Cyber-Physical Thermal Testbed for Real-Time Microreactor Digital Twin Development

Nolan Shute[1], Korebami O. Adebajo[1], Andrew Huebner[1], Matthew Whettman[1], Drew Hanson[1], Robert Demuth[1], Austin R.J. Downey[1,2] , and Travis W. Knight[1]

[1]Department of Mechanical Engineering, University of South Carolina
[2]Department of Civil and Environmental Engineering, University of South Carolina

ARTS-Lab
Adaptive Real-Time Systems Laboratory

Background

Advancements in the field of nuclear energy have led to adaptations of the traditional nuclear reactor, where a small modular reactor (SMR) design has filled this role. However, a large issue with SMR research has been to isolate a method for monitoring pressure, temperature, and power efficiency for the system as well as controlling the reactor from a remote location and ensuring secure connection. To solve this, research into producing a digital twin model of a physical testbed has provided a solution to this issue in nuclear power generation. A digital twin is a dynamic, virtual replica of a physical object, process, or system that uses real-time data from sensors to simulate, monitor, and optimize performance. Using a mix of physical and cyber aspects, a digital twin can be developed that actively monitors a prototype Thermal Testbed.

Figure depicts a typical nuclear control panel, where no option for remote operations and digital twin testing is present.

Figure depicts intended design for a remote panel with a digital twin able to be tested on. Monitoring conditions of the reactor can be done securely and effectively.

To ensure that the security of the reactor is not compromised before the development of a database and control panel that allows full manipulation of the thermal loop, a simulation of an SMR Thermal Loop has been built to model a digital twin off for monitoring pressure and temperature, and to perform tests on without affecting the physical structure.

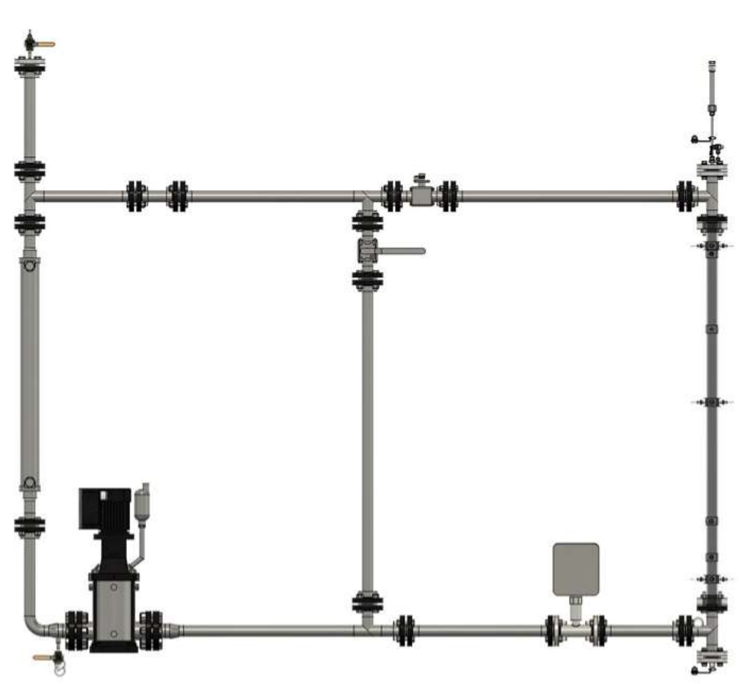


Figure shows a CAD model of the thermal loop reconstructed in Fusion360.

