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SENSITIVITY ANALYSIS THERMAL HYDRAULIC OF THE LIQUID-SALT-COOLED HIGH-TEMPERATURE REACTOR

Mario Cerrogrande Ramos
Antonella Lombardi Costa
Maria Elizabeth Scari
Wilmer Aruquipa Coloma
Claubia Pereira
Maria Auxiliadora Fortini Veloso

Departamento de Engenharia Nuclear, Universidade Federal de Minas Gerais
Av. Antônio Carlos, 6627, Campus UFMG, Escola de Engenharia, Pampulha, CEP 31270-90 Belo Horizonte, MG, Brasil
marc5663@gmail.com
antonella@nuclear.ufmg.br
melizabethscari@yahoo.com
wilmer.fcpn.fis@gmail.com
claubia@nuclear.ufmg.br
dora@nuclear.ufmg.br

Abstract. *A thermal model for the LS-VHTR (Liquid-Salt-Cooled High Temperature Reactor) has been developed using the RELAP5 code. The reactor operates at 2400 MW(t) and it is cooled by liquid Li2BeF4 (Flibe) salt. Two initial thermal analysis of the LS-VHTR was performed in a previous work where the simulation of only one unit cell was considered. In the present work, the RELAP5 model was increased to represent the complete core with all hexagonal blocks with two sensitivity analysis. Also the salt recirculation has been simulated. The LS-VHTR core inlet and outlet coolant temperatures, heat structures temperature and pressure drop have been simulated. The results have been compared with the available data and demonstrate that the developed model is capable to reproducing the thermal behavior of the reactor in steady state operation*

Keywords: *LS-VHTR; RELAP5; Thermal Analysis*

1. INTRODUCTION

The Liquid-Salt-Cooled Very-High-Temperature Reactor (LS-VHTR) is one of the IV generation reactors and combines several new technology assets such as successful use of coated-particle graphite-matrix fuel in helium-cooled reactors; reactor plant and safety systems similar to that developed to the liquid-metal cooled fast reactors; low-pressure liquid-salt coolants studied and researched for liquid fuel reactors; and Brayton power cycles at high-temperatures. The LS-VHTR project goal is to provide an advanced design which offers the potential for higher power output, improved efficiency of electricity production, and higher operating temperatures leading to significant reduction in plant capital costs, as well as its use in high-temperature process heat applications that can economically produces hydrogen (Ingersoll, et al, 2005).

The LS-VHTR core uses TRISO (TRiISOtopic) fuel particles, which consists of a fuel kernel made of uranium oxycarbide (UCO) or uranium dioxide (UO2), surrounded by four different layers of carbon. These TRISO particles are incorporated into a graphite-matrix fuel compact, which, in turn, is loaded into a hexagonal fuel block which provides more control of the fuel and coolant volume fractions and geometry. A total of 265 columns of 10 fuel blocks stacked axially are assembled into a cylindrical geometry with nonfueled graphite reflector blocks filling in the region between the outer diameter of the core and the reactor vessel. This reactor core configuration is identical as that of the FY-2005 ORNL design (Ingersoll *et al*., 2006). Figure 1 provides a plan view of the core and reflector geometry.

The advantages of using liquid salt as coolant is mainly related with its high efficiency of heat transfer, operation at low pressures, high volumetric heat capacity compared with gas and sodium, possible optical inspection and low corrosion rate. A drawback aspect of liquid salts is the high melting temperature (between 350°C and 450°C), however, since the reactor operates at high temperature, this is not a problem. The salt used for coolant is called Flibe (66% LiF and 34% BeF_2). The Flibe has a small neutron cross section, which makes it relatively transparent to neutrons (Davis, *et al*., 2006).

