IAEA's Coordinated Research Project on EBR-II Shutdown Heat Removal Tests: An Overview

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Abstract. A Coordinated Research Project (CRP) on "Benchmark analysis of EBR-II Shutdown Heat Removal Tests (SHRT)" was launched by the International Atomic Energy Agency (IAEA) in 2012. A series of transient tests were conducted on the EBR-II reactor at Argonne National Laboratory (ANL) to improve the understanding of thermal hydraulics and neutronics of fast reactors. Shutdown heat removal tests conducted in 1984 and 1986 demonstrated mechanisms by which fast reactors can survive severe accident initiators with no core damage. Two SHRT tests, SHRT-17 representing Protected Loss of Flow (PLOF) transient and SHRT-45R representing Unprotected Loss of Flow (ULOF) transients have been studied in the IAEA CRP.

The objectives of the CRP were to improve design and simulation capabilities in fast reactor thermal hydraulics, neutronics and safety analyses through benchmark analysis of these two important tests. At the first stage of the benchmark, ANL provided the input data on EBR-II geometry, as well as initial and boundary conditions for the SHRT-17 and SHRT-45R tests to perform "blind" calculations. At the second stage, ANL released the experimental observations and participants had the chance to discuss the difference and refine the models. Nineteen organizations from eleven countries participated in the CRP making it one of the largest CRP coordinated by the IAEA fast reactor team.

The papers provides a general CRP overview while the companion papers presented both on this session and at the poster session give the details of the EBR-II reactor design, describe the shutdown heat removal tests, the benchmark setup, results of numerical simulations, and the detailed discussion on this CRP.

Key Words: EBR-II, Benchmark, IAEA-CRP, Shutdown Heat Removal Tests, Sodium-cooled fast reactors

1. Introduction

The IAEA supports Member States in the area of advanced fast reactor technology development by offering a broad and established platform for information exchange, international cooperation and collaborative research. Technical working group on fast reactors (TWG-FR) is the advisory body that assists IAEA in implementation of relevant activities in order to ensure that they are in line with the needs of the Member States (MS). Among this spectrum of activities proposed by TWG-FR and supported by IAEA, the IAEA proposes and establishes coordinated research projects (CRPs), aimed at improving Member States capabilities in fast reactor design and analysis. One such opportunity to undertake collaborative research activity was proposed by Argonne National Laboratory (ANL) in 2012. ANL conducted several shutdown heat removal tests (SHRT) at its Experimental Breeder Reactor – II (EBR-II) in 1980's and offered to open the experimental data of two of its tests – SHRT17, representing Protected Loss of Flow (PLOF) transient [1], and SHRT45R, representing Unprotected Loss of Flow (ULOF) transient [2] – under the umbrella of IAEA's CRP program. After a careful review by the TWG-FR, IAEA launched the CRP on "Benchmark Analyses of EBR-II Shutdown Heat Removal tests" in 2012.

19 organizations from 11 Member States participated in this CRP and contributed to improving capabilities in sodium cooled fast reactors simulation through code verification and validation, with particular emphasis on shutdown heat removal phenomena: China Institute of Atomic Energy (CIAE), China, North China Electric Power University (NCEPU), China, Xi'an Jiatong University (XJTU), China, Institut de Radioprotection et de Sûreté Nucléaire (IRSN), France, Karlsruhe Institute of Technology (KIT), Germany, Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), Italy, Nuclear and Industrial Engineering (N.IN.E.), Italy, Politecnico di Torino, Italy, Indira Ghandi Centre for Atomic Research (IGCAR), India, Japan Atomic Energy Agency (JAEA), Japan, Kyushu University, Japan, University of Fukui, Japan, Korea Atomic Energy Research Institute (KAERI), Republic of Korea, Korea Institute of Nuclear Safety (KINS), Republic of Korea, Nuclear Research and Consultancy Group (NRG), Netherlands, Nuclear Safety Institute of the Russian Academy of Sciences (IBRAE-RAN), Russian Federation, Paul Scherrer Institute (PSI), Switzerland, Argonne National Laboratory (ANL), USA, TerraPower, USA.

