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# JAEA HTTR Secondary System Modeling

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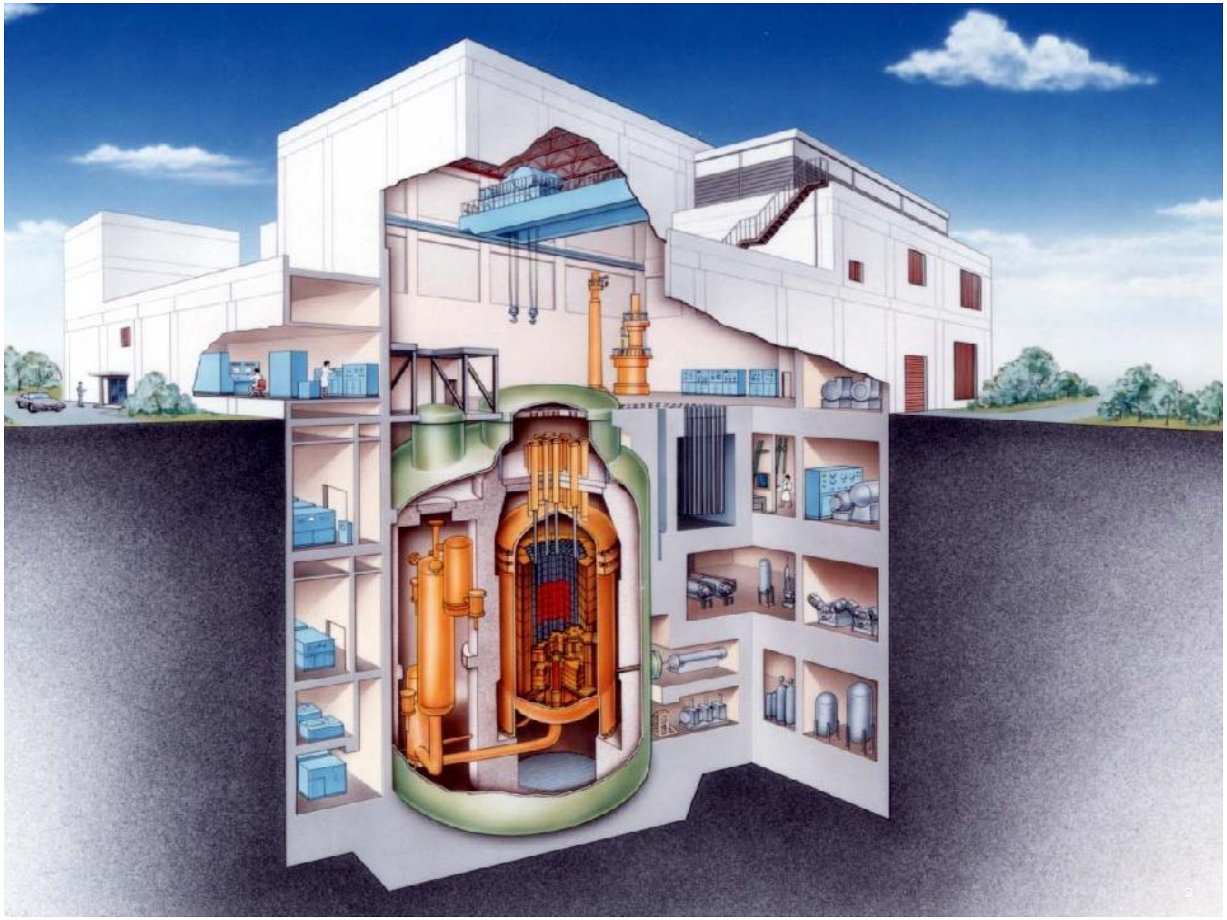
# This presentation will cover:

- Background
- Introduction
- Secondary System Modeling
- Steady-State Results
- Transient Scenario
- Conclusions

# Background

- This modeling effort was initiated by Paul Humrickhouse (his modeling efforts were described in the 2018 RELAP5-3D Users Seminar).
- Input models for the various components of the HTTR secondary system (compressors, turbines, heat exchangers, etc.) were developed.
- For some of the components insufficient information was available when the model was previously developed.
- In these cases, the component models were refined/modified with additional information that was provided by the Japanese Atomic Energy Agency (JAEA).

