" measures. Obviously it is also known that success of the severe accident management procedures depends not only on the existence of engineered systems or of validated procedures but also on the ability, competence and training of plant operators - which is an area covered by other EC programmes.

EC-SPONSORED ACTIVITIES OF INTEREST TO UTILITIES AND VENDORS

Amongst utilities and vendors there is a consensus that the EC research activities on severe accidents should aim at developing a quantitative database of accident sequences and phenomena with the following scopes:

- setting the bases of the physical understanding and the correct prediction of a series of severe accidents, in existing and advanced reactors, including also MOX or high burn-up fuel

- developing accident management strategies, by providing the input for Probabilistic Safety Assessments (PSA) of level 2

- investigating the benefits and drawbacks of a variety of prevention/mitigation measures, including the case of inadvertent use of accident management procedures.

Another important objective is to assist East-European countries in the development of a safety culture comparable to the western standards.

The above mentioned objectives are largely covered in the EC research programmes. A state of the art of these activities has been presented at the FISA-95 Symposium [2].

SAFETY DESIGN STRATEGY OF THE EUROPEAN PRESSURIZED REACTOR (EPR)

To meet the above mentioned requirements of the safety authorities for future reactors (namely: no evacuation nor foodstuff contamination), the stack release should be as low as reasonably achievable (ALARA). This critical release term has to be calculated for a number of significant isotopes (e.g. Xe 133, I 131 and Cs 137), based on a reference source term taking into account the reactor features, i.e. core inventory, severe accident scenarios, leaktightness of the inner containment, filtration and stack release of the leaks. As a result a safety design strategy is set up.

In the case of EPR, for example, the continuity with the existing design and construction practices was an important criterion. In their safety strategy with respect to severe accidents, the French and German utilities and vendors involved in the EPR project put the emphasis on maintaining the containment function far into the domain of hypothetical accidents. This is done by applying the French type of containment technology in connection with a number of other advanced concepts both for accident prevention and mitigation like: avoidance of early containment failure or bypass, cooling of the corium in the containment, pressure reduction of the containment by means of a containment heat removal system, control of hydrogen risk, collection of the leakages in the reactor building annulus and release into the environment via the stack after filtration, and finally preservation of the containment functions.

Most of the features introduced in EPR are thus of the evolutionary type. Actually they fit well with the objectives of the main research projects under the current EC Framework Programme 1994-1998 on severe accidents.

MAIN ACHIEVEMENTS OF THE EC RESEARCH PROGRAMME 1994-1998

Some of the main objectives and achievements of the EC research activities under the current Framework Programme 1994-1998 are summarized below in a short description of each of the 7 "clusters" of research projects, namely: INV, EXV, ST, CONT, AGE, INNO, and AMM.

Experiments about molten fuel / coolant interaction are conducted in the INV (IN-Vessel) cluster and will produce results of interest to the understanding of both early and late phase core degradation, as well as in-vessel debris coolability, including for example steam explosions. Measurements of molten corium / concrete interactions are performed in the EXV (EX-Vessel) cluster, with the aim to develop a databank for high-temperature materials properties and to contribute to the design of core-catchers. Experiments are conducted in the ST (Source Term) cluster about fission products release from irradiated fuels at high temperatures and about aerosol reentrainment in containment under various atmospheric conditions. Also examined are the revaporization of aerosols due to decay heating and the integrity of the piping from this heat source. In the CONT (CONTainment) cluster, tests about aerosol behaviour and high temperature loads are conducted and analyzed, with emphasis on containment thermo-hydraulics and deflagration-to-detonation criteria for hydrogen. Leakage of radionuclides through the containment is also examined.

Of interest to the present generation of reactors, especially those proposed for life extension, are the activities on ageing of reactor components, which are conducted in the AGE (AGEing) cluster. Of interest to the next generation of reactors is the development of innovative (passive) safety features for ensuring the main safety functions: this is the scope of the INNO (INNOvative) cluster, especially devoted to passive decay heat removal systems.