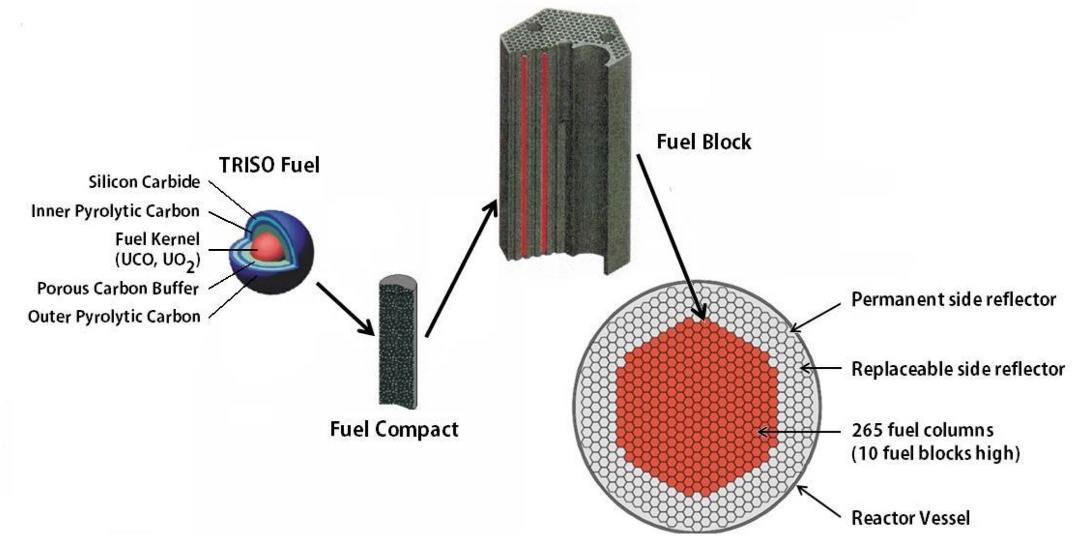

Figure 1. Design of the LS-VHTR core.

2. METHODOLOGY

An initial thermal analysis of the LS-VHTR was performed in a previous work (Davis, 2006; Scari, 2013) where the simulation of only one unit cell was considered in the RELAP5-3D code. Each unit cell, represented as a part of the hexagonal fuel block, was modeled to represent one coolant channel, filled with Flibe, and two fuel channels, with two gaps, immersed in graphite moderator matrix. In the present work, the RELAP5-3D model was incremented to represent the complete core with all hexagonal blocks for two sensitivity analyses for cylindrical and annular heat structures.

The LS-VHTR core has been modeled using the RELAP5-3D code. In the developed model, 10 thermal hydraulic channels represent ten regions or ring across the core, so that a group of n assemblies of a ring are simulated by a pipe. Each ring has different distribution power but each fuel block of a ring has the same power. This model is used to perform the simulation in steady state conditions and to analyze the influence of some design parameters on the temperature and flow distributions in the core. A summary of the characteristics of the rings are given in the Figure 2.

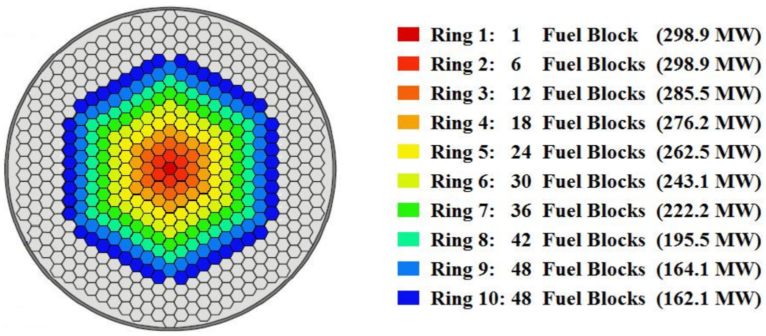

Figure 2. Different rings of the LS-VHTR core.

In the model, two types of heat structures with cylindrical and annular geometry (HS) have been implemented for each ring of the core, the HS simulate the power source and their outer boundary is attached to the corresponding coolant channel hydrodynamic component. They were divided axially according to the same quantity of the thermal channel volumes.

The Heat Structure (HS) simulate the power source of each channel and they were divided axially according to the same quantity of the thermal channel volumes. All HS have 12 radial meshes, being 6 intervals to the fuel region, 1 interval for the helium gap and 4 intervals representing the graphite region, this HS are represented in the Figure 3. The thermodynamics properties of the LiF-BeF2 were selected to perform the calculations. The point kinetics option was used in the calculations, the data of volumetric heat capacity and heat transfer coefficient of the standard fuel compact, the helium in the gap and the graphite were considered. The initial conditions used to simulate the core are shown in Tab. 1.

