IAEA
International Atomic Energy Agency

CRPI31018 - Programme

1. Title of CRP

"Development of Methodologies for the Assessment of Passive Safety System Performance in Advanced Reactors"

2. Summary

This CRP aims on development of a common approach to assess performance of passive safety systems. Such an approach could facilitate design optimization and safety qualification of the future advanced reactors, contributing to their enhanced safety levels and improved economics. The project is expected to pool together efforts of all principal developers of the relevant approaches and methodologies worldwide, and also to attract capable new participants.

3. Background Situation Analysis

Strong reliance on passive safety design options has become a 'trademark' of many advanced reactor designs, including several evolutionary designs and the majority of innovative small and medium sized reactor (SMR[1]) designs [1, 2, 3, 4]. While the wording 'passive safety design options' as used above denotes various possible combinations of inherent and passive safety features (recently often referred to as by-design safety approaches [3]) and reasonable combinations of active and passive safety systems incorporated in reactor design. These include passive safety systems, such as those incorporating moving liquids or expanding solid structures, direct action devices, or stored energy sources (i.e., passive systems of categories B, C, and D defined in IAEA-TECDOC-626 [5]). The passive safety systems require validation and testing to demonstrate and prove their reliable operation and, if necessary, adjust their design accordingly.

While individual processes may be well understood, the combinations of these processes, which determine the actual performance of passive safety systems, may vary depending on changes in the conditions of state, boundary conditions and failure or malfunctioning of components within the system, the circuit or the plant. Passive safety systems of category A, or inherent safety features incorporate no moving liquids or moving solid structures, direct action devices, or stored energy sources. There is a consensus that such systems have strong advantages [3, 4]. Therefore, the issue of process performance reliability becomes important for passive safety systems of categories B, C, and D [5].

There are certain accomplishments regarding the testing, construction, licensing or validation of passive systems of B, C, or D types, such as more recent Russian VVER-1000s and the KLT-40S, or the US AP1000 [1, 2]. Experiment-based deterministic approaches to the validation of passive systems including separate-effect tests and integral tests of reactor models with subsequent qualification of analysis models and computer codes have been established and accepted by the regulators in some countries, in line with conventional safety requirements also applied to active safety systems. The indicated deterministic approaches are

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[1] According to the classification adopted by the IAEA, 'small reactor' is a reactor with the equivalent electric power less than 300 MW, 'medium sized reactor' is a reactor with the equivalent electric power between 300 and 700 MW.

generally successful with regulators when the basic technology involved (e.g., that of water cooled reactors) is evolutionary, i.e., backed by many years of validation and testing and reactor operation experience, and when passive systems are reasonably conventional in their design. When the technology is innovative and passive systems have a somewhat non-conventional design, the application of established deterministic approaches may require multi-year efforts on validation, testing and demonstration of reliable operation of such systems, prior to licensing approval of the corresponding advanced NPP.

The regulations in Argentina, China, Japan, Germany, India, France, the Russian Federation, and the USA already make provisions for accepting the results of probabilistic safety assessments (PSAs) on a complementary basis. In order to ensure that the PSA used in the risk-informed decision making (RIDM) process is of acceptable technical quality, the effort is being made in different countries to provide PSA standards that define inherent technical features of a PSA acceptable for regulatory body. An example is the ASME Probabilistic Risk Assessment (PRA) Standard[2] recently endorsed by the US NRC. In line with the worldwide trends, the IAEA is developing a series of publications in the Safety Standards Series on PSA and RIDM. One of the latter, namely the Safety Guide on 'Development and Application of Level-1 PSA for NPPs,[3] which will be published in the middle 2008, will provide recommendations on the technical content of PSA studies to reliably support various PSA applications.

The general trend toward a more risk informed approach is pursued with a focus on what is really important from the safety perspective and to achieve a design that is more favourable from the cost-benefit perspective, could potentially result in a more competitive advanced nuclear power plant. A methodology for reliability assessment of passive safety systems would enable quantification of the reliability to treat both active and passive safety systems within a common PSA approach. Several such methodologies are under development in Europe, India, and the USA [6, 7, and 8] What is important from a perspective of the overall risk assessment, these methodologies take into account uncertainties associated with unforeseen physical phenomena that may affect the operation of passive systems, worsening their reliability. All of the methodologies are at a preliminary stage of development and no consensus on a common approach has been established so far among their proponents.

