INL/MIS-23-71786-Revision-0

Nuclear Thermal Propulsion Experiments in TREAT

April 2023

Changing the World's Energy Future

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Idaho National Laboratory

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Outline

- NASA Nuclear Thermal Propulsion (NTP) project
  - Why do we need experiments with hydrogen?
- Ongoing R&D work at INL related to NTP
  - Irradiation Experiments at TREAT
    - Design and Assembly
    - Fuels work
    - Post Irradiation Examination (PIE)*
  - Addition of a gaseous hydrogen (GH2) system in TREAT
  - Challenges and New Conditions with the first flow-through experiment with hydrogen

*Publications by Jason Schulthess, Robert O'Brien

NASA Program

- Space Nuclear Propulsion Program
  - Nuclear Thermal Propulsion (NTP) Project
    - Develop a HALEU fuel and moderator block reactor design with a specific impulse (Isp) suitable for a Mars mission
    - Flight or ground demonstration in this decade
      - Build upon experiences with the DRACO flight demonstration
  - Fuel and Moderator Development Plan
    - Primary goals
      - Fabrication experience
      - Material data after irradiation to high temperatures
  - Computational model of an NTP reactor-engine provides the basis for experiment conditions

Why Hydrogen?

- Hydrogen is used as rocket fuel due to its low mass and ability to produce intense heat.
- The interactions of hydrogen and irradiated NTP materials at high temperature is not yet well understood.
  - Facilities exist for exposures to
    - high temperature in static hydrogen and
    - radiation
  - Facilities do not exist for neutrons + flowing hydrogen
- As the continuation of a series of irradiations for NTP fuel and moderator development, future experiments require a flowing gaseous hydrogen environment to get closer to simulating space flight conditions. The ultimate goal is for humans to reach Mars.

NTP Material Irradiation Progression at INL

Sirius-1 Cermet → Sirius-2A Cermet → Sirius-2B Cermet → Sirius-2C Cercer

- Progression:
  - These experiments contained a single fuel specimen. Cross sections varied between hexagonal and cylindrical. Material composition was varied starting with 2 different types of Cermet, followed by a Cercer.
- What we've learned:
  - All irradiations to date have shown prototypic fuels maintain a coolable geometry at NTP temperatures and startup ramp rates. (No fragmentation or disruption.)
  - From the temperature data, we have been learning how to optimize the available TREAT transient profiles to obtain the desired conditions.
  - Information from Sirius-1, - 2A and -2B has been used to guide design of the Sirius-2C experiment fixturing and assembly.

NTP Material Irradiation Progression at INL

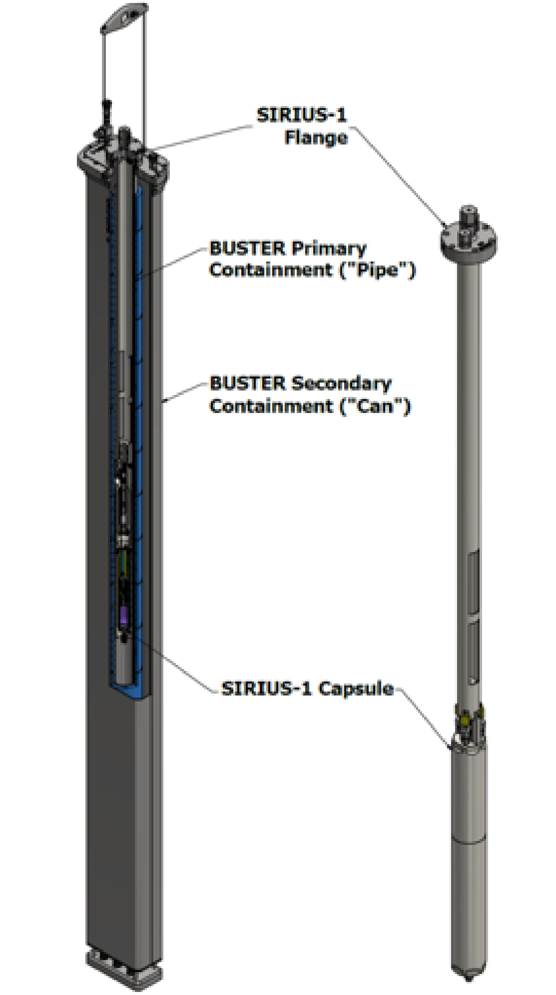
Sirius-3:
- 8” long Stack
- 7 flow channels with Mo tubes

Sirius-4:
- Ended at Final Design Phase
- 10” long Stack
- 7 flow channels

- Progression:
  - These experiments utilize a stack of fuel specimens with increasing lengths and a cylindrical cross-section.
  - Sirius-4 planned to incorporate
    - Multi-layered Test Article with Fuel, Insulator, and Moderator materials
    - Flowing hydrogen vs. the static capsule of previous experiments.
    - A new TREAT irradiation vehicle which has a larger cross section.
  - Preliminary plans for Sirius 5 are similar
- What we’ve learned:
  - PIE has not started. Sirius 3 is now ready for transport and hot cell handling.

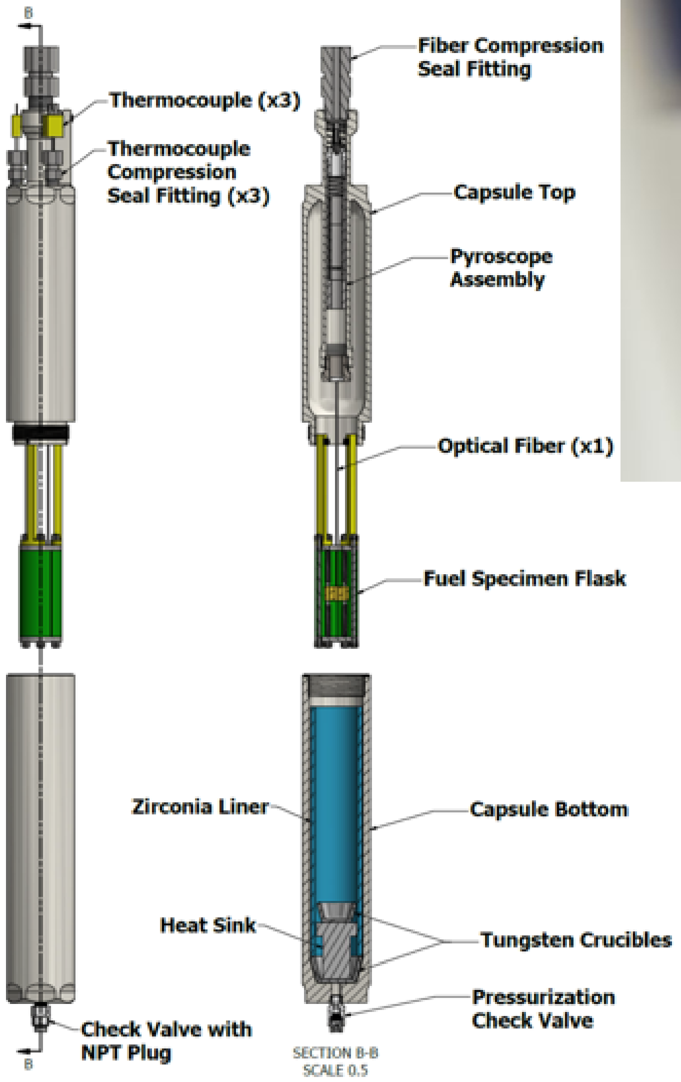
Legend: Irradiated (blue) — Not irradiated (green)

Sirius 1

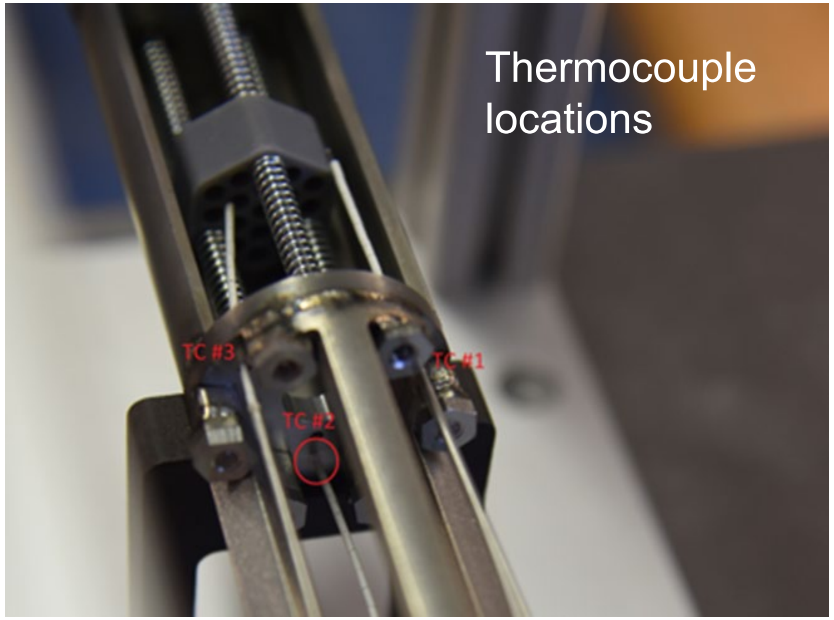


MARCH System with
SIRIUS-1 Insert Assembly

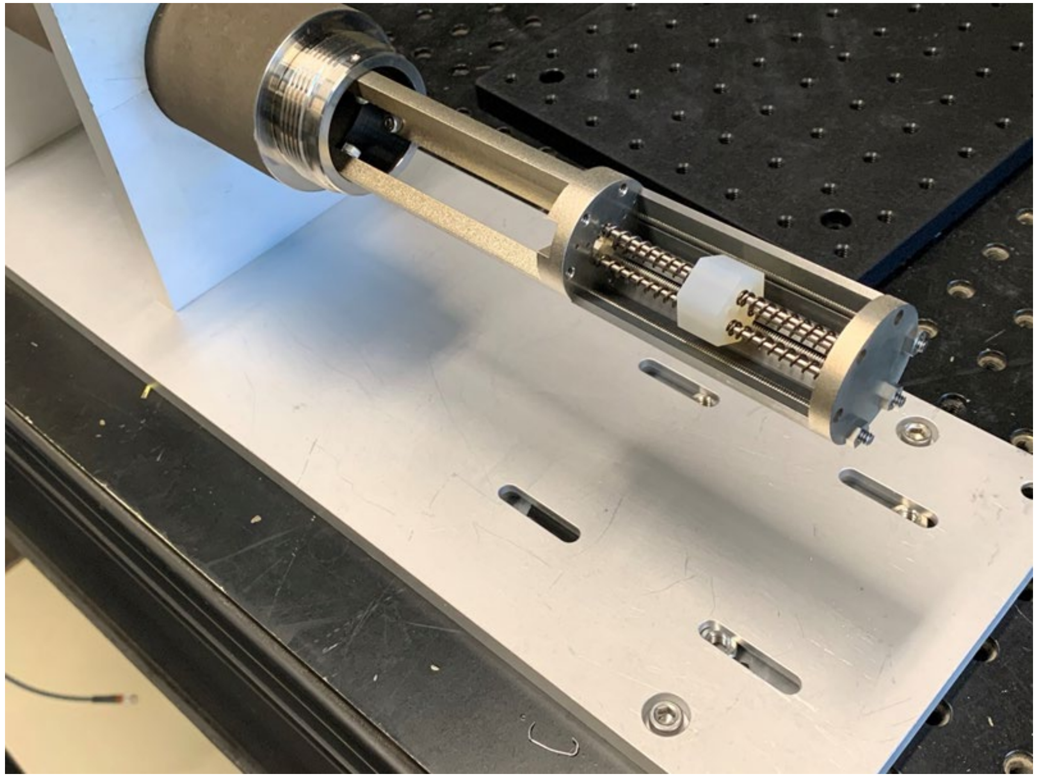
SIRIUS-1 Overall Capsule
Assembly

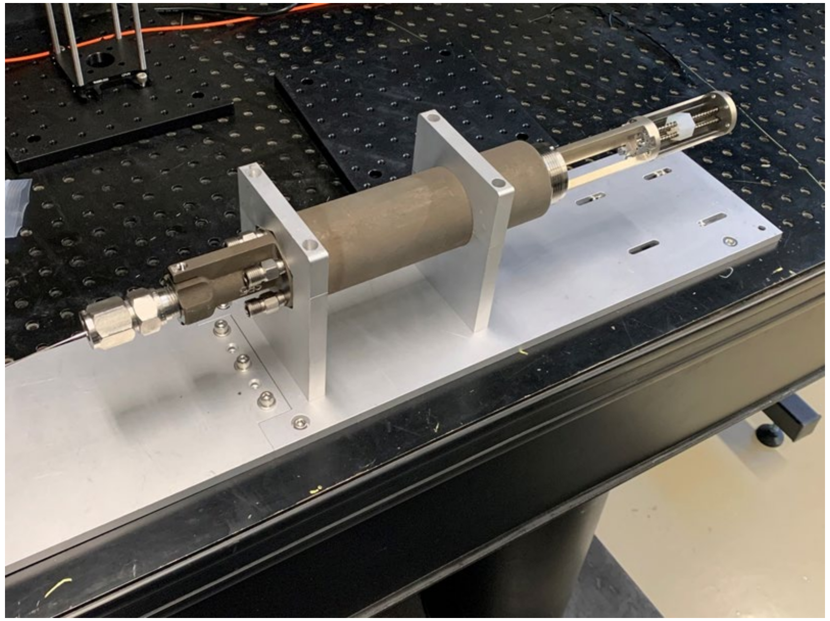


SIRIUS-1 Capsule



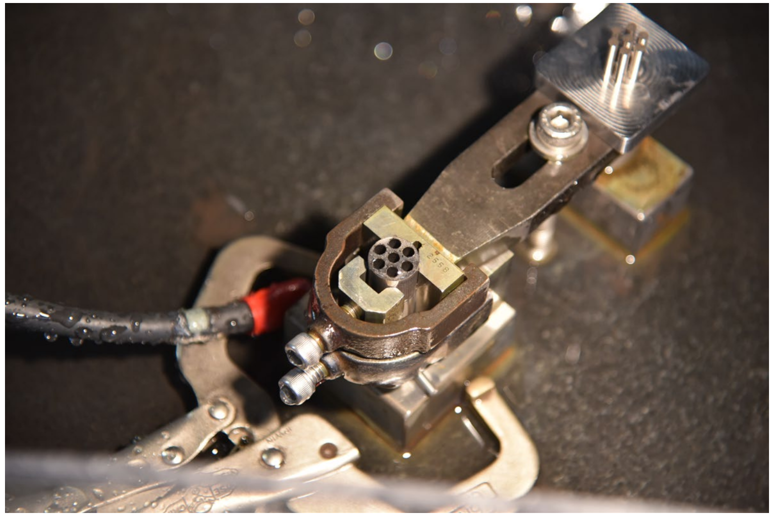
Sirius 2 – A, B and almost C





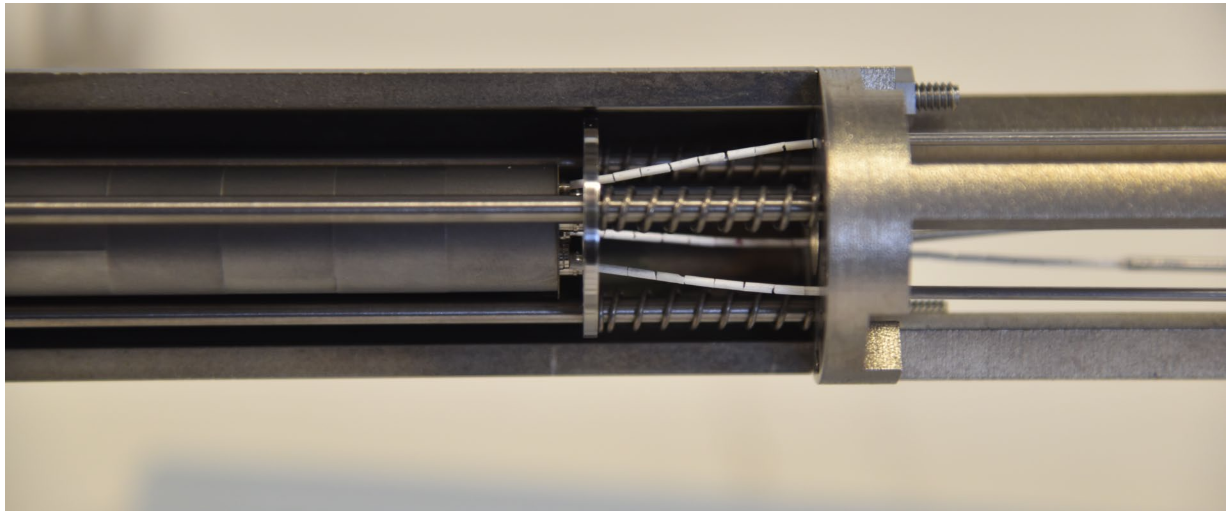
Assembly work often started at the Measurement Science Laboratory in town and then completed out at the Materials & Fuels Complex (MFC).

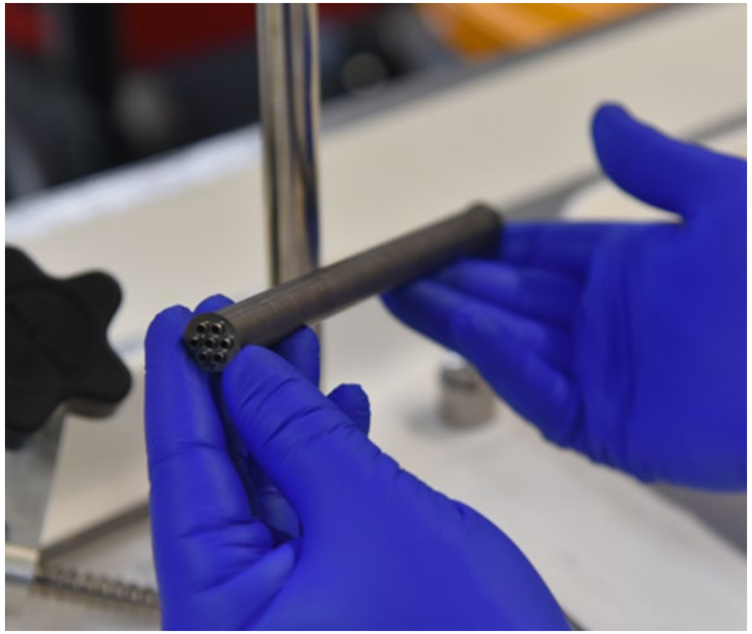
Sirius 3 fuel wafers

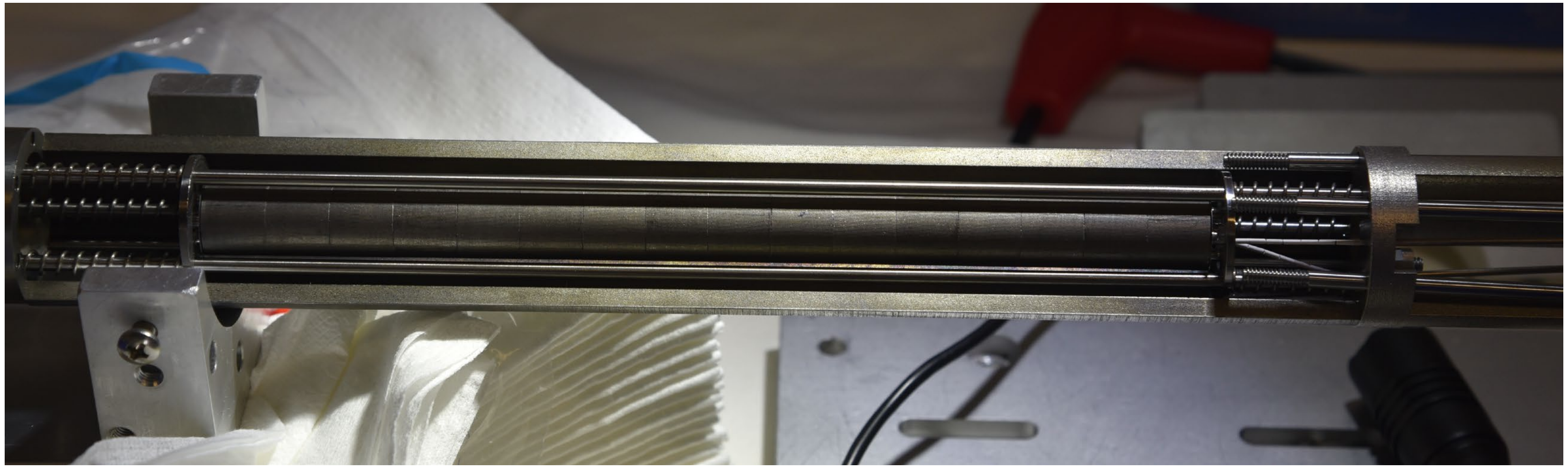


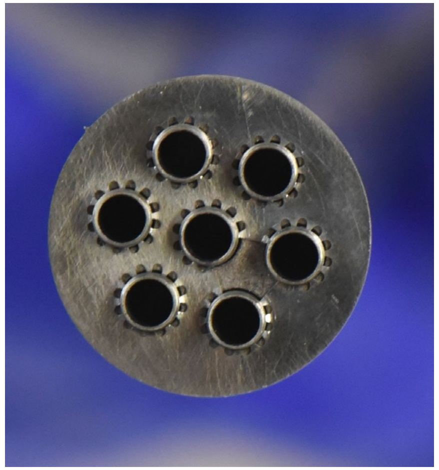
Work performed primarily at the Advanced Fuels Facility out at the Materials & Fuels Complex.

Sirius 3 assembly

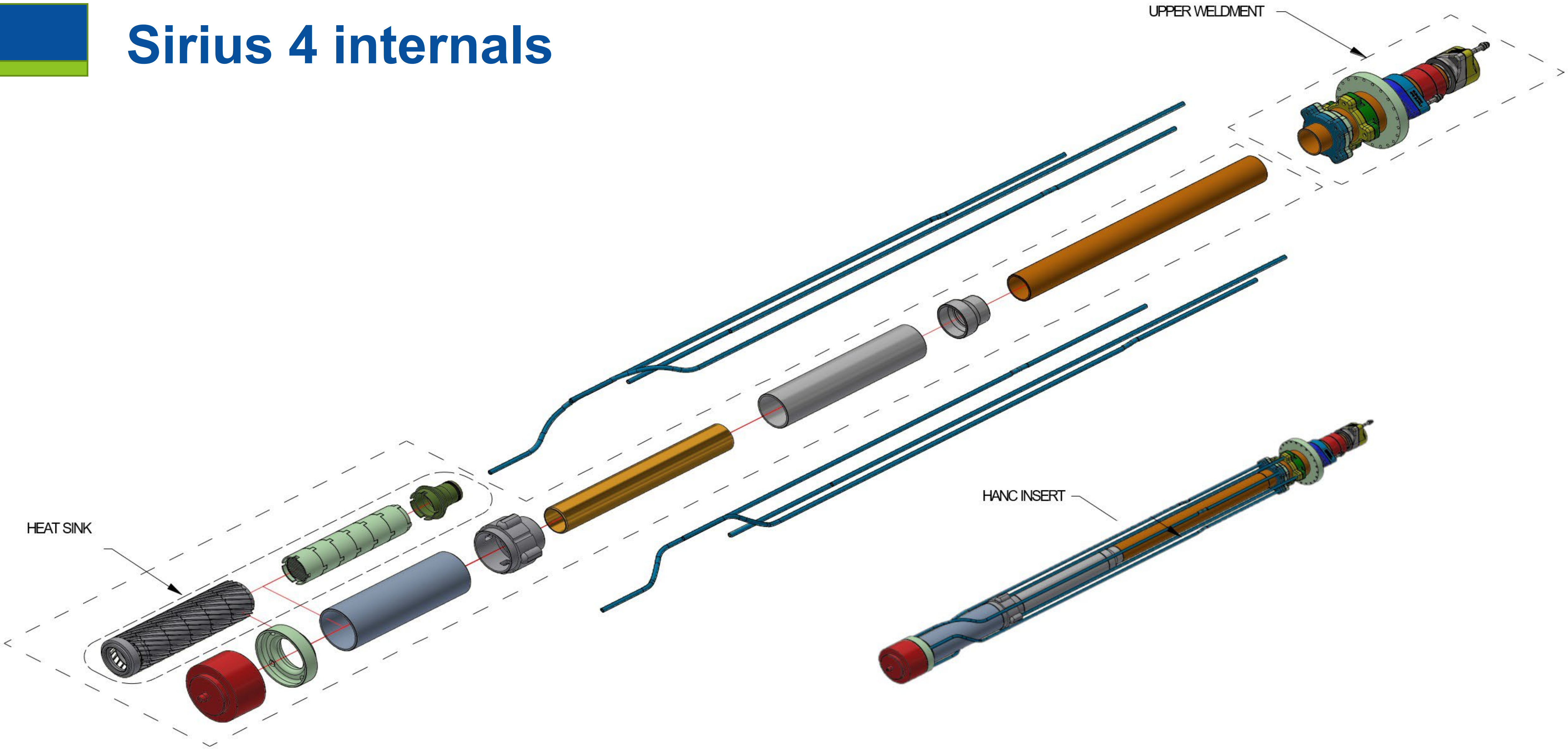








Sirius 4 internals



Sirius 4 inside of Big BUSTER

GH2 System Design and Fabrication

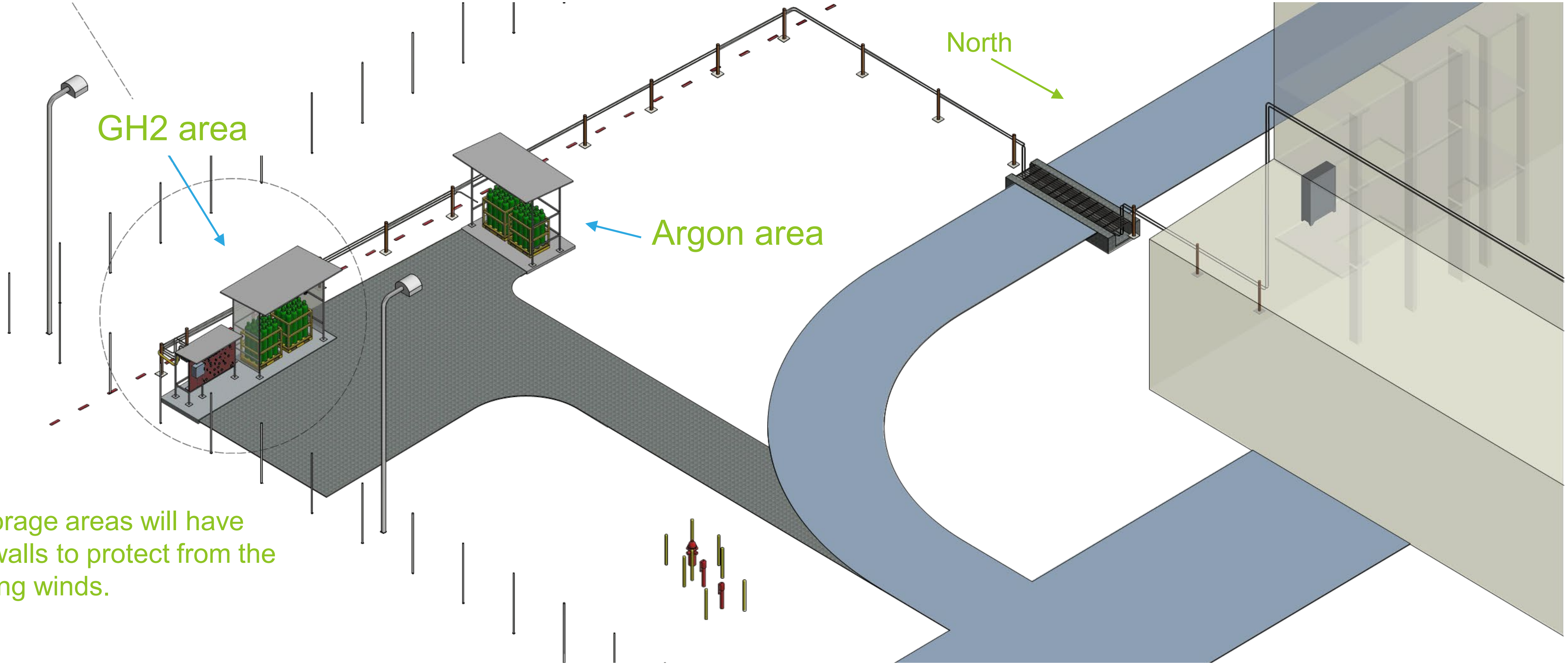
- Joint design effort between INL and NASA
  - NASA has expertise using hydrogen in a variety of test conditions
    - NASA is building the control panels and cabinets
    - NASA is providing subject matter expert support for design and usage questions
  - INL has expertise with nuclear reactors and irradiation experiments
    - INL is creating all the drawings, engineering calculations, safety and hazard assessments, and procedures
    - All INL processes in place for work at TREAT are engaged – engineering, quality, regulatory, safety, environmental, seismic, design reviews, etc.
      - Added an Independent Safety Review
- NASA and INL engineers are designing for TREAT, a DOE reactor
  - The authority over a DOE facility belongs to DOE
  - Final overall system readiness and acceptance will be performed by TREAT

GH2 – gaseous hydrogen

Design: Parameters

- All flows are **gaseous**
- Argon is the inert gas supply for purges and valve operations
- Capable of supplying GH2 flow of <10 g/s to 200 g/s at a maximum of 1000 psig
  - GH2 total initial volume of <6300 SCF at 2400 psig
- No pre-heating or pre-cooling of inlet gas streams
- Commercial grade components can be used for NASA built systems
  - The supply system itself does not provide exhaust treatment beyond dilution.
  - Containment boundary as determined by TREAT personnel will be within the experiment envelope.
- Determined 2 years prior to design of an experiment

Design: Proposed System Layout - External

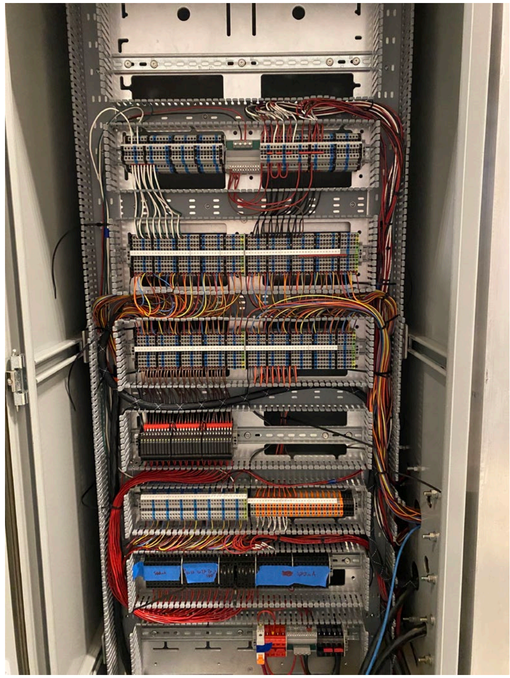


Gas storage areas will have shield walls to protect from the prevailing winds.

Most of the piping is outside the TREAT building.

Control Panel #1 under construction at NASA-Marshall






Control Panel #2 under construction at NASA-Marshall

Design: GH2 driven features

- Orbital welding (aka autogenous welding)
- ASME B31.3 vs. B31.12
  - B31.12 lacks discussion of some materials and high temperatures and often refers to ASME B31.3
  - Differences in NDE, erosion calcs and allowable materials
- Training for hydrogen handling
  - Specialized tools
  - Maintenance
- Understanding of hydrogen combustion
  - Flammability (oxidizers), ignition source, confinement/expansion
  - Fires not visible to naked eye

NDE- Non-destructive examination

Challenges and New Conditions

- Experiment Design
  - Balance hydrogen flow with desired peak and outlet temperatures
  - First flow-through experiment in TREAT
    - Assembly, disassembly and reactor insertion
    - Containment boundaries
  - Using a new experiment vehicle
- GH2 Supply System Design
  - Integration of NASA knowledge, design and fabrication
  - Hydrogen handling
    - Materials, required locations, volumes
    - Ignition prevention

The Sirius-4 Design Team led by Cindy Fife

- Fuel Wafers
  - BWXT – Jason Price
  - NASA - MSFC – Jhonathan Rosales
  - INL – Nathan Jerred
- Moly Alignment Pins/Assembly
  - BWXT – Dustin Hill
- Insulator
  - ORNL – Tyler Gerczak
  - LANL – Chris Hamilton
- Fuel Assembly Outer Structure
  - BWXT – Scott Fitzner
- Moderator
  - LANL – Tarik Saleh
- Analysis Support
  - INL – Sebastian Schunert
- INL Team
  - Design – Harmon Veselka & Justin Lower
  - Neutronics Analysis – Connie Hill
  - Thermal Analysis – Austen Fradeneck
  - Structural Analysis – Ryan Sandbek
  - Experiment Safety Analysis – Cody Race & Sterling Morrill
  - TREAT Support – Jack Blackwell, John Carter, Anthony Maestas, Brandon Moon Robert Neibert, Josh Smith, Dave Start, Ben Tessmer

The GH2 Supply System Team

- Core Design Team
  - Katey Lenox and Harmon Veselka (INL)
  - Peyton Pinson (NASA - SSC)
  - Mike Schoenfeld, James W. Post (NASA - MSFC)
- Expanded Team
  - INL Facility Design and Project Engineering team members led by Jason Toomer
    - Doug Clark, Kelly Ellis, Don Lewis, John Mahoney, Younis Munsi, Hannah Ovre, Phil Ozmun, Paul Petersen, Tyler Thurman
  - TREAT personnel (biweekly design meetings & topical discussions) – Jack Blackwell, John Carter, Doug Crawford, Doug Gerstner, Helen Guymon, Matt Krawczyk, Casey Lynch, Anthony Maestas, Brandon Moon, Sterling Morrill, Robert Neibert, Gary Owens, Dave Start, Cody Race, Josh Siems, Josh Smith, Andreas Scheibe, Justin Scott, Nathan Singleton, Ben Tessmer, Paul Young, Steve Wood
  - NASA-MSFC – Adam Elmore, Kristian Miasek, Tom Godfroy
  - Experiment Design Team led by Cindy Fife, Experiment Manager
  - SR Martin – Scott Loose

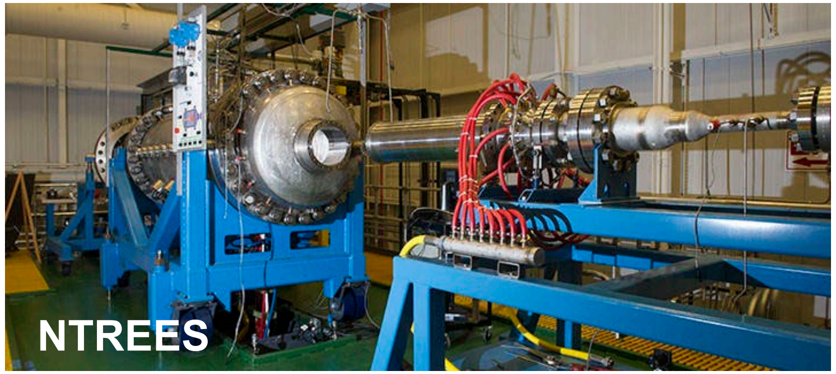
Idaho National Laboratory

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy. INL is the nation's center for nuclear energy research and development, and also performs research in each of DOE's strategic goal areas: energy, national security, science and the environment.

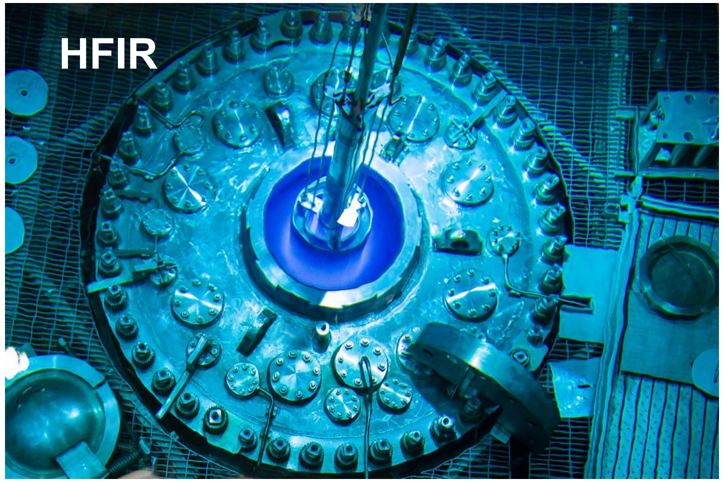
Backup Slides

Test Facilities

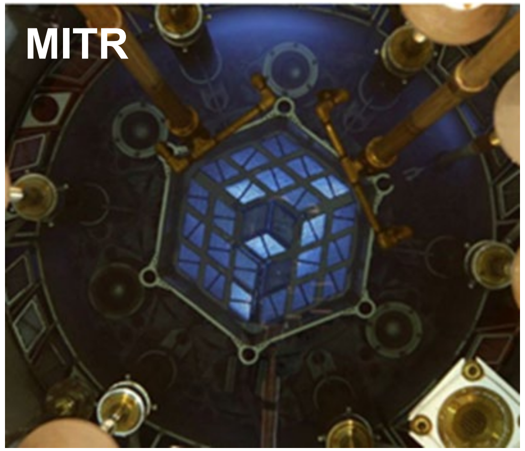
Nuclear Thermal Rocket Element Environmental Simulator



High Flux Isotope Reactor

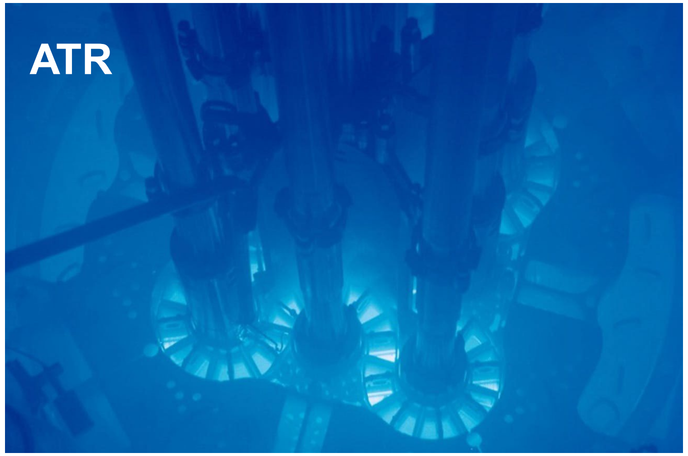


Transient Reactor Test Facility



Massachusetts Institute of Technology Reactor

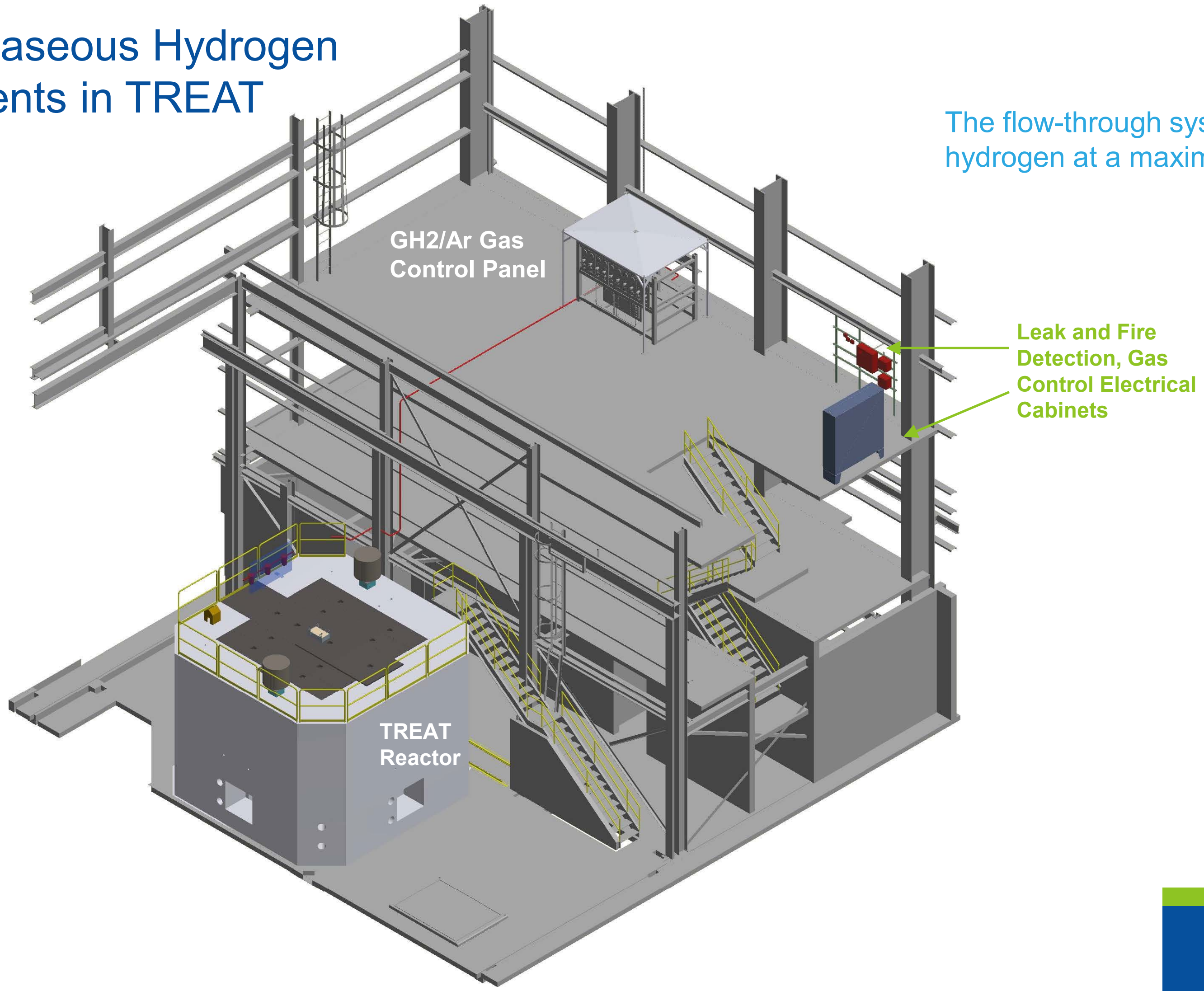
Advanced Test Reactor



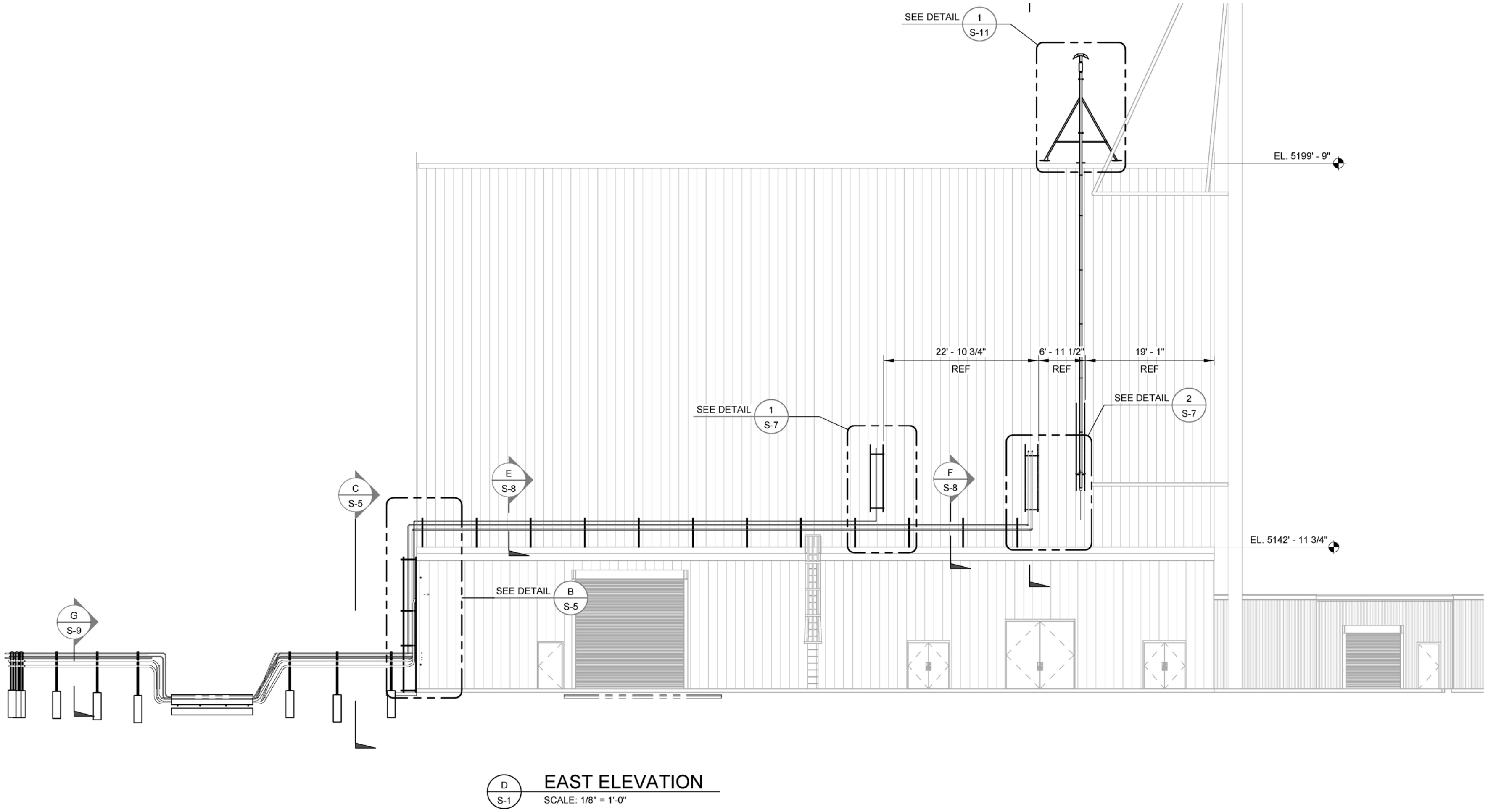
Design: Proposed System Layout - Internal

Internal Layout of Gaseous Hydrogen Supply for Experiments in TREAT

The flow-through system will supply 10-200 g/s of gaseous hydrogen at a maximum of 1000 psig.



Design: Proposed External Piping Layout



Sirius 4 – internals showing gas lines