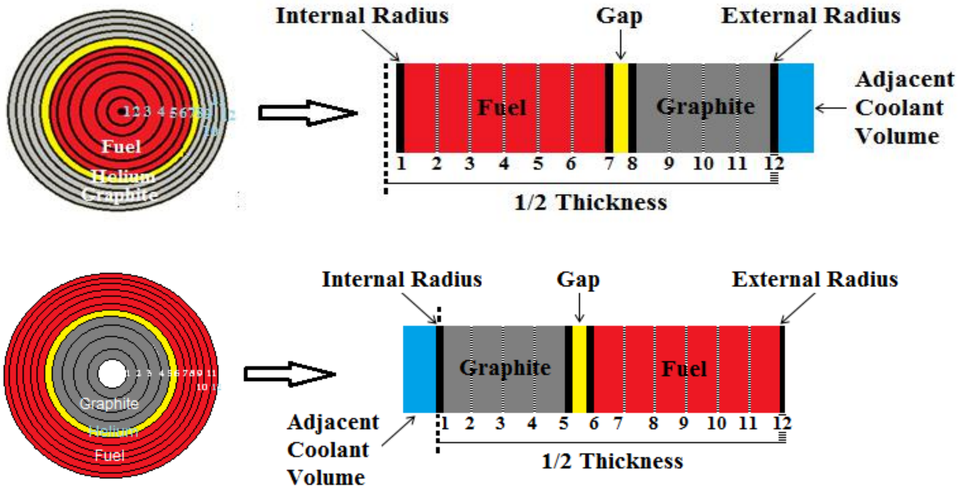

Figure 3. Representation of heat structures in RELAP5-3D model. Cylindrical heat structure of cylindrical (upper figure) and annular heat structure (lower figure).

Table 1. Initial conditions for the LS-VHTR.

Parameter	Value
Core total power	2400 MW
Core mass flow rate	10,264 kg/s
Core inlet temperature	900 °C
Core outlet temperature	1000 °C
Core pressure drop	0.211 MPa

The fuel used in the LS-VHTR is a fuel compact, made of TRISO fuel particles assembled together in a graphite moderating matrix. Finding a model that would exactly reproduce the TRISO fuel performance was intricate. Thus, assumptions were made to model the fuel as accurately as possible. The effective thermal properties of fuel compacts were determined the same way as in reference (Jensen, 2010; Folson, 2012).

The radial power distribution profile used in this work was that calculated by ORNL (Ingersoll *et al*., 2006). The distributions were generated using MCNP with a 10-ring core model. The axial power distribution profile is used by RELAP to calculate the heat transferred to the coolant channels in each axial segment of the pipes modeling the core to obtain the power generated in the heat structure (RELAP5-3D Code, 2009). The axial power profile chosen is based on a profile used by ORNL to model the LS-VHTR (MacDonald, 2003).

3. RESULTS

The calculated average temperature along the heat structure is shown in Figures 4 and 5. Each point represents an axial node from 1 up to 24 of the structures 301 to 310. The temperature of each point is the average radial temperature of the corresponding axial node in the structure.

The behavior of the axial temperature along each heat structure for the cylindrical configuration is shown in Figure 4. This distribution has the same shape as the reference axial profile, and smoothes from the fuel until it is linear in the coolant; in addition, this distribution along the channels also smoothes from the channel 301 until it is almost linear in the channel 310.

