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Benchmark Tests of GAMMA+ using EBR-II BOP experiments

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1. Introduction

A series of comprehensive verification and validation works for a system code are essential to design a nuclear reactor for both points of view: performance and safety. GAMMA+ code, which was originally developed for analyzing multi components gas mixture by oxidation in gas-cooled reactors, has been being extended to component code and even computational fluid dynamics code in addition to system code capable of handling working fluids of variety ranging to non-water reactors such as noble gases, liquid metals, and molten salts [1].

This benchmark test is for validating the code using Experimental Breeder Reactor(EBR)-II Balance Of Plants(BOP) tests such as BOP-301 and BOP-302R simulating unprotected loss of heat sink events: 1) validation with a condition of low uncertainty in flow measurements; 2) use of a proved case with the same core arrangement as in SHRT-45R; 3) validation of numerical models for reactivity feedback by change in temperature at core inlet.

Based on the given information [2,3,4,5] and works previously done [6], the nodalization [6] was revised to facilitate to catch the phenomena by loss of heat sink in EBR-II BOP experiments and the results of benchmark tests are presented.

2. Definition of EBR-II BOPs

Both experiments such as BOP-301 and BOP-302R simulate loss of heat sink in EBR-II as shown in Fig. 1 and are similar in that the transients are initiated by trip of intermediate pump: main difference comes from initial condition of power [2].

Tab. I defines initial conditions of BOP-301 and BOP-302R: the test starts as the intermediate pump stops as shown in Fig. 2 for BOP-301 and Fig. 3 for BOP-302R, respectively. Core inlet temperature increases as heat rejection is limited through intermediate heat exchanger due to the pump stop. Because of this increase in temperature, power approaches to zero close to decay power with support of negative feedback in reactivity without drop of control rod as shown in Fig. 4 for BOP-301 and Fig. 5 for BOP-302R, respectively.

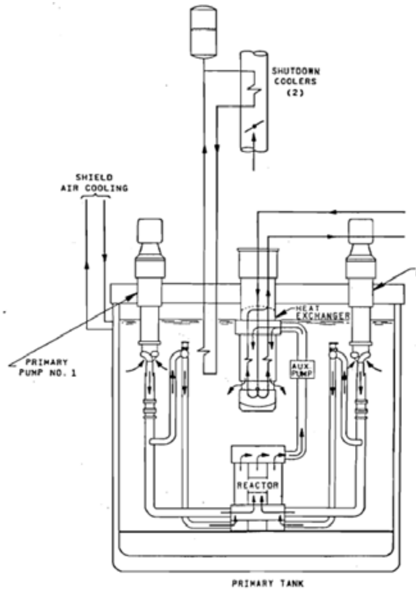

Fig. 1. EBR-II Primary Tank Sodium Flow Paths

Table I: EBR-II BOP-301/BOP-302R Initial Conditions

Parameters	Initial Conditions		Remarks
	BOP-301	BOP-302R	
Power	31.98	59.89	MW
Inner Core Flow	392.9	391.4	kg/s
Outer Core Flow	75.8	75.5	kg/s
Core Bypass Flow	3.91	3.89	kg/s
Intermediate Flow	202.2	307.2	kg/s
Core inlet Temperature	616.9 (343.75)	616.4 (343.25)	K (℃)

