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Revised Benchmark Test of GAMMA+ code against 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 a 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] had been revised to facilitate to catch the phenomena by loss of heat sink in EBR-II BOP experiments and the results of benchmark tests had been presented [8] with some discrepancy. In this paper, the nodalization is revised to test the effects of perfect mixing in the pool of the EBR-II.

2. Definition of EBR-II BOPs

Definition of the experiments are all the same as before but here are represented in order to deliver key aspects of those [8] in this paper.

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].

Initial conditions of BOP-301 and BOP-302R are defined as in Tab. I: 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.

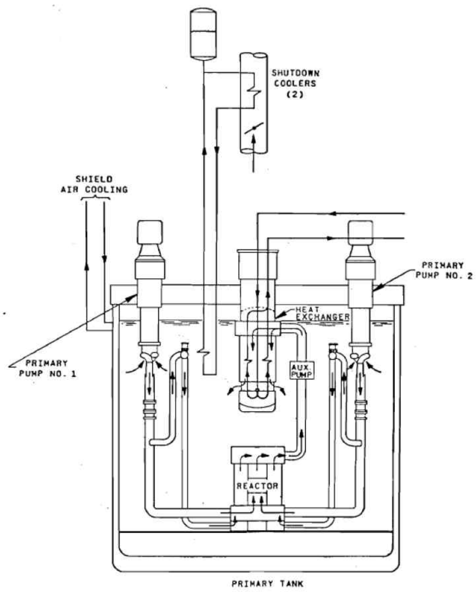

Fig. 1. EBR-II Primary Tank Sodium Flow Paths

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 (℃)

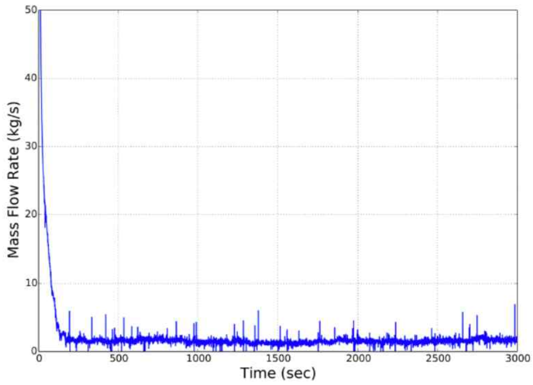

Fig. 2. BOP-301: Transient Intermediate Flow

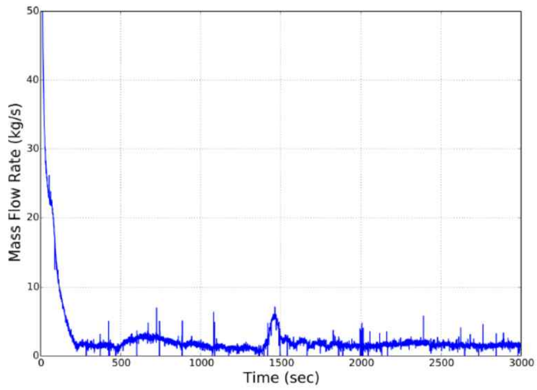

Fig.3. BOP-302R: Transient Intermediate Flow

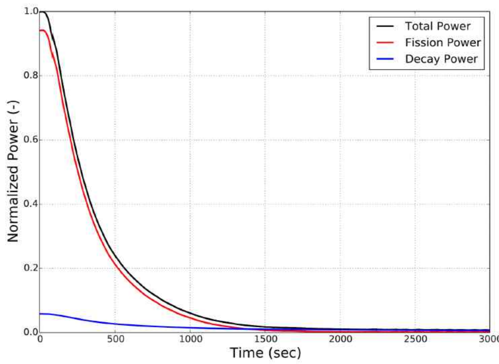

Fig. 4. BOP-301: Transient Power

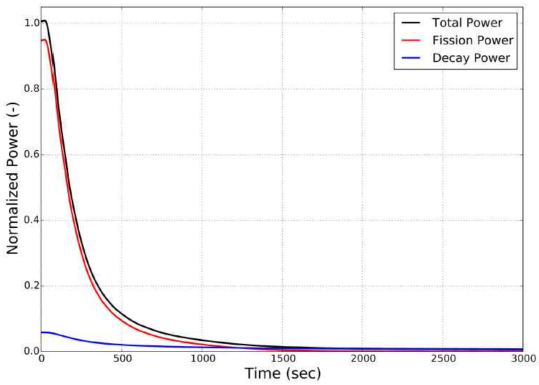

Fig.5. BOP-302R: Transient Power

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. 6. 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. 7.

