Sensitivity Analysis of Uncertainty Parameter based on MARS-LMR Code on SHRT-45R of EBR II

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1. Introduction

A preliminary study for applying the Best-Estimate plus uncertainty quantification(BEPU) to Design Extension condition(DEC) of Prototype GEN-IV Sodium Cooled Fast Reactor(PGSFR) is being performed. In order to assess the uncertainty quantification of the MARS-LMR code, the code has been improved by modifying the source code to accommodate calculation process required for uncertainty quantification. In the present study, a transient of Unprotected Loss of Flow(ULOF) is selected as typical cases of as Anticipated Transient without Scram(ATWS) which belongs to DEC category. The MARS-LMR input generation for EBR II SHRT-45R and execution works are performed by using the PAPIRUS program[3].

2. Analysis and Method

2.1 The description of EBR-II reactor

The Experimental Breeder Reactor II(EBR-II) plant is located in Idaho and designed and operated by Argonne National Laboratory from 1964 to 1994. EBR-II is Sodium cooled, pool-type fast reactor operating at a thermal power of 62.5MWt and an electric power of about 20MWe. The corresponding reactor, secondary, and steam system flow rates are roughly 485, 315, and 32 kg/s. respectively. A schematic of the EBR-II plant, as is shown in fig. 1, the reactor core is submerged in the primary tank which contains approximately 340 m^3 of liquid sodium. The two primary pumps draw sodium from cold pool and provided sodium into the two inlet plena. Subassemblies in the inner core regions received sodium from the high-pressure inlet plenum and the blanket and reflector subassemblies in the outer blanket region received sodium from the low-pressure inlet plenum. The coolant from the core outlet directly flowed to the Z-pipe, which connected the core outlet and the intermediate heat exchanger (IHX) inlet. The hot sodium was transferred to the intermediate cold sodium due to temperature difference, and then exited the IHX back into the cold pool. The IHX is a tube-shell unit with the primary flow on the shell side.

2.2 Modeling of EBR II SHRT-45R

The SHRT-45R test was performed to demonstrate the effectiveness of EBR-II's a natural feedback feature.

Also starting from full power and flow, SHRT-45R was initiated by concurrently tripping both the primary and intermediate coolant pumps to simulate the natural process that shut down the reactor with adequate cooling without control rod insertion or operator insertion.

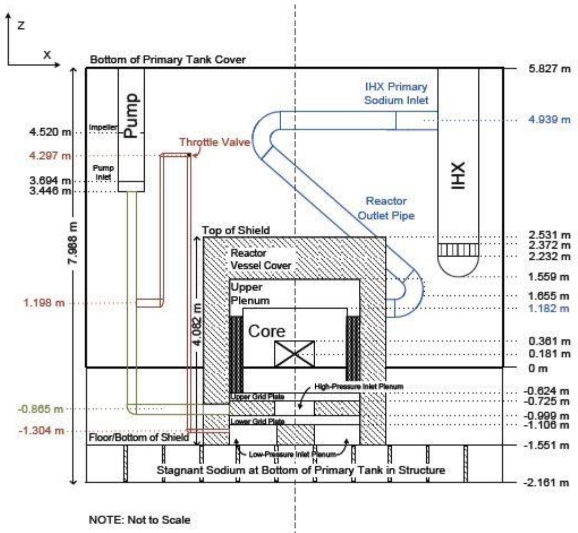

Fig. 1. Schematic of the EBR II primary system [1]