Ultimately, severe accident research aims at the confirmation of the safety margin, the quantification of the associated risk, and the evaluation of the effectiveness of the accident management measures of the nuclear power reactors. This is to be assessed in particular by the AMM (Accident Management Measures) cluster, devoted to research on accident management measures, including signal validation techniques in connection with reactor instrumentation under extreme conditions of irradiation, temperature, pressure and humidity.

PHEBUS-FP RESEARCH ABOUT SEVERE CORE DEGRADATION

The above mentioned ST activities are performed in close cooperation with the international PHEBUS-FP programme. The PHEBUS-FP (Fission Product) programme is carried out by the French Commissariat à l' Energie Atomique (CEA/IPSN) in its Research Centre at Cadarache, in the framework of a broad international cooperation and with considerable support from the European Commission. The international partners are numerous scientific organisations from the Member States of the EU, the Joint Research Centre (JRC establishment of Ispra/Italy), the US Nuclear Regulatory Commission (USNRC), the Japanese Nuclear Power Engineering Corporation (NUPEC) as well as the Japanese Atomic Energy Research Institute (JAERI), the Canadian CANDU Owners Group (COG) and the Korean Atomic Research Institute (KAERI).

This programme consists of a series of 6 unique integral in-pile experiments to study phenomena linked to hypothetical severe accidents in water-cooled nuclear power plants like the meltdown of nuclear reactor fuel, the release of radioactive fission products from this fuel and the behavior of these fission products along their release paths. These experiments are carried out in a test rig which is positioned in the centre of the annular PHEBUS test reactor in Cadarache. Started in 1988, the PHEBUS-FP Programme will be terminated after the year 2000.

MAIN ACTIVITIES OF THE “INV” CLUSTER

The severe accident at the TMI-2 reactor stimulated research to understand how a beyond-design-basis accident is initiated and then progresses, how its consequences can be mitigated, and how to terminate it. A central issue during a severe accident, tackled by the INV cluster, is the behaviour of the reactor core : when and how the core loses its original geometry in function of different variables, what configurations are formed before being transformed into a molten pool or a debris bed, how much hydrogen is generated and how core degradation influences the coolability and the release of fission products.

The potential for recriticality occurrence, especially for partially degraded BWR cores, is examined in the SARA project, with emphasis on the impact on accident management.

In the COBE project, the emphasis is on the evaporation and transportation of solid and liquid materials, the progression of the debris bed and molten pool towards the lower head of the pressure vessel. Other late phase core degradation processes, like the oxidation of core materials by air ingress and the resulting hydrogen production, are examined in the OPSA project.

The thermochemistry of the various material interactions is particularly important. The CIT project is building up a materials properties databank about dissolution and solubility processes as well as viscosity effects on the corium formation and progression during different severe accident scenarios. This is of direct interest to the MFCI project which looks at accident management strategies, especially the late phase quenching potential, using real materials experiments in the FARO facility with up to 150 kg of prototypical UO_2/ZrO_2 melts. The steam explosion risk and the achievable energy conversion rates are also examined in this project. Other studies of in-vessel melt retention capabilities are performed in the MVI project which is validating powerful predictive models for the coupled thermo-mechanics of a naturally convecting corium pool and the boundary crust, with a view to optimize the external cooling of the reactor vessel.

The vessel capability to withstand severe accidents is further examined in two different projects, that is: various vessel steels are characterized and mechanical strength models are developed in the REVISA project to understand the creep failure mechanisms under severely damaged core conditions. Further, the melt-through failure of the lower vessel head, especially at the penetrations, and molten fuel slug impact effects on the upper vessel head, due to hypothetical in-vessel steam explosions, are investigated in the RPVSA project.

As a result of the INV cluster, it is expected to better understand the margins to failure and the failure itself of the two first barriers, namely the fuel pin and the reactor pressure vessel, when they are confronted with severe core damage conditions. It is further expected to develop accident management strategies capable of retaining the molten corium under coolable conditions within the pressure vessel without untolerable risks for steam explosions or hydrogen burns.