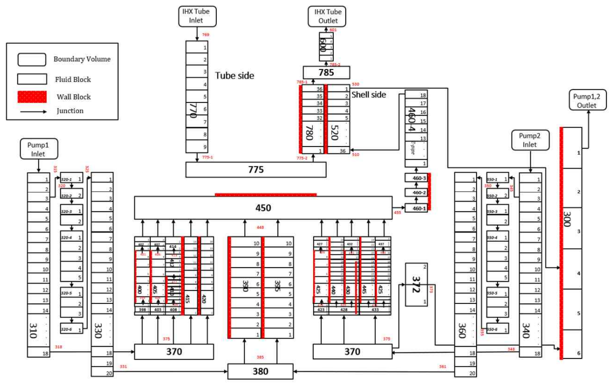

Fig.6. Nodalization for EBR-II using GAMMA+ [6]

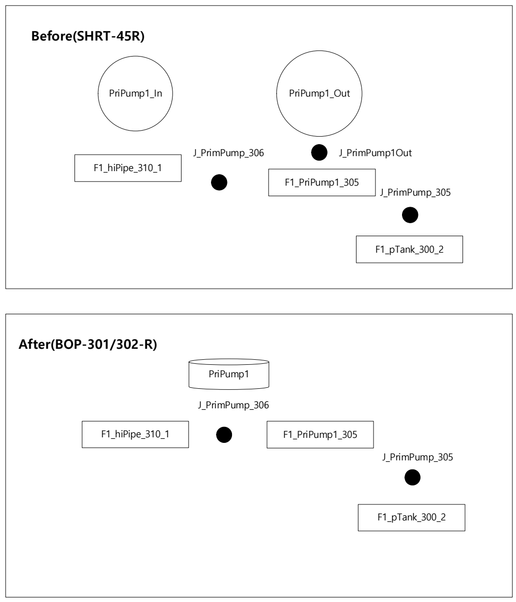

Fig.7. Nodalization (key change) for EBR-II BOP using GAMMA+

The previous results of a simulation had shown that there were significant differences in temperature of coolant flowing through the pool [8]. In this phase of benchmark tests, modeling of the pool is revised to investigate sensitivity of pool modeling in a way like perfect mixing, i.e., a single volume instead of multiple volumes.

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 presented in the previous results [8].

Fig. 8 shows coolant temperature at inlet and outlet of the core in case of BOP-301. The effects of change in modeling of the pool act on a favorable direction: much better reproduction of the experimental results in both points of saturated temperature and rates of rise/drop in temperature.

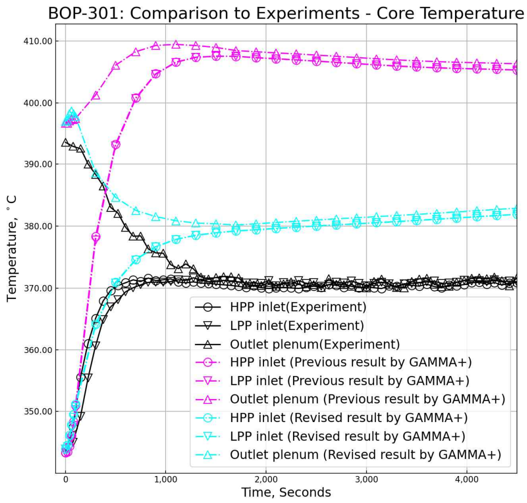

Fig.8. EBR-II BOP-301: Temperature of Coolant

Fig. 9 shows coolant temperature at inlet and outlet of the core in case of BOP-302R. The effects of change in modeling of the pool act on a favorable direction as in the case for BOP-301. Difference between BOP-301 and BOP-302R is the difference in saturated temperature against the experimental results: about 10- and 20-degrees C for BOP-301 and 302R, respectively.

4. Conclusions

GAMMA+ code was re-validated by a benchmark against EBR-II BOP experiments, unprotected loss of heat sink. The original comparison showed GAMMA+ can be used successfully to analyze thermal-hydraulic phenomena in open pool-typed sodium-cooled fast reactor but with some discrepancy. The discrepancy, which may result from so many sources, can be significantly reduced by adopting a perfect mixing model, i.e., simply not multiple volume but only two volumes representing flowing and stagnant regions. It should be continually investigated in more detail before applying the code in a real reactor.

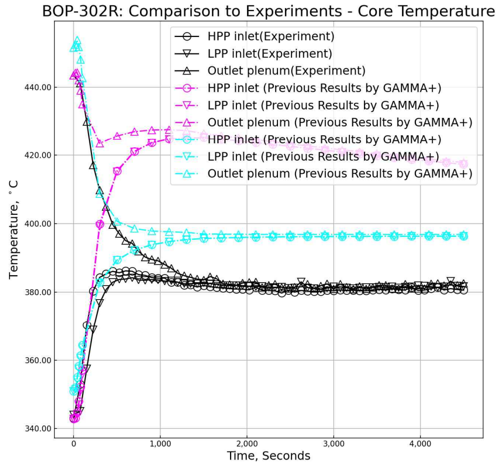

Fig.9. EBR-II BOP-302R: Temperature of Coolant

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