As an example, in the late 1990s, a methodology known as REPAS was developed cooperatively by ENEA, the University of Pisa, the Polytechnic of Milan and the University of Rome in Italy that was later incorporated in the European Commission's Reliability Methodology for Passive Systems (RMPS) project within the EC's 5th Framework programme. The RMPS methodology is based on the evaluation of a failure probability of a system to carry out the desired function for a given set of scenarios taking into account the uncertainties of those physical (epistemic) and geometric (aleatoric) parameters the deviations of which can lead to a failure of the system. The RMPS approach considers a probability distribution of failure (pdf) to treat variations of the comparative parameters considered in the predictions of codes.[4]

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[2] THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS, Standard for Probabilistic Risk Assessment for Nuclear Power Plant Applications, ASME RA-S-2002, ASME, New York (2002).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Guide: Development and Application of Level-1 PSA for NPPs, DRAFT (DS394), February 2007.

[4] A test case of the RMPS methodology is currently underway for a CAREM-like passive residual heat removal system within the CRP on "Natural Circulation Phenomena, Modelling and Reliability of Passive Systems That Utilize NC".

A different approach followed is the "APSRA" methodology developed at BARC, India. In this approach, the failure surface[5] is generated by considering the deviation of all those comparative parameters which influence the system performance. Then, the causes of deviation of these parameters are found through root diagnosis. It is attributed that the deviation of such physical parameters occurs only due to a failure of mechanical components such as valves, control systems, etc. Then, the probability of failure of a system is evaluated from the failure probability of these mechanical components through classical PSA treatment. Moreover, to reduce the uncertainty in code predictions, BARC makes use of the in-house experimental data from integral facilities as well as separate effect tests.

During a dedicated IAEA technical meeting of 12-16 June 2006, held with broad representation of interested stakeholders, it was noted that APSRA and RMPS are complementary in the following:

- APSRA incorporates an important effort on qualification of the model and use of the available experimental data. These aspects have not been studied in RMPS, given the context of this project;
- APSRA includes in the PSA model the failure of those components, which cause a deviation of the key parameters resulting in a system failure, but does not take into account the fact that the probability of failure of a physical process could be different from unity.
- RMPS proposes to take into account in the PSA model the failure of a physical process. It is possible to treat such data (best estimate code plus uncertainty approach is suitable for this purpose).
- In fact, two different philosophies or approaches have been used in RMPS and APSRA, and the two developed methodologies are, therefore, different. At the same time, CEA concludes that certain parts of the APSRA and the RMPS could be merged in order to obtain a more complete methodology.

During the IAEA technical meeting mentioned above and after it several other distinct approaches for reliability assessment of passive safety system performance and differences between them were noted [8, 9, and 10], and the consensus was that a common approach might be helpful for further design and qualification of future advanced nuclear reactors.

Reflecting on these developments in Member States, the IAEA recommended coordinating a research project "Development of Methodologies for the Assessment of Passive Safety System Performance in Advanced Reactors".

4. Nuclear Component

Advanced nuclear power plants and their passive safety systems are essentially nuclear components.

5. Overall Objective

The objective is to determine a common method for reliability assessment of passive safety system performance. Such a method would facilitate application of risk-informed approaches

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[5] Failure surface [7] is an experiment-backed predicted boundary of reliable operation of a passive safety system defined against all variables that may affect such performance and used to support the subsequent root cause analysis (actually, the failure surface defined in [7] is of iterative nature, also supporting the identification of the tests still missing).

in design optimization and safety qualification of the future advanced reactors, contributing to their enhanced safety levels and improved economics.