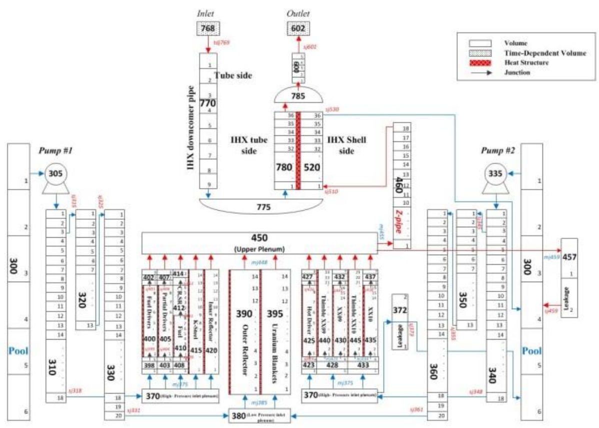

Fig. 2. Node diagram of MARS-LMR for EBR-II

Fig 2 shows the node diagram of MARS-LMR for the EBR-II SHRT-45R. The sodium cold pool and two primary pump are modeled as pump the primary coolant to the inlet plenum. The inlet plenum is divided into a high pressure plenum and a low pressure plenum. The subassemblies in the reactor core are divided into ten flow channels. The two flow channels are modeled as the uranium blanket and outer reflector connected to the low pressure plenum. The other flow channels are connected to the high pressure inlet plenum. The coolant heating up in the core flows up into upper plenum and enters into Z-pipe, which connected the the intermediate heat exchanger (IHX) shell side inlet. IHX tube side outlet is modeled as boundary condition.

2.3 Procedure for sensitivity analysis of uncertainty parameter in MARS-LMR code

The procedure for sensitivity analysis of uncertainty parameter in MARS-LMR code consists of the following steps.

(1) Selection of main event
The first consideration for sensitivity is to determine a main event. In Phenomena identification and Ranking Table(PIRT)[4] procedure, Unprotected Transient Overpower(UTOP), Unprotected Loss of Heat Sink(ULOHS) and Unprotected Loss of Flow(ULOF) were chosen corresponding to DEC. In this study, ULOF the most restrictive event in three events was chosen.

(2) Selection of Figure of Merit(FoM)
Because the event classified as DEC may threaten the structural integrity of nuclear fuel and cause a decrease in the cooling ability, nuclear fuel, cladding and coolant temperature major concern factor can be selected.

(3) Selection of phenomena and input parameter
some phenomena, which affect FoM defined in step (2), are selected in ULOF event, and some input parameters related to the phenomena are selected. In this step, the method called Phenomena Identification and Ranking Table(PIRT)[4] is used. In PIRT, phenomena are ranked based on the expert opinions and selected. In ULOF, parameters for phenomena are selected among many parameters as shown Table.1

(4) Specification of uncertainty range of parameter
Input parameter has an uncertainty, although the relative uncertainty range is different to each parameter. the relative uncertainty range of each parameter defined in Table. I is specified. The range is used as a change width of each parameter in sensitivity analysis following this step. The uncertainty ranges are basically determined based on expert opinions and literatures

Table I: uncertainty model and input parameter

No.	Models and Parameters	PDF	Uncertainty range
M1	Fuel thermal Conductivity	normal	±0.58W/mK
M2	Modified Schad correlation	normal	0.8~1.2
M3	Coolant Density reactivity coefficient	normal	0.674~1.326
M4	Grid Plate strain coefficient	uniform	0.9~1.1
M5	ACLP strain coefficient	uniform	0.9~1.1
M6	Radial core expansion reactivity coefficient	normal	0.694~1.306
M7	Fuel density	uniform	0.9~1.1
M8	Cladding strain coefficient	uniform	0.9~1.1
M9	Fuel Axial expansion reactivity coefficient	normal	0.694~1.306
M10	CRDL expansion reactivity feedback	uniform	0.9~1.1
M11	RV expansion reactivity feedback	uniform	0.9~1.1
M12	Control and shutdown rod worth	normal	0.802~1.198
M13	Doppler reactivity feedback	normal	0.7~1.3
M14	duct to sodium conduction	uniform	0.9~1.1
M15	Chen-Todreas correlation	normal	0.7~1.3
M16	Pump coastdown curve	uniform	0.9~1.1
M17	Core inlet form loss	Log-uniform	0.5~2.0
M18	heat capacity	uniform	0.9~1.1
M19	Aoki correlation (inter structure)	normal	0.8~1.2
M20	Aoki correlation (IHX tube side)	normal	0.8~1.2
M21	wall roughness	uniform	0.1~2.0
M22	Spacer grid form loss	uniform	0.5~1.5
M23	Grabber-reiger correlation	normal	0.878~1.122

