EUROPEAN UNION RESEARCH IN SAFETY OF LWRs WITH EMPHASIS ON ACCIDENT MANAGEMENT MEASURES

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Abstract

On April 26th 1994 the European Union (EU) adopted via a Council Decision a multiannual programme for community activities in the field of nuclear research and training for the period 1994 to 1998. This programme continued the EU research activities of the 1992-1995 Reactor Safety Programme which was carried out as a Reinforced Concerted Action (RCA), and which covered mainly research activities in the area of severe accident phenomena, both for the existing and next-generation light water reactors.

The 1994-1998 Framework programme includes activities regarding Research and Technological Development (R&TD), such as demonstration projects, international cooperation, dissemination and optimization of results, as well as training, in a wide range of scientific fields, including nuclear fission safety and controlled thermonuclear fusion.

The 1994-1998 specific programme for nuclear fission safety has five main activity areas: (i) Exploring Innovative Approaches, (ii) Reactor Safety, (iii) Radioactive Waste Management, Disposal, and Decommissioning, (iv) Radiological Impact on Man and Environment, and (v) Mastering Events of the past. The specific topics included in this work programme were chosen in consultation with the EU Joint Research Centres (JRC), and with experts in the different fields taking into account the needs of the end users of the Community research, i.e. vendors, utilities and licensing and regulators authorities.

This paper briefly discusses the objectives and achievements of the 1992-1995 RCA and also describes the projects being (or to be) implemented as part of the 1994-1998 programme in the areas of "Reactor Safety/Severe Accidents", particularly those related to Accident Management (AM) Measures. In addition to this, some relevant projects related to AM which have been funded via independent PHARE/TACIS assistance programmes will also be mentioned.

1 - Introduction

Background of reactor safety research at the European Commission

Developing concepts and techniques aimed at improving the safety of nuclear power reactors has always been a key objective of the Research and Technological Development (R&TD) programmes of the European Union (EU).

The legal basis for EU research is set out in the EURATOM Treaty (1957) which specifies to the EU to "contribute to the raising of the standard of living in the Member States and the development of relations with other countries by creating the conditions necessary for the speedy establishment and growth of nuclear industries" (Title I, Article 1) and to "provide for the encouragement of progress in the field of nuclear technology" (Title II).

The latter Title assigns the EU among others to "promote and facilitate nuclear research programmes", in particular in the areas of physics and chemistry applied to reactor technology (Annex I), with the aim of "creating the conditions of safety necessary to eliminate all hazards to life and health of the public" connected to nuclear energy (preamble of the Treaty). More specifically, another obligation of the EURATOM Treaty for the EU is to "lay down basic standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiations" (Title II, Chapter 3). These research tasks have been carried out either "indirectly" through shared cost or concerted actions involving the EU member states and coordinated by the European Commission (EC/Brussels), or "directly" through programmes executed in any of the institutes of the Joint Research Centre (JRC) devoted to nuclear reactor safety activities.

There are actually 3 main actors interested in reactor safety research, namely: the nuclear research organisations, the regulatory authorities, and the utilities and designers. The task of the EU within this frame consists in proposing a structure for integrated work programmes, providing partial funding of the joint research projects, coordinating the teams involved and promoting the exploitation of the results achieved.

On this basis the EU, acting in concert with these main actors, 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 executed in connection with existing national projects of the member states. This resulted in a specific programme which was executed as a Reinforced Concerted Action (RCA) in the period 1992-95.

Before the conclusion of this programme, originally planned for early 1995, the European Union (EU) adopted via the Council Decision 94/268/EURATOM of April 26th 1994, a new multiannual programme (to be executed under the EU 4th Framework Programme) for community activities in the field of nuclear research and training for the period 1994 to 1998. The Reactor Safety related activities of this programme extended the EU research about severe accident phenomena with more emphasis on the measures to prevent possible radioactivity release under these conditions. Other areas like Accident Management Measures, plants ageing phenomena, and exploitation of innovative approaches to improve the safety of new and operating reactors were introduced in this new programme.