The CRP will be implemented as a programmatic activity of the IAEA sub-programme 1.1.5 “Technology Development for Advanced Reactor Lines” (involving collaboratively the projects 1.1.5.1, 1.1.5.2, and 1.1.5.4) and the IAEA project 3.2.3.3 “Fostering technical developments and trends in safety analyses”, starting with the IAEA Program and Budget Cycle 2008 – 2009. The sub-programme 1.1.5 has the objective to achieve progress in the development of advanced nuclear power technologies that have competitive economics and meet stringent safety objectives through international information exchange and coordinated research, and the Project 3.2.3.3 has the objective to facilitate, among others, technical developments of new trends and issues in safety analyses, and to share with Member States. Given its aforementioned overall objectives, the CRP clearly responds to the objectives of the IAEA sub-programme 1.1.5 and project 3.2.3.3.

Inter- and intra-departmental coordination in the Agency

The proposed CRP foresees a broad intra-departmental and inter-departmental cooperation. The project would be implemented in conjunction with the Nuclear Energy Department’s Technical Working Groups on Advanced Light Water Reactors (LWRs), Heavy Water Reactors (HWRs), Gas Cooled Reactors (GCR) and Fast Reactors (FR) of NENP and the Safety Assessment Section and Engineering Safety Section of the Department of Nuclear Safety and Security. Specifically, the IAEA Safety Assessment Section of the Department of Nuclear Safety and Security would be engaged to provide peer reviews of the PSA methodologies applied and of the results obtained in PSA studies for advanced NPP designs.

One of the methodological approaches that could be addressed within this project, the RMPS approach developed within the EU framework programmes, is currently undergoing a trial application to the assessment of the passive system design of the CAREM type reactor of Argentina within an IAEA CRP "Natural circulation phenomena, modelling and reliability of passive systems that utilize natural circulation", coordinated jointly within the Technical Working Groups on Advanced Technologies LWRs and HWRs within NENP.

The CEA has proposed in the framework of INPRO a collaborative project called “Reliability Assessment of Passive Gaseous Provisions”. This proposal, dedicated to the issues of passive decay heat removal from a fast gas cooled reactor concept being developed by the CEA, could be a task of the present CRP or close cooperation between the two efforts could be established.

6. Specific Research Objectives

The scope of the problems associated with further development of methodologies for reliability assessment of passive safety systems was elaborated at the IAEA technical meeting “Status of Validation and Testing of Passive Safety Systems for Small and Medium Sized Reactors (SMRs)” held in Vienna on 12-16 June 2006 and through direct communications with the developers of such methodologies. In line with these discussions, the specific research objectives of this CRP are:

- Identify requirements for a method of reliability assessment of passive safety systems for future advanced NPPs ;
- Work out a set of definitions for reliability assessment of passive safety systems and their treatment by PSA, e.g., ‘reliability of a passive safety system’, ‘safe end state’ of accident sequences, ‘mission time’, etc. (a consensus should also be reached on

whether proving the ability of passive systems to perform their function is clearly related to the selection of a certain PSA modelling approach);

- Identify a benchmark problem for comparison and validation of methodologies for reliability assessment of passive safety system performance, including such issues as systematic failure modes and effects analysis (FMEA), component failure rates, treatment of dependencies in fault tree (FT) models, impact from internal and external hazards, etc.;
- Select reliability assessment methodologies and perform trial applications, including evaluation of the uncertainties, for a selected benchmark problem;
- Compare the results and prepare recommendations for a common analysis-and-test based unified approach ;
- Draft suggestions for further elaboration of IAEA Safety Standards.

7. Expected Research Outputs

The CRP's output will be an IAEA Nuclear Energy series report responding to the overall objective of increasing the Member States capability to achieve progress in the development of a common approach to reliability assessment of passive safety system performance. This report will present:

- The requirements for a method of reliability assessment of passive safety systems for future advanced NPPs;
- A set of definitions for reliability assessment of passive safety systems and their treatment by PSA;
- Description of a benchmark problem to compare and validate methodologies for reliability assessment of passive safety system performance;
- Descriptions of selected methodologies for reliability assessment of passive safety systems involved in trial application for the defined benchmark problem;
- Results of trial applications of the methodologies for a selected benchmark problem, results of the uncertainty analyses;
- Analysis of results of the trial applications with recommendations for a common analysis-and-test based unified approach;
- Draft suggestions for further elaboration of IAEA Safety Standards.