2.4 Sensitivity Analysis

Sensitivity analysis was performed by using the PAPIRUS program. Among the uncertainty parameter, Sensitivity coefficient(S) is calculated by dividing the reactivity and non-reactivity parameter from the following equation:

$$S = \frac{(r'-r_0)/r_0}{(p'-p_0)/p_0} \quad (1)$$

where p_0 and r_0 are the nominal value of the parameter and the response, respectively, p' is the perturbed parameter, and r' is the simulation result calculated using the perturbed parameter. In this case, p_0 and p' are uncertainty parameters, r_0 *and* r' are FoM.

Fig. 3, 4, 5 show sensitivity to FoM of the the reactivity–relevant parameters in ULOF and it indicates relative sensitivity coefficient of each parameter to FoM. As the result of the sensitivity analysis of FoM of the reactivity–relevant parameters in ULOF, following 2 dominant parameters, which have large sensitivity, are selected: ‘‘M5-ACLP strain coefficient”, “M6-Radial core expansion reactivity coefficient’’. Fig. 6, 7, 8 show sensitivity to FoM of the the non-reactivity–relevant parameters in ULOF and it indicates relative sensitivity coefficient of each parameter to FoM. As the result of the sensitivity analysis of FoM of the non-reactivity–relevant parameters in ULOF, following 2 dominant parameters, which have large sensitivity, are selected: ‘‘M16-Pump coastdown curve”, ‘‘M17-Core inlet form loss”.