Understanding the key phenomena before, during and after core materials relocation is essential to predict the progression of the accident. These phenomena provide the initial and boundary conditions for (1) all ex-vessel phenomena investigated in the EXV cluster, (2) all radiological source term effects considered in the ST cluster, and (3) all thermal and mechanical loadings examined in the CONT cluster.

MAIN ACTIVITIES OF THE "EXV" CLUSTER

Once the reactor pressure vessel would have failed, ex-vessel melt interaction effects would take place. Those phenomena are investigated in the EXV cluster. In the COMAS project, involving up to three tons of prototypical molten corium containing metallic and oxidic phases, special attention is devoted to phenomena like the erosion of the sacrificial layer and/or of the concrete basemat. In the accompanying HTCM project, heat transfer characteristics are measured between melts and (un)protected steel structures under extreme thermo-shock conditions.

Experiments on corium spreading under dry and wet conditions are performed in the CSC project, together with corium coolability tests by direct water contact, based on flooding on the top of the corium or on water injection from the bottom of the core-catcher. During the molten corium/concrete interaction, aerosols may be generated by evaporation from the hot melt surface and by the mechanical agitation of sparging gases, which contributes to the increase of the radioactive source term : this is also examined in this project.

As a result of the EXV cluster, it is expected to optimize the design of core catchers, aimed at providing the right surface for spreading and cooling down the molten core debris in case of pressure vessel rupture.

MAIN ACTIVITIES OF THE "CONT" CLUSTER

Once the first 2 barriers have failed, only one ultimate barrier is left, namely the containment, to protect the population and the environment against radioactive consequences of a severe accident. Therefore the assurance of its integrity is a key issue. In the CONT cluster, three aspects determining the containment integrity are examined : (1) the containment thermal-hydraulics, (2) the risk of hydrogen deflagrations and detonations, and (3) the leakage processes through penetrations or micro-cracks in the containment wall.

In the DABASCO project, thermal-hydraulic correlations are developed to cope with passive decay heat removal phenomena, including non-condensible gas effects and spray effects on the stratification behaviour. In the EUCOFA project, containment experiments are proposed to study various accident management strategies both of the preventive and mitigative type.

In the HYMI project, numerical models are developed for turbulent hydrogen combustion and catalytical recombination. In the accompanying VOASM project, experiments are performed under extreme conditions of steam and hydrogen concentrations. Models and criteria for predicting deflagration-to-detonation transition in hydrogen-air-steam systems are developed in the H2DDT project. In the HDC project, three-dimensional models for hydrogen distribution and turbulent combustion are applied to full scale plant conditions with the aim to optimize the location and the distribution of hydrogen catalysers and igniters.

Full scale tests on a personnel airlock are performed in the ATHERMIP project with a view to study the behaviour of the sealing areas at the containment penetrations. In the CESA project, a very large scale model of a double wall concrete containment is tested beyond its design limits in order to evaluate the cracking behaviour and the leakage processes under various air-steam-aerosol conditions.

As a result of the CONT cluster, it is expected to extend the traditional defence-in-depth strategy and to optimize the systems of accident mitigation techniques, which will be introduced in the containment as an additional line of defence, required by the safety authorities.

MAIN ACTIVITIES OF THE "AGE" CLUSTER

Within the context of preventing severe accidents, questions concerning the ageing of reactor components and materials due to neutron irradiation and other adverse operational influences like corrosion, start-up or shutdown transients, thermal mechanical fatigue etc. are of major importance. This holds also for the envisaged life extension for existing and future nuclear power plants.

Of particular interest to the mechanical aspects of reactor accidents are the two projects of this cluster devoted to neutron irradiation and its consequences. Within the AMES project, dosimetry and irradiation programmes are established for the European Network on Ageing Materials Evaluation and Studies, with a view to improve the harmonization of neutron dosimetry activities. Under the project MADAM, the actual situation in the fields of neutron damage indexation, neutronics codes and data libraries for PWR, BWR VVER and Magnox reactors are reviewed and the creation of a Conversion Table of Material Neutron Damage Indexation for all major European reactor types is under preparation.