To conclude the 1992-95 R&TD programme a symposium, called FISA-95, was organised on 20-22 November 1995 in Luxembourg [1] with presentations by the main actors of the programme. A mid-term review of the current programme (1994-1998) for all projects related to "Conceptual Design Features" and "Reactor safety - Severe Accidents", also under the form of a symposium, will take place in Luxemburg from November 17th to 19th 1997.

2 - EU research in the area of severe accident

One of the guiding principles for the research policy at the Community level is subsidiarity. Actions should be undertaken by the European Commission (EC) only under the following conditions: they should bring more value added to the project than if they were conducted separately at the single national level; they are of interest to the EU as a whole; they cannot be treated by a member state alone. The research activities in the area of severe accidents are generally just too complex and too expensive to be supported by a single country. Therefore they satisfy not only the above mentioned EURATOM obligations of EU commitment for nuclear reactor safety but also the subsidiarity principle of the Maastricht Treaty of 1992.

TABLE 1. PRELIMINARY CLASSIFICATION OF SEVERE ACCIDENT PHENOMENA IN LWRs

1. - a severe accident is initiated by some event like a reactivity accident or the loss of coolant function, especially LOCA circulation failure or loss of heat sink, assuming that no safety system is working, and this initial phase is ending with the start of core uncovery

2. - fuel heats up due to inadequate cooling and large core uncovery begins with subsequent oxidation of Zircalloy materials and hydrogen generation, till the start of core melting

3. - extensive core melt occurs, leading to relocation of fuel, cladding and control rods, and debris beds are formed in the lower head (late phase core degradation phenomena)

4. - in-vessel corium/water interactions like upwards ejection of water masses hitting the reactor vessel head and steam explosions (e.g. maximum release of 200-400 MJ of mechanical energy), with subsequent challenges to the integrity of the vessel (e.g. at the location of vessel penetrations)

5. - in-vessel hydrogen burns or explosions with pressure peaks up to 5 bar and high temperature creep phenomena which further challenge the integrity of the entire primary circuit

6. - relocation of large masses of molten core to the lower plenum with risks of additional steam and hydrogen explosions challenging the integrity of the primary circuit, with subsequent reactivity releases in the primary circuit

7. - reactor pressure vessel failure causing core debris to relocate into the reactor cavity sump in the case of lower head failure or creation of missiles challenging the integrity of the containment and its equipment

8. - sudden increased containment pressure and temperature due to ex-vessel hydrogen and steam explosions, and subsequent direct containment heating in the case of high pressure melt ejection (DCH / e.g. maximum containment pressure of 1 MPa and temperatures up to 700 °C for 45 tons of melt)

9. - high containment pressure due to fires and steam effects, with subsequent reactivity releases with radiation challenges to the performances of the safety equipments in the containment

10. - corium/concrete physical and chemical interactions in the sump, like formation of solid barrier crusts, early ablation of the basemat and releases of various gases which increase the containment pressure (e.g. hydrogen and carbon monoxide with increased risks of explosions)

11. - loss of containment integrity due to high gas pressures and thermal stresses (accident scenarios with either short term dynamic or long term quasi-static effects) or local instantaneous missile impacts

12. - basemat failure or melt-through and core debris release to the underlying ground

13. - off-site radioactivity releases via containment leakage paths, containment by-passing, leaking or venting of gases.

Considering the substantial amounts of funding and the large experimental facilities needed for severe accidents R&TD, coordinated research programmes are certainly most appropriate. International research programmes can offer indeed the most cost effective opportunity to investigate multidisciplinary and expensive problems like degraded core cooling or hydrogen risk mitigation. Moreover it is an optimum way to confront various experiences and to reach an international consensus about the understanding of severe accident phenomena and about the development of accident management strategies.