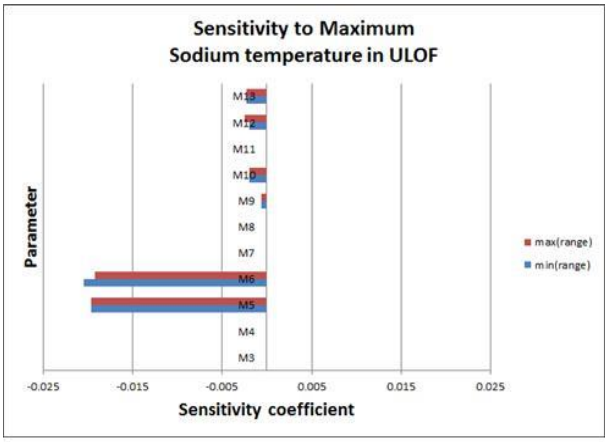

Fig. 3. Sensitivity to sodium temperature of the reactivity –relevant parameters

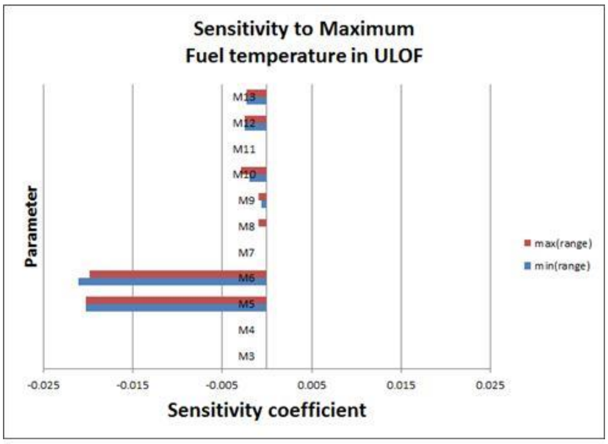

Fig. 4. Sensitivity to fuel temperature of the reactivity –relevant parameters

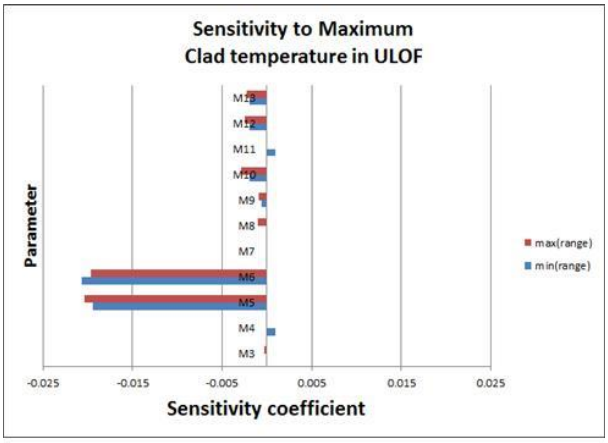

Fig. 5. Sensitivity to clad temperature of the reactivity –relevant parameters

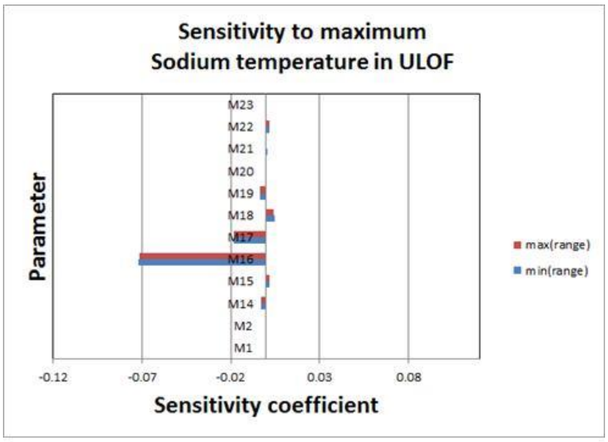

Fig. 6. Sensitivity to sodium temperature of the non-reactivity –relevant parameters

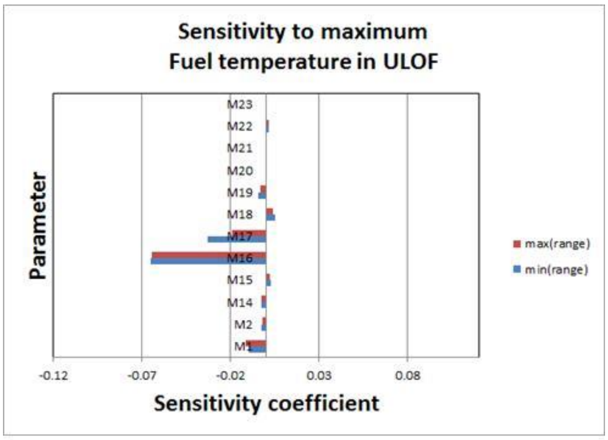

Fig. 7. Sensitivity to fuel temperature of the non-reactivity –relevant parameters

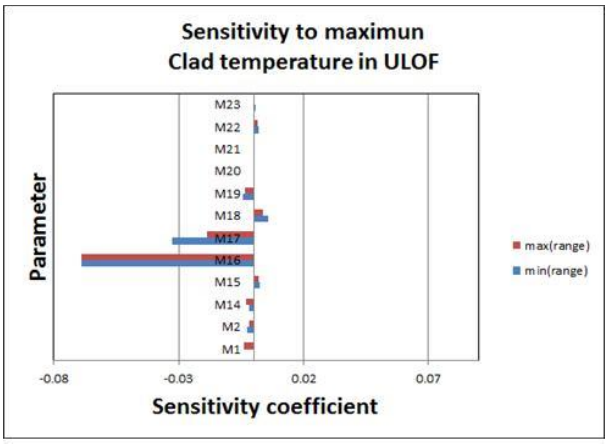

Fig. 8. Sensitivity to clad temperature of the non-reactivity –relevant parameters

3. Conclusions and future Works

The sensitivity analysis is carried out with Uncertainty Parameter of the MARS-LMR code for EBR-II SHRT-45R. Based on the results of sensitivity analysis, dominant parameters with large sensitivity to FoM are picked out. Dominant parameters selected are closely related to the development process of ULOF event.

Further study will be carried out with data assimilation using PAPIRUS, because prediction of the input(model) parameters are improved by data assimilation and the uncertainty ranges effectively cover the experimental data. After data assimilation calculation, Evaluations for uncertainty propagation will be carried out.

Acknowledgments

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