Meeting Report of the First Research Coordination Meeting of a Coordinated Research Project on Development of Methodologies for the Assessment of Passive Safety System Performance in Advanced Reactors (CRP i31018)

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1. Objectives of the meeting

The First Research Coordination Meeting (RCM) of a Coordinated Research Project (CRP) on Development of Methodologies for the Assessment of Passive Safety System Performance in Advanced reactors was held during 31 March – 3 April 2009 in Vienna with 9 participants and 2 observers representing 10 research institutes and organizations in Argentina, India, Italy, Japan, France, the Russian Federation, Sweden, and the United States of America, and had the following main objectives:

- To present and discuss the state-of-the-art in research on, and development of, the methodologies for the assessment of passive safety system performance in advanced reactors;
- To elaborate detailed plans of collaborative activities for the next year of work and beyond;
- To define the important points and the general structure of the requirements to common analysis-and-test based method for reliability assessment of passive safety systems that would enable their inclusion into PSA and comparison with active safety systems
- To compile a list of terms for reliability assessment of passive safety systems and their treatment by PSA, and elaborate some definitions.

2. Scope of the meeting

The Agenda of the meeting and the list of participants are enclosed as ANNEX I and ANNEX II respectively. Mr. D. Saha (BARC, India) was elected as meeting Chairman.

The presentations delivered at the meeting highlighted:

- The state of the art in validation of passive safety systems and reactors with passive safety systems in member states;
- Approaches currently used for validation of passive safety system performance in advanced reactors;
- Status and trends in the development of methodologies for the assessment of reliability of passive systems and examples of their application;
- Issues related to the inclusion of passive safety systems in plant PSA;
- Certain suggestions for meeting the objectives of the first research coordination meeting.

The presentations made at meeting and the materials submitted to the meeting are available on a CD, upon request from the project officer, V. Kuznetsov: v.v.kuznetsov@iaea.org.

Next research coordination meeting of the project will be convened tentatively in March 2010.

3. Observations from participants of the meeting

3.1. Observations from the Chairman of the Meeting

(1) During the course of deliberations, the role of test data vis-à-vis methodologies under consideration, especially in respect of APSRA methodology, was well comprehended. It was pointed out that test data is used mainly for evaluating code uncertainty in APSRA methodology.

(2) The term "Benchmarking" was given due consideration during the course of discussions. Consensus on this aspect was reached. As a result, proposals were made for benchmarking of methodologies adopting both theoretical and experimental approaches.

(3) Ambiguities of terms used in the area of methodology for reliability assessment of passive systems were removed to a great extent. This resulted in the proposal for creating a Glossary specific to this area. It is expected that this might become part of IAEA Safety Glossary after review by appropriate authority.

(4) This meeting, being the forum for first direct interaction between participants, resulted in better understanding of original proposals of participants and led to the adoption of a consensus course of action to achieve the goals of the CRP. However, this may require redefining the scope of work of some of the original proposals.

3.2. Observations from CEA (France)

(1) Regarding the existing methodologies to assess the reliability of passive safety systems, two major types of methodologies seem to be conflicting, "RMPS-type" methodologies with identification and quantification of uncertainties in the form of probability distributions, propagation of these uncertainties directly into a thermal-hydraulic code or indirectly in using a response surface or an adjoint operator, and the APSRA methodology where it is attempted to assess not the uncertainty of parameters but the causes of deviation from nominal conditions, which can be in the failure of active or passive components or systems. However, it is interesting to compare these two methodologies in different benchmarks, and it seems possible to merge certain parts of the two types of methodologies in order to obtain a more complete methodology fulfilling the requirements identified within the CRP.

(2) Concerning the proposals of benchmarks - the identified benchmarks cover a large part of the requirements identified for the common method for reliability assessment of passive safety systems. The only topic not really addressed by the benchmarks is the integration of passive safety system reliability in the overall PSA, but this topic is intended to be addressed in the second year. A relevant benchmark could be of high interest for the comparison of methodologies on this topic also. One of the objectives of the first benchmark (based on a test facility), which is evaluating experimentally the failure probability of a system (via increasing this probability artificially) for a comprehensive validation of the proposed methods, will be a challenge due to the difficulty to generate a really random experimental design prerequisite for the failure probability evaluation.

3.3. Observations from IGCAR (India)

(1) The meeting was very useful to learn about the state-of-art in research and development of methodologies for passive safety system performance assessment, based on presentations by the experts and the discussion. There was excellent coordination of the activities, especially as comes to the brainstorming session facilitated by the scientific secretary. In this respect, I would

like to thank IAEA and the project officers V.V. Kuznetsov., S. Michael Modro, Alexander Stanculescu and Ms. Sama Bilbao Y Leon, as well as all other participants.

