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Sensitivity Analysis of a Research Reactor Nodalization Modeled in the RELAP5 Code

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1. Introduction

The user of a thermal hydraulic system code has several elements to develop a detailed reactor nodalization. In the case of the RELAP5 code, a physical system consisting of flow paths, volumes, areas, etc., is simulated by building a network of volumes connected with junctions. In this way the reproduction of a physical system to a system of volumes and junctions is an approximate process [1]. Different results for a same system can be found due in part to the use of different computer codes; however, a substantial variation is also observed when different users apply the same codes. In this way, the main aim of this work was to identify how much the code results are affected by the code user in the choice, for example, of the number of thermal hydraulic channels (THC) in a nuclear reactor nodalization. To perform this, modifications on the number of thermal hydraulic channels of previously validated nodalization (with 13 and 91 THC)developed for the IPR-R1 Triga research reactor were considered [2].

The idea was to reduce the number of channels in the model to reduce the transient calculation time. For example, for the model with 91 channels, it took about 3 days to run the simulation. For the 3 THC model, it takes less than an hour to perform the calculation. To verify the results, analysis of forced recirculation off transient in the IPR-R1 Triga research reactor has been analyzed. Experimental data were taken from the reference [3] to compare the behavior of the reactor for different types of modeling. In the experiment, the reactor operated during about 2.5 h with the forced cooling system switched off and with an indication of 100 kW at the linear neutronic channel. The experimental measurements have demonstrated an average increase of the coolant temperature of (4.8 ± 0.2) ◦C/h [3]. For the model presented in this work (3-THC) it was found an average increase of (4.7 ± 0.2) °C/h, that is in very good agreement with the experimental result [3] and also with the models of 91-THC (4.74 ± 0.01) ◦C/h and 13-THC (4.75 ± 0.01) ◦C/h [2].

The IPR-R1 Triga Mark-I research reactor is installed at the Nuclear Technology Development Center (CDTN) of Brazilian Nuclear Energy Commission (CNEN), in Belo Horizonte City, Brazil, and it is in operation since 1960. It is a light water, graphite-reflected, open-pool type research reactor. Since 1970, IPR-R1 works at 100 kW but it is ready to operate at power of 250 kW. It presents low power and low pressure, for application in research, training, and radioisotopes production. The reactor is located in a 6.625 m deep pool with 1.92 m of internal diameter and filled with demineralized light water.

2. Methodology

The IPR-R1 has been modeled in the Nuclear Engineering Department of the Federal University of Minas Gerais using the RELAP5 code with the aim to reproduce the measured steady-state and transient conditions [2, 4, 5]. In a previous work, the RELAP5 steady-state calculation was performed considering models with 13-THC and 91-THC at 100 kW [5]. The point kinetics model was used in both simulations. The axial power distribution was calculated considering a cosine profile. The temperature values at the outlet of the TH channels were calculated for both nodalizations and compared with the experimental data at core positions *Ea*, *Eb* and *Ec* provided by [6]. To simplify the nodalization, in this work, the model has been modified to simulate de reactor core using only 3-THC as it can be seen in the Figure 1. The reactor pool was modeled using two pipe components composed by ten volumes (pipes 020 and 050). A time dependent volume (TDV 500) was used to simulate the atmospheric pressure on the pool surface. Each of the 63 fuel elements was modeled separately and 63 heat structure (HS) components were associated with the 3-THC according to the region (pipes 201, 202, 203).

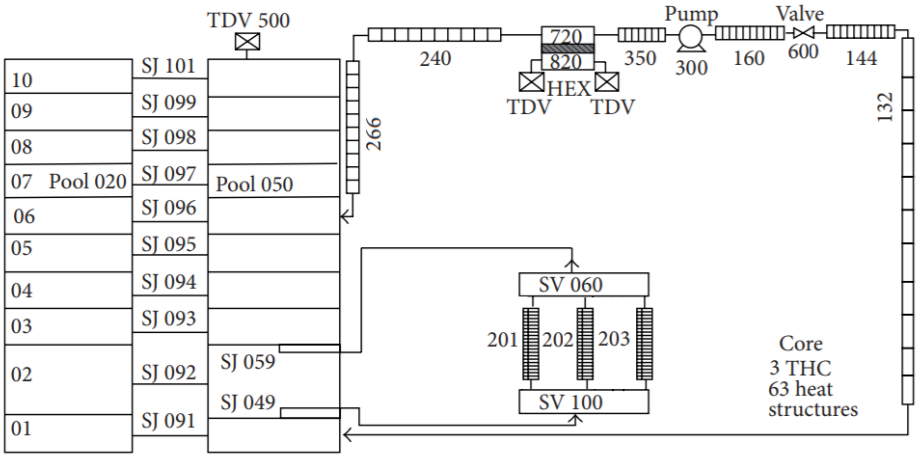

Figure 1: RELAP5 nodalization with 3 THC. Adapted from [5].

Then, for the transient simulation (forced recirculation off), the pump velocity was decreased (represented by the element 300 in the nodalization) after 5000 s of calculation bringing the reactor to operate with natural circulation condition to remove the heat of the core. The results were compared with that from the nodalizations of 13 and 91 THC [2] and also with the experimental data [3].