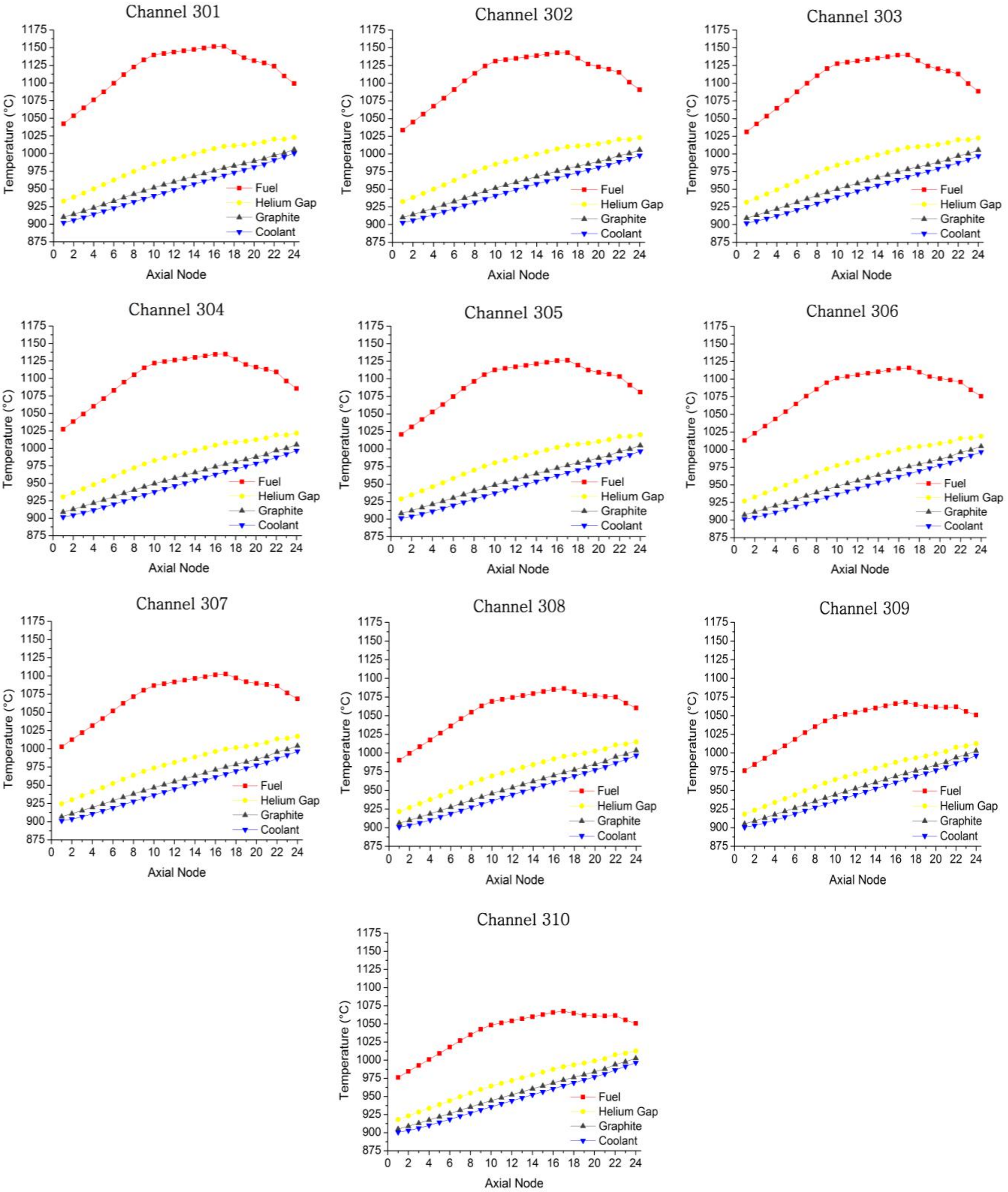

Figure 4. Mean axial heat structure temperature along the high of the heat structures 301 to 310 for cylindrical geometry.

The axial temperature distribution along the heat structure has the same almost linear shape in the fuel and decreases gradually until it is linear in the coolant. In addition, this distribution along the channels will also soften from the channel 301 until it becomes almost linear in the channel 310. In Figure 5, the axial temperature distribution is shown for the annular configuration.