8. Expected Research Outcomes

The expected research outcome is increased capability in Member States to achieve progress in the development of a common approach to reliability assessment of passive safety system performance.

9. List of Potential Participating Institutes

At the IAEA technical meeting "Status of Validation and Testing of Passive Safety Systems for Small and Medium Sized Reactors (SMRs)" held in Vienna on 12-16 June 2006 and through direct communications with stakeholders after it, the following expressions of interest regarding participation in the CRP were provided by representatives of organizations in Member States who are involved or interested in development and furthering of methodologies for reliability assessment of passive systems for advanced reactors.

France: Research Centre Cadarache of the CEA of France (CEA/DEN/DER/SESI/LCFR) has participated in IAEA technical meeting of 12-16 June 2006 and expressed a priori interest to participate in the CRP. The CEA is currently proposing in the framework of INPRO a benchmark called "Reliability Assessment of Passive Gaseous Provisions". This benchmark could be a task of the CRP.

India: Bhabha Atomic Research Centre (BARC) of India has participated in IAEA technical meeting of 12-16 June 2006 and is interested to participate in the CRP.

Italy: The University of Rome "La Sapienza" (Italy) has participated in IAEA technical meeting of 12-16 June 2006 and has expressed interest to participate in the CRP.

Italy: The ENEA of Italy has expressed interest to participate in the CRP, specifically, with reference to the activities 1, 2, 3, 6, and 7 (see the activity list given below).

USA: The Massachusetts Institute of Technology was represented at IAEA technical meeting of 12-16 June 2006 and expressed interest to participate in the CRP.

Russian Federation: EDO "Gidropress" has participated in IAEA technical meeting of 12-16 June 2006 and confirmed its interest to participate in the CRP.

Brazil: Instituto de Engenharia Nuclear/CNEN of Brazil has participated in IAEA technical meeting of 12-16 June 2006 and has expressed interest to participate in the CRP.

Other organizations involved in design and safety analysis of advanced NPPs are expected to join.

Netherlands: Institute for Energy of the European Commission (DG-JRC) has reviewed the proposal and has expressed interest to participate in the CRP.

Justification for more than one participating institute per Member State

Two organizations from Italy have expressed their interest to participate – the University of Rome "La Sapienza" and the ENEA – the regulatory body.

The University of Rome has been extensively involved in activities on design development and qualification for advanced reactors with passive safety systems (e.g., MARS, [3]), as well as in elaboration and application of the advanced methods of uncertainty analysis.

The ENEA has a broad experience of participation in the previous and ongoing research efforts on reliability assessment of passive safety systems, such as REPAS, RMPS, the IAEA CRP "Natural circulation phenomena, modelling and reliability of passive systems that utilize the natural circulation" etc., see [6, 12].

Joining the efforts of these two organizations will add value to the overall project via combining the design/R&D and regulatory perspectives related to the topics addressed.

10. Action plan (Activities)

Following the establishment of an international team by putting in place research agreements and contracts, the activities foreseen are as follows:

Activity 1: Identification of the requirements for a method of reliability assessment of passive safety systems for future advanced NPPs;

Activity 2: Working out a set of definitions for reliability assessment of passive safety systems and their treatment by PSA;

Activity 3: Identification of a benchmark problem for a specific, adequately developed system design to compare and validate methodologies for reliability assessment of passive safety system performance;

Activity 4: Trial application of the methodologies for a selected benchmark problem, evaluation of the uncertainties;

Activity 5: Carrying out comparative analysis of the results; and working out suggestions for a common analysis-and-test based unified approach;

Activity 6: Drafting the suggestions for further elaboration of IAEA Safety Standards.

The CRP is anticipated to have 4-year duration, with a possible extension. First year research contracts and research agreements are planned to be signed in January – May 2008. The timeframes for implementation of the activities are identified in the chart on the next page.