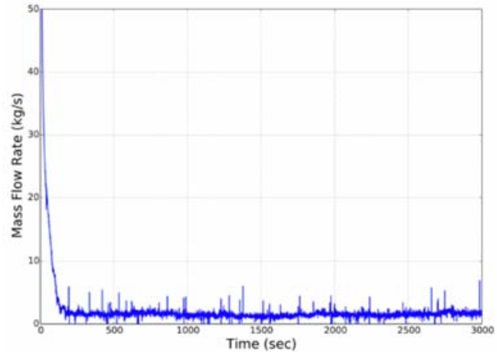

Fig. 2. BOP-301: Transient Intermediate Flow

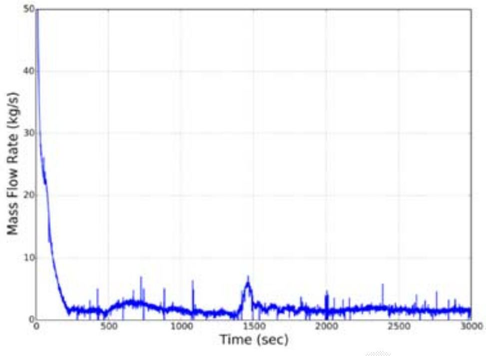

Fig.3. BOP-302R: Transient Intermediate Flow

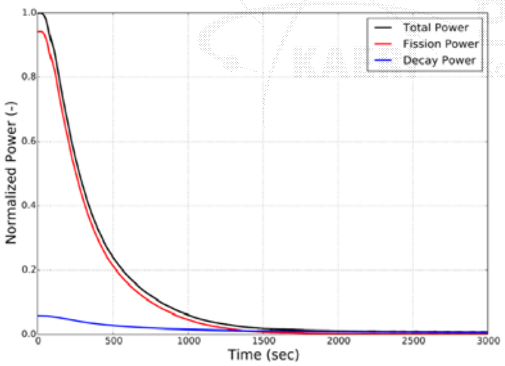

Fig. 4. BOP-301: Transient Power

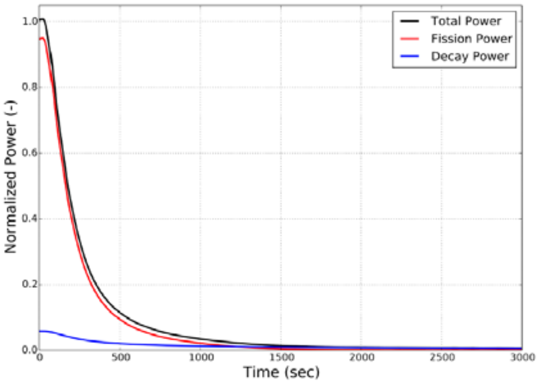

Fig.5. BOP-302R: Transient Power

3. Methodology & Results

3.1 EBR-II Modeling

The base nodalization of EBR-II using GAMMA+ was from the reference [6] for Shutdown Heat Removal Test(SHRT), enough to validate core arrangement with fixed primary flow condition, as shown in Fig. 4. For benchmark tests of BOP, where increase in temperature of primary coolant, i.e., sodium, at core inlet should be simulated, a pump model must be included in the heat transfer circuit such that the transient after reduction in heat rejection can be represented from intermediate heat exchanger to core inlet through pool and inlet structures as shown in Fig. 5.

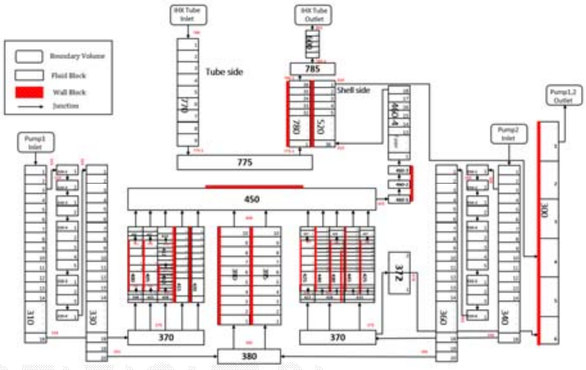

Fig.4. Nodalization for EBR-II using GAMMA+ [6]