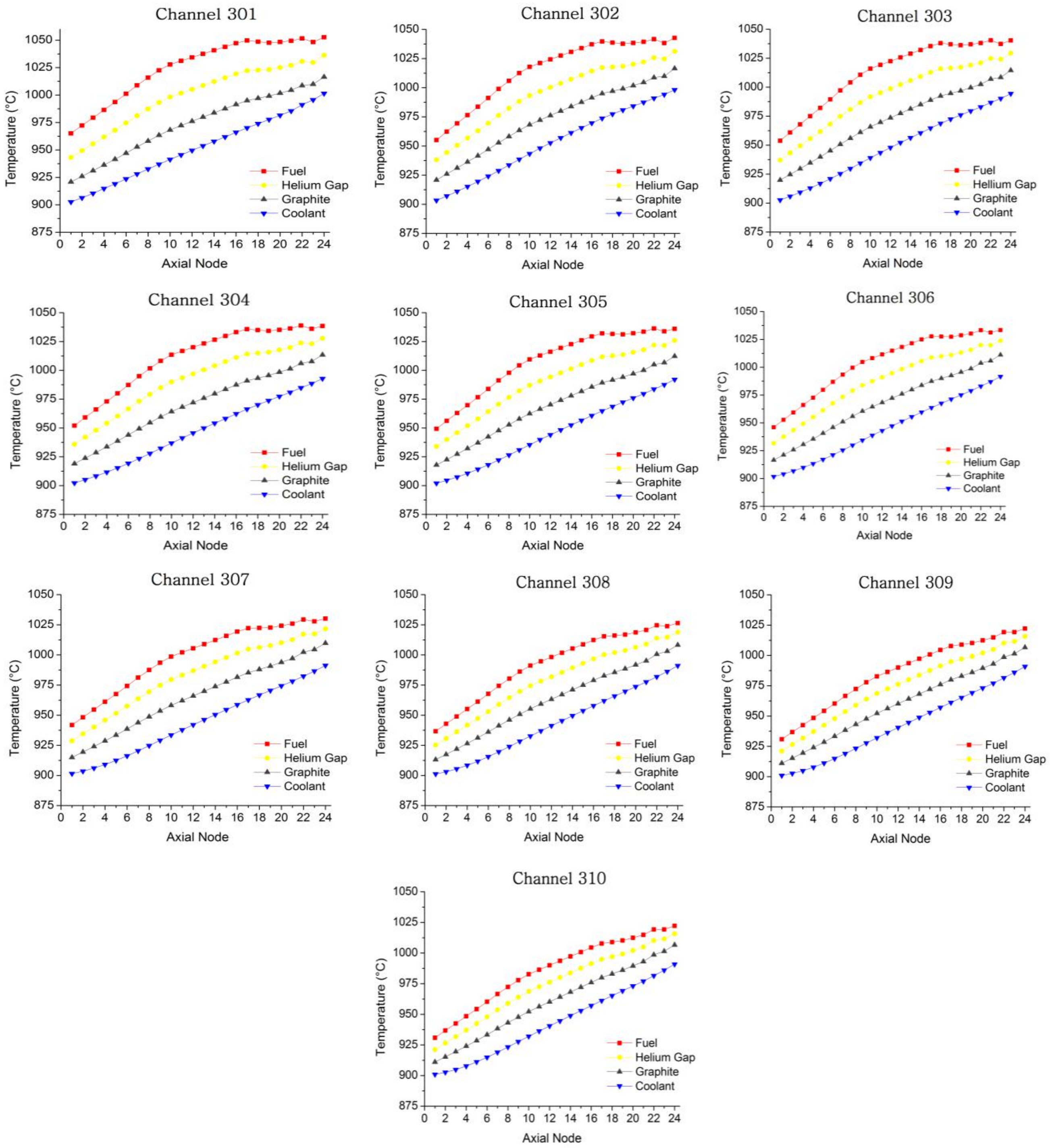

Figure 5. Mean axial heat structure temperature along the high of the heat structures 301 to 310 for annular geometry.

In Figures 6 and 7, the temperature distribution for each axial and radial node of the heat structures 301 to 310 are plotted. For cylindrical geometry the inner region represents the fuel compact (1 to 6 radial node), middle region is Helium (only 7 radial node) and outer region is graphite (8 to 12 radial node). For annular geometry the inner region is graphite, middle region is Helium and outer region is the fuel compact.

The temperature distribution in the ten thermohydraulic channels, using the cylindrical configuration, is shown in Figure 6. As can be seen, the temperature decreases along the channels from 301 to 310. In each channel, the higher temperature regions are located near the central position of the heat structure.

