Thermal-Hydraulic Experimental Facilities for Advanced Reactor Development at INL

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Advanced Reactor Technology Integral System Test (ARTIST) Facility

High-temperature multi-fluid, multi-loop test facility to support thermal hydraulic, materials, and thermal energy storage research for nuclear and nuclear-hybrid applications is being developed.

O'Brien, J. E., Sabharwall, P., and Yoon, S., and Housley, G. K., "Strategic Need for a Multi-Purpose Thermal Hydraulic Loop for Support of Advanced Reactor Technologies," **INL/EXT-14-33300**, October, 2014.

Sabharwall, P., O'Brien, J.E., and Yoon, S.J., "Experimental facility for development of high-temperature reactor technology: instrumentation needs and challenges," EPJ Nuclear Science and Technology, 2015

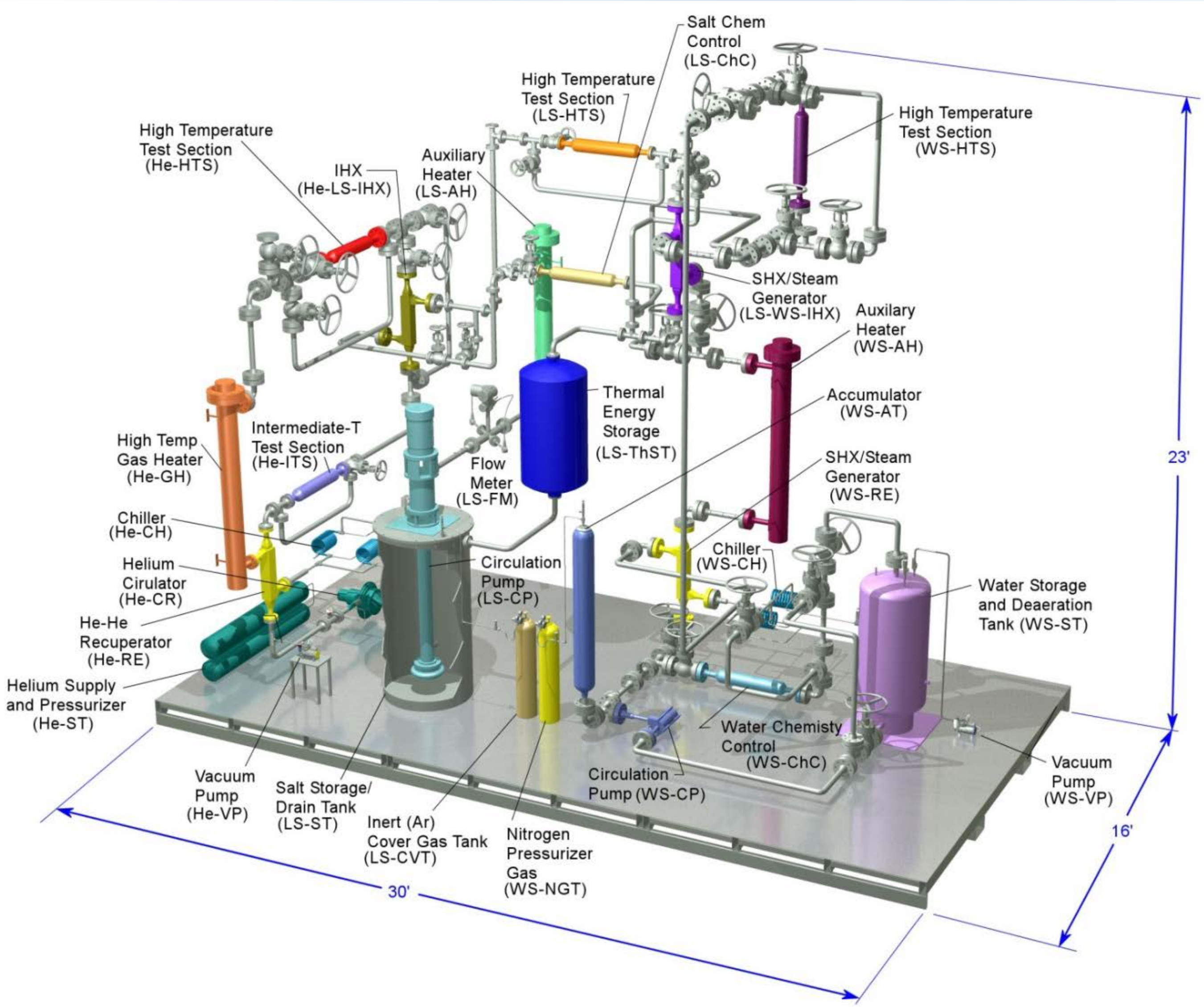
New INL Experimental Capability

- INL has initiated development of a new multi-fluid multi-loop thermal hydraulic test facility at INL, and associated technology development
- Based on its relevance to advanced reactor systems, the new test facility has been named the Advanced Reactor Technology Integral System Test (ARTIST) facility

