Heat Transfer Analysis of a Conceptual Horizontally-Oriented High Temperature Gas-Cooled Reactor


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HEAT TRANSFER ANALYSIS OF A CONCEPTUAL HORIZONTALLY-ORIENTED HIGH TEMPERATURE GAS-COOLLED REACTOR

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ABSTRACT

High temperature gas-cooled reactors (HTGRs) have been constructed around the world since the 1960s. Compared to light water reactors, HTGRs feature a low core power density, which ultimately results in the need for larger components and structures. The successful widespread deployment of HTGRs will likely require a significant reduction in reactor building size per kW, to compete with other sources of carbon-free energy. The Modular Integrated Gas-cooled High Temperature Reactor (MIGHT-R) has been recently proposed to leverage inherent safety characteristics of HTGRs and its proven technology, while increasing its reactor building power density by 4 to 5 times. Contrarily to the vertical side-by-side orientation of the reactor core and steam generator of the typical HTGR design, the MIGHT-R primary system components are laid horizontally, in-line with one another. In this paper, a design embodiment of MIGHT-R concept is presented and preliminary heat transfer analysis under normal operating conditions is performed adopting a simplified porous representation of the flow behavior inside the reactor core and steam generator. The predicted mass flow rates in the fuel region, inner reflectors and outer reflectors agree with analytical estimations. A set of sensitivity tests for components variations are presented to provide insights on the influence of design parameters. A preliminary design reactor cavity cooling system (RCCS) is presented which is basically a 100 °C “water shell” surrounding the reactor vessel and it only covers the reactor core regions. Comparison of the same design with different orientations is also made and indicates that the mass flow and temperature distribution inside the reactor core have low dependence on orientation. Based on the computational results, the stratification of the coolant in the horizontal configuration for normal operation is deemed negligible. The presented work supports the normal operation feasibility of a horizontally-oriented HTGR concept with its potential to significantly reduce HTGR capital cost.

Keywords: HTGR, advanced reactor, horizontal-oriented, CFD, porous media model

1. INTRODUCTION

Gas-cooled reactors have a long history and are in use today. The earliest development of gas-cooled reactors began in the United Kingdom (UK) and France. The original gas-cooled reactors in the UK were designed with natural uranium fuel cladded in a magnesium alloy, hence the name Magnox. The UK’s Magnox reactor was then followed by the Advanced Gas-cooled Reactor (AGR). The AGRs utilized 2–4% enriched uranium oxide fuel. Compared to the Magnox reactor, the AGR had a higher power density, enriched fuel, higher burnup rate and were 10% more efficient [1]. The second generation of gas cooled reactors, termed high temperature reactors (HTRs), used graphite as a moderator and helium for its coolant. In addition, these early plants also demonstrated coated particle fuel, a fuel form that employs ceramic coatings for containment of fission products at high temperature, a key feature of HTGRs.

Dragon was the first experimental HTR and served as a demonstration plant. It was built in the UK with a power of 20 MWth and went critical in 1964. Following the experience of the Dragon reactor, more HTR designs were introduced in Europe, the United States and Japan. The Peach Bottom Unit 1 was built in the U.S. with a power of 40 MWt and went critical in 1966 followed by the Fort Saint-Vrain (FSV) which had a power of 330 MWt. Both of these reactors had cores consisting of prismatic graphite blocks cooled by helium and served as an experimental platform that provided valuable experience in the operation and design of gas-cooled reactors. Meanwhile, Germany began building its first HTR in 1961, the AVR, which was a 15 MW(e) reactor using the pebble bed concept. Following the experience of the AVR, Germany then built a second HTR named Thorium High-Temperature Reactor (THTR-300) which went critical in 1983.

More recently, two additional HTGR test reactors have been constructed and are successfully being operated, the 30 MWt High Temperature Test Reactor (HTTR) in Japan and the 10 MWt High Temperature Reactor (HTR-10) in China, with design outlet temperatures of 950 °C and 700 °C respectively [2].
Compared to the light water reactors (LWRs), the main limitation of HTGR is the low power density which results in a high degree of safety but also larger components and structures. Current HTGRs like the HTR-PM in China require a 65 m tall building for a 210 MWe power output. The same building could house an 1100 MWe LWRs. This motivates a need to reduce the size per kW, i.e., increase the HTGR power density, to compete with other sources of carbon-free energy. HTGR innovation should center around a design that adapts to today’s safety and security requirements and requires minimum development.