MAIN ACTIVITIES OF THE "AMM" CLUSTER

To operate the above mentioned engineered systems for accident management, special operating procedures are needed which in turn are based on the knowledge of the most risk relevant accident scenarios and on the interpretation of measurements performed during the accident. Research in this area is conducted in the AMM cluster which is aiming at implementing the results of severe accident research into practical accident management, mainly by identifying and assessing candidate management strategies. Current research shows that methods and tools need to be developed for dealing with uncertainties regarding phenomena, possible adverse effects of operator actions, interpretation of measurements, equipment performance, instrument survival and human error under stress. At present, the AMM cluster is composed of five different projects.

Two of these projects are related to Level 2 Probabilistic Safety Analysis. In the BEEJT project, different Expert Judgment Techniques will be assessed and their effectiveness ascertained in a benchmark exercise. In the PSAL2 project, the data requirements and characterization for a level 2 PSA will be defined with reference to the hydrogen in the containment issue, for which relevant data will also be collected.

The potential survival potential of instruments needed for Critical Safety Functions monitoring and the use of algorithms for processing plant measurements in order to allow accident identification and signal validation on PWRs will be addressed in the ASIA project.

The SAMEM project has, as main objectives to develop integrated Accident Management (AM) models for the assessment of the feasibility and effectiveness of potential severe accident management measures.

Finally, a joint safety research index is collecting information related to research within the EU member states relevant to nuclear safety aspects of the design, operation and accident management of Light Water Reactors. This project, known as JSRI, is intended for the research programmes managers to optimize synergies and avoid duplications.

CONCLUSIONS

Even though the vast majority of operating plants have an excellent safety record, there is considerable debate among safety and nuclear power experts on how to do even better. This quest for excellence has been illustrated throughout this report devoted to the EC sponsored research activities on reactor safety and rests essentially upon three factors:

- there is a natural tendency for any industrial activity to become safer and more efficient as it develops over time

- there is a common desire to maintain the current extremely low level of severe accident frequency, as the number of nuclear power plants world-wide grows in the future

- there is a common desire to further reduce the magnitude of the consequences of hypothetical severe accidents and their potential for large off-site releases.

The research activities in the area of severe accidents are generally just too complex and too expensive to be supported by a single country. Firm conclusions about frequency and magnitude of severe accidents can be drawn only on an international basis. Considering the substantial amounts of funding and the large experimental facilities needed for this kind of research, co-ordinated international research programmes are the most appropriate. International research programmes can offer indeed the most cost effective opportunity to investigate multidisciplinary and expensive problems like those encountered in the development of mitigation measures for severe accidents like: in-vessel melt retention systems, ex-vessel core catchers or techniques for removing the hydrogen risk in the containment.

Throughout this report it has been shown to what extent the EC research programmes have been contributing to the above mentioned quest for excellence in the area of reactor safety, by providing the tools for gaining the necessary physical knowledge for understanding severe accident phenomena and designing appropriate safety systems to minimize their consequences.

In future EC programmes, complementary research activities should help to identify and implement efficient severe accident management strategies and to develop appropriate training programmes and guidance for the plant staff. This should contribute further to the improvement of the defence-in-depth strategy which is at the heart of nuclear reactor safety.

REFERENCES

1. Hofmann, P., Fineschi, F., Berthoud, G., Schulz, H., Alsmeyer, H., Bowsher, B.R., Combescure, A. & Wach, D., November 1996
Reactor Safety Programme / Final Report (December 1992 - June 1995),
Office of EU publications, , EUR 17126 EN, ISBN 92-827-6942-9

2. Van Goethem, G., Balz, W., Della Loggia, E. (Editors), 20-22 November 1995
FISA-95 - EU Research on Severe Accidents, Proceedings of the FISA-95 symposium,
Office of EU publications, Luxembourg, EUR 16896 EN, ISBN 92-827-6980-1