Call for Research Proposals for participation in the New Coordinated Research Project (CRP) sponsored by the International Atomic Energy Agency (IAEA)

<< Developing a phenomena identification and ranking table (PIRT) and a validation matrix, and performing a benchmark for In-Vessel Melt Retention >>

<< J46002>>

Summary of the CRP

This CRP was recently approved and will be jointly implemented by the Division of Nuclear Installation Safety, Safety Assessment Section (SAS) and the Division of Nuclear Power, Nuclear Power Technology Development Section (NPTDS).

The CRP aims to progress the understanding and modelling and simulation of major physical phenomena occurring in the strategy of In-Vessel Melt Retention (IVMR), which may be adopted for mitigating the consequences of a severe accident with core melting. It will aim at harmonizing the international understanding of scientific and technological bases underpinning crucial parts of the safety demonstration of the IVMR strategy. Participants are expected first to develop a Phenomena Identification and Ranking Table (PIRT) and then a validation matrix for IVMR. Subsequently, the CRP will organise a series of benchmarks (which will include comparison of modelling and simulation results with experimental data – when available) representative of medium, as well as high-power reactors implementing IVMR, to mainly address the following: corium properties and stratification in the lower plenum of the reactor pressure vessel, heat transfer in stratified corium pools; external reactor vessel cooling and mechanical resistance of ablated wall.

Duration

4 years
Expected starting date: July-2020

Background Situation Analysis

The physical processes involved in the late in-vessel phase of severe accidents in Light Water Reactors are very complex and affected by large uncertainties. Under postulated severe accident conditions, large quantities of molten core material relocate to the lower plenum of the Reactor Pressure Vessel (RPV) and interact with water, lower plenum and RPV structures. The heat transfer from the molten debris causes evaporation of any remaining water and heat-up of the lower plenum and RPV structures. If the reactor cavity is flooded before melt relocation into the lower plenum, the vessel wall would be initially cooled and the outer-vessel temperature would remain close to the cavity water saturation temperature. Nucleate pool boiling of the cavity water is an efficient mechanism for heat removal from the molten debris in the lower plenum.

This strategy of severe accident management is referred to as “In-Vessel Melt Retention (IVMR)” and represents – together with the alternative strategy of “Ex-Vessel Corium Cooling”, which aims at collecting, spreading and cooling the corium outside the RPV – a possible mitigation feature of the consequences of severe accidents at Defence-in-Depth level 4. The safety demonstration of IVMR aims at proving that this strategy effectively retains the corium inside the RPV, hence ensuring the containment integrity and confinement of radioactive materials.

The IVMR concept was first proposed in 1989 and its technical feasibility was further demonstrated as a backfit measure for the WWER-440 reactor of the Loviisa Nuclear power Plant in Finland, thanks to the effort undertaken at University of Santa Barbara (UCSB) by T.G. Theofanus et al., which had involved methodological developments, experimental and analytical works. The IVMR concept was further approved by the Finnish regulatory authority STUK in the late ‘90s. Almost in parallel with the Loviisa study, in the mid-1990s, IVMR was assessed and developed ad-hoc for the newly designed evolutionary Gen III Westinghouse AP600 reactor, and then later incorporated into the AP1000 reactor design. The design certification of AP1000 was issued by the USNRC in 2006.

More recently, also the Korean APR1400 design and the Chinese CAP1400 (developed by SNPTC) and HPR1000 (jointly designed by CNNC and CGN) designs incorporate an IVMR strategy for severe accident mitigation.