# Introduction



HTTR Specifications
Reactor Power – 30 MWth

Helium gas cooled

Reactor Out. Temp. – 850/950°C

Primary Pressure – 4 MPa

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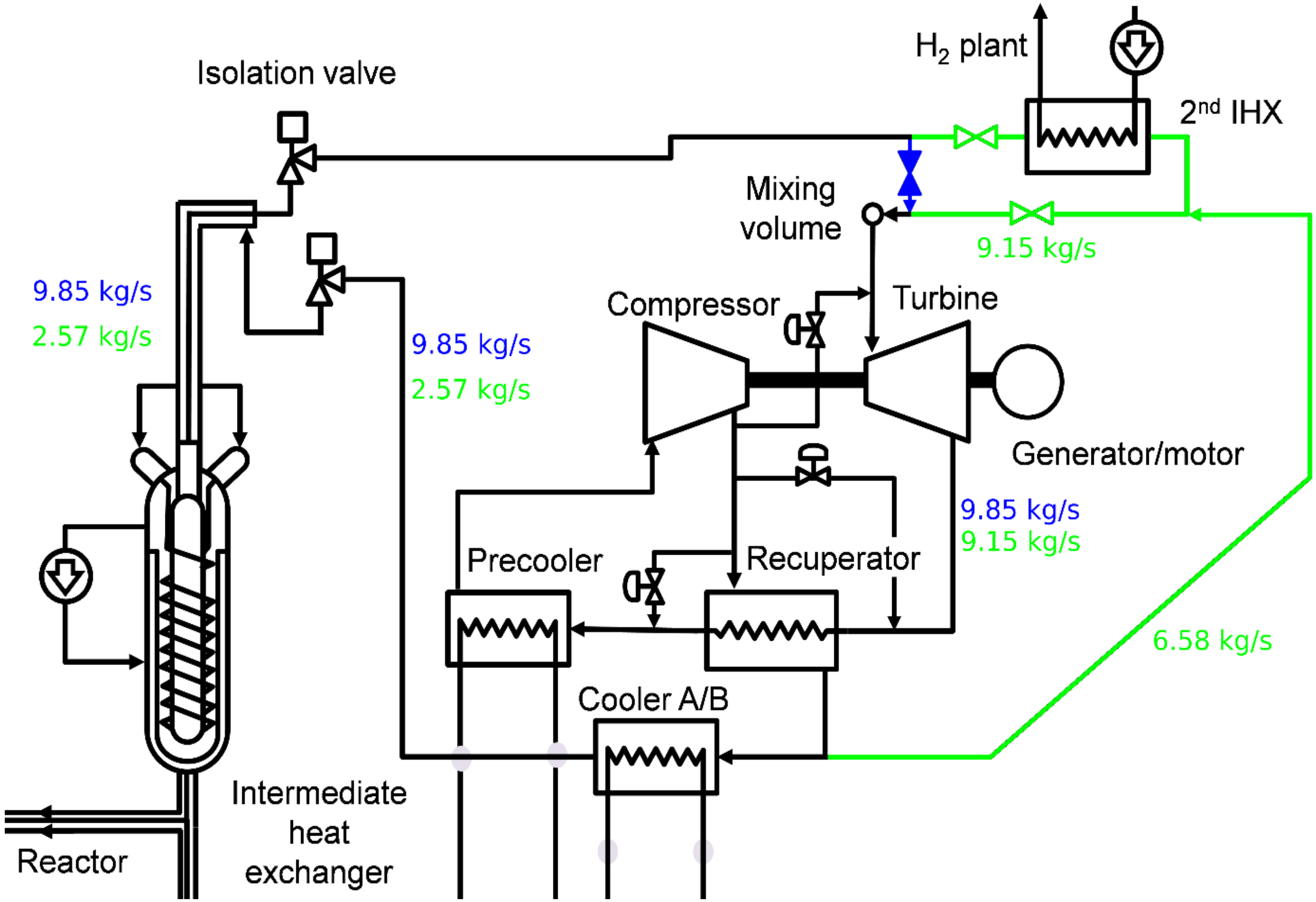
# Introduction – Cont.

- The HTTR outlet temperature (950°C) is sufficiently high that using the process heat for hydrogen production is being explored (Fujikawa, S., Hayashi, H., et al., 2004).
- The HTTR could be operated in two modes, Sole Power Generation (SPG) and Hydrogen Co-Generation (HCG).
  - In SPG mode the reactor is used to generate electricity only.
  - In HCG mode the generated heat is split such that a portion of the reactor heat is used to generate electricity and the remainder is sent to a tertiary system to produce hydrogen using a Sulfur-Iodide process.