Materials and Methods

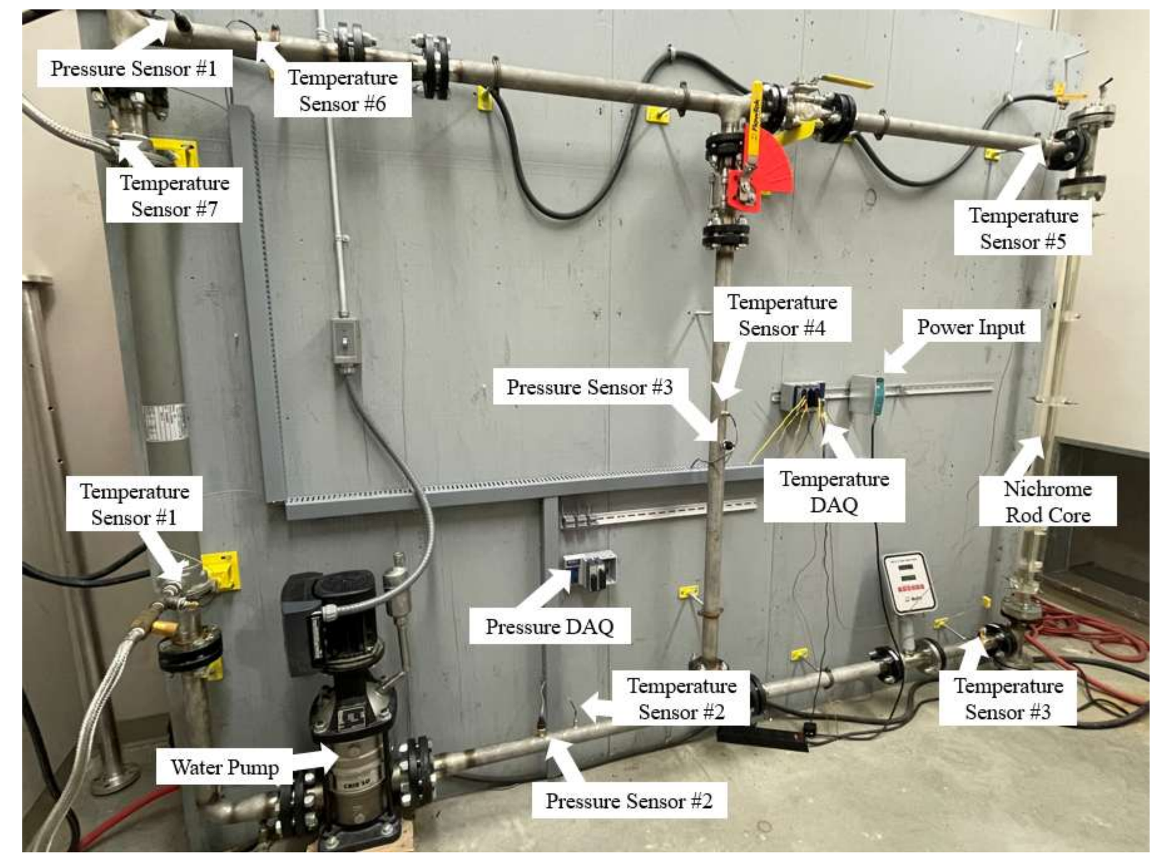


Figure shows the physical Thermal Testbed with each component labeled.

Sensors:
3 Pressure Transducers
7 Type K Thermocouples
Power Supply:
10 kW
Water Pump:
Max flow of 15 m^3/hr 10 meter head
Max Temp of 180 °C

Electrically Heated Test Section:
@ 14.5 m^3/hr:
T_{in} = 103.1 °C ; T_{out} = 103.5 °C; ΔT = 0.4 °C
Total thermal power added to loop = Q = 6.66 kW
Heat Exchanger:
Theoretical maximum of 1.8 m^3/hr