Despite an effort spanning over three decades which has requested considerable methodological developments (based on both deterministic and probabilistic approaches), as well as experimental and numerical simulation works, aiming at building a large and robust scientific base underpinning the safety demonstration of IVMR effectiveness, previous IAEA meetings on this topic and state-of-the-art knowledge conclude that further work would be necessary on various aspects including the following topics, which are more relevant when incorporation of IVMR to high-power reactors:

- Experimental data needed for validating individual models are often considered limited in covering relevant phenomena (e.g. focusing effect, influence of layer inversion on the heat flux towards the vessel wall), insufficient quality (e.g. contradictory CHF experimental data) and quantity (e.g. data for material behavior of RPV steel, hampering the performance of structural integrity analyses);

- The quality of numerical simulations, through the improvement of models for the simulation of lower plenum phenomena, identified as those responsible of most of the deviation with respect to experimental data, i.e. on the heat flux on the outer vessel wall;

- Related to the previous item, the limitation of a purely steady-state approach is also widely recognized, pushing for a methodological improvement towards a more comprehensive consideration of transient effects (all kinetic effects since the beginning of the transient should be taken into consideration, including possible heat flux spikes, to address the effect on the RPV wall and to assess its possible failure);

- The identification of most pertinent acceptance criteria to be considered in the safety demonstration. However, it is recognized that these are design dependent and that the minimum vessel thickness appears to be one of the most critical for the RPV failure (probably more relevant than the critical heat flux as it includes all kinetic effects since the beginning of the transient, including possible heat flux spikes).

Scope of the CRP

The Coordinated Research Project will aim at providing a platform facilitating interactions among IAEA Member States with the objective of tackling the abovementioned topics.

The general objective of the CRP is to harmonize the international understanding of scientific and technological bases underpinning crucial parts of the safety demonstration of IVMR, including for (but not limited to) high-power reactors.

The scope of the CRP remains open to all water-cooled reactors (WCR) unless there is a clear indication of the MS operating a specific type of WCR that they are not interested in including it in the scope of the CRP.

Participants in the CRP are expected to be involved or having been recently involved in similar activities on IVMR.

Specific Research Objectives

Specific objectives of the CRP will be:

1) To develop an IVMR Phenomena Identification and Ranking Table (PIRT) and validation matrix;
2) To progress the identification of relevant high-quality experimental data requested for the validation of computer codes for simulation of IVMR, including for recently developed and more advanced models (e.g. corium properties and stratification in the lower plenum of the reactor pressure vessel, heat transfer in the stratified pool; external reactor vessel cooling, mechanical resistance of ablated wall);
3) To improve the quality of modelling and simulation, through both improvement of individual physical, thermomechanical and chemical models, and possibly improvement of the methodology developed for lower- to medium-power reactors (traditionally based on the assessment of the heat flux towards the vessel wall from the corium pool, which is then compared to the critical heat flux);
4) To harmonize the international understanding of R&D conclusions underpinning the safety demonstration of IVMR.

The implementation of the CRP on ‘Developing a phenomena identification and ranking table (PIRT) and a validation matrix, and performing a benchmark for in-vessel melt retention’ will be carried out through 4 tasks.

- Task 1: Development of a PIRT

The PIRT is aimed at identifying and ranking phenomena relevant for IVMR safety justification. The PIRT will be used as a basis for developing a validation matrix (Task 2).

The development of the PIRT will start from existing PIRTs, in particular the PIRT developed within the H2020 IVMR Project[1] and will be extended to cover the scope that will be agreed. The development of the PIRT will take also into account justified expert judgment, new sensitivity analyses and feedback that may come from related activities, in particular the CRP on 'Advancing the State-of-Practice in Uncertainty and Sensitivity Methodologies for Severe Accident Analysis in Water Cooled Reactors'. Participation of reactor designers and experimenters to the PIRT development is strongly recommended. Due attention should be given to the weight attributed by the experts when discussing the importance of the phenomena and their ranking. Preparatory work (e.g. collection of existing PIRTs and new sensitivity studies) might start in the early stage of the CRP.

- Task 2: Development of a validation matrix

The objective of the validation matrix will be selection of data (separate-effect tests, integral tests, qualitative tests, etc.) which can be used for the validation of computer codes used for the IVMR analysis. The data should be well characterised by the provider in terms of qualification and availability. The shortcomings of the data should also be identified. The data should be accessible by all Member States participating in this CRP.