# Introduction – Cont.




Note: The blue represents SPG mode and the green represents HCG mode.

# Secondary System Modeling

- The secondary system model consists of various components that are connected by piping.
- Each of the components was modeled individually.
- The components were connected to time-dependent volumes at the inlet and outlet, with a time-dependent junction to provide the proper amount of flow.
- The friction/heat transfer multipliers are adjusted to obtain the proper pressure drop and heat transfer between components.
- The components are then assembled into a combined model.
- Valves are used to switch between the SPG and HCG modes.
  - Some components are only used in one or the other mode.

# Secondary System Modeling – Cont.

- Previously developed in-depth modeling details are described in Paul Humrickhouse's 2018 presentation.
- This presentation primarily covers the refinement and modification of the original model and the results.

# Secondary System Modeling – Turbine Component

- The turbine component was modified.
- It was reported initially that the turbine component form loss could not be controlled by a control system, but in inspecting the turbine component it was found to be a possibility.
- The form loss across a turbine component is defined as:

$$K = \frac{(1-\eta)(P_1 - P_2)}{0.5\rho v^2}$$

- This equation was used as a basis for the form loss across the turbine.
- When this equation was applied with control variables, the code minimized the pressure drop resulting in an excessively large mass flow rate.

# Secondary System Modeling – Turbine Component – Cont.

- To obtain more reasonable results, the pressure ratio relationship was used. The pressure ratio is defined as:

$$P_r = \frac{P_1}{P_2}$$

- After substituting for $P_1$ the equation becomes

$$K = \frac{(1-\eta)(P_r - 1)P_2}{0.5\rho v^2}$$

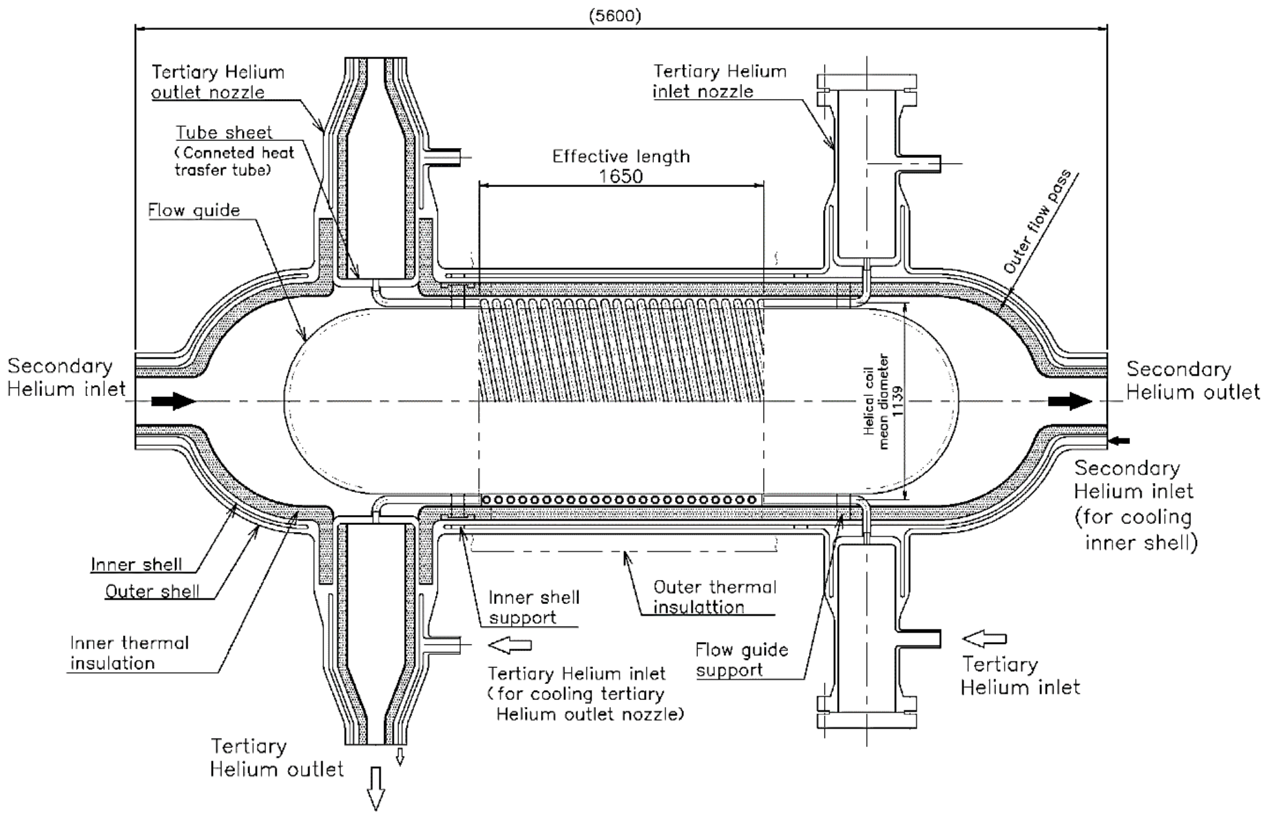
- Using control variables, this relationship was used for the variable form loss across the turbine components. The results were much more reasonable.