The concept of the Modular Integrated Gas-cooled High Temperature Reactor (MIGHT-R or “Mighty Reactor”) was recently proposed at MIT. As an inherently safe, near-term concept that can provide all the service typical of the HTGR: efficient and flexible electricity generation, district heating, hydrogen production and water desalination. The MIGHT-R relies solely on proven technology and does not require years of research and development. The technology basis includes design, licensing, construction and operation of several HTGR plants. Two key characteristics of HTGRs are the use of helium coolant and graphite moderator. The use of helium in lieu of CO2 as the coolant in combination with a graphite moderator offers enhanced neutronic and thermal efficiencies. The combination of helium cooling and graphite moderator makes possible production of high temperature nuclear heat. MIGHT-R is conceived with a design-to-build mindset, so that the nuclear building sizes are more than 30% smaller than in any other HTGR, on a per unit kW basis [3].

As opposed to the vertical, side-by-side orientation of the reactor core and steam generator typical of the HTGR design, the MIGHT-R primary system components lay horizontally, in-line with one another as shown in Figure 1. The modules, as depicted in the Figure 1, have flanges screwed to one another, and can slide together or separately along the rails. This feature facilitates replacement and maintenance operations as well, while eliminating the necessity of overhead cranes and their associated complexity. The superior efficiency in space utilization stems from removal of the cross vessel and the associated space utilization of that layout, removal of the overhead crane and its space utilization and the removal of floors and stairs to have access to every part of the primary system. The lower height of the building makes it easier to construct. The reactor hall consists either on a covered trench, an above grade classical concrete building or a surface mounted building, i.e., covered by soil or a silo-type cavity in rock, adaptable to site conditions.

In this paper, a simplified MIGHT-R model is constructed and the analysis is focused on the primary heat transfer characteristics. Physics-based models incorporated in 3D computational fluid dynamics (CFD) code, STAR-CCM+ [4], are utilized to perform the analysis considering both the temperature and flow distributions.

2. MIGHT-R design

In this section, design details of the MIGHT-R are briefly discussed due to the page limit. More information can be found in the literature [3], [5].

2.1 Reactor systems

The precise dimension of the primary system can be found in the report [5] whereas the simplified design can be found in Figure 2. The reactor core size follows the design of General Atomics' HTGR: efficient and flexible electricity generation, district heating, hydrogen production and water desalination. MIGHT-R is conceived with a design-to-build mindset, so that the nuclear building sizes are more than 30% smaller than in any other HTGR, on a per unit kW basis [3].

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Detailed comparison between GA HTGR and MIGHT-R can be found in Table 1 including the design parameters and geometrical information. The pressure drop of reactor core is comparable to the values from GA HTGR.

Table 1. Comparison between General Atomics HTGR and MIGHT-R.

<table>
<thead>
<tr>
<th></th>
<th>GA HTGR</th>
<th>MIGHT-R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor orientation</td>
<td>Vertical</td>
<td>Horizontal</td>
</tr>
<tr>
<td>Thermal capacity (MW)</td>
<td>350</td>
<td>350</td>
</tr>
<tr>
<td>Gross electrical capacity (MW)</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>System pressure (MPa)</td>
<td>6.39</td>
<td>6.39</td>
</tr>
<tr>
<td>Core helium flow rate (kg/s)</td>
<td>157.1</td>
<td>157.1</td>
</tr>
<tr>
<td>Core pressure drop (kPa)</td>
<td>34.7</td>
<td>34.4</td>
</tr>
<tr>
<td>Steam generator primary side pressure drop (kPa)</td>
<td>250</td>
<td>257.6</td>
</tr>
</tbody>
</table>

Geometrical information

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Room height (m)</td>
<td>65</td>
<td>9.207</td>
</tr>
<tr>
<td>Reactor vessel overall height or length (m)</td>
<td>22</td>
<td>30.817</td>
</tr>
<tr>
<td>Reactor vessel outside diameter (m)</td>
<td>6.8</td>
<td>6.8</td>
</tr>
<tr>
<td>Reactor vessel inside diameter (m)</td>
<td>6.55</td>
<td>6.36</td>
</tr>
<tr>
<td>Core diameter (m)</td>
<td>5.8</td>
<td>5.8</td>
</tr>
<tr>
<td>Core height (m)</td>
<td>9.5</td>
<td>9.5</td>
</tr>
</tbody>
</table>