The objective of the CRP was the analyses of the SHRT-17 protected loss of flow and SHRT-45R unprotected station blackout tests. Both tests were initiated from full power and flow and were the most severe tests of their respective types performed during the SHRT program. The benchmark was performed in two phases, initial "blind" and further simulations with updated models. An additional objective of the CRP is training of the next generation of analysts and designers through international benchmark exercises. The detailed CRP technical document is under publication process at the IAEA [3]

2. CRP Description

CRP participant analyses were performed in two phases over the four years of the CRP. During the first phase, no experimental data was provided to the CRP participants; the experimental data was released only after all phase 1 calculation were complete – marking the beginning of phase 2. Phase 1 of the CRP began with the first Research Coordination Meeting (RCM), held in June 2012. At this meeting, the participants received the benchmark specifications [4,5] prepared by ANL for both SHRT-17 and SHRT-45R. Blind simulations took around one year and the set of recorded data was distributed to the participants after the second RCM, in November 2013. At this RCM, participants reported on their phase 1 simulation results and discussed various modelling problems encountered during the process and their possible solutions. After gathering the final results from all the participants by the proposed deadline of February 2014, ANL distributed the experimental data to all the participants. Two additional RCMs were held to discuss progress on the simulations and compare results among the participants. The third RCM was held in March 2015 and the fourth and final RCM was held in April 2016 in Vienna marking the end of this CRP.

2.1. Codes used by the participating organizations

The major objective of this benchmark exercise was the validation and verification of various codes used for liquid metal cooled reactor safety analysis across the world. A total of 14 system analysis codes and 11 neutronics codes were used. Table 1 provides the summary of all the codes used by different participating organizations.

TABLE I: SIMULATION CODES USED BY PARTICIPATING ORGANIZATIONS.

Organization	System analysis code	Neutronics code	Other codes
China Institute of Atomic Energy (CIAE)	SAS4A/SASSYS-1		
North China Electric Power University (NCEPU)	SAC-CFR		
Xi'an Jiatong University (XJTU)	THACS		
Institut de Radioprotection et de Sûreté Nucléaire (IRSN)	CATHARE		
Karlsruhe Institute of Technology (KIT)		ERANOS PARTISN TRAIN	SIMMER-III (Multi-Physics Code for Severe Accident Analysis)
Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)	RELAP5-3D	MCNP6 PHISICS SCALE6.1	ANSYS CFX
Nuclear and Industrial Engineering (N.IN.E.)	RELAP5-3D		

Politecnico di Torino	FRENETIC	SERPENT	
Indira Ghandi Centre for Atomic Research (IGCAR)	EBRDYN		STAR-CD
Japan Atomic Energy Agency (JAEA)	Super-COPD		ASFRE
Kyushu University	SIMMER		Thermo-Calc
University of Fukui	NETFLOW++ RELAP5-3D	ERANOS NJOY	ANSYS CFX COBRA4i
Korea Atomic Energy Research Institute (KAERI)	MARS-LMR		
Korea Institute of Nuclear Safety (KINS)	TRACE		
Nuclear Research and Consultancy Group (NRG)	SPECTRA TRACE		ANSYS CFX
Nuclear Safety Institute of the Russian Academy of Sciences (IBRAE-RAN)	SOCRAT-BN		
Paul Scherrer Institute (PSI)	TRACE	SERPENT	
Argonne National Laboratory	SAS4A/SASSYS-1	DIF3D MC^2-3 VARI3D PERSENT	
TerraPower	SAS4A/SASSYS-1		COBRA4i

2.2. Experiment Description

A series of tests were conducted in EBR-II addressing anticipated off-normal conditions and severe accident indicators that are of importance to liquid metal cooled reactors. Details about the EBR-II reactor could be found in [6]. Shutdown heat removal tests conducted are of particular interest. They demonstrated the capability of a sodium-cooled fast reactor to survive such sever accident initiators without core damage. The experimental data collected during these tests is an excellent basis for code and data verification, validation and qualification. Most sever of these SHRTs were the SHRT-17 and SHRT-45R transients, and both were analysed under the discussed IAEA CRP.