3. Results and Discussion

In Table I are presented the results for steady state simulation for 3-THC in comparison with experimental data [6] and also the nodalizations with 13 and 91 THC [2]. The coolant temperatures were taken at the outlet of the channels. As it can be observed, the 3-THC model presents higher percentage errors. However, considering the simplification of the core, the found values can be considered acceptable. In this way, the model was used to simulate the transient of loss of the forced coolant recirculation.

In Figure 2 it is shown the result of the transient simulation. In the graphic it is possible to verify the average temperature in the inlet and outlet of the core taken at the single volumes 100 and 600, respectively (see Figure 1). The temperature increase after the forced recirculation off at 5000 s of calculation. To calculate the rate of temperature increasing, a linear regression was performed considering a part of the inclination, as it is illustrated in Figure 3. As it is possible to verify the rate found was (4.7 ± 0,2) °C/h. This value is in very good agreement with experimental result (4.8 ± 0.2) ◦C/h [3] and also with the models of 91-THC (4.74 ± 0,01) ◦C/h and also to 13-THC (4.75 ± 0,01) ◦C/h [2].

Table I: Results for steady state calculation. Experimental and calculated core outlet coolant temperatures (fro 100 kW of power operation).

Experimental Temperatures (K) [6]		Calculated Temperatures in RELAP5 models (K)					
Position	Value	3-THC (this work)	Error (%)*	13-THC [2]	Error (%)*	91-THC [2]	Error (%)*
Ea	304.0	300.6	1.1	301.4	0.9	303.6	0.1
Eb	300.5	298.0	0.8	298.0	0.8	301.1	0.2
Ec	301.5	298.0	1.2	300.9	0.2	301.8	0.1

*Error = 100 × (calculation − experimental)/experimental

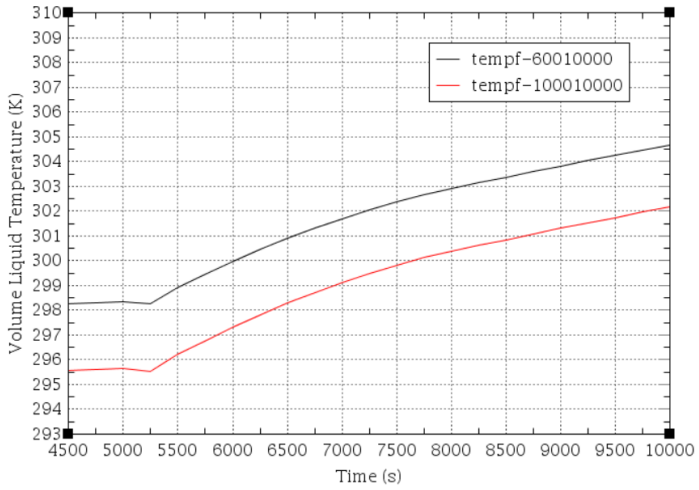

Figure 2 : Time evolutions of the coolant temperature (core inlet and outlet) after the loss of the forced recirculation at 5000 s of calculation for the 3-THC model.

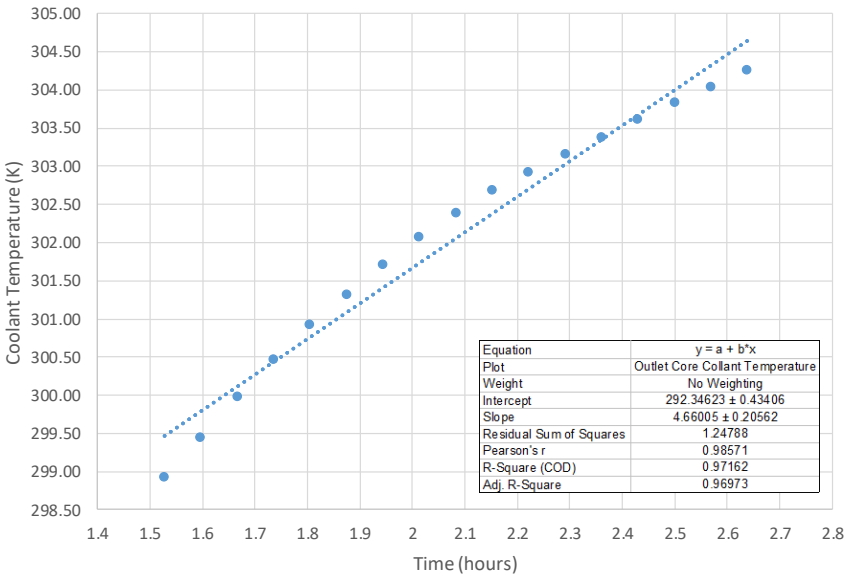

Figure 3 : Calculation of the rate of temperature increase (linear regression).

4. Conclusions

In this work, a previous modeling of the IPR-R1 Triga research reactor has been modified to simulate the core coolant circulation with 3-THC in steady state and in transient conditions. The forced recirculation off transient has been analyzed. The results proved that the simplification of the nodalization implies in a high computational time economy. For the 91-THC model, the transient simulation spends 3 to 4 days to be performed. For the 3-THC model, it taken less than an hour to perform the transient calculation and the result found was in very good agreement with the experimental data. Then, in transient cases where core details are not important in the analyses, it is possible to use a simplified core modeling with few THCs. For more detailed analysis, such as channel blockage transient, more detailed modeling becomes mandatory. Therefore, it all depends on the type of analysis that the code user wants to do.

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