In MIGHT-R, the helium is heated up in the reactor core and cooled down in the steam generator. Due to unavailability of detailed data for the 350 MWth GA HTGR design, the power distributions of the reactor core are scaled based on the 600 MWth GA HTGR [6] and implemented through user field functions. Power distribution of the MIGHT-R are shown in Figure 3. In the steam generator region, uniform negative heat source is implemented which serves as the heat sink. Volume-integrated powers of both reactor core and steam generator are monitored to ensure that the power level meets users’ design.

2.2 RCCS

Dedicated Reactor Cavity Cooling System (RCCS) is under pre-conceptual design for MIGHT-R which aims at reducing the room temperature to an acceptable level. The current RCCS design is basically a “water shell” surrounding the reactor vessel and it only covers the reactor core regions. It is filled with water and assumes heat generated from the reactor vessel boils the water up to 100 °C. The CAD model of MIGHT-R is shown in Figure 4 where RCCS and five supports are implemented around the reactor vessel. The supports shape is explicitly modeled as their existence will impact the heat transfer in the room. RCCS inner and outer radius are assumed to be 3.6 m and 3.7 m, respectively. Since the RCCS is assumed to operate at boiling point, a constant temperature (100 °C) boundary condition is applied on the RCCS boundaries instead of directly modeling the boiling heat transfer inside the RCCS. All the other boundaries in the room assume adiabatic boundary condition.
3. CFD models

All the simulations discussed in this work are performed with the commercial finite volume flow solver, STAR-CCM+ version of 15.04 [2]. A porous media representation is used to model the reactor core and steam generator. Surface-to-surface radiation heat transfer model [4] is used to model the radiative heat transfer. Emissivity of the vessel surface is set as 0.90 based on the properties of low alloy steel. A segregated flow solver is used, based on the SIMPLE algorithm and is applied on co-located variables using Rhie-Chow interpolation. A steady flow solver is adopted in this work to evaluate the overall performance of the system, while transient flow solutions will support future analysis. The under-relaxation coefficients were mildly modified to ensure solution convergence at the end of the simulation. The following under-relaxation factors are used: 0.6 for velocity, 0.2 for pressure, 0.6 for segregated energy and 0.8 for the turbulence model. The convective terms are interpolated by a non-oscillatory second-order upwind scheme for the turbulence model. Standard $k-\varepsilon$ model with high $y+$ wall treatment [7], [8] is used to model the turbulent flow field given the chosen mesh resolution. Since room region has minimal convective flow, laminar flow model is used to model the natural circulation in the room region. Helium properties are temperature/pressure dependent [9], [10] and they are summarized in Table 2. Validation of the current CFD method is performed through comparing the solution with analytical derivation of mass flow split which will be discussed in the section 4.2 and 4.3. Further validation will be performed in the future once dedicated experimental data are available.

Table 2. Summary of helium properties in the model where $T$ is the absolute temperature (K).

<table>
<thead>
<tr>
<th>Flow properties</th>
<th>Helium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (kg/m$^3$)</td>
<td>2824.97-0.989</td>
</tr>
<tr>
<td>Dynamic viscosity (Pa.s)</td>
<td>3.0629$\times$ 10$^{-7}$(7 + 21.33)$^{0.7243}$</td>
</tr>
<tr>
<td>Specific heat (J/(kg.K))</td>
<td>5197.61</td>
</tr>
<tr>
<td>Thermal conductivity (W/(m.K))</td>
<td>0.154933</td>
</tr>
</tbody>
</table>

3.1 Mesh

Depending on the regions’ shape and functionality, different types of meshers are leveraged as shown in Figure 5 and Figure 6. A fully structured mesh is adopted for the fuel loading space, reactor core, connection and steam generator regions because the helium flow in those regions is mostly unidirectional, and the structured mesh allows optimal performance of the porous representation. A surface extrusion is applied for the vessel shell (0.22 m) and core barrel (0.03 m), and enables the mesh to align with the boundaries’ curvature. Trimmed mesh is applied to the two semi-spheres, helium inflow/outflow passage channels and room with different base mesh sizes and prism layers. Refinements are added near the complex structures, like supporters and RCCS, to resolve the disturbed flow fields. The number of cells is 1.11 million which makes the model computationally affordable for efficient design. A fully converged solution is obtained in 372.8 core-hours. Mesh sensitivity is performed to justify the validity of the mesh and will be discussed later.