The subject of severe accident phenomena in LWRs is usually just too complex to understand physically and to predict numerically although there has been extensive research worldwide for over a decade. As a result of many discussions with the main actors, the preliminary classification indicated in Table 1 was agreed for the most relevant phenomenological events to be investigated in the work programme. Although it is believed that the qualitative aspects and the major possible problems in this area are well identified, there is still a need to quantify the risk and hence to reduce the many uncertainties still left in most severe accident scenarios.

It is worth mentioning that, in the EU, the main actors of the nuclear power plant community, namely: the research organisations, the regulatory authorities and the electrical utilities, have been able recently to sign different cooperation agreements, and that in all these agreements the need for additional research about severe accidents has been clearly pointed out.

Regarding extension of R&TD activities outside the EU , it should be added that some severe accident research projects with participation of East-European countries are being coordinated by the EC in the framework of the TACIS (Technical Assistance to the Commonwealth of Independent States) and PHARE (Poland-Hungary Assistance in the Restructuring of Economies) programmes.

3 - (1992-95) EU Research Programme on Reactor Safety

The 1992-95 EU Research Programme on reactor safety was focused on the understanding of scenarios and phenomena of beyond design-basis-accidents (beyond DBA) and on the development of accident management measures for Light Water Reactors (LWRs) of both the present and the future generation.

Special emphasis was put on the applications of this research programme to the development of measures for the mitigation of the consequences of severe accidents in LWRs, mostly of the evolutionary type in Western Europe, in the hypothetical case that the accident prevention measures fail. The attention was focused on the conduction of separate effects tests as well as large integral experiments of common interest to provide a database against which numerical codes could be validated in view of the extrapolation towards the real reactor situation. A few plant specific assessments have also been performed to compare the impact of several accident scenarios on different LWRs designs with emphasis on the source term issue [3].

This research programme was conducted through a 2.5 years joint effort from end 1992 till early 1995 and involved 20 contracting organisations coming from 9 EU member states, in cooperation with some Central- and East-European research organisations. A wide spectrum of severe accident scenarios and phenomena have been investigated both from an

TABLE 2. PROJECTS OF THE 1992-1995 EU RESEARCH PROGRAMME ON REACTOR SAFETY

Area 1—accident progression analysis, i.e. the study of in- and out-of-vessel phenomena due to severe accident scenarios

- project No. 1: modelling of core degradation progression based on large scale experiments like CORA and PHEBUS
  1. CORE DEGRADATION (CORE)

- project No. 2: problems related to the hydrogen behaviour including combustion phenomena and countermeasures like inerting and recombining techniques
  2. HYDROGEN BEHAVIOUR (H_2)

- project No. 3: molten fuel / coolant interaction with emphasis on the molten corium/water premixing and the potential for steam explosions
  3. MOLTEN FUEL / COOLANT INTERACTION (MFCI)

- project No. 4: reactor pressure vessel response including high temperature creep failure modes and in- as well as ex-vessel coolability techniques for melt retention
  4. REACTOR PRESSURE VESSEL (RPV)

- project No. 5: molten corium / concrete interaction with emphasis on ex-vessel corium retention devices
  5. MOLTEN CORIUM / CONCRETE INTERACTION (MCCI)

- project No. 6: radioactive source term behaviour including release from fuel and transportation in the reactor coolant circuit
  6. SOURCE TERM (ST)

Area 2—behaviour and qualification of the containment system in order to evaluate the safety margins

- project No. 7: investigation of containment integrity problems through studies of thermal and dynamic loading effects of short and long term types, the characterization of the containment thermalhydraulics and the identification of possible leakage modes through cracks, e.g. in the concrete structure
  7. CONTAINMENT INTEGRITY (CONT)

Area 3—accident management support

- project No. 8: signal validation under extreme accidental conditions and development of improved man-machine interfaces in advanced nuclear power plant control rooms with a view on new strategies for accident management support.
  8. ACCIDENT MANAGEMENT SUPPORT (AMS)

experimental and an analytical point of view. The work programme addressed 3 main areas, namely accident progression, containment integrity and accident management support, subdivided in 8 projects, each under the responsibility of a project coordinator nominated amongst the participants, as indicated further down in Table 2.