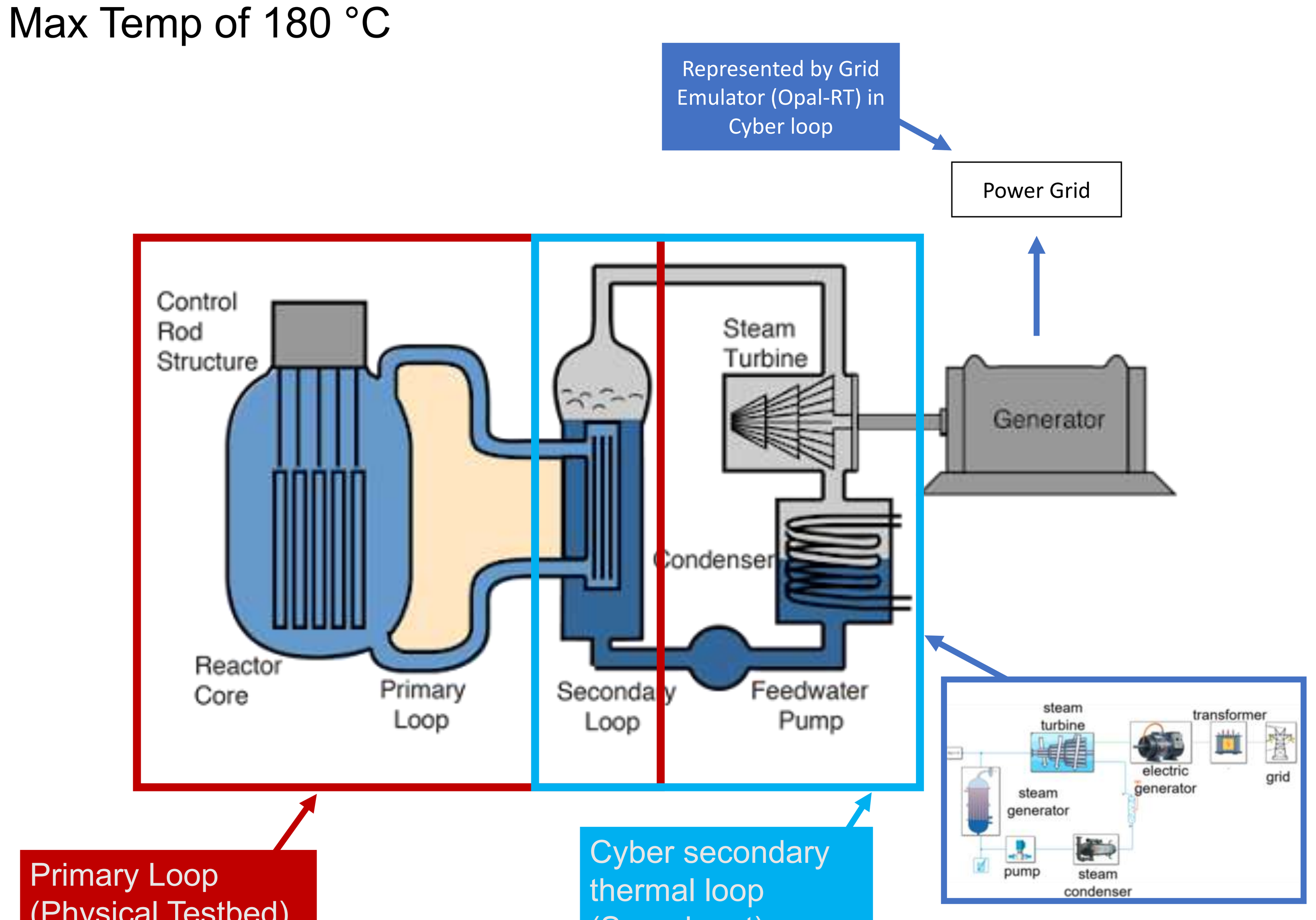
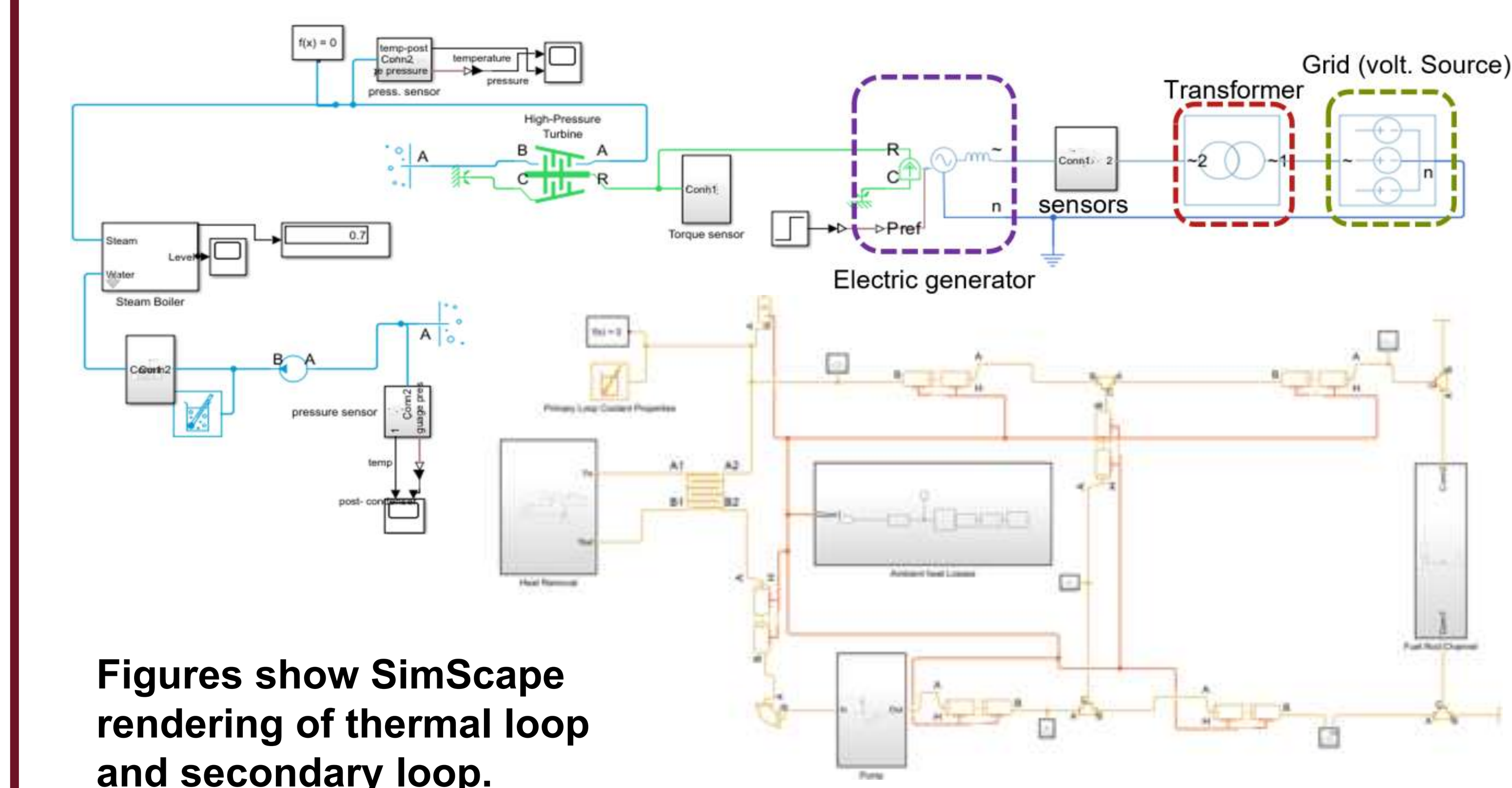


Figure shows Cyber-Physical breakdown of setup.

Software and Data Display



Figures show SimScape rendering of thermal loop and secondary loop.

Applications

With methods adopted in this project, applications of the digital twin development from the testbed allow nuclear reactor operations to act remotely as opposed to consolidation in the immediate area surrounding the reactor. Standard pressurized water reactors (PWR) will benefit greatly from the ability to remotely monitor and control these water loops while maintaining proper security.

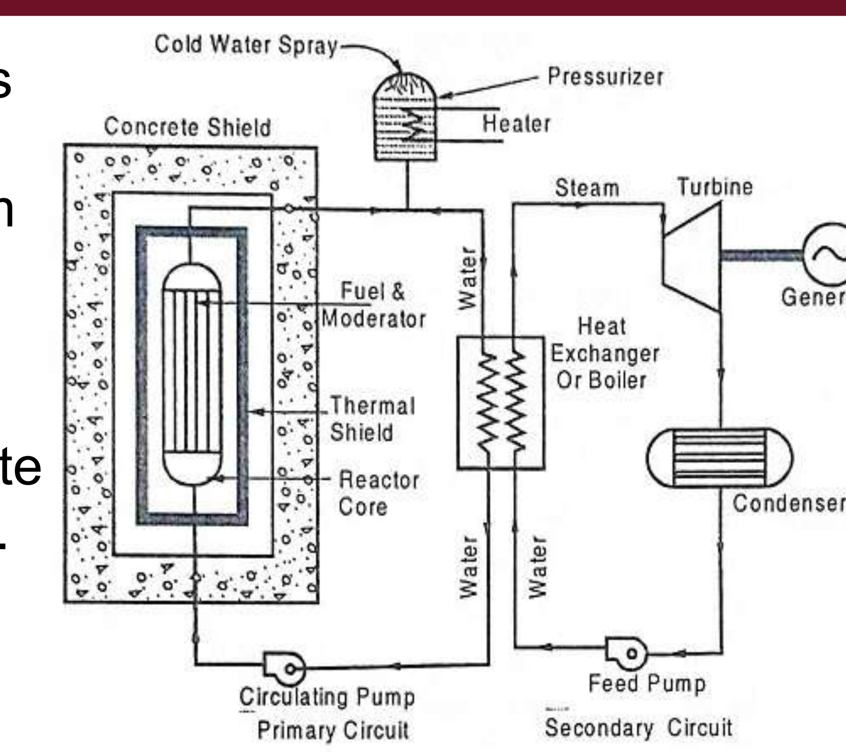


Figure shows standard PWR design, where transfer of heat from primary loop moved into the generation.

Sources

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