3.2 Porous media model

In the reactor core and steam generator, helium flow passes through a number of small diameter channels. A cross-sectional view of a standard fuel element is shown in Figure 7. It is computationally expensive to model the helium flow behavior in the reactor core considering thousands of flow channels.
Instead of modeling individual flow channels, helium flow in the reactor core and steam generator can be approximated using calibrated loss coefficients in a porous media model. This is an effective approach to simulate the transport of a fluid or energy through mostly highly geometrically constrained regions. The porous media representation in CFD adds appropriate source terms to the governing equations to account for the influence of the geometrical configuration that is not represented explicitly.

Porosity is defined as the ratio of the volume \( V_f \) that is occupied by the fluid and the total volume \( V \) of a cell

\[ \chi = \frac{V_f}{V} \]  

(1)

In the present study, porosity represents the ratio between helium flow channel and area occupied by the solid. Table 3 summarizes the values of porosities in each region. Note that there are three separate regions in the reactor core as shown in Figure 8. The fuel region has the maximum porosity of 0.221 which reflects the high numbers of flow channels required to cool the fuel. Porosity in the steam generator is 0.65, and is based on the assumptions of a staggered tube configuration. The estimation of steam generator porosity is approximate due to the limited details of the steam generator design.

Table 3. Summary of porosities in each region.

<table>
<thead>
<tr>
<th>Regions</th>
<th>Porosities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor core</td>
<td></td>
</tr>
<tr>
<td>Inner reflectors</td>
<td>0.039</td>
</tr>
<tr>
<td>Fuel</td>
<td>0.221</td>
</tr>
<tr>
<td>Outer reflector</td>
<td>0.021</td>
</tr>
<tr>
<td>Steam generator</td>
<td>0.65</td>
</tr>
</tbody>
</table>

Figure 8: Porosities distribution in the reactor core where red and blue regions representative high and low porosity values.

In the adopted porous representation the increase in physical velocity for lower porosity regions is not computed, instead only the superficial velocities are calculated. The superficial velocity is related to the physical velocity as

\[ v_s = \chi \cdot v \]  

(2)

The pressure losses in the porous region are modeled as sink terms in the momentum equations that accounts for the resistance to the flow imparted by the porous medium. The porous media resistance force is defined in terms of the superficial velocity \( v_s \) and the porous resistance tensor \( P \):

\[ f_p = P \cdot v_s \]  

(3)

The porous resistance tensor consists of two components:

\[ P = P_v + P_i |v_s| \]  

(4)

where \( P_v \) is the viscous (linear) and the \( P_i \) is the inertial (quadratic) resistance tensor. This source terms represents a momentum sink that creates a pressure drop.

\[ \Delta P = \rho (P_v + P_i |v_s|) v_s \]  

(5)

where \( v_s \) is the superficial velocity in the streamwise direction. \( P_{v,n} \) and \( P_{i,n} \) represent the resistance in the streamwise direction.

Analytical formulations of the resistance coefficients are derived based on the pressure drop expression in the classic form

\[ \Delta P = \frac{f_0 L}{D} \frac{\rho v^2}{2} + 2K \frac{\rho v^2}{2} = \frac{f_0 L}{D} \frac{(\dot{m}/A)^2}{2\rho} + 2K \frac{(\dot{m}/A)^2}{2\rho} \]  

(7)

where the friction correlation, \( f_0 \), adopts McAdams’ correlation \( [11] \) and is valid for bulk Reynolds number between \( 3 \times 10^5 \) and \( 1 \times 10^6 \). \( K \) is the form loss coefficient and calculated as 8.79, 32.86 and 32.83 for the fuel, inner reflector and outer reflector regions, respectively, at operational flow condition.

By generating a set of mass flow rates around the ideal values in each region, plots of pressure drop versus superficial velocity are obtained. By fitting the curve, the values of inertial and viscous resistance coefficients are obtained and used to define the porous media model of the reactor core. Table 4 summarizes the ideal mass flow split assume equal pressure drop at different region. The estimated inertial and viscous resistances are shown as well.