ARTIST Facility Engineering and Research Objectives

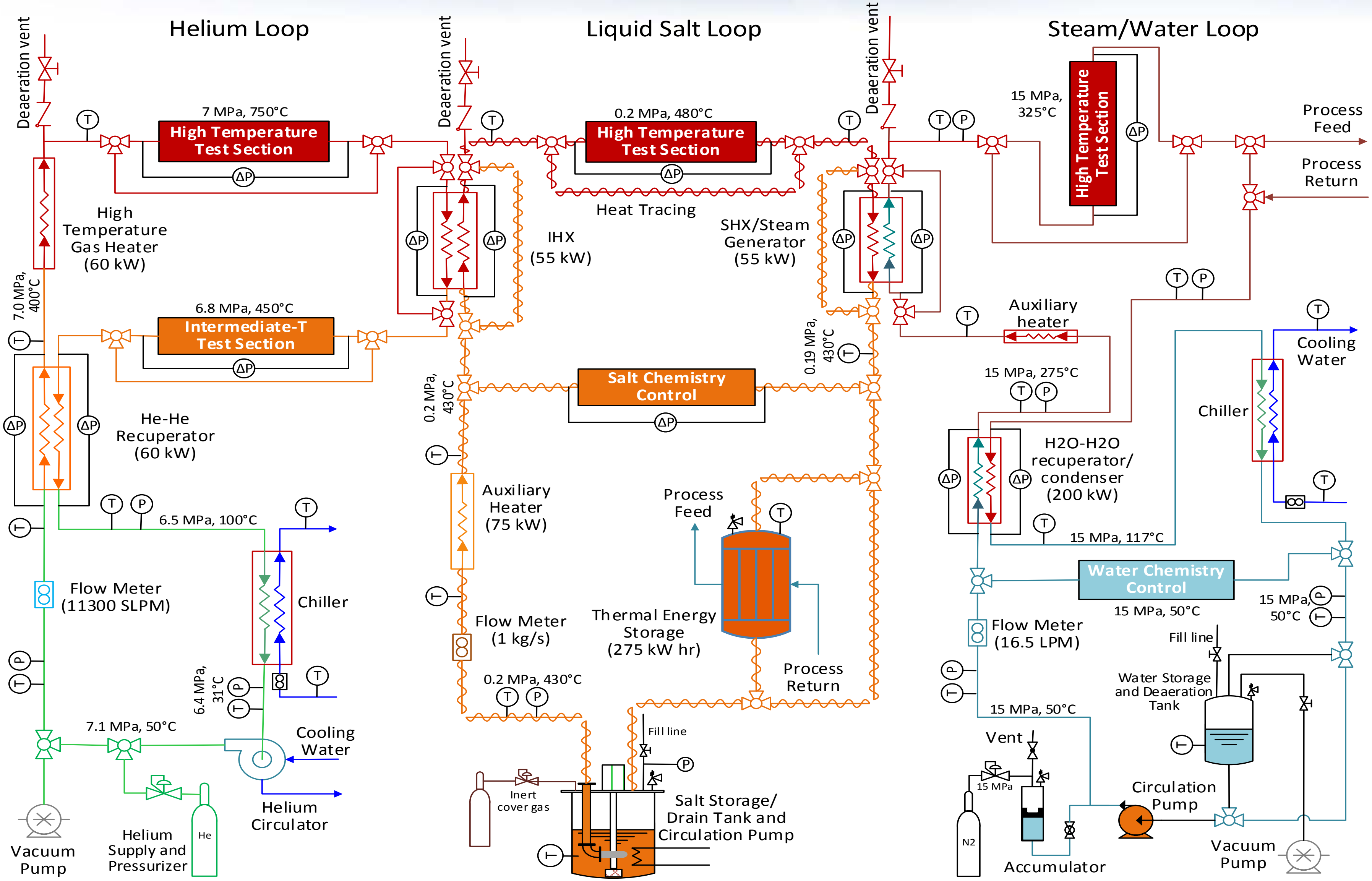
- Performance evaluation of candidate compact heat exchangers such as printed circuit heat exchangers (PCHEs) at **prototypical operating conditions** for IHX and SHX applications
- Characterization of flow and heat transfer issues related to core thermal hydraulics in advanced helium-cooled and salt-cooled reactors, and evaluation of corrosion behavior of new cladding materials and accident-tolerant fuels for LWRs at prototypical conditions
- Provide V&V data for new TH codes
- Demonstration of advanced instrumentation at prototypical conditions
- Integration with co-located energy systems for characterization of dynamic behavior

3-D CAD model of the ARTIST Facility



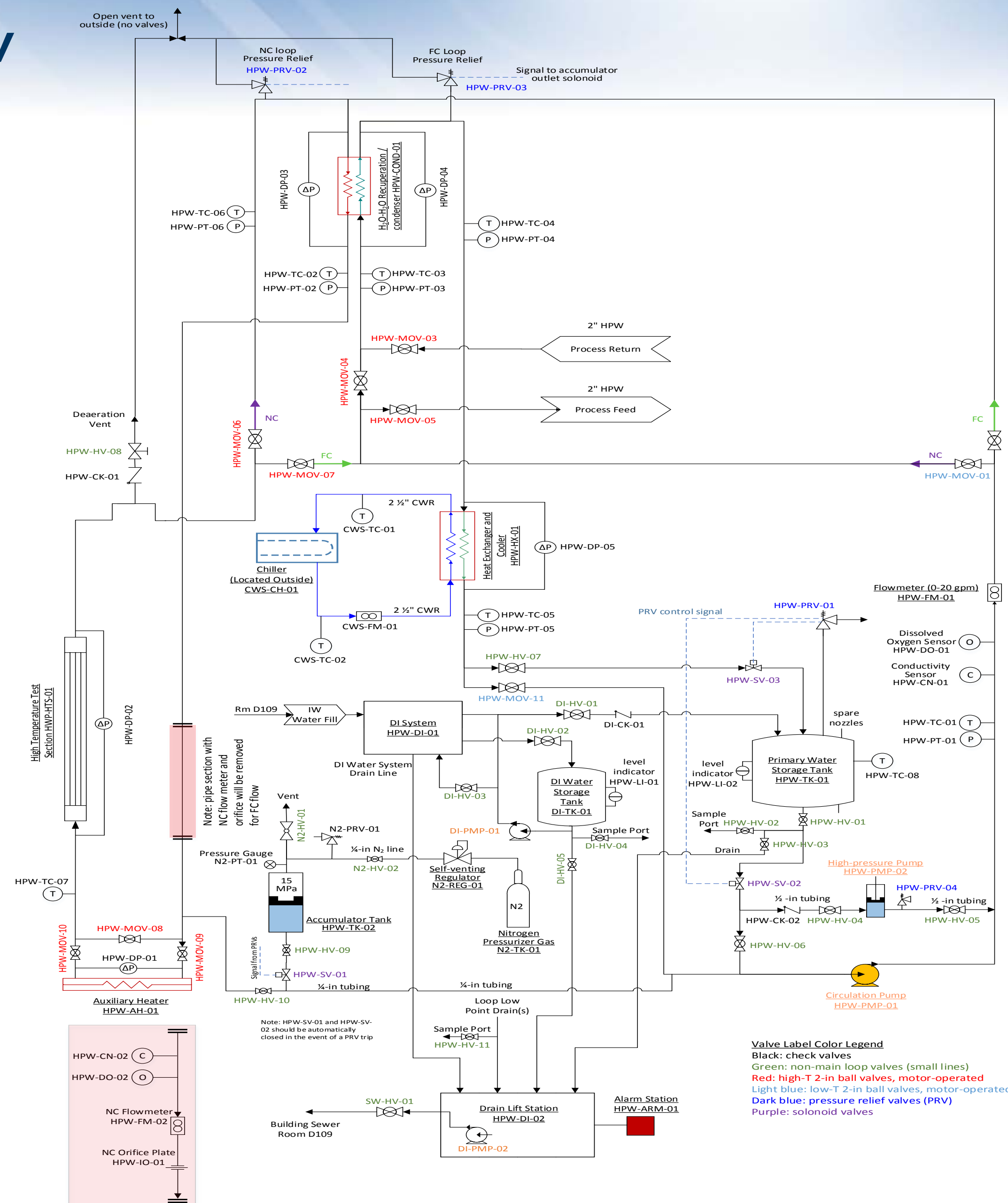
O'Brien, J.E., Sabharwall, P., Yoon S.J., and Housley, G.K., "Strategic Need for Multi-Purpose Thermal Hydraulic Loop for Support of Advanced Reactor Technologies," *External Report*, INL/EXT-14-33300, Idaho National Laboratory, Idaho, September, 2014.