The 1992-1995 EU Research Programme was structured in 8 specific projects described further down in Table 2 . The final report of this programme, covering the outcomes of all 8 projects, will be published soon as a EUR report [2].

4 - The 1994-1998 EU Programme on Reactor Safety

The 1994-1998 EU Framework programme includes activities regarding Research and Technological Development (R&TD), such as demonstration projects, international cooperation, dissemination and optimization of results, as well as training, in in a wide rage of fields, including nuclear fission safety (441 Mio ECU) and controlled thermonuclear fusion (840 Mio ECU). The nuclear fission safety activities are broken down under direct actions under the responsibility of the EU Joint Research Centres (264 Mio ECU), and indirect actions coordinated by EC DGXII/F/5 and -6, Brussels.

The indirect actions (shared cost and concerted actions) of the Nuclear Fission programme (1994-1998) consist of five main activity areas:

1. Exploring Innovative Approaches
2. Reactor Safety
3. Radioactive Waste Management, Disposal, and Decommissioning
4. Radiological Impact on Man and Environment
5. Mastering Events of the past

The research projects of the Reactor Safety related areas will be conducted through a 3 years joint effort from beginning 1996 till end 1998, and will be funded between the Community (about ECU 30 million) and contractors from 20 organisations coming from 11 out of the 15 member states of the EU.

The Reactor Safety area is structured into 6 clusters, each containing several projects, and addresses in particular the field of Severe Accidents, that is:

i) In-Vessel Core Degradation and Coolability (8 projects) — Cluster "INV"
Corium formation and behaviour
Molten corium coolant interactions
In-vessel corium coolability
RPV behaviour

ii) Ex-vessel Corium behaviour and Coolability (4 projects) — Cluster "EXV"
Thermochemical modelling and data
Corium release and spreading
Corium retention and cooling

iii) Source term (10 projects) — Cluster "ST"
In-vessel fission product behaviour
Ex-vessel fission product behaviour
Benchmark calculations

iv)	<u>Containment Performance and Energetic Containment Threats</u> Hydrogen distribution and combustion Containment thermalhydraulics and cooling Material data and structural response Containment leakage	Cluster "CONT" (10 projects)
v)	<u>Accident management measures</u> (5 projects)	Cluster "AMM"
vi)	<u>Ageing</u> (7 projects)	Cluster "AGE"

Workshops, widely open to the international research Community along the lines of FISA-95, will be organised at mid-terms and at the end of theProgramme in order to present the results and conclussions.

5. PHARE and TACIS Programmes on Severe Accident Research Activities

Under the EU Framework Programmes, the Central and Eastern European Countries (CEEC) and Newly Independent States (NIS) research organizations have two main options for cooperating in EU sponsored nuclear safety research projects, i.e. either becoming subcontractors for projects of these programmes or joining a PHARE/TACIS assistance programme oriented towards the improvement of the safety level of NPPs of Russian design.

Recently, some research related projects of CEEC/NIS have been recently allowed to enter the PHARE and TACIS programmes in order to cover - further to the industrial assistance- also nuclear safety research activities to be mainly performed in CEEC/NIS countries. For the PHARE/TACIS 1995 and 1996 assistance programmes some of these research projects in the nuclear safety field have been discussed with the DGXII . However the funding as well as the coordination of these PHARE/TACIS activities in the field of nuclear fission safety falls under the responsibility of DGI-A.

6. Research related to Accident Management Measures

Through the 1992-95 Research Programme the European Community has undoubtfully contributed to the scientific basis for improving the evaluation of most of the challenges of severe accidents. As a result improvements are currently under discussion to optimize the balance between prevention and mitigation measures for the safety design against unlikely extreme events, should the prevention systems fail.