# Secondary System Modeling – Recuperator Component

- The recuperator is used to recover turbine exhaust heat and improve system efficiency.
- The original component that was developed used 7 heat exchange modules, but the design only uses 4 modules.
- This change reduced the flow length and heat exchange area of the recuperator component.
- The form loss and heat transfer multipliers were adjusted to obtain the appropriate pressure and temperature drops across the recuperator.

# Secondary System Modeling – 2nd IHX Component

- The 2nd IHX component is used only in HCG mode to transfer process heat to the tertiary Sulfur-Iodide process.

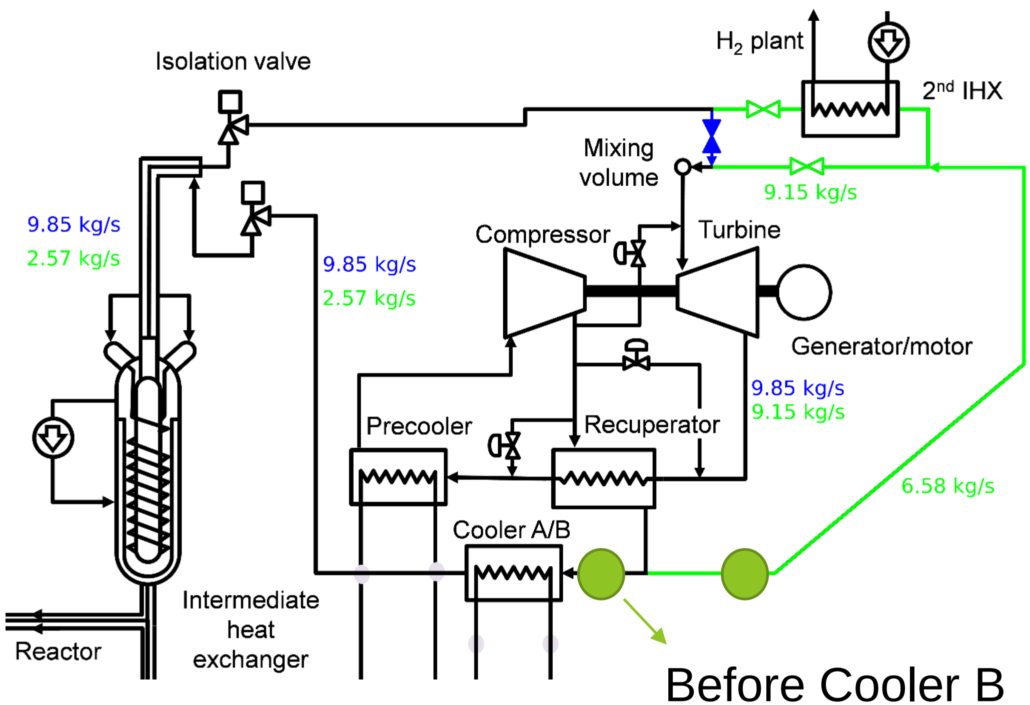


# Secondary System Modeling – $2^{nd}$ IHX Component, Cont.

- The $2^{nd}$ IHX component is a horizontally oriented shell and helical tube heat exchanger.
- The tube side heat exchanger is modeled with the default heat transfer correlation.
- The form loss coefficients were set to 0.72 to obtain the proper pressure drop.
- The heat transfer multiplier on the turbulent forced convection heat transfer coefficient was set to 2.5 to obtain the proper heat transfer.

# Secondary System Modeling – Flow split for HCG mode

- The flow is split for the HCG mode.
- Servo valves were added to the input deck to properly split the flow as shown in the diagram.