The Research Coordination Meetings (RCMs) are foreseen as follows:

1st RCM:	11/2008
2nd RCM:	11/2009[6]
3rd RCM:	11/2010
4th RCM:	11/2011

The objectives and outputs of the RCMs are summarized in the Logical Framework Table given below.

[6] - The need to convene the 2nd and the following RCMs in less that 18 months from the previous ones is justified by complex character of the tasks and expected intense interactions of the participants of the CRP

Schedule of activities

Activity	Year 1	Year 2	Year 3	Year 4
Activity 1: Identification of the requirements for a method of reliability assessment of passive safety systems for future advanced NPPs				
Activity 2: Working out a set of definitions for reliability assessment of passive safety systems and their treatment by PSA				
Activity 3: Identification of a benchmark problem for a specific, adequately developed system design to compare and validate methodologies for reliability assessment of passive safety system performance				
Activity 4: Trial application of the methodologies for a selected benchmark problem, evaluation of the uncertainties				
Activity 5: Carrying out comparative analysis of the results; and working out suggestions for a common analysis-and-test based unified approach				
Activity 6: Drafting the suggestions for further elaboration of IAEA Safety Standards				

12. Assumptions

For the CRP to meet its objectives, it is assumed that:

- Design and technology development for advanced NPPs with passive safety systems in Member States continues at a currently observed or increased pace;
- The interest in Member States to deployment and application of nuclear power plants is not decreased substantially against what is observed at the moment of the project start-up;
- IAEA financial and staff resources will be available.

13. Logical Framework

The Logical Framework is provided in a Table, starting from the next page.

Logical Framework Table

Project Design Elements	Verifiable Indicators	Means of Verification	Important Assumptions
Overall Objective: is to determine a common method for reliability assessment of passive safety system performance.	N/A	N/A	Continued progress in design and technology development for advanced NPPs with passive safety systems in Member States
Specific Research Objectives: • Identify requirements for a method of reliability assessment of passive safety systems for future advanced NPPs ; • Work out a set of definitions for reliability assessment of passive safety systems and their treatment by PSA, • Identify a benchmark problem for comparison and validation of methodologies for reliability assessment of passive safety system performance; • Select reliability assessment methodologies and perform trial applications, including evaluation of the uncertainties, for a selected benchmark problem; • Compare the results and prepare recommendations for a common analysis-and-test based unified approach ; • Draft suggestions for further elaboration of IAEA Safety Standards.	Nuclear Energy Series (NES) report[s] resulting from CRP is acknowledged by experts as presenting state of the art in the definition and elaboration of issues included in the specific research objectives Percentage of positive replies from questionnaires on project publications (NES[s]) Number of members states using the consolidated approach developed within the project	Technical papers and reports of the nuclear power reactor industry, research institutes and universities referencing the NES reports[s] and using the information therein Data collected and processed by NPTDS	National support is provided to participating institutes, at least at the level characteristic of the moment of CRP initiation (2008) Intense coordination occurs among contract / agreement holders and with IAEA Appropriate technical support is provided to CRP by Project Officer

Logical Framework Table (continued 1)

Project Design Elements	Verifiable Indicators	Means of Verification	Important Assumptions
Expected Research Outcomes: Increased capability in Member States to achieve progress in the development of a common approach to reliability assessment of passive safety system performance.	NES Report[s] presenting the expected output for each of the 6 specific research objectives	NES Report[s] approved by the Publications Committee	Sufficient technical skills applied by participating institutes and sufficient involvement of the Project Officer in working with the chief scientific investigators to assimilate results of activities for clear presentation in NES Report[s] Sufficient resources applied at participating institutes to prepare and present papers at international conferences and in technical journals
Activities (First year) **Activity 1:** Identification of the requirements for a method of reliability assessment of passive safety systems for future advanced NPPs; **Activity 2:** Working out a set of definitions for reliability assessment of passive safety systems and their treatment by PSA;	Number of Research Contract and Research Agreement Proposals submitted	Approval of Agreements and Contracts by the Nuclear Energy and Safety Research Contract Sub-committee of the PCC	Suitable proposals submitted including provision of detailed work plans and appropriate information on the previous research of relevance
Activity 3: Identification of a benchmark problem for a specific, adequately developed system design to compare and validate methodologies for reliability assessment of passive safety system performance.	Number of Progress Reports from CRP Participants submitted on-time after the first Year	Report evaluation by the Project Officer Participants presentations at the RCM RCM Working Material Meeting Report	Support of participating institutes by national or bilateral programmes is consistent with plans described by representatives of member states at the IAEA technical meeting held on 12-16 June 2006.