In addition to the traditional prevention techniques for the short term failure modes in the containment, measures for the mitigation of the consequences of long term failure modes have been investigated for existing as well as for future reactors. As a result it can be stated that the present knowledge about severe accident phenomena allows to extend the traditional defense-in-depth concept by introducing, as an additional line of defense, accident management procedures, and in particular mitigation measures for the consequences of severe accidents.

Successful accident management includes many tasks related to the use of information technologies, such as reliable identification of the actual plant and components state, information for assessing the accident progression and the plant response to operator action, and information for planning the mitigation strategy with potential uncertainties due to failed or misleading instrumentation. As a result of the fast progress in numerical techniques and the availability of very powerful computer systems with acceptable economic conditions, the area of accident management support is considered one of the most promising R&TD fields in which very effective solutions can be reached with reasonable efforts and in realistic time frame.

Following is a summary of the main projects which have been funded by the EU to assist the operators and the personnel of the Technical Support Centres in the application of Accident Management strategies in the event of a severe accident in a Light Water Reactor. One of them was performed as part of the 1992-1995 Research Programme, and therefore is already completed, and the others are being (or will be) performed as part of the 1994-1998 Framework Programme (see "AMM" Cluster of section 4) or as part of PHARE/TACIS assistance programmes.

6. 1 *Project "Accident Management Support" (AMS)*

This project was the result of the combination of two originally envisaged projects of the 1992-1995 Programme, namely "Instrumentation and Signal Validation" and "Operator Assistance". Since the overall objective of these two projects was very similar, i.e. to provide comprehensive and reliable information for identification, prevention or planning of mitigation of an accident with up-to-date supporting technology for plant operators or emergency teams, only one common group was established to work in a multi-partner (10 parties) action coordinated by GRS/ISTec (Germany).

In order to be able to control and mitigate an accident, the operators should have at any time a realistic and correct picture of the accident and its progress. Hence instrumentation and signal validation are main issues under severe accident conditions, especially if instruments are working beyond their specification range. The objectives of the "Accident Management Support" (AMS) project were (i) to define, investigate and develop means and methods providing reliable information and diagnostics as well as support tools for accident management, and (ii) investigate the different signal validation methodologies with emphasis on the existing instrumentation rather than new instrumentation needs. The basic scope of this project was:

(1) To carry out investigations about real-time monitoring and decision-making techniques, using neural networks, advanced modelling and noise analysis techniques. Expert system based strategies were further developed for design and maintenance of emergency guidelines in connection with an "automatic operator model". Adaptative algorithms and extrapolations from recorded plant data have been developed with the aim of predicting critical milestones and optimising command/control under emergency conditions such as to enable the operator to take the optimal recovery actions in response to an accident.

(2) To conduct investigations in signal validation methodology and sensor modelling/signal processing. There are two basic approaches to match the requirements of reliabilility and validity of a plant signal: model-based methods realizing functional redundancy and noise diagnostic methods, using the signatures of inherent signal noise as "finger prints" of specific sensors and plant conditions. Sensor modelling activities were performed for a fission chamber model in a an extended range of faulty operating conditions. Noise diagnostic methods were developed using advanced signal identification techniques.

The work started with writing state-of-the-art reports (SOARs) in the two main areas: Operator support systems [4] and Instrumentation/Signal Validation [5]. In parallel to the compilation of the SOARs, specific research activities were performed in areas such as:

- Signal validation using advanced digitized techniques, i.e. model-based and noise diagnostic methods
- Sensor modelling and signal processing
- Man-machine interface: Operator role in advanced control room environment
- New tools, methods and computerised systems for accident management:
    . Development and Implementation of Accident Management procedures (DIAM)
    . Transient Analyzer for accident state assessment (TRANSAL)
    . Design and Maintenance of Emergency Guidelines (SAMARIA)
    . Recommendations for VDU display design and their use in accidents (INTERACT)
    . A decision Support system for containment release management (CRM)
    . Situation Related Operator Guidance (SIROG)
    . Knowledge based Operator Advisor system for use in severe accidents (OPA)

The main conclusion of the project was that, due to the availability of powerful information processing systems, substantial progress was made in the feasibility of advanced methods and systems such as signal validation, process and system state assessment, man-machine interface optimisation, and operator advising and assisting systems for diagnosis, execution of accident management procedures, and safety-function or situation-related decision-making.