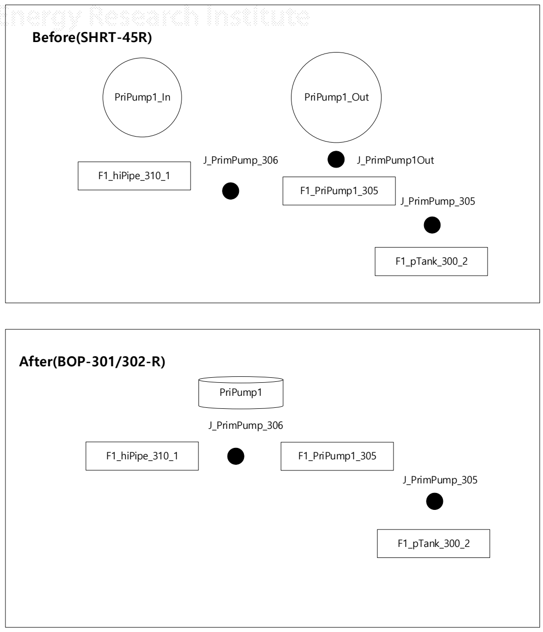

Fig.5. Revised part of Nodalization for EBR-II BOP using GAMMA+

At this phase of benchmark tests, thermal-hydraulic phenomenon is a single figure of merit of great importance to validate GAMMA+ code using the measured transient flow and power with no regard of reactivity feedback.

3.2 Benchmark Tests results

The steady states solutions were obtained with minor discrepancy against the initial conditions for BOP-301 and BOP-302R, respectively, given in Tab. I.

As was stated that this test as blind is only for validating capability to catch up loss of heat sink in terms of core inlet temperature. Using the transient flow and power conditions as transient input, therefore, both cases of unprotected loss of heat sink were simulated as follows:

For BOP-301, flow condition for intermediate flow and power were well verified as the given data as in Fig. 6. With loss of heat sink, at high and low pressure chamber temperature increases and at upper plenum and around intermediate heat exchanger within primary side increases as shown in Fig. 7. The comparison shows that GAMMA+ is capable of capturing loss of heat sink but the difference is around 20 degrees in Celsius. The same holds for BOP-302R as shown in Fig. 8 and Fig. 9.

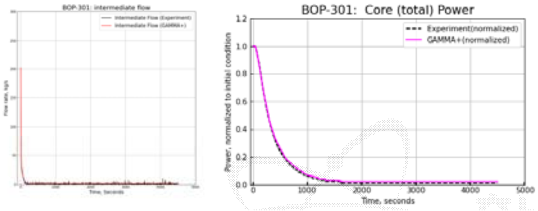

Fig.6. EBR-II BOP-301: Flow and Power

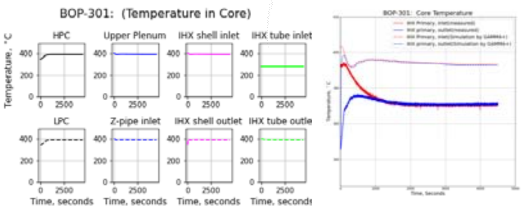

Fig.7. EBR-II BOP-301: Temperature

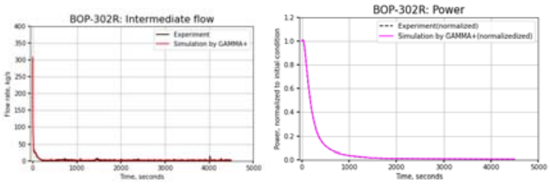

Fig.8. EBR-II BOP-302R: Flow and Power

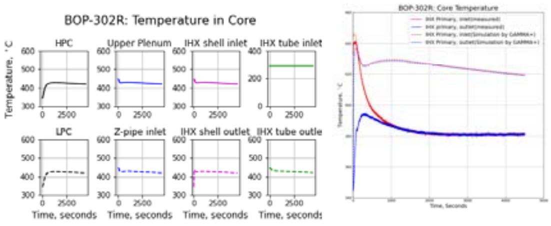

Fig.9. EBR-II BOP-302R: Temperature

3. Conclusions

GAMMA+ code was validated by benchmark tests using EBR-II BOP experiments, unprotected loss of heat sink. Comparison against the experiments showed GAMMA+ can be used successfully to analyze thermal-hydraulic phenomena in open pool-typed sodium-cooled fast reactor with some discrepancy.

Origin of the discrepancy may result from so many sources such as node dependency, operating uncertainties, limitation on representation of 3D effects around pools and structures using a system code, heat transfer packages, and so on. It should be investigated in more detail before applying the code in a real reactor.

Acknowledgement

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