(2) The meeting has attempted to address the entire spectrum of issues related to the topic, such as the state-of-the-art in passive safety system validation, requirements for an acceptable common methodology, benchmarks, experiments, databases and advanced techniques to boost computation efficiency.

(3) I hope this CRP makes it possible to arrive at an acceptable methodology the application of which would produce qualitative insights, as well as a set of numbers (metrics), capturing all quantifiable uncertainty, which would be of use in design optimization and risk-based/risk-informed decision making process for advanced/next generation reactors.

3.4. Observations from ENEA (Italy)

(1) The meeting has been successful, because it allowed highlighting most of the open issues related to the reliability of passive safety systems, pointing out needs for further research in this area. In particular, the following points have been addressed:

- Evaluation of the uncertainties related to passive system performance, both as regards the best estimate codes and the system reliability assessment;
- The dependencies among the parameters playing a key role in the whole process;
- The integration of the passive systems within an accident sequence in combination with active systems and human actions;
- Consideration for time-dependence of physical processes and involved physical quantities, implying, for instance, the development of a dynamic event tree to incorporate the interactions between the physical parameter evolution and the state of the system and/or the transition of the system from one state to another;
- Comparison between active and passive safety systems, from a functional viewpoint.

(2) In addition, it is worth mentioning once again that the applications of the proposed methodologies are quite dependent upon the assumptions underlying the methods themselves. This concerns, for instance, the choice of the distributions to be assigned to the parameters, i.e., probabilistic characterizations of the parameters. This aspect is very important as it is the major goal of the CRP to reach a consensus about the different approaches in order to add credit to the models and the resulting reliability figures.

3.5. Observations from ISU (USA)

(1) Three main approaches to reliability analysis were presented, RMPS (CEA/Cadarache, France), REPAS (University of Pisa, Italy), and APSRA (BARC, India). The challenges of this CRP will be to apply these three methodologies to the evaluation of specified natural circulation safety system problems, be capable of determining the relative accuracies of each methodology in predicting system reliability, and compare the results of these methodologies to quantify the confidence implied in the reliability assessment.

(2) From the standpoint of an experimentalist, it was informative to learn of the various impacts that a well-defined and executed experiment would have on the confidence in a methodology's ability to predict reliability. For example, the uncertainty in a critical parameter (e.g., friction along PRHS tubes) might have a high (e.g., 50%) value as included in the numerical models associated with a methodology. A phenomenological experiment could be devised that would measure the friction in the PRHS tubes to a higher accuracy, thus reducing the uncertainty propagated in the numerical model. In addition, an experiment may be used to fine tune the results of a methodology through comparisons with the test data.

4. Recommendations of the meeting

4.1. Work plan for the next year and beyond

The detailed plan of activities for the next year and beyond was elaborated as shown in Table 1.

Table 1. Plan of collaborative activities for the next year and beyond

#	Activity title	Milestones in implementations	Collaborative team	First year outputs
1	*Activity title in the approved CRP programme:* • Identify requirements for a method of reliability assessment of passive safety systems for future advanced NPPs			
1.1	Elaboration of requirements to the method of reliability assessment of passive safety systems	• Develop the skeleton (done, see Section 4.2) • Develop a final set of the requirements	**Editors: *D. Saha and M. Marques*** All participants	Final draft of the requirements (Input from all participants to the Scientific Secretary and the editors – in 4 months)
2	*Activity title in the approved CRP programme:* • Work out a set of definitions for reliability assessment of passive safety systems and their treatment by PSA			
2.1	Elaboration of a set of definitions for reliability assessment of passive safety systems and their treatment by PSA	• Compile the list of terms (done, see Section 4.3) • Produce suggestions for the definitions	**Editors: *A. Lyubarsky (NSNI) and V. Siryapin*** All participants	Final suggestions for the definitions (Input from all participants to the Scientific Secretary and the editors – in 2 months)
3	*Activity title in the approved CRP programme:* • 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;			

Table 1 (continued 1)