6. 2 *Project "Development of methodology for the evaluation of severe accident management strategies" (AMEM)*

This project of the 1994-1998 Framework Programme started in January 1996, and is being performed by a multi-partner team (4 organisations) under the coordination of NNC Ltd (Great Britain).

Accident management (AM) strategies with the potential to terminate or mitigate degraded core accidents are currently being developed and implemented at nuclear power plants worldwide. Decisions on their implementation are however, not straightforward as the actions may cause potential adverse effects and also involve physical phenomena that are not well understood. Current research emphasis has centred mainly on achieving a better understanding of the phenomena. Apart from the phenomenological issues, each accident management strategy also requires consideration of the following key interrelated issues :

- operator performance
- equipment availability and performance
- instrumentation availability and performance

The qualitative assessment and quantification of these thus entails a high degree of uncertainty. The framework for any assessment must therefore be able to address these issues in an integrated fashion and to allow the uncertainties to be addressed. A guiding principle must be that AM measures must have a certain robustness against uncertainties.

The objectives of the AMEM project are twofold. The first objective is to further develop integrated AM models for the assessment of the feasibility and effectiveness of potential severe accident management measures. The second objective is to apply these AM models in relevant case studies while contrasting the unique features and understanding the limitations of these models.

This project comprises the following tasks :

1. a detailed review of existing models and their recent applications in the assessment of the potential impact of severe accident management measures;
2. examination of the different criteria currently used for the assessment of the effectiveness of potential severe accident management measures and recommendations for the most appropriate one;
3. development of integrated AM models to consider key issues such as severe accident phenomena, operator response, systems availability and instrumentation availability;
4. on the basis of case studies agreed (and derived from different AM actions), demonstrate the proposed methodology, based on reference reactor designs (PWR, BWR, VVER).
5. perform an evaluation of the benefits and drawbacks of the different methodologies, as a result of the case studies selected

The final report for this project is expected by the end of 1998. Preliminary results will be probably presented at the FISA-97 Symposium.

6. 3 Project "Algorithm Support for Accident Identification and Critical Safety Functions Signal Validation " (ASIA)

This other project of the 1994-1998 Framework Programme is expected to start beginning 1997, and will be performed by a multi-partner team (4 organisations) under the coordination of NNC Ltd (Great Britain).

The AMS project of the 1992-1995 Research Programme mentioned above (see section 5.1) concluded that Critical Safety Functions (CSF) instruments may only survive for a limited period in a severe accident. It also provided recommendations on signal validation, and identified algorithms -based systems as holding great promise for validation of instruments and for identification of postulated accidents. The "ASIA" project will extend and build on the "AMS" work already done and will consist of three work packages:

1. Further development of operator aids based on physical models. Two particular aspects will be addressed: (a) validation of CSF measurements, and (b) understanding of accident progression, i.e. accident diagnosis.

The aim of the validation is to transform a set of raw measurements in a global consistent set of physical values; for faulty or non-measured values the system will attempt to provide substituted values. The solution of the system of relationships linking measurements will be carried out with search algorithms and constraint methods. The set of validated values will be then transmitted to a thermal-hydraulics module which will provide analytical redundancy. The results of the analysis could be then used to identify the behaviour of measurable CSF signals.

2. Study instrument survival in severe accidents. This will start by identification of a list of CSF measurements and complementary instrumentation needed for accident management for representative PWR designs.