Table 4. Summary of mass flow split, inertial and viscous resistances in each region.

<table>
<thead>
<tr>
<th>Regions</th>
<th>Fuel</th>
<th>Inner reflector</th>
<th>Outer reflector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass flow split</td>
<td>92.5%</td>
<td>1.4%</td>
<td>6.1%</td>
</tr>
<tr>
<td>Resistance</td>
<td>Inertial</td>
<td>108.98</td>
<td>38523</td>
</tr>
<tr>
<td>(kg/(m³.s))</td>
<td>Viscous</td>
<td>41.41</td>
<td>1446</td>
</tr>
</tbody>
</table>

Compared to the resistance calculation in the reactor core, the resistance in the steam generator is defined as 27000 kg/(m³.s) for viscous resistance and 0 for the inertial resistance. Due to the complex structures and limited knowledge of the steam generator, the simple approach is to apply a constant resistance for the entire steam generator region to let the pressure drop matches the designed pressure drop, 250 kPa.
4. RESULTS AND DISCUSSION

The simulation results are presented in this section. These include a general mesh sensitivity study and a sensitivity to the radial orientation of the vessel is also performed to provide a direct comparison with the horizontal MIGHT-R design.

4.1 Mesh sensitivity analysis

In this section, sensitivity tests for the mesh resolution inside the reactor vessel and building are performed separately. The wall boundary layers are identical while the mesh resolution in the bulk increases by a factor of 1.2. Figure 9 shows the front view of the temperature distribution of the whole system and it is observed that finer mesh resolution provides improved prediction of temperature gradients. Figure 10 compares the mean temperature in each region. It is noted that the mean room temperature is more than 100 °C due to the not fully realistic set of boundary conditions for the building surface in combination with the RCCS design. Temperature inside the vessel will not be influenced by the resolution in the room. The trend of room temperature, however, does not consistently follow the mesh resolution and the fluctuation range is ~9 K. The potential reason is that the refinement near the RCCS depends on the bulk mesh resolution which causes the fluctuation of mean room temperature over the mesh resolution. Additional mesh sensitivity studies without RCCS structures has very close prediction of mean room temperature. The mesh configuration with Δ=0.50 m is selected as the room mesh resolution considering the acceptable accuracy and computational efficiency.

Figure 10: Comparison of mean temperature in each region with different mesh resolutions in the room.

Figure 11 shows a side-view of the different mesh resolutions inside the vessel. It is observed that the mean core temperature only changes by 5 K while the mean temperature of steam generator and vessel changes by less than 1 K for the different mesh refinements. Thus, the chosen mesh resolutions inside the vessel sufficient to deliver consistent predictions, and the intermediate mesh resolution (mesh 2) is selected as the reference mesh configuration.

Figure 11: Comparison of mean temperature in each region for different mesh resolutions inside the reactor vessel.
4.2 Sensitivity of Radial Resistance in Porous Media Model

As discussed in section 3.2., inertial and viscous resistances in the streamwise direction are analytically calculated and then tuned to optimize the mass flow distribution and the pressure drop prediction. In the reactor core, the resistances in the radial directions are usually defined as extremely high values to ensure that negligible cross flow occurs in the radial directions. This setup is driven by the actual vertical flow channel configuration where helium is constrained inside the coolant channel and flow along the streamwise direction. For the horizontal HTGR investigated here, gravity-driven cross flow may occur and influence the heat transfer characteristics. Thus, it is important to check whether the values of radial resistance used in the porous media model effectively limit the cross flow on the radial directions. A set of radial resistances is tested and their magnitudes are 10%, 100% and 1000% of the values of resistance in the streamwise directions. Figure 12 shows negligible differences for the flow distribution for different radial resistance. Figure 13 quantitatively compares the ratio of mass flow rate to the total mass flow rate. It is shown that the mass flow ratio in the fuel region increases from 91.25% to 92.46% as the radial resistance decreases from 1000% to 10% of the streamwise resistance. Since the resistances in the fuel region is much less than the values in the inner reflectors and outer reflectors region, helium coolants tend to pass the fuel region and a small amount of cross flow is thus observed when the radial resistances decrease. Although these three cases have comparable mass flow ratio to the ideal distribution, the radial resistances in the final model are set as 1000% as most conservative.