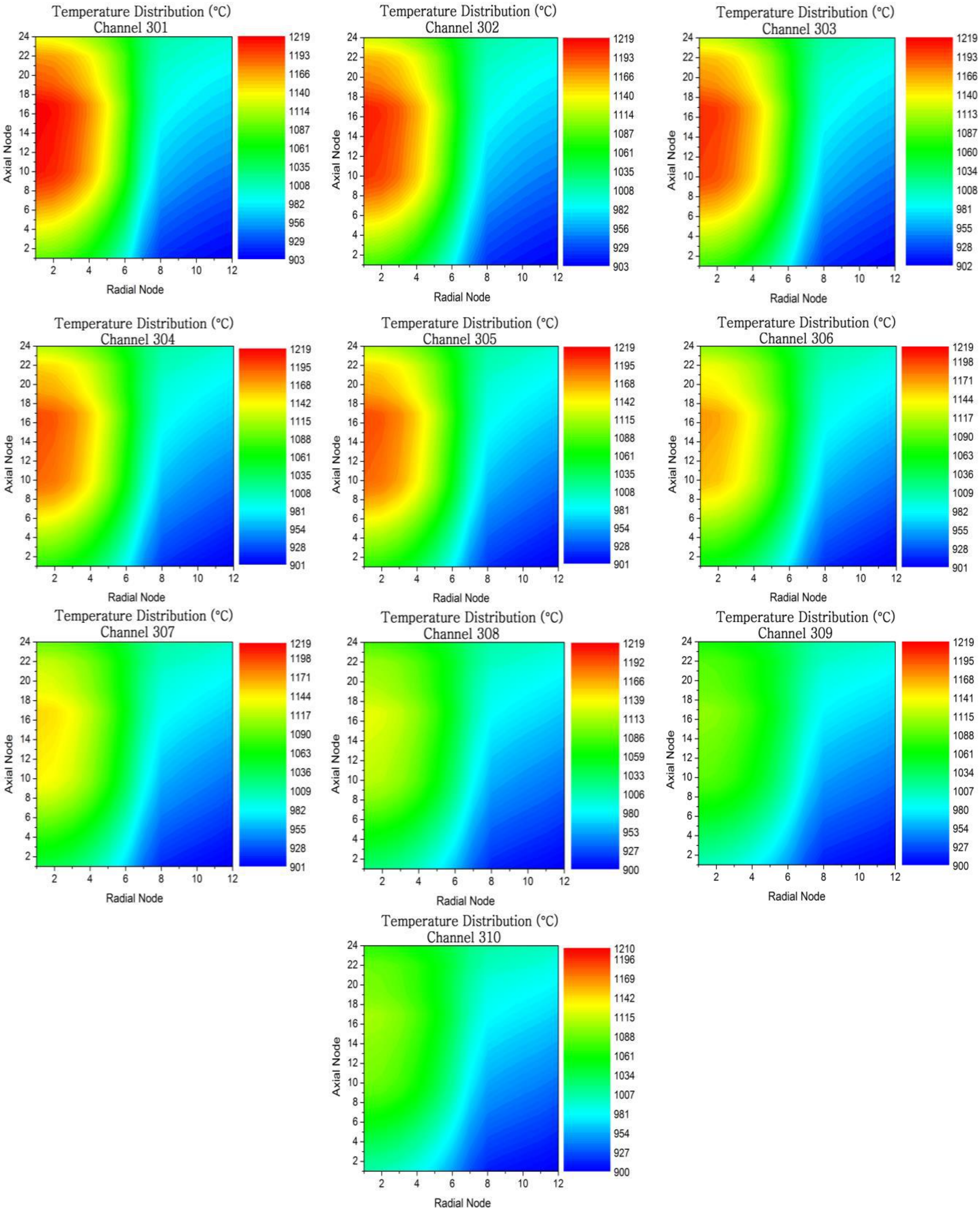

Figure 6. Temperature distribution of the heat structures from 301 to 310 for cylindrical geometry.

The annular configuration can be seen in Figure 7, in the same way as in the case of the annular configuration, the temperature distribution decreases in each thermohydraulic channel from channel 301 to 310. The temperature in each channel has regions with greater temperatures located at the top of each heat structure.