Logical Framework Table (continued 2)

Project Design Elements	Verifiable Indicators	Means of Verification	Important Assumptions
Convene 1st RCM to review progress on Activities 1, 2, 3 and to plan further collaboration in Activities 2, 3, 4, 5			
Activities (Second Year) **Activity 2:** Working out a set of definitions for reliability assessment of passive safety systems and their treatment by PSA; **Activity 3:** Identification of a benchmark problem for a specific, adequately developed system design to compare and validate methodologies for reliability assessment of passive safety system performance; **Activity 4:** Trial application of the methodologies for a selected benchmark problem, evaluation of the uncertainties; **Activity 5:** Carrying out comparative analysis of the results; and working out suggestions for a common analysis-and-test based unified approach **Convene 2nd RCM** to review progress on Activities 2, 3, 4, 5 and to plan further collaboration in Activities 2, 4, 5, 6	Number of Progress Reports from CRP Participants submitted on-time after the first Year	Report evaluation by the Project Officer Participants presentations at the RCM RCM Working Material Meeting Report	Support of participating institutes by national or bilateral programmes is consistent with plans described by representatives of member states at the IAEA technical meeting held on 12-16 June 2006.

Logical Framework Table (continued 3)

Project Design Elements	Verifiable Indicators	Means of Verification	Important Assumptions
Activities (Third Year) **Activity 2:** Working out a set of definitions for reliability assessment of passive safety systems and their treatment by PSA; **Activity 4:** Trial application of the methodologies for a selected benchmark problem, evaluation of the uncertainties; **Activity 5:** Carrying out comparative analysis of the results; and working out suggestions for a common analysis-and-test based unified approach; **Activity 6:** Drafting the suggestions for further elaboration of IAEA Safety Standards. **Convene 3rd RCM** to review progress on Activities 2, 4, 5, 6, to plan further collaboration in Activities 5, 6, and to assign responsibilities for drafting a NES report on the results of the project.	Number of Progress Reports from CRP Participants submitted on-time after the first Year	Report evaluation by the Project Officer Participants presentations at the RCM RCM Working Material Meeting Report	Support of participating institutes by national or bilateral programmes is consistent with plans described by representatives of member states at the IAEA technical meeting held on 12-16 June 2006.

Logical Framework Table (continued 4)

Project Design Elements	Verifiable Indicators	Means of Verification	Important Assumptions
Activities (Fourth Year) **Activity 5:** Carrying out comparative analysis of the results; and working out suggestions for a common analysis-and-test based unified approach; **Activity 6:** Drafting the suggestions for further elaboration of IAEA Safety Standards. **Convene 4th RCM** to review progress on Activities 5, 6, to review draft NES report and plan completion of the report	Will be verified when NES report is [NES Reports are] approved for publication by the Publications Committee Defined common approach to reliability assessment of passive safety system in advanced reactors Draft NES report on the results of the project	Approval of NES Report[s] manuscript by the Publications Committee	Support of participating institutes by national or bilateral programmes is consistent with plans described by representatives of member states at the IAEA technical meeting held on 12-16 June 2006.
Outputs	NE series publication summarizing the results of the CRP for the six specific research objectives	Delivery of expected outputs	Acceptance by IAEA Publications Committee
	Various external publications in peer-reviewed journals and conference proceedings	Delivery of expected outputs	Acceptance by external reviewers
Inputs	See a dedicated table above	N/a	N/a

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