![Figure 12: Flow distributions inside the reactor vessel for different radial resistances of reactor core. (a), (b) and (c) represent 10%, 100% and 1000% of the resistance in the streamwise direction.](image)

![Figure 13: Comparison of mass flow split in the reactor core for different radial resistances.](image)

4.3 Horizontal VS Vertical MIGHT-R

In this section, the different reactor orientations are compared to analyze their influence on heat transfer performance. Note that for the vertical HTGR the supports around the reactor vessel are removed as shown in Figure 14. Figure 15 compares the mass flow split of vertical and horizontal MIGHT-R, and both of them match the ideal mass flow distribution.

![Figure 14: Cross-sectional view of the geometries of horizontal (a) and vertical (b) HTGR.](image)
Temperature distributions for the horizontal and vertical MIGHT-R are shown in Figure 16. Due to the gravity orientation, vertical MIGHT-R has more efficient natural circulation which increases the mean room temperature as shown in Figure 17 while the temperature inside the vessel are identical. The mean temperature of the reactor core is ~440 °C and the average temperature of helium at the core exit surface is about 550 °C which is lower than the value of GA HTGR by 200 °C. The calculated resistance coefficients relied on the assumption of equal pressure drop for the fuel and reflectors regions which results in overpredicting the mass flow rate in the fuel region (mass flow slit: 92.5%), thus having lower fuel temperature. The room mean temperature increases by 26 °C in vertical MIGHT-R. In addition to the mean temperature, the wall surface temperature next to the reactor core are analyzed as well to support future safety analysis. As shown in Figure 18, both mean and maximum temperature of the wall surfaces in vertical MIGHT-R are higher than the values in horizontal MIGHT-R which is also attributed to the better natural circulation with the vertical orientation which transports the local high temperature areas to the entire room. Figure 19 also shows that the temperature distribution in the room is more uniform in vertical MIGHT-R while horizontal MIGHT-R has more distinct temperature contours.

As mentioned, the design of RCCS is simplified with constant temperature of 100 °C on the boundaries in the current model. CFD can provide insights to optimize the RCCS design and cooling system in the room. Figure 19 shows the boundary heat flux distribution on the inner and outer surfaces of RCCS where the averaged boundary heat flux on the top and bottom half inner surfaces are 3709.2 and 3890.7 W/m², respectively. Alternative designs of RCCS are being developed and can be included in the CFD simulations as lower constant temperature and constant negative heat flux boundary conditions.
5. CONCLUSION

In this paper, a novel concept of horizontal high temperature gas-cooled reactor, MIGHT-R is formalized to a simplified design and its heat transfer characteristics are preliminarily evaluated using CFD methods. Instead of modeling each individual flow channel, the porous media model is utilized to represent the flow in the reactor core and steam generator. Surface-to-surface radiation heat transfer is included to model the radiative heat transfer in the complete system. Different mesh strategies are combined to deliver an optimal mesh configuration, and mesh sensitivity analyses are preformed to select the appropriate resolution. A sensitivity study for the resistance coefficients is also performed to justify their influence.

By assembling the CFD models and design components step-by-step, the final model of MIGHT-R has mass flow split of 91.6%, 6.5% and 1.6% which agrees with the analytical calculation of mass flow splits. The predicted mean temperature is 177.5 °C and the core exit surface temperature is ~550 °C which is ~200 °C less than GA HTGR, which is attributed to the assumptions involved in the derivation of the resistance coefficients. A vertical configuration of the MIGHT-R is further simulated, and shows close agreement for the temperature inside the vessel, while the room mean temperature is increases by 25.8 °C due to the more efficient natural circulation. In both cases the room temperature is beyond 100 °C due to the simplified representation of the boundary conditions applied on the surrounding room surfaces.

In summary, a simplified design of MIGHT-R is proposed and preliminary evaluation using CFD methods involves a list of reasonable assumptions. The goal is to evaluate the feasibility of the design rather than representing the real operation. The move to the horizontal orientation did not result in noticeable thermal stratification. In future studies the porous media model inside the core will be refined to deliver more accurate mass flow split and core exit temperatures. Alternative practical and efficient RCCS designs are also being developed and aim at cooling the room to habitable temperature. In addition, the boundary conditions on the surrounding room surfaces will need to be improved to reflect realistic conditions.

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