SHRT-17 is a protected loss of flow transient, during this test the plant protection system was used to simultaneously scram the reactor. SHRT-45R is an unprotected loss of flow transient, during this test the plant protection system was disabled to prevent initiation of a scram.

The initial conditions and transient initiators for both the tests are provided in TABLE II.

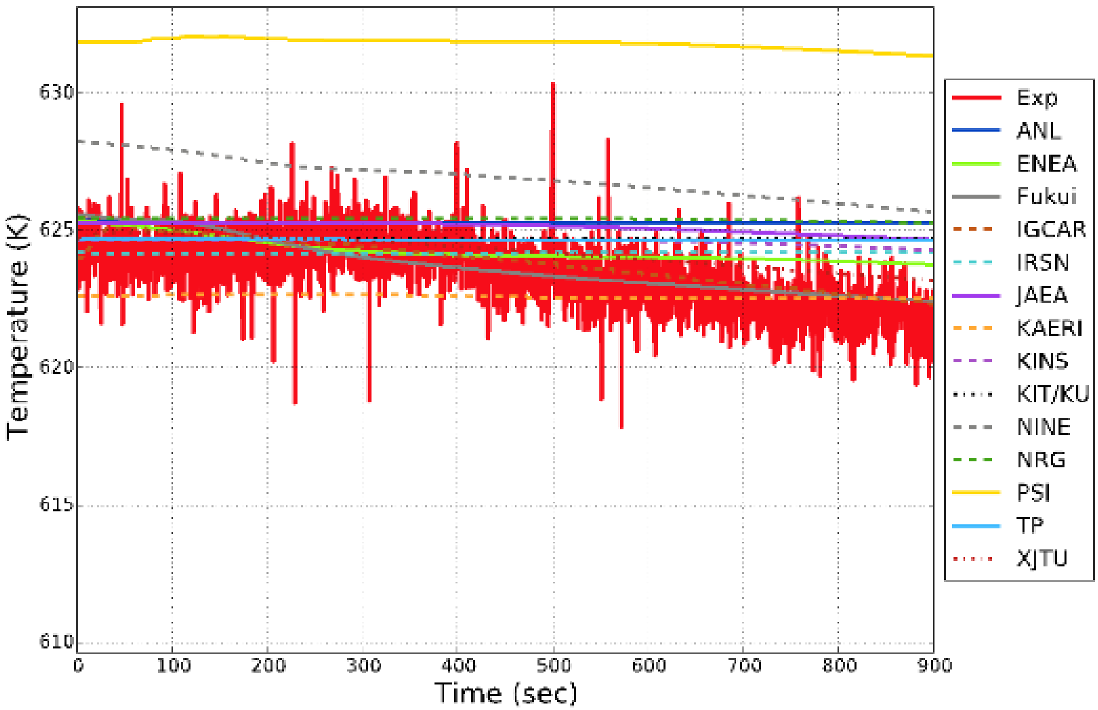
TABLE II: SHRT 17 and SHRT 45R TEST DESCRIPTION.