#	Activity title	Milestones in implementations	Collaborative team	First year outputs
3.1	Define the goals for methodology validations. Develop the requirements for adequate tests. Consider possible tests. Existing facilities in participating countries could be checked. Steps addressed, see Section 4.2: (3.2), (3.3), (3.4)	• Define goals for validation of methodology, including failure criteria, and link these goals to the steps in reliability assessment • Select a facility • Develop failure parameter test matrix, including pre-test simulations of anticipated facility performance • Check whether parameter uncertainty could be simulated in selected facility • Modify the facility for parameter simulation, if needed • Perform tests • Apply the methodologies • Analyze the results and make conclusions on validity of the methodologies	**Team leader** **D. Araneo**, M. Bykov, D. Saha, M. Marques L. Burgazzi J. Arul, M. Gimenez, Potentially – P. Kudinov.	• Goals defined (6 months) • Existing Facilities checked (6 months) • Failure parameter test matrix developed, depending on the output of the second item (12 months) (Input from all participants to the Scientific Secretary and the editors – in defined terms)
3.2	Exchange of information and planning of the application of APSRA to the analysis of IRIS/ PCCS. Design activities and planning of tests for the ISU test facility. No immediate link to the steps	• Share the information with BARC • Design, fabricate and test the ISU facility • Develop test matrix • Apply the methodologies	**Team leader:** ***B. Williams***, D. Saha Open to other participants	• Preliminary facility layout • Preliminary test matrix • Information on PCCS shared with BARC (Input from all participants to the Scientific Secretary and the editors – in 12 months)

Table 1 (continued 2)

#	Activity title	Milestones in implementations	Collaborative team	First year outputs
3.3	(i) Development of a benchmark problem, and (ii) development and application of efficient methods to minimize the number of calculations needed for reliability assessment of passive safety systems Steps: (3.8)	• Develop a benchmark problem • Explore possible methods • Apply methods to the selected benchmark • Assess the efficacy of the methods	**Team leader:** ***J. Arul,*** M. Marques M. Gimenez (ii) Potentially P. Kudinov	• Benchmark problem specification (6 months) • Draft report on possible methods (12 months) (Input from all participants to the Scientific Secretary and the editors – in 12 months)
3.4	Comparison of different methodologies for reliability assessment of passive safety system on the benchmark problem of an isolation condenser of a light water cooled reactor, developed by ENEA Steps: (3.4), (3.5), (3.8)	• Define the problem • Share the RMPS results • Assess the problem using APSRA	**Team leader** ***D. Saha*** L. Burgazzi, J. Arul	• Problem description (6 months) • Results by RMPS and REPAS (available) • Inputs for CATHARE/RELAP5 (9 month) • Repeat RMPS modelling initiated by IGCAR (after 9 months) • Assessment using APSRA started (after 9 months)

Table 1 (continued 3)

#	Activity title	Milestones in implementations	Collaborative team	First year outputs
3.5	Integration of the assessed reliability of a passive safety system in the overall PSA Steps: (3.9)	• Comparison of methods for the integration of component failure and functional failure (by event tree, fault tree or analytical formulas?) • Analyze the issue of code uncertainties (should it be included in PSA?) • Explore the state-of-the-art in dynamic event tree analysis	**Team leader - TBD** M. Marques M. Gimenez L. Burgazzi, J. Arul Potentially – P. Kudinov	Will not be addressed in the first year of work
4	*Activity title in the approved CRP programme:* • Additional activity not specified in the approved CRP programme			
4.1	Develop a framework for creating a databank to generate probability density functions for process parameters. Later on, the Agency could consider including the activity on creation of such a databank in its programme. Steps: (3.3), (3.4), (3.7)	• Identify the parameters and ranges of parameter variation corresponding to different plant conditions, and classify them as groups or families • Identify possible sources of data (test facilities, NPPs, expert judgements) • Identify methods for obtaining probability density functions • Suggest the structure of the databank • Identify procedures for data qualification	**Team leaders:** ***D. Araneo,*** L. Burgazzi, J. Arul, M. Marques	• Draft structure of the databank and an example (9 months) • Main families of parameters identified (9 months) • Suggestions for software produced (12 months or as appropriate)

4.2. Skeleton of the requirements to common analysis-and-test based method for reliability assessment of passive safety systems in advanced reactors

The skeleton of the requirements to common analysis-and-test based method for reliability assessment of passive safety systems in advanced reactors was developed as follows:

(1) Introduction:

- State-of-the-art of deterministic and probabilistic approaches to safety assessment.
- Limitations of the PSA (Presentation at RCM-1 by L. Burgazzi; IAEA-TECDOC-1474, page 621)

(2) Objective:

- To obtain a consensus on methodology for the reliability assessment of passive safety systems, to enable their treatment by PSA and comparison with active safety systems.

