An experimental loop for simulating nuclear reactors in space

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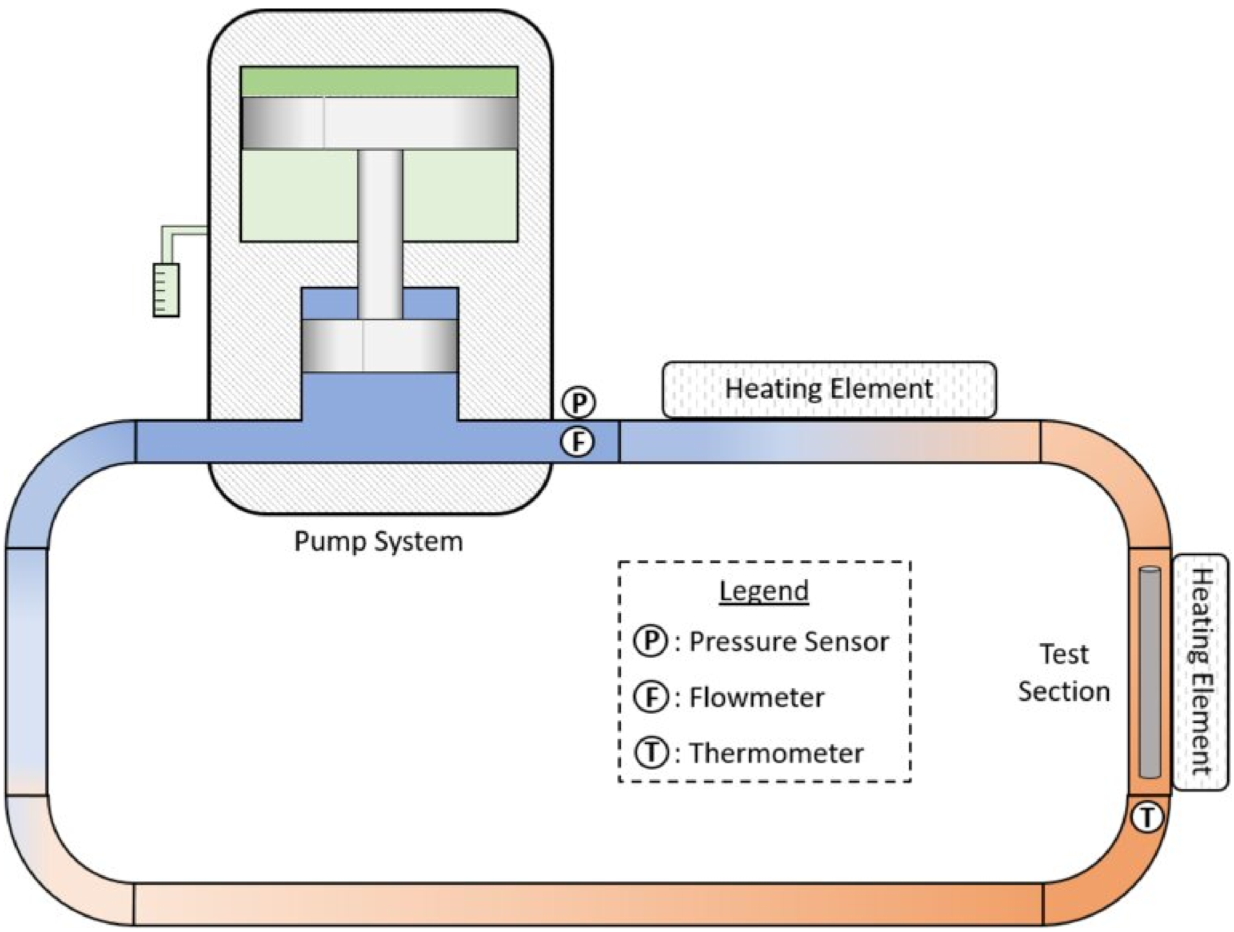

The hot hydrogen test loop, shown in this diagram, will circulate hydrogen gas at high temperatures for materials testing. Credit: Image provided by Will Searight

Nuclear thermal propulsion, which uses heat from nuclear reactions as fuel, could be used one day in human spaceflight, possibly even for missions to Mars. Its development, however, poses a challenge. The materials used must be able to withstand high heat and bombardment of high-energy particles on a regular basis.

Will Searight, a nuclear engineering doctoral student at Penn State, is contributing to research that could make these advancements more feasible. He published findings from a preliminary design simulation in *Fusion Science and Technology*, a publication of the American Nuclear Society.

To better investigate nuclear thermal propulsion, Searight simulated a small-scale laboratory experiment known as a hydrogen test loop. The setup mimics a reactor's operation in space, where flowing hydrogen travels through the core and propels the rocket—at temperatures up to nearly 2,200 degrees Fahrenheit. Searight developed the simulation using dimensions from detailed drawings of tie tubes, the components that make up much of the test loop through which hydrogen flows. Industry partner Ultra Safe Nuclear Corporation (USNC) provided the drawings.

"Understanding how USNC's components behave in a hot hydrogen environment is crucial to bringing our rockets to space," Searight said. "We're thrilled to be working with one of the main reactor contractors for NASA's space nuclear propulsion project, which is seeking to produce a demonstration nuclear thermal propulsion engine within a decade."

Advised by Leigh Winfrey, associate professor and undergraduate program chair of nuclear engineering, Searight used Ansys Fluent, a modeling software, to design a simulation loop from a stainless steel pipe with an outer diameter of about two inches. In the model, the loop connects to a hydrogen pump and circulates hot hydrogen through a test section adjacent to a heating element.

Searight found that while consistent heating of hydrogen to 2,200 degrees Fahrenheit was possible, it was necessary to include a heating element directly above the test section to prevent a reduction in heating. Data collected from the modeling software showed that the flow of hydrogen through the test section was smooth and uniform, reducing uneven distribution of heat through the loop that could jeopardize the setup's safety and lifespan. Analysis of the results also verified that stainless steel would allow for more convenient and cost-effective construction of the loop.

"We are excited to take the first steps in developing a unique capability for extreme environment simulation at Penn State," Winfrey said. "This preliminary work will enable us to pursue research that could have a major impact on the future of space exploration."

With further research, Searight's preliminary work could enable expanded testing of materials that could one day be implemented to create faster, more efficient space travel using reactor-fueled rockets.

Recently, Searight received the George P. Shultz and James W. Behrens Graduate Scholarship from ANS. Searight will use the award to support his future work on the test loop. The $3,000 scholarship honors Shultz, a nuclear nonproliferation advocate and Presidential Medal of Freedom recipient who died in February, and Behrens, a previous ANS board member who held numerous positions in the national security sector.

More information: William Searight et al, Preliminary Design of a Hot Hydrogen Test Loop for Plasma-Material–Interaction Evaluation, *Fusion Science and Technology* (2021). DOI: 10.1080/15361055.2021.1913373

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