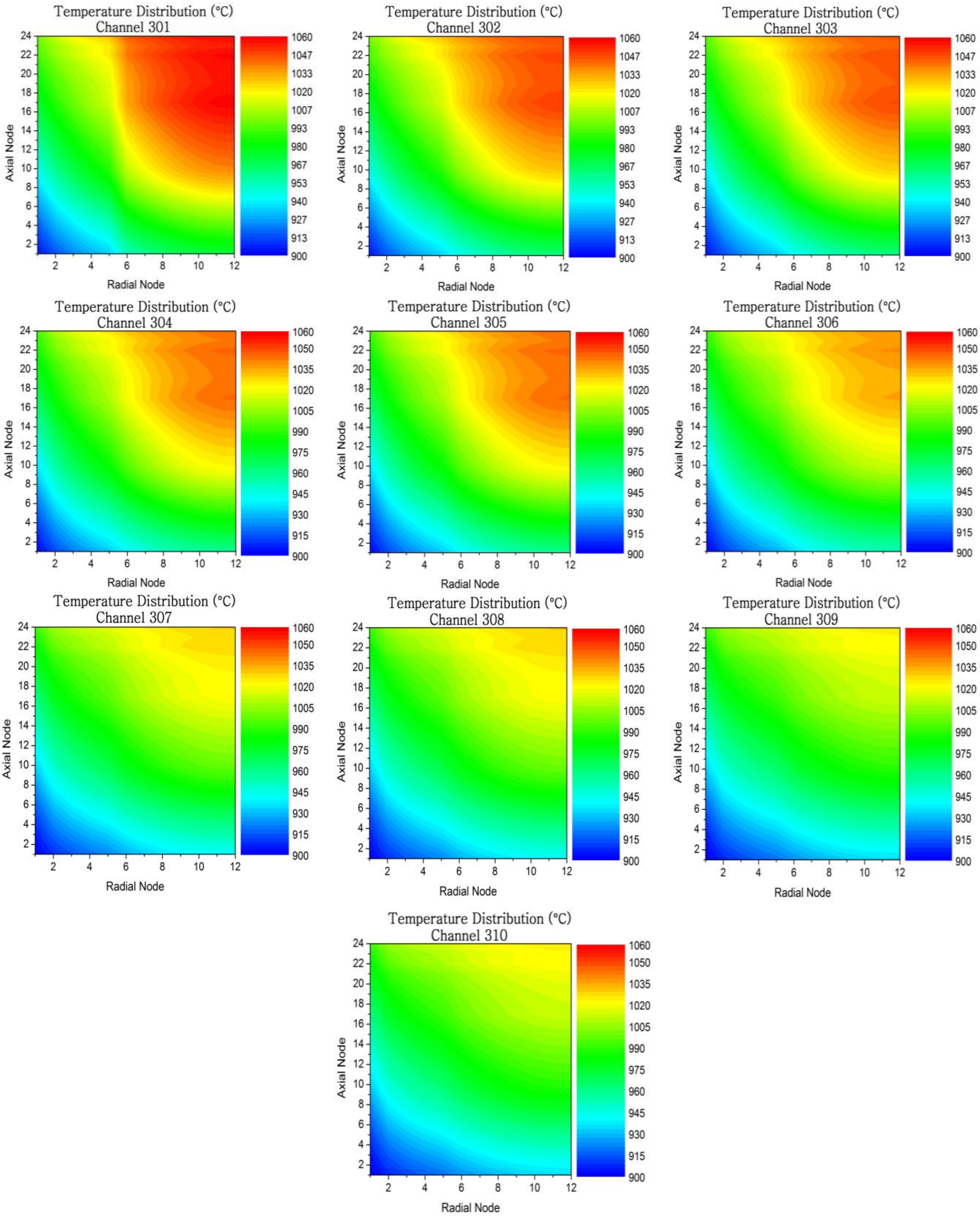

Figure 7. Temperature distribution of the heat structures from 301 to 310 for annular geometry.

4. CONCLUSIONS

This work presented a methodology to simulate the core of the LS-VHTR reactor, using the thermal hydraulic analysis code RELAP5-3D, which can be extended to other reactors with the same configuration of the core of this reactor and with other coolants.

The work presents different aspects related to the modeling, the study and the characterization of the LS-VHTR reactor, including thermal hydraulic evaluations of the nucleus, different models to simulate the fuel and the coolant channels. Several models have been developed and tested; to obtain a complete view of the problem, some approximations have been introduced in calculating the temperature distribution, since a relatively low number of discretized meshes are desirable to maintain fairly small computational time and data production, particularly in the case of model of the whole nucleus.

The models provided a good description of the LS-VHTR fuel element, but more work is needed to improve its capabilities. In particular, the model would have to be adapted to consider conducting heat in 2D and 3D, for a better description of the temperature distribution.

It was observed that the annular configuration presents lower temperatures in the fuel compared to the cylindrical configuration, in such a way that the latter configuration in thermal hydraulic terms can be used to represent not only the LS-VHTR reactor core, but also to represent other cores of prismatic block type reactors. The comparison between the simulated results demonstrates that the developed model is capable to reproducing the thermal behavior of the reactor in steady state operation. More investigations are necessary mainly in relation to the heat transfer between the components of the heat structures. Future work consists in to incorporate more reactor details beyond the core in the model and also to simulate transient events.

5. ACKNOWLEDGEMENTS

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