The methodology, being developed for advanced reactors, should:

- Cover all plausible scenarios with a potential of passive safety system functioning
- Take into account different kind of uncertainties in parameters, phenomena, hardware and software
- Be easy to use and efficient
- Meet licensing criteria
- Assist in design optimization
- Facilitate the application of a risk-informed approach
- Consider time dependence of event sequences
- Offer reliability indicator(s) allowing to compare passive and active safety systems

The results of method application should allow clear and unambiguous interpretation.

(3) Steps in the methodology (and some requirements; other requirements – to be elaborated):

(3.1) Description and characterization of the system:

- Identification of the mission (safety function)
- Definition of the initial and boundary conditions
- Identification of accident scenarios (external, internal events or combinations thereof) for which the interactions between a given passive system and other systems are important

(3.2) Identification of the physical phenomena relevant to the operation of the system

- Compilation of a comprehensive list of all phenomena related to the accident scenario
- Adequate modelling of all identified phenomena in the selected code

(3.3) Identification of the parameters influencing physical phenomena

- Identification based on present knowledge and available information
- Determination of inter-dependence of the parameters
- Sensitivity / importance analysis
- Basis for identification: Codes and tests, expert judgement

(3.4) Identification of components and events influencing the above mentioned parameters

- Active or passive components that are part of the system

- Active or passive components that are not part of the system
- External and internal events and their combinations

(3.5) Identification of failure modes and failure mechanisms, and characterization of the criteria:

- Options available to identify failure modes (FMEA, HAZOP, codes)
- Success/failure criteria: deterministic or probabilistic
- Criteria for the selection of adequate performance indicators
- Provisions for inclusion of human factors

(3.6) Qualification level of analytical tools

- Range of validation of the code (on the results of both, separate effect and integral tests) should cover the range of parameters under both normal and abnormal conditions
- All identified phenomena should be adequately modelled in the code
- Uncertainty of code prediction should be quantified through verification and validation; user effect should be considered
- Uncertainty quantification of relationships and physical models used in analytical tools

(3.7) Uncertainty quantification of the parameters influencing physical phenomena:

- A weak point is the absence of unambiguous rules and validated data for the assignment of probability distributions to parameters
- A data bank to generate probability density functions for parameters would be useful
- Inter-dependence of parameters
- Sensitivity analysis
- Additional tests to reduce high uncertainty of important parameters

(3.8) Propagation of uncertainties and quantification of reliability

- Methods should be accurate and efficient
- Methods to quantify reliability of a passive safety system, e.g., determination of a response surface

(3.9) Passive safety system integration to PSA

- Effective method for such integration needs to be elaborated, e.g., treating the scenario families rather than individual scenarios
- Integration of component failure and functional failure for the passive system
- Integration of passive safety systems in plant PSA
- Incorporation of human factors

4.3. List of terms for reliability assessment of passive safety systems and their treatment by PSA, and some definitions

The list of terms was compiled as shown in Table 2. Some definitions were proposed and discussed at the meeting, as also shown in Table 2. The terms present in the IAEA Safety Glossary and rated satisfactory by the meeting participants are not included in Table 2.

Table 2. List of terms for reliability assessment of passive safety systems and their treatment by PSA, and some definitions

#	Term	Definition/Source or Potential Source	Who will elaborate further
1	**Reliability**	The probability that a system or component will meet its minimum performance requirements when called upon to do so/ IAEA The probability that a system will perform its intended function in a satisfactory manner for a given period of time [0, t], when used under specified operating conditions. Noted R(t)/ RCM-1	A. Lyubarsky (NSNI) and V. Siryapin
2	**Unreliability (Synonym of Failure Probability)**	The complement of reliability. Noted F(t) = 1 - R(t)/ RCM-1	A. Lyubarsky (NSNI) and V. Siryapin
3	**Available**	The fraction of time for which a system is capable of fulfilling its intended purpose/ IAEA The state of a system, structure or component being able to perform its required function, under given conditions and at a given time/ RCM-1	A. Lyubarsky (NSNI) and V. Siryapin
4	**Availability**	The probability of finding a component, system, or structure in a success state at given time and under given conditions Noted A(t)/ RCM-1	A. Lyubarsky (NSNI) and V. Siryapin
5	**Unavailability**	The complement of availability. Noted 1-A(t) / RCM-1	A. Lyubarsky (NSNI) and V. Siryapin
6	**Failure**	Inability of a structure, system or components to function within acceptance criteria/ IAEA The loss of ability of a system, structure or component to perform a required function during the mission time. Note: A fault may cause failure. "Failure" is an event, as distinguished from "fault", which is a state.	A. Lyubarsky (NSNI) and V. Siryapin
7	**Failure criteria**	Logical and/or numerical relationships which define the system failure/ RCM-1	A. Lyubarsky (NSNI) and V. Siryapin
8	**Failure mode**	The manner or state in which a structure, system or component fails/ IAEA The manner in which a structure, system or component fails/ RCM-1	A. Lyubarsky (NSNI) and V. Siryapin