Development of the validation matrix will be performed in two steps. First, the existing PIRT from the recently finished IVMR project will be used to identify facilities that can address the issues in a cross-reference table. Creation of this table is not directly connected to Task 1 of the CRP thus enabling the commencement of this activity early in the project. In the second step, the experiments will be selected that can address the phenomena identified in the extended PIRT performed in Task 1 of the CRP. If experimental facilities will be identified but the results are not available for the code validation within the CRP, this will be explicitly mentioned. Both the cross-reference table and the validation matrix will be periodically revised identifying possible progress of the CRP.

- Task 3: Benchmark involving code-code comparison and comparison with experimental data on individual phenomena

Based on the outcomes of the PIRT and the validation matrix developed in previous tasks, a few phenomena identified as relevant for IVMR will be selected for the development of benchmark exercises involving a comparison against experimental results as well as code to code comparison. Topics for individual benchmarks include corium properties and stratification in the lower plenum of the reactor pressure vessel, heat transfer in stratified corium pools and external reactor vessel cooling. The benchmark exercises aim at characterizing the state-of-the-art of modelling and simulation capabilities for the individual phenomena, while also providing useful inputs for further code improvements of individual models, and uncertainty reduction.

During this task, the results obtained by the code developers will be considered separately from those of code users in order to better characterize user effects.

These benchmarks will be selected in the CRP based on their relevance for IVMR (outcome of the PIRT) and provided that experimental data on related experiments will be made available within the CRP (by other participants or by organizations providing the experimental data).

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[1] Fichot F., Carénini L., Bakouta N., Esmaili H., Humphries L., Laato T., Le Tellier R., Saas L., Melnikov I., Pandazis P., Weber S., Park R.J., Filippov A., Strizhov V., Elaboration of a PIRT for the modelling of in-vessel retention, Proceedings of 9th ERMSAR conference (European Review Meeting on Severe Accident Research), Prague, Czech Republic, 18-20 March 2019

- Task 4: Analytical benchmark

The aim of the analytical benchmark is to identify improvements in the models used after the implementation of modifications resulting from Task 3 on the basis of an IVMR exercise representative of a comprehensive scenario.

In order to have consistent initial and boundary conditions for all the codes, analysis should start from the situation where the molten material has been relocated to the lower plenum. It is proposed to consider as a basis for the analytical benchmark the cases described in the IVR code benchmark performed in the H2020 IVMR Project[2] and to adapt them to this Task, possibly by considering different designs and scenarios that will be agreed by the participants. Mechanical calculations may be also considered. In order to demonstrate any improvements in the models, it is proposed to run the defined cases before and after the implementation of the modifications in the models. Preparatory work (adaptation of the cases described in the IVR code benchmark performed in the H2020 IVMR Project) might start in the early stage of the CRP.

The CRP will provide opportunities for training and education of young engineers and scientists, including from countries embarking on a nuclear power programme, as appropriate.

Activities (to be undertaken by the participants under IAEA coordination) with tentative schedule:

- Submission of proposals – January to 15 April 2020
- Preparatory work for the development of the PIRT – as from July 2020
- Participation in the 1st Research Coordination Meeting (RCM-1), during which the following tasks will be developed –Q4-2020
    - Development of a preliminary PIRT (Task 1)
    - Preparatory work for the development of the validation matrix (Task 2)
    - Expression of interest from participants on individual phenomena benchmarks involving code-code comparison and comparison with experimental data (Task 3)
    - Preparatory work (adaptation of the cases described in the IVR code benchmark performed in the H2020 IVMR Project) for the analytical benchmark
- Initiation of definition of individual phenomena benchmarks (Task 3) – May 2021
- Documentation of the preliminary validation matrix (Task 2) – September 2021
- Development of individual phenomena benchmark specifications – October 2021
- Execution of calculations of individual phenomena benchmarks – November 2021/April 2022
- Submission of the results of individual phenomena benchmarks – May 2022
- Participation in the 2nd Research Coordination Meeting (RCM-2), during which the following tasks will be developed – May/June 2022
    - Discussion on results of individual phenomena benchmarks (Task 3)
    - Possible updating of the PIRT (Task 1)
    - Possible updating of the validation matrix (Task 2)
    - Definition of the analytical benchmark (Task 4)
- Development of specifications of the analytical benchmark (Task 4) – September 2022
- Submission of final results on individual benchmarks – November 2022
- Execution of calculations of analytical benchmark (Task 4) – October 2022/April 2023
- Submission of preliminary results on analytical benchmark (Task 4) and discussion on results – May 2023
- Whether applicable, second round of calculation of analytical benchmark (Task 4) – June/September 2023
- Submission of final results on analytical benchmark – October 2023
- Finalization of PIRT (Task 1) and preparation of draft final task report –October 2023/March 2024
- Finalization of validation matrix (Task 2) and preparation of draft final task report –October 2023/March 2024

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[2] Carenini L., Fichot F., Bakouta N., Filippov A., Le Tellier R., Viot L., Melnikov I. Pandazis P., Main outcomes from the IVR code benchmark performed in the IVMR project, proceedings Proceedings of 9th ERMSAR conference (European Review Meeting on Severe Accident Research), Prague, Czech Republic, 18-20 March 2019

- Finalization of individual phenomena benchmarks (Task 3) and preparation of draft final task report – October 2023/March 2024
- Finalization of analytical benchmark (Task 4) and preparation of draft final task report – October 2023/ March 2024
- Participation in the 3rd Research Coordination Meeting (RCM-3) – June-2024
  - Discussion and completion of the PIRT final task report
  - Discussion and completion of the validation matrix final task report
  - Discussion and completion of the individual phenomena benchmarks final task report
  - Discussion and completion of the analytical benchmark final task report
  - Preparation of the CRP summary report
  - Preparatory work for the final workshop
- Final workshop – Q3-2024.

Outputs

- Task report on PIRT
- Task report on validation matrix
- Task report on individual benchmark involving code-code comparison and comparison with experimental data
- Task report on the analytical benchmark
- CRP summary report.

Outcomes

- Strengthened knowledge and understanding of severe accidents, in particular IVMR
- Improvement of safety assessment of IVMR through modelling and simulation
- Harmonized international understanding of R&D conclusions underpinning IVMR safety demonstration
- Enhanced confidence in the safety demonstration of IVMR
- Training and education of young engineers and scientists, including from countries embarking on a nuclear power programme.

Financial Support

The IAEA will contribute €3000 per year towards each contract with organisations from developing Member States. Additionally, the IAEA will support financially the attendance of CRP participants that have made substantial contributions (through either research contracts or research agreements) to the three research coordination meetings (RCM) planned to be held during the CRP, and to the final workshop.

Application Procedures

Interested institutions should submit their "Proposal for a Research Contract" or Proposal for a Research Agreement" that covers part(s) or all of the scope of the CRP (*the scope of the coverage of a proposal is to be determined by the Project Officer after evaluating the proposal and the capacity of the scientist(s) involved and the capability of the institute)*. The research contract/agreement proposal form templates are available at https://www.iaea.org/services/coordinated-research-activities/how-to-participate.

Research proposals should be submitted by email to research.contracts@iaea.org by 15 April 2020.

Administrative questions should be addressed to the Research Contracts Administration Section (NACA) via research.contracts@iaea.org.

Technical enquiries should be addressed to the project officers for this CRP:

- Mr Abdallah Amri (A.Amri@iaea.org)
- Mr Simone Massara (S.Massara@iaea.org)
- Mr Alexei Miassoedov (A.Miassoedov@iaea.org)

Further general information relating to the participation in CRPs and Coordinated Research Activities in general is available on http://cra.iaea.org.