Process flow diagram for the ARTIST test facility



High-Pressure Water Flow Loop

- Designed to operate at PWR conditions
- Can support both forced and natural circulation modes
- Will be deployed at the INL Energy Systems Laboratory during FY17
- Co-located with various hybrid energy systems
- Currently in final design phase

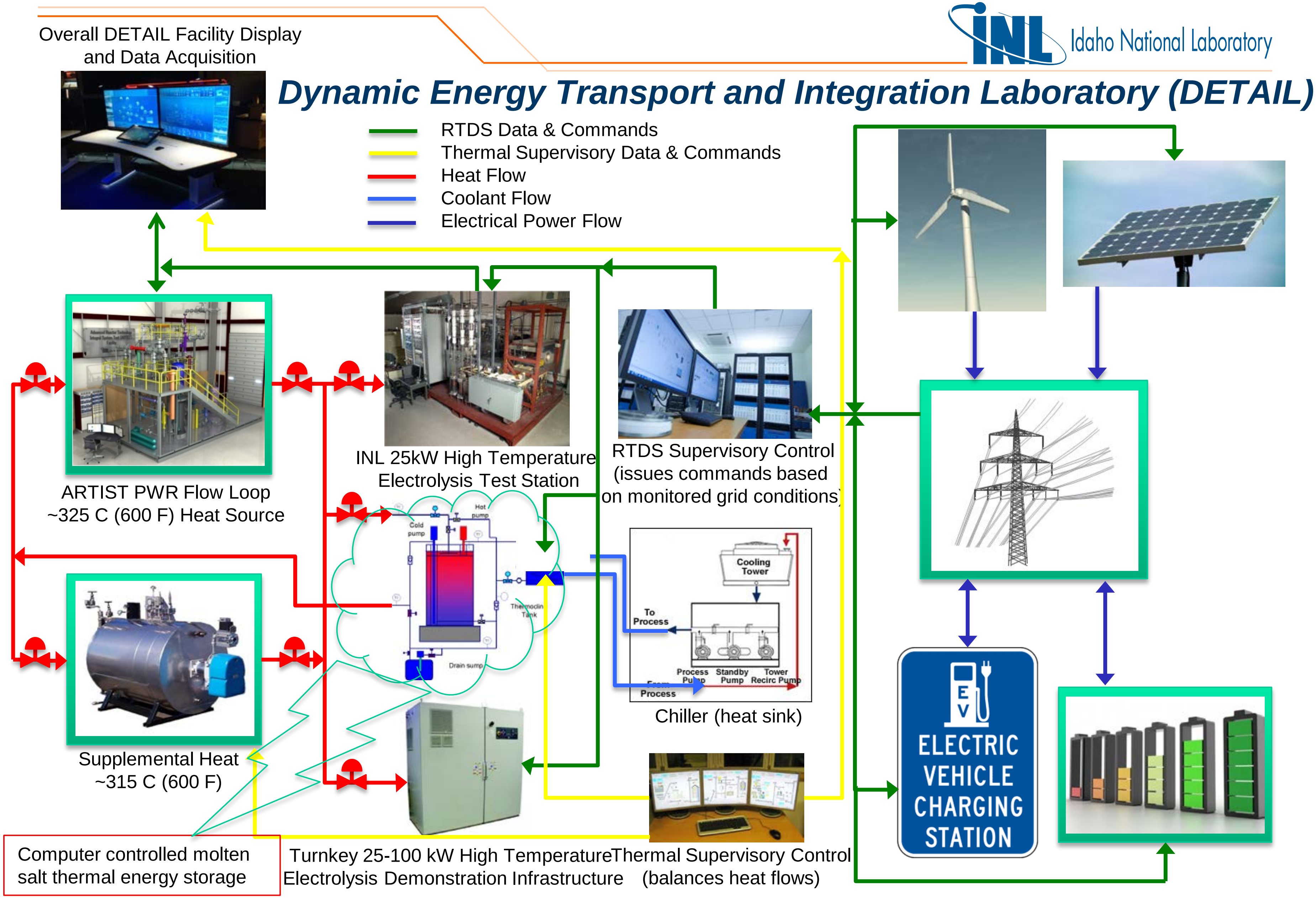


General Loop Operating Conditions

Pressure	15 MPa (2176 psia)
Temperature : low-T section	50°C
Temperature : high-T section	up to 325°C
Water mass flow rate: nominal	720 kg/hr
Water mass flow rate: maximum	2475 kg/hr
Water volume flow rate (nominal)	16.5 L/min (4.4 gpm)
Water volume flow rate (maximum)	56.8 L/min (15 gpm)

Specific Research topics: Water Loop High-Temperature Test Section

- prototypic evaluation of new cladding materials accident-tolerant fuel materials
- characterization of thermal, chemical, and structural properties of candidate advanced fuel cladding materials and designs under various simulated flow and internal heating conditions to mimic operational reactor conditions prior to in-reactor testing
- evaluate performance of advanced heat exchanger designs such as PCHEs for high-temperature, high-pressure heat transfer with intermediate fluids such as molten salts
- flow-induced vibration of simulated sodium-cooled reactor fuel rod bundles
- reactor-safety-relevant natural circulation studies
- provide dynamic thermal energy source for co-located systems including HTE and thermal energy storage systems