Table 2 (continued 1)

#	Term	Definition/Source or Potential Source	Who will elaborate further
9	**Functional failure (of a passive safety system)**	(1) Failure that defeats or degrades the natural mechanisms that are the principles for the operation of the passive system/ RCM-1 (2) Failure that defeats or degrades the natural mechanisms that effect the operation of the passive system/ RCM-1	A. Lyubarsky (NSNI) and V. Siryapin
10	**Hardware failure (of a passive safety system)**	Failure of a component or structure of the passive system/ RCM-1	A. Lyubarsky (NSNI) and V. Siryapin
11	**Passive component**	A component which does not need any external input to operate/ IAEA–TECDOC–626	
12	**Passive system**	Either a system which is composed of passive components (see #11) and structures or a system which uses active components in a very limited way to initiate subsequent passive operation/ IAEA–*TECDOC–626*	
13	**Performance**	Assessment of the performance of a system or subsystem and its implication for protection and safety at an authorized facility/ IAEA Operation within the specified range of parameters/ RCM-1	D. Saha
14	**Cumulative distribution function**	Function giving, for all value x, the probability that the random variable X will be less than or equal to x. Noted F(x)/ RCM-1	A. Lyubarsky (NSNI) and V. Siryapin
15	**Probability density function**	Derivative, if exists, of the cumulative distribution function of a random variable. Noted f(x)/ RCM-1	Check with standard book – J. Arul

Table 2 (continued 2)

#	Term	Definition/Source or Potential Source	Who will elaborate further
16	**Uncertainty, Epistemic and Aleatoric uncertainties**	Uncertainty analysis: an analysis to estimate the uncertainties and error bounds of the quantities involved in, and the results from, the solution of a problem/ IAEA Three types of uncertainties can be identified/ RCM-1: 1. Uncertainty due to variability of input and / or model parameters when the characterization of the variability is available (e.g., with probability density function, pdf), 2. Uncertainty due to variability of input and/or model parameters when the corresponding variability characterization is not available, 3. Uncertainty due to an unknown process or mechanism Note: Type 1 uncertainty, which depends on chance, may be referred to as aleatoric or statistical uncertainty. Type 2 and 3 are referred to as epistemic or systematic uncertainties.	General Definition of Uncertainty - V. Kuznetsov, D. Saha, J. Arul J. Arul J. Arul J. Arul
17	**Code uncertainty**	(1)Uncertainties of code physical models, correlations and numerical solution scheme/ RCM-1 (2) Calculation error related to the physical models and correlations adopted in a code/ RCM-1	A. Lyubarsky (NSNI) and V. Siryapin
18	**Benchmark(ing)**	OECD documents	V. Kuznetsov
19	**Risk-informed approach**	US NRC documents	B. Williams
20	**Dynamic PSA?**	Unknown source	P. Kudinov
21	**Expert judgement**		D. Araneo
22	**Elicitation process**		D. Araneo
23	**Failure mode and effect analysis (FMEA)**		L. Burgazzi
24	**Limit state function**		J. Arul
25	**First-order reliability method (FORM)**		M. Marques

Table 2 (continued 3)

#	Term	Definition/Source or Potential Source	Who will elaborate further
26	**Second order reliability method (SORM)**		M. Marques
27	**Perturbation theory**		J. Arul
28	**Adjoint equation, Adjoint code**		J. Arul
29	**Human factor**		S. Bilbao y Leon
30	**Reliability indicator**		J. Arul
31	**Response surface**		J. Arul
32	**Actual and virtual components**		D. Saha
33	**Local sensitivity**		M. Marques
33	**Global sensitivity**		M. Marques
34	**Fuzzy logic, Fuzzy set**		J. Arul
35	**HAZOP – Hazard and operability study**		L. Burgazzi
36	**Failure mechanism**		J. Arul
37	**Failure surface**		J. Arul, D. Saha
38	**Discrete and continuous probability density function**		M. Marques
39	**Mission time**	Time interval during which a system has to carry out its safety function/ RCM-1	A. Lyubarsky (NSNI) and V. Siryapin
40	**Propagation of uncertainty**		M. Marques