Then, based on the environment expected after a severe accident as defined in the state-of-art reports produced in the "AMS" project, the survival of all neutron flux sensors will be assessed.

The output of this work package will be a document listing the measurements, instruments concerned, the survival times expected for accidents referenced, any potential for improvement in survival, the symptoms of failure expected and the potential for validation of the measurement.

3. Implementation strategy. The objective will be to study the needs of the operating staff, Technical Support Centre and Emergency Management for appropriate algorithms, and the formulation of recommendations for their implementation.

   The work will integrate the investigations on instrument survival of work package 2 with the algorithms investigated in work package 1. The output will be a strategic recommendation of the algorithms for each class of operational use, related to the different stages of progression of accidents from precursor stage through beyond design basis condition, and to severe accident conditions with fuel melting.

The final report for this project is also expected by the end of 1998. Preliminary results will be probably presented at the FISA-97 Symposium.

6. 4 "VVER 440-213 Beyond Design Basis Accidents Analysis and Accident Management" (PHARE Project 4.2.7.a)

The project will cover various aspects of severe accident analysis for VVER-440/213 plants, identification and validation of preventive and mitigative strategies, and provision of the basis for future implementation of severe accident management guidelines. In addition to that, the appropriate analytical tools (codes and models) for accident analysis and for specific VVER (namely the MAAP/VVER code) will be supplied to all beneficiaries of the project together with the necessary training.

The project started beginning 1996 and has a duration of two years. The reference plant is Bohunice V2 440/213 (Slovakia), but tasks to evaluate the applicability of the results to both Paks (Hungary) and Dukovany (Czech Republic) are included in the work scope.

6. 5 "VVER-1000 Severe Accidents Management" (TACIS Project 93-3.8)

The goal of this project is the transfer of Western technology and experience on Severe Accident (SA) analyses and phenomenology and on Accident Management (AM) strategies and procedures to the Russian counterpart, and the assistance and collaboration in the application and improvement of available SA codes to VVER plants as well as in the preparation of AM procedures.

This project includes the performance of a number of analyses for beyond design basis accidents (BDBAs) and SA analyses for the reference plant (Balakovo NPP, Unit 4) of the VVER-1000 scenarios which have been identified for the successful completion of TACIS Project 3.1 ("Probabilistic Safety Analysis") and which are also needed to support the development of AM measures for this type of reactor.

7 - Conclusions and future research needs

In conclusion the 1992-1995 EU Research Programme about severe accidents has proven to be very valuable for the improved understanding of some of the key safety problems of LWRs. This EU programme contributed to develop tools for further reducing the frequency and the consequences of core-meltdown accidents, while ensuring negligible releases from the vessel and from the containment under hypothetical beyond design-basis-accidents.

Activities performed as part of such programme have led to new cooperations in the research community, in particular with the industry. The background knowledge and the working methods of all partners were put together for the benefit of all. The main actors of this EU programme, that is: the research organisations, the regulatory authorities, and the utilities and designers, have expressed their satisfaction about the outcome of this Programme.

There seems to be a consensus to reduce the EU effort in some research areas like early core degradation which has been extensively investigated over the last decades, as well as high-pressure melt ejection and direct containment heating which are supposed to be "practically eliminated" for future reactors. Reversely there is a growing number of questions left open for future EU research about severe accidents, in particular in the areas of late phase molten corium coolability, hydrogen risk management, source term effects and containment bypass sequences as well as advanced accident management measures. This was taken into account in the objectives of the Reactor Safety area of the present 1994-1998 Research Programme of the EU as it has been reflected in the specific projects discussed in this programme.

Finally there is a common consensus among all the parties involved to extend the traditional defense-in-depth concept by introducing, as an additional line of defense, accident management (AM) procedures, and in particular mitigation measures for the consequences of severe accidents. Therefore the area of AM support is considered one of the most promising R&TD fields in which very effective solutions can be reached with reasonable efforts and in realistic time frame.

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