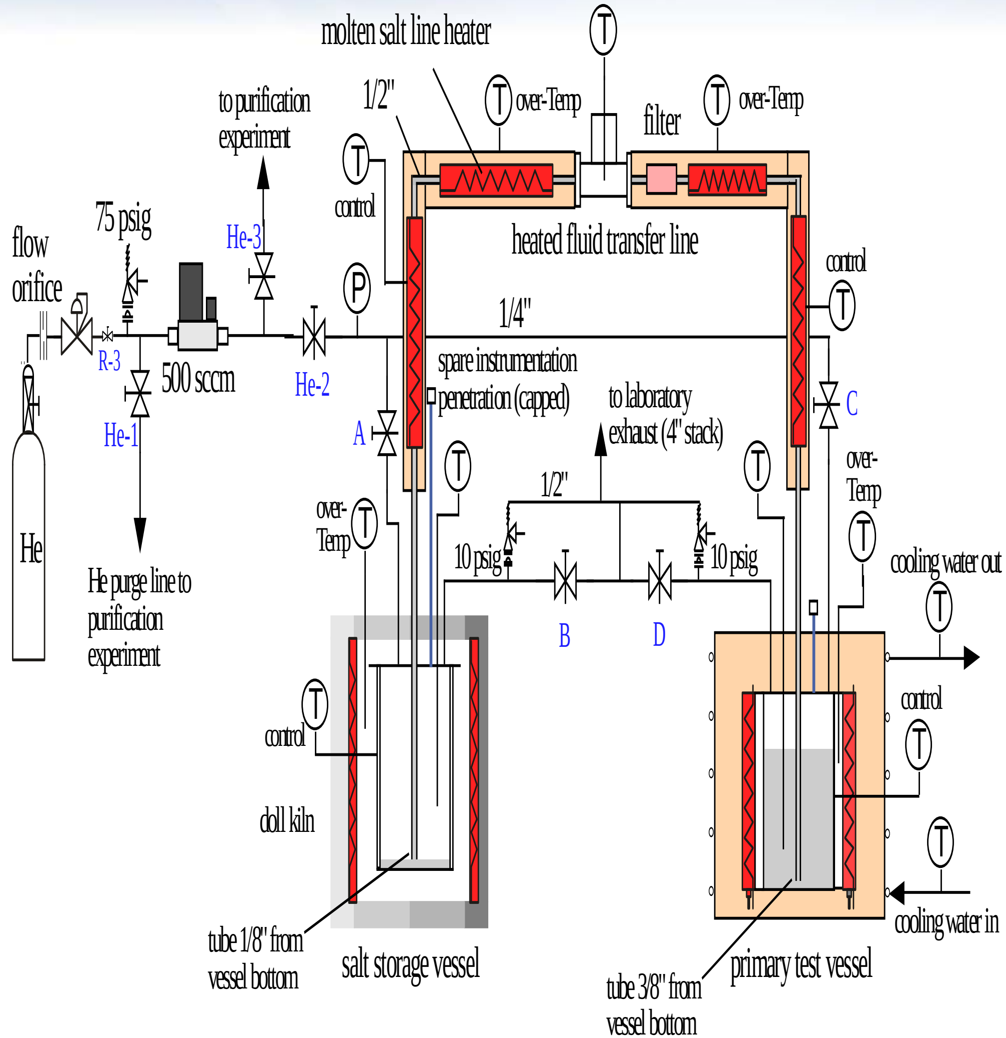
Credit: Dr. Carl Stoots
Carl.Stoots@inl.gov

Salt Preparation and Purification Setup
&
Molten Salt Transfer Experiment

Molten Salt Transfer Experiment

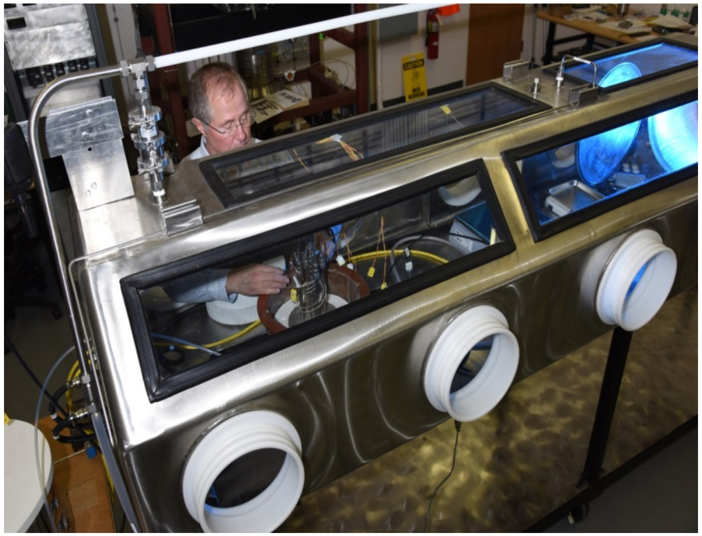
- Liquid salts will be transferred from one pot to another to validate high temperature trace heating and flow measurement methods

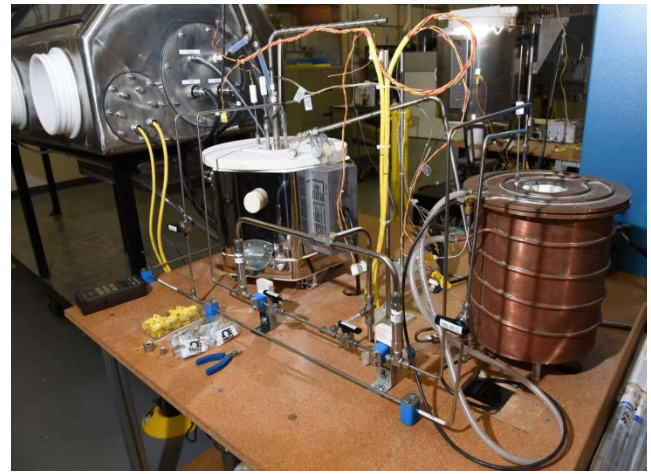
- Primary system components include an inert gas supply, mass flow controller, pressure relief valve, pressure transducer, a water-cooled furnace assembly, a doll kiln, a primary test vessel, fluid storage vessel, a filter, and a heat-traced fluid transfer line



Salt Preparation and Purification to support ARTIST

Salt Preparation, property measurement, and flow experiment





Glove box for molten salt preparation and salt transfer/flow experiment.