Parameter	**SHRT-17**	**SHRT-45R**
Initial Power	57.3 MW	60.0 MW

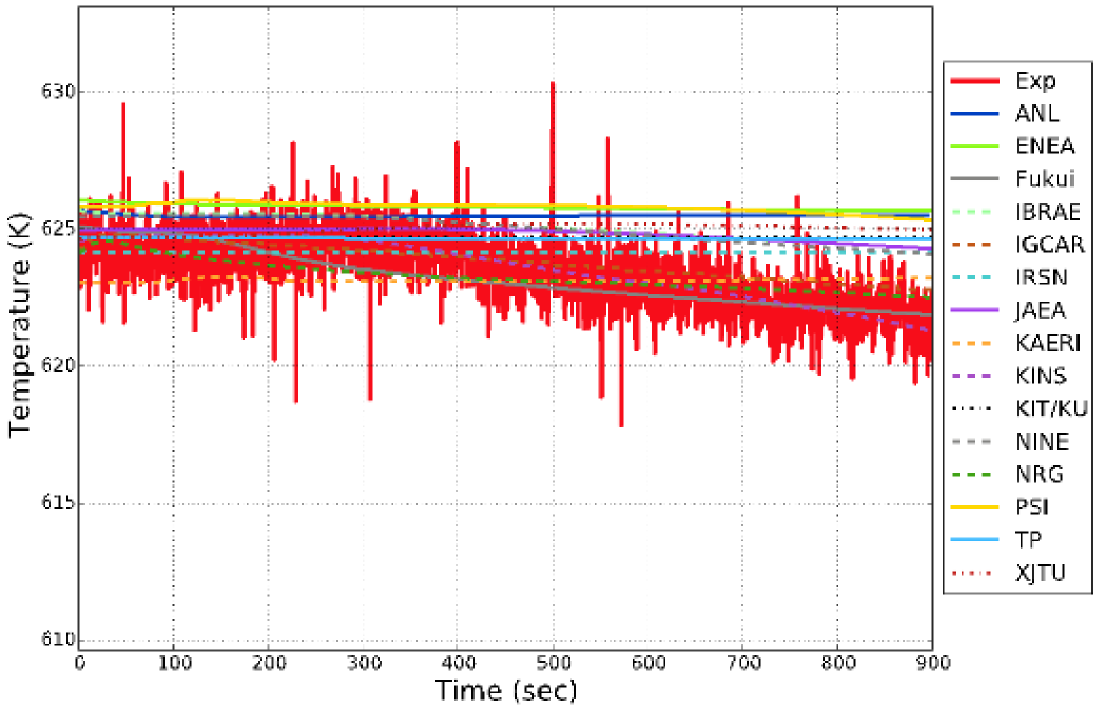
Initial Primary Coolant Flow Through Core	8500 gpm at 800^{o}F	8972 gpm at 800^{o}F
Initial Intermediate Coolant Flow	5615 gpm at 582^{o}F	5475 gpm at 582^{o}F
Initial Core Inlet Temperature	665^{o}F	651^{o}F
Primary and Intermediate Pump Coastdown Conditions	Power to motor-generator sets removed	• Power to motor-generator sets removed • Flow coastdown controlled by coupling and decoupling of motor-generator set clutch • Approx. 95 seconds before pump stop
Control Rods	Full insertion at test initiation	Insertion disabled
Auxiliary EM Pump Conditions	Power to Auxiliary EM Pump removed	On battery

2.3. Benchmark Results

The CRP participants were able to predict most plant parameters (requested in the CRP benchmark specification) with acceptable accuracy. The results shown in the paper are only for indicative purposes. A detailed paper on benchmark results titled, "EBR-II Passive Safety Demonstration Tests Benchmark Analyses" will be presented during this conference [7].