# Secondary System Modeling – Boundary Condition Modifications for HCG mode

- The inlet temperature for the tertiary helium loop (of the 2nd IHX) was reduced from 766.15 to 623.15 K per design conditions (Imai, Sato, et al., 2017).
- Primary system boundary conditions modified per design conditions (Imai, Sato, et al., 2017).
  - Reactor outlet temperature increased from 1123.15 to 1223.15 K.
  - Mass flow rate reduced from 4.16 to 3.47 kg/s.

# Steady-State Results – SPG Mode

| Location | Temperature [K] | | ΔT [K] | | Pressure [MPa] | | ΔP [MPa] | |
|---|---|---|---|---|---|---|---|---|
| | Design | RELAP | Design | RELAP | Design | RELAP | Design | RELAP |
| IHX secondary side outlet | 843.15 | 846.06 | - | - | 4.11 | 4.103 | - | - |
| Turbine inlet | 841.35 | 842.68 | | | 4.059 | 4.059 | | |
| Turbine outlet | 776.65 | 782.09 | -64.7 | -60.59 | 3.152 | 3.101 | -0.907 | -0.958 |
| Recuperator LP side inlet | 776.65 | 782.09 | | | 3.151 | 3.100 | | |
| Recuperator LP side outlet | 391.65 | 394.22 | -385 | -387.87 | 3.143 | 3.092 | -0.008 | -0.009 |
| Precooler inlet | 391.65 | 394.22 | | | 3.143 | 3.092 | | |
| Precooler outlet | 298.15 | 298.17 | -93.5 | -96.05 | 3.14 | 3.088 | -0.003 | -0.004 |
| Compressor inlet | 298.15 | 298.17 | | | 3.13 | 3.087 | | |
| Compressor outlet | 348.85 | 353.87 | 50.7 | 55.7 | 4.307 | 4.307 | 1.177 | 1.220 |
| Recuperator HP side inlet | 348.85 | 353.85 | | | 4.304 | 4.306 | | |
| Recuperator HP side outlet | 733.85 | 740.76 | 385 | 386.91 | 4.298 | 4.300 | -0.006 | -0.007 |
| Cooler A inlet | 733.85 | 740.7 | | | - | 4.297 | | |
| Cooler A outlet | 647.15 | 652.05 | -86.7 | -88.65 | - | 4.267 | - | -0.030 |
| IHX secondary side inlet | 647.15 | 652.14 | | | 4.26 | 4.264 | | |

# Steady-State Results – HCG Mode

| Location | Temperature [K] | | ΔT [K] | | Pressure [MPa] | | ΔP [MPa] | |
|---|---|---|---|---|---|---|---|---|
| | Design | RELAP | Design | RELAP | Design | RELAP | Design | RELAP |
| IHX secondary side outlet | 1173.15 | 1172.8 | - | - | 4.11 | 4.1093 | - | - |
| 2nd IHX secondary side inlet | 1160.55 | 1170.5 | | | - | 4.10317 | | |
| 2nd IHX secondary side outlet | 1108.15 | 1116.3 | -52.4 | -54.2 | - | 4.09988 | - | -0.00329 |
| Turbine inlet | 841.35 | 815.13 | | | 4.077 | 4.07664 | | |
| Turbine outlet | 779.45 | 740.13 | -61.9 | -75 | 3.283 | 3.11917 | -0.794 | -0.95747 |
| Recuperator LP side inlet | 779.45 | 740.13 | | | 3.282 | 3.11874 | | |
| Recuperator LP side outlet | 389.65 | 379.23 | -389.8 | -360.9 | 3.275 | 3.11257 | -0.007 | -0.00617 |
| Precooler inlet | 389.65 | 379.23 | | | 3.267 | 3.11248 | | |
| Precooler outlet | 298.15 | 297.22 | -91.5 | -82.01 | 3.265 | 3.10906 | -0.002 | -0.00342 |
| Compressor inlet | 298.15 | 297.23 | | | 3.265 | 3.10865 | | |
| Compressor outlet | 347.35 | 341.76 | 49.2 | 44.53 | 4.402 | 4.13551 | 1.137 | 1.02686 |
| Recuperator HP side inlet | 347.35 | 341.75 | | | 4.138 | 4.13448 | | |
| Recuperator HP side outlet | 737.15 | 702.02 | 389.8 | 360.27 | 4.134 | 4.13032 | -0.004 | -0.00416 |
| Cooler B inlet | 737.15 | 702.06 | | | - | 4.13019 | | |
| Cooler B outlet | 423.15 | 420.42 | -314 | -281.64 | - | 4.12857 | | -0.00162 |
| IHX secondary side inlet | 423.15 | 422.57 | | | 4.125 | 4.12832 | | |