Nickel (alloy 201) vessels for salt purification and transfer experiments

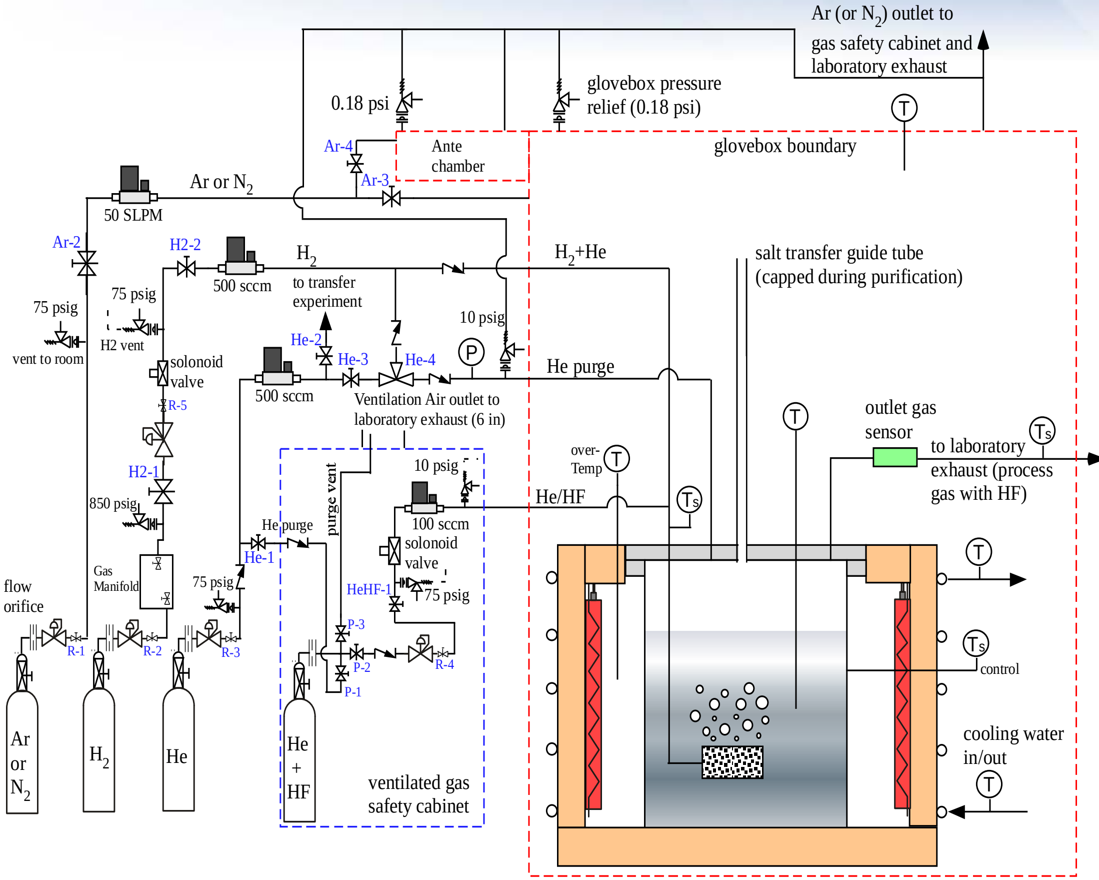
FLiNaK ingot and glassy carbon crucible

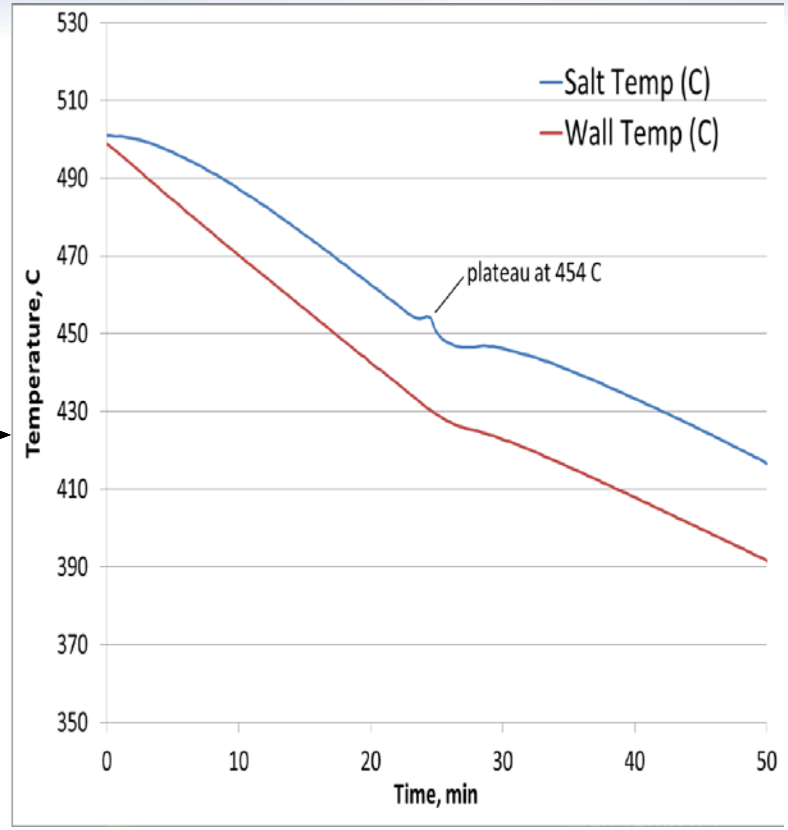
a) unpurified

b) after one purification run

FLiNaK ingot top surface

Salt Preparation and Purification (Hydrofluorination HF/H_2/He)