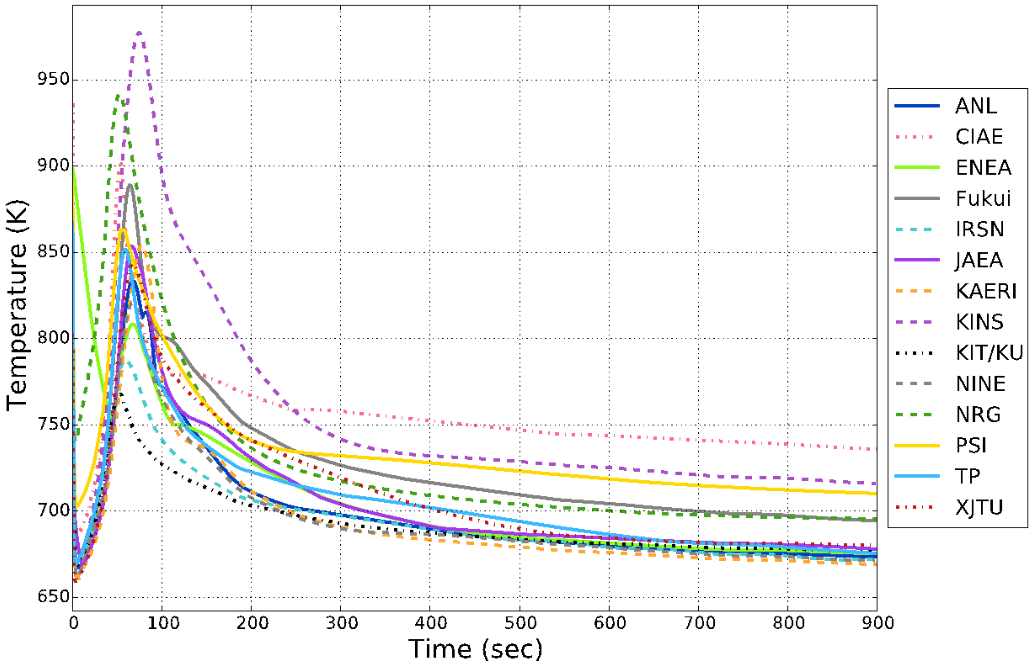


(a) blind results

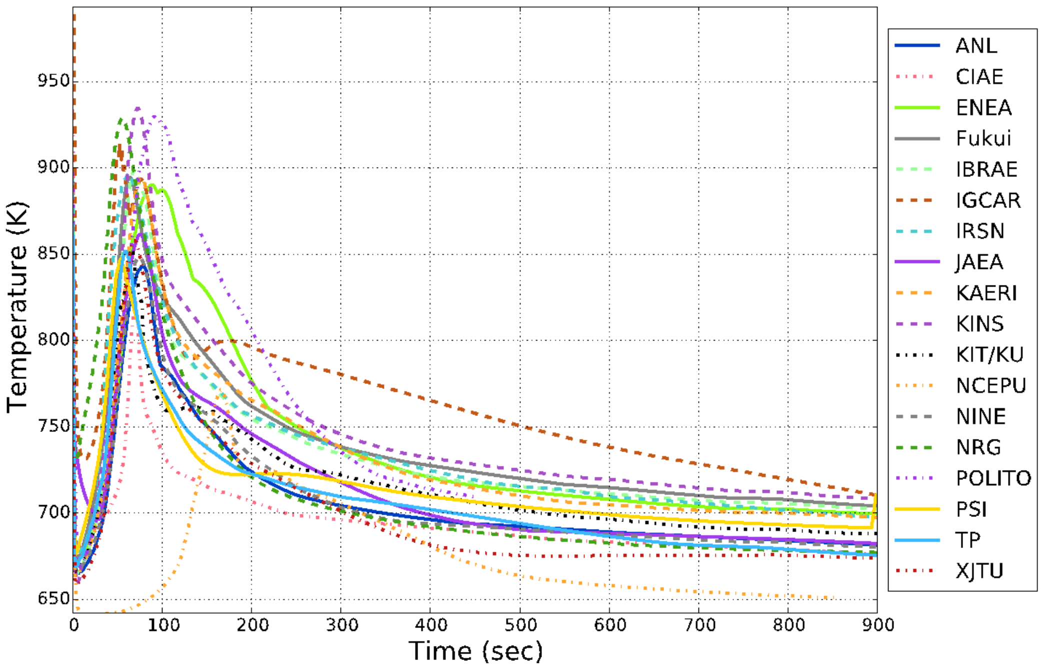


(b) final results

FIG.1. SHRT-17 low-pressure plenum inlet temperature.



(a) blind results



(b) final results

FIG. 1. SHRT-17 peak fuel temperature (no experimental data).

3. Conclusions

Both the thermal-hydraulic and neutronic simulations performed for the CRP were challenging to produce, however the participants were able to predict most plant parameters with acceptable accuracy. An IAEA technical document titled, "*Benchmark Analyses of EBR-II Shutdown Heat Removal Tests"* is under publication and will soon be available to all IAEA Member States. IAEA appreciates the untiring effort that all the participating organizations have put in order to bring out a very comprehensive document analysing simulations done by each organization, comparing their results to the experimental data and thus providing a perfect environment for verification and validation of a number of simulation codes.

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