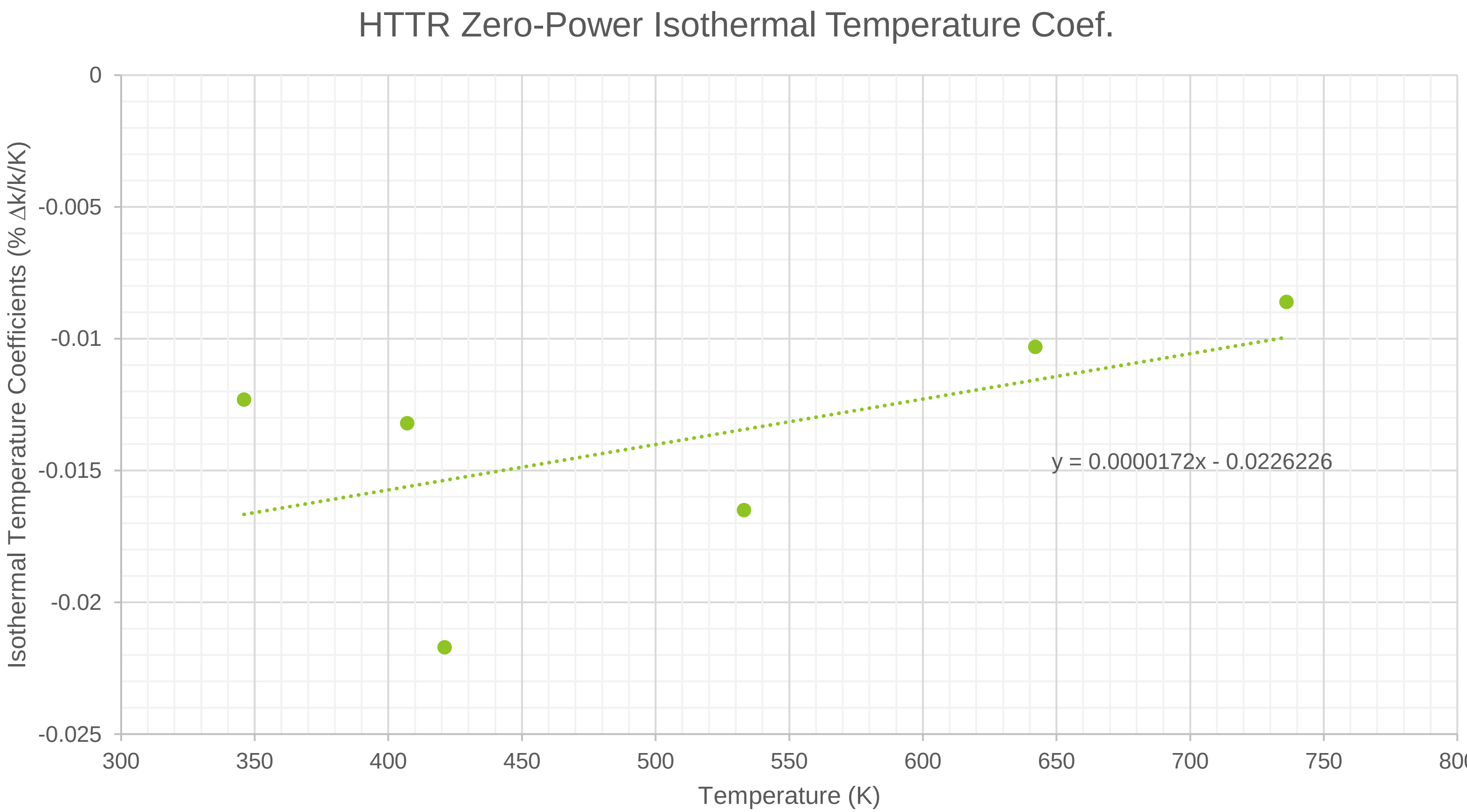
# Steady-State Results – HCG Mode, Cont.

- The temperature and pressure results did not match design values as well for the HCG case. The largest differences were observed across the turbine component. These differences were approximately 35-39 K.
- The pressure differences were also larger for the HCG mode. The largest difference in pressure drop occurs across the turbine components which could be due to RELAP5-3D calculating a loss factor that is too large.
- The compressor component did not increase the pressure of the system as significantly as expected, the implementation of the pressure ratio for this component may need some refinement. The recuperator was also observed to transfer less heat than expected. There may be a need to increase the heat exchange area of this component to improve the results.
- The largest differences appear in locations where the coolant flow is either split or combined.

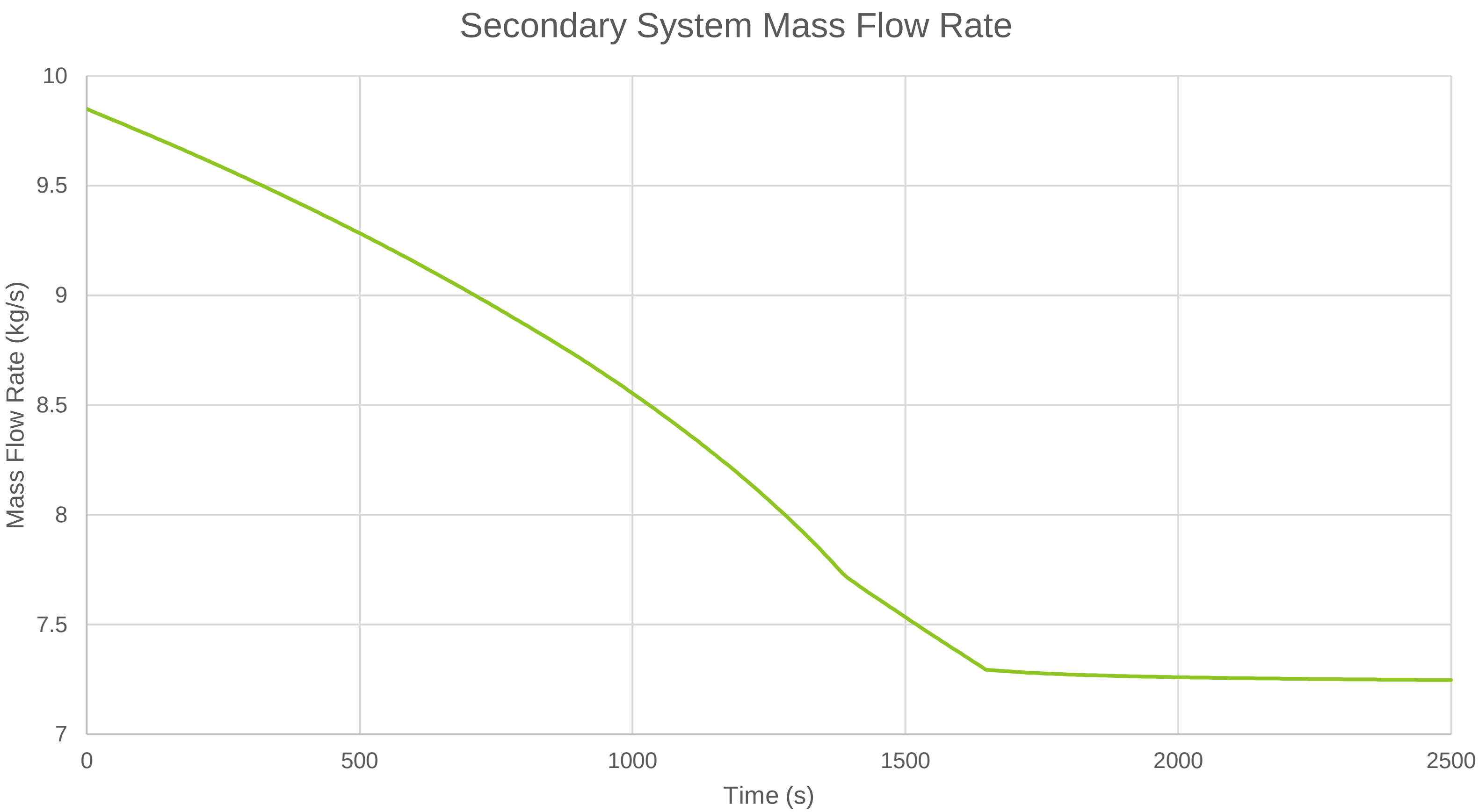
# Transient Scenario

- The mass flow rate through the IHX is reduced when the switching between SPG and HCG modes.
- A transient reduction in secondary system mass flow rate was investigated.
- In an actual transient, the primary helium coolant temperature will increase with the reduced mass flow rate.
- The temperature of the primary helium exiting the IHX will increase, and it is assumed that this temperature increase is reflected in the reactor in entirety.
- The zero-power isothermal temperature coefficients for the HTTR are reported in (Bess and Fujimoto, 2014). These values are plotted and curved to correlate reactivity to temperature.

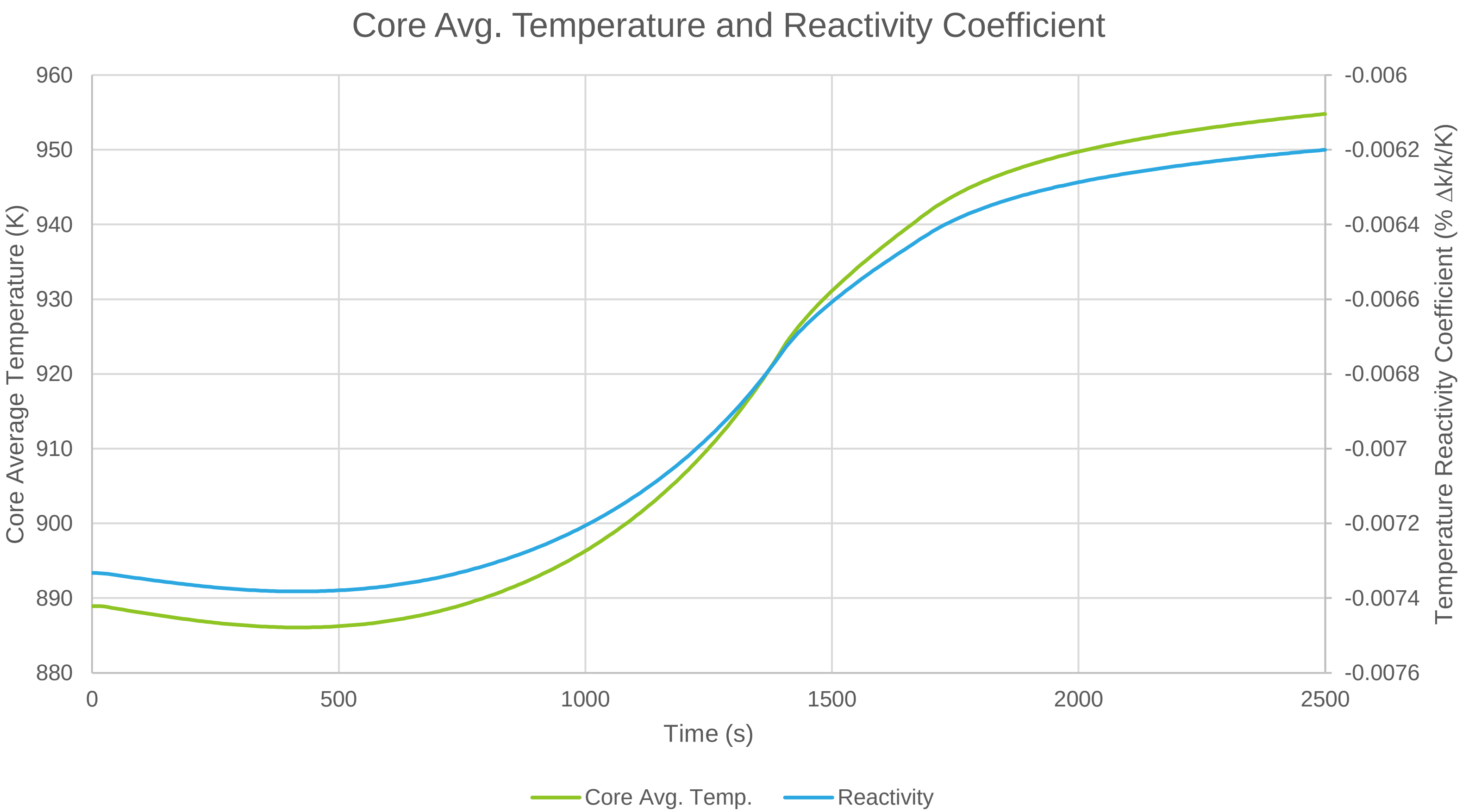
# Transient Scenario, Cont.



# Transient Scenario, Cont.



# Transient Scenario, Cont.



# Conclusions

- The SPG mode compared favorably with design conditions, with small variations.
- The HCG mode compared less favorably. The largest temperature and pressure results were 39 K and 0.27 MPa different than design conditions.
- The pressure ratio of the compressor component and heat exchange area of the recuperator may be areas where improvement could be made.
- The transient temperature rise of the primary system will add negative reactivity to the reactor.

# References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