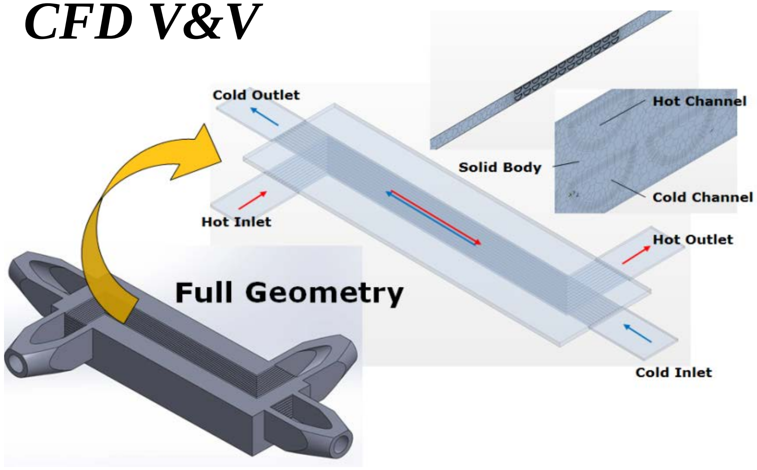


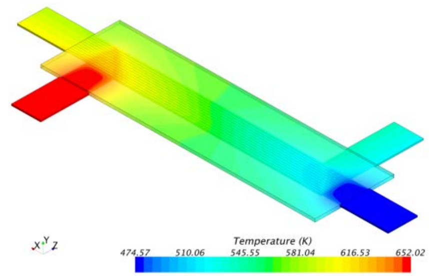
Expected Outcomes

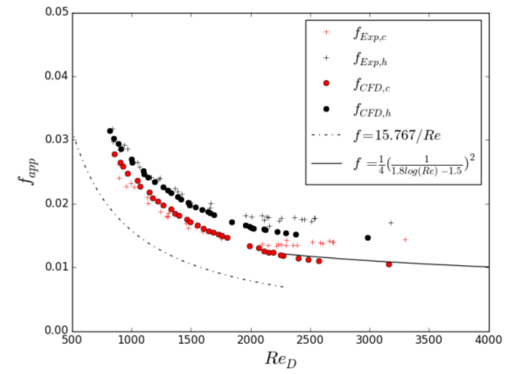
- Gain experience with safe methods of fluoride salt mixture handling, preparation, and purification
- Characterize salt impurities
- Measure eutectic salt mixture thermophysical properties such as thermal conductivity and specific heat

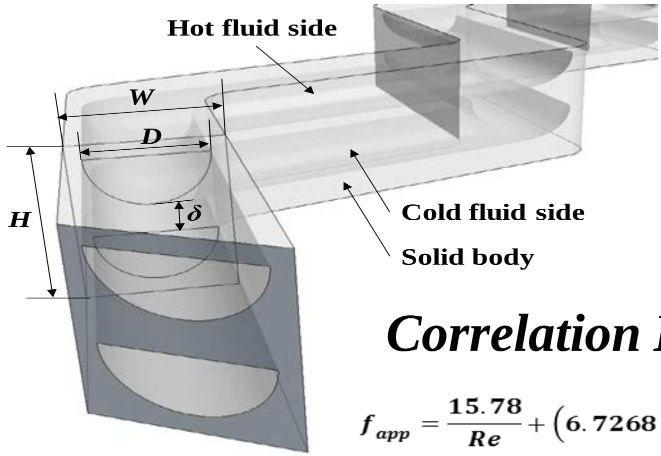
PCHE CFD Analysis and V&V

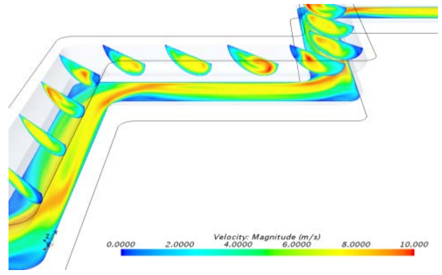
CFD V&V

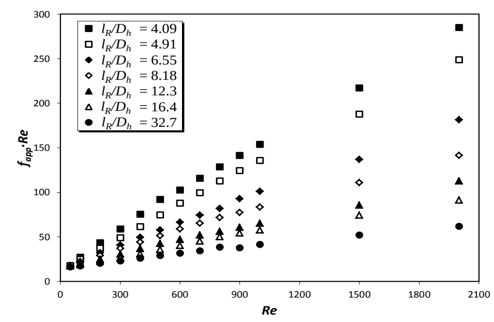












Correlation Development

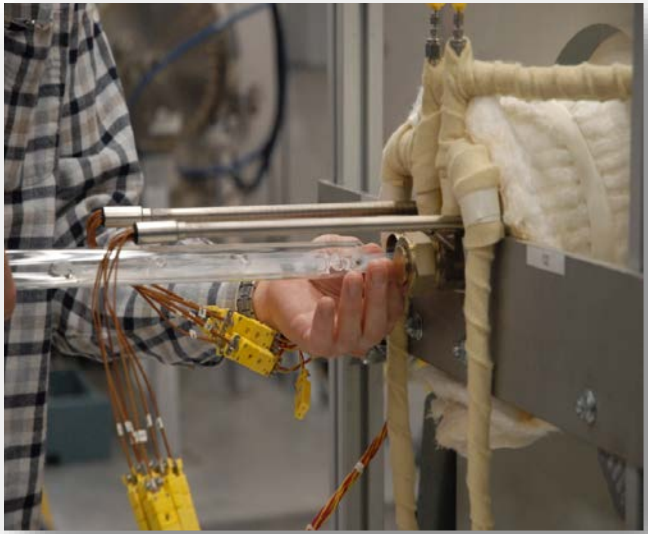
$$f_{app} = \frac{15.78}{Re} + \left(6.7268\times10^{-3}\cdot exp(6.6705\cdot\alpha)\right)\cdot\left(\frac{l_R}{D_h}\right)^{-2.3833\cdot\alpha+2.6648\times10^{-1}} + (4.3551\cdot\alpha - 1.0814)\times10^{-2}$$

Yoon, S., O’Brien, J.E., Chen, M., Sabharwall, P., and Sun, X., “Development and Validation of Nusselt Number and Friction Factor Correlations for Laminar flow in Semi-circular Zigzag Channel of Printed Circuit Heat Exchanger,” *Applied Thermal Engineering,* 2017

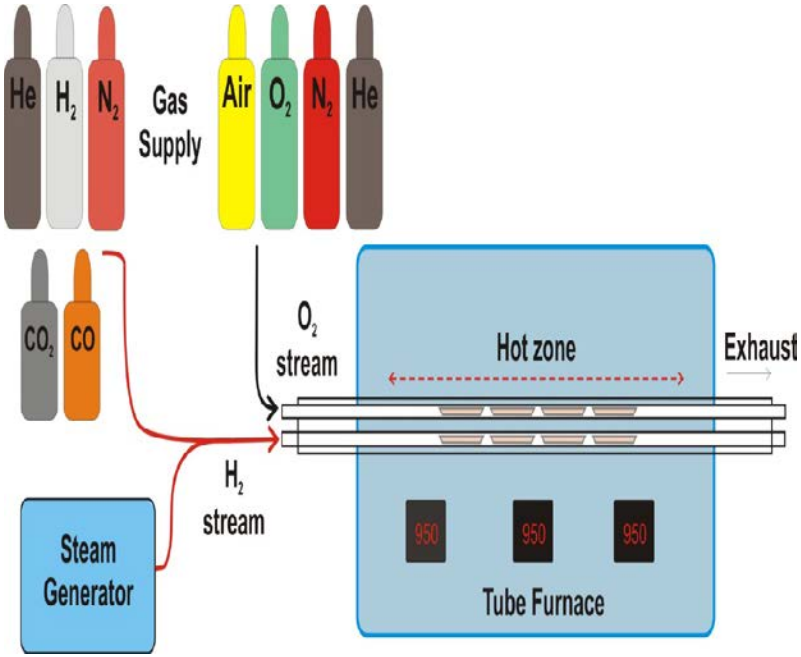
Component Test Facilities (Test Rigs)

Mixed Stream Test Rig (MISTER): Corrosion Testing of Small Specimens in Multiple/varied Gas Streams

- Provides high pressure/temperature gas mixtures to small test article
- Furnace temperatures up to 1000°C
- Completed first test of HTSE alloys



Loading specimen into MISTER using quartz boats



Conceptual drawing of MISTER

- Completed start-up in January 2011 (L2 milestone)
- 500 hour test of high temperature electrolysis "balance of plant" specimens completed
- Specimens undergoing analysis
- Minor upgrades, additions to spares, etc., completed in April 2011

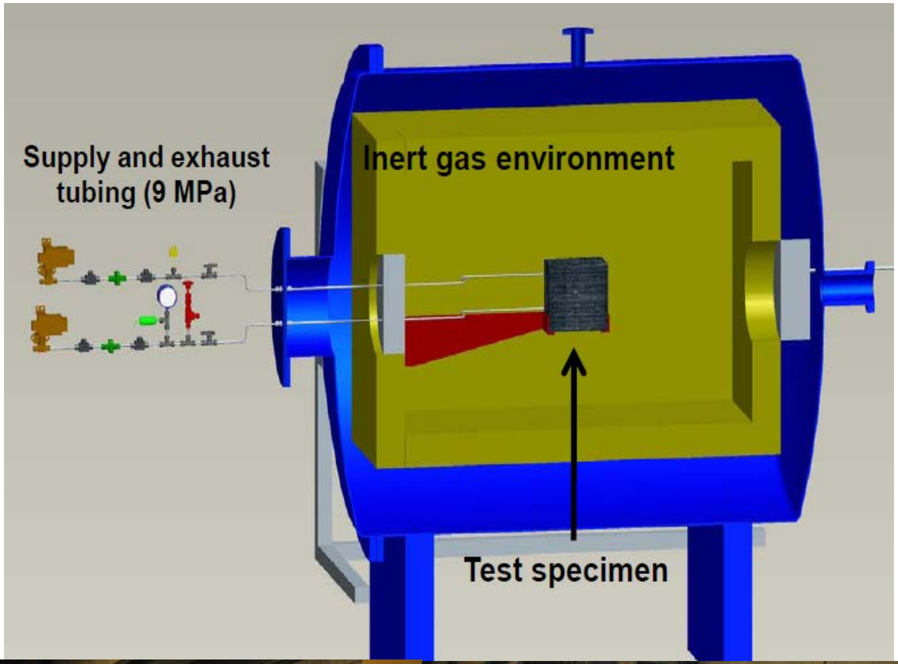
Kevin Dewall*

Small Pressure Cycling Test Rig (SPECTR): Mechanical Testing of Small (up to 8 in^3 HX sections)

SPECTR Purpose

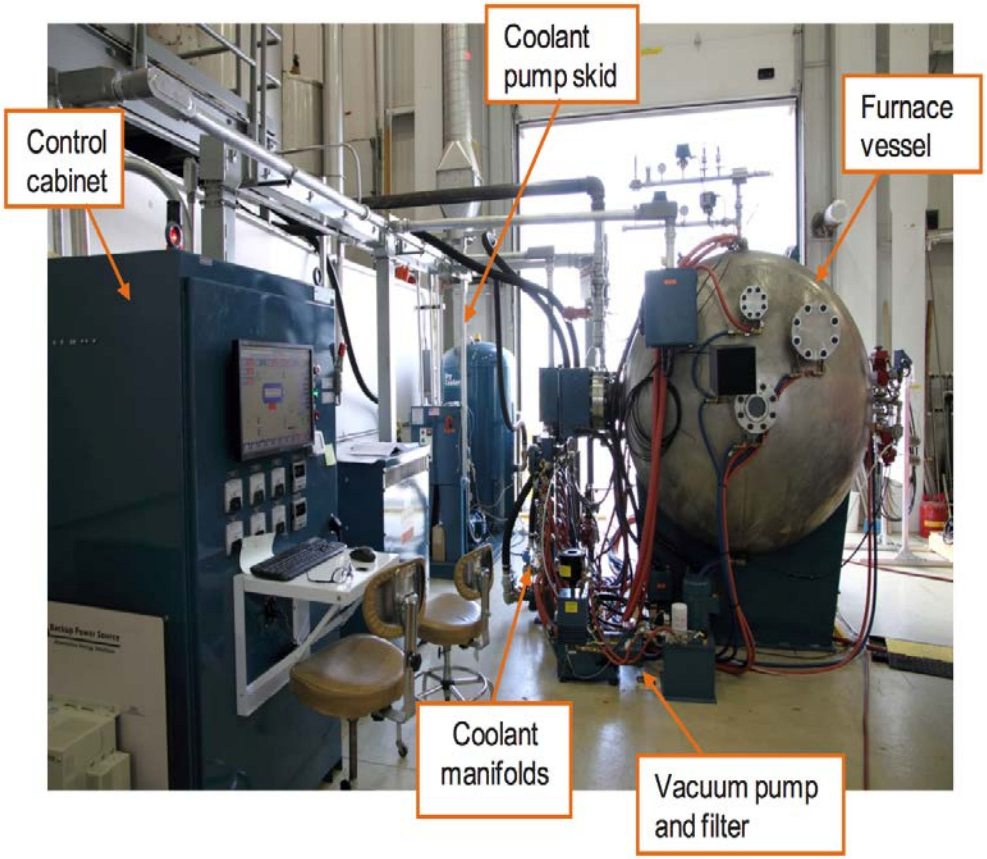
- Proof test diffusion bonded IHX to draft ASME code case procedure
- Demonstrate IHX performance for cyclic pressures
- Used to answer several DDNs

- Provides high pressure gas to primary and secondary of test article
- Furnace temperatures up to 1000°C
- Operational summer 2011 (L2 milestones)
- Capable of SOEC pressurized testing for TRL 5



SPECTR furnace fabrication at AVS

Bill Landman*

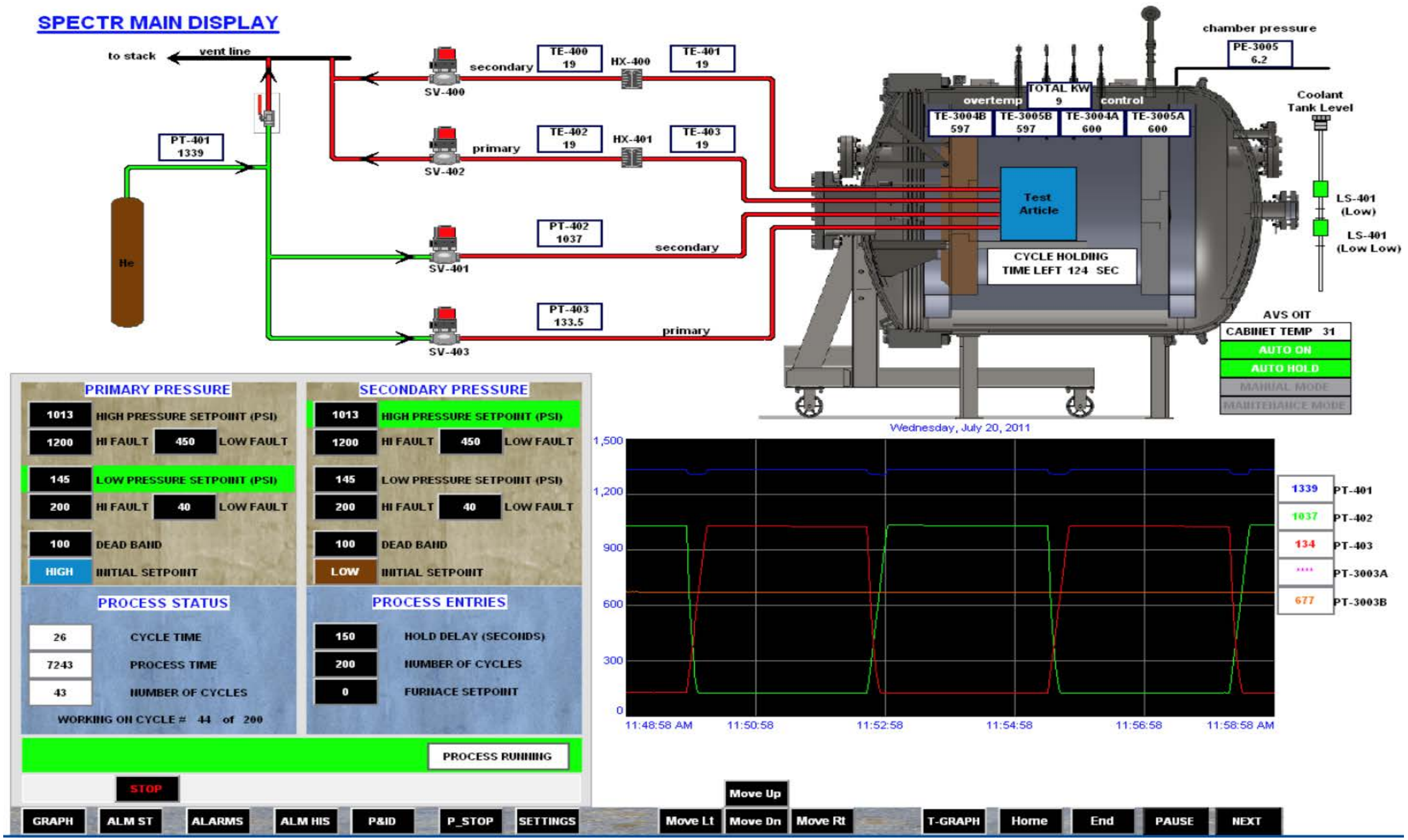


SPECTR system viewed from inside Bay W-3 of IEDF

Test article gas supply and exhaust system

Landman, W.H., “SPECTR System Operational Test Report.,” **INL/EXT-11-22903**, August 2011.

Main Display Screen for Control System



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Matched Index of Refraction Flow Facility

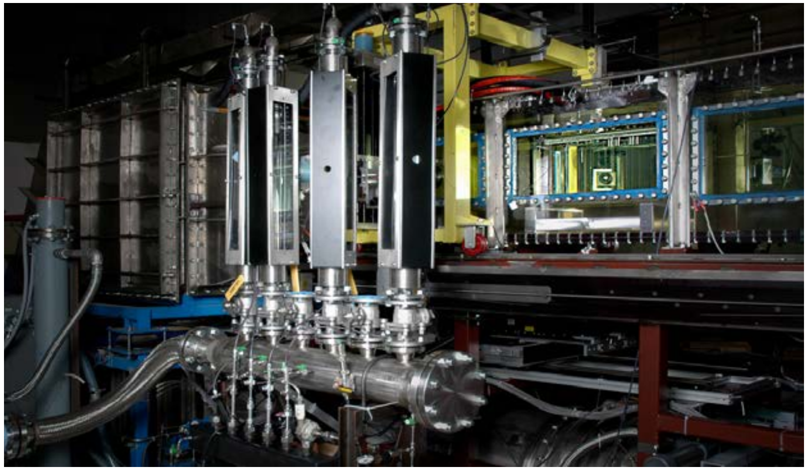
(https://mir.inl.gov)

Stoots, C., S. Becker, K. Condie, F. Durst, and D. McEligot, 2001, "A Large Scale Matched Index of Refraction Flow Facility for LDA Studies Around Complex Geometries," *Exp. in Fluids*, Vol. 30, pp. 391–398.

Conder, T.E., "Particle Image Velocimetry Measurements in a Representative Gas Cooled Prismatic Reactor Core Model For the Estimation of ByPass Flow," *Doctoral Dissertation*, December 2012.

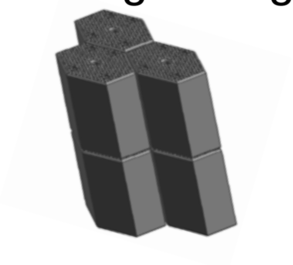
MIR Experiment Facility

- INL has a variety of 21st century (i.e. state of the art) flow facilities and measurement techniques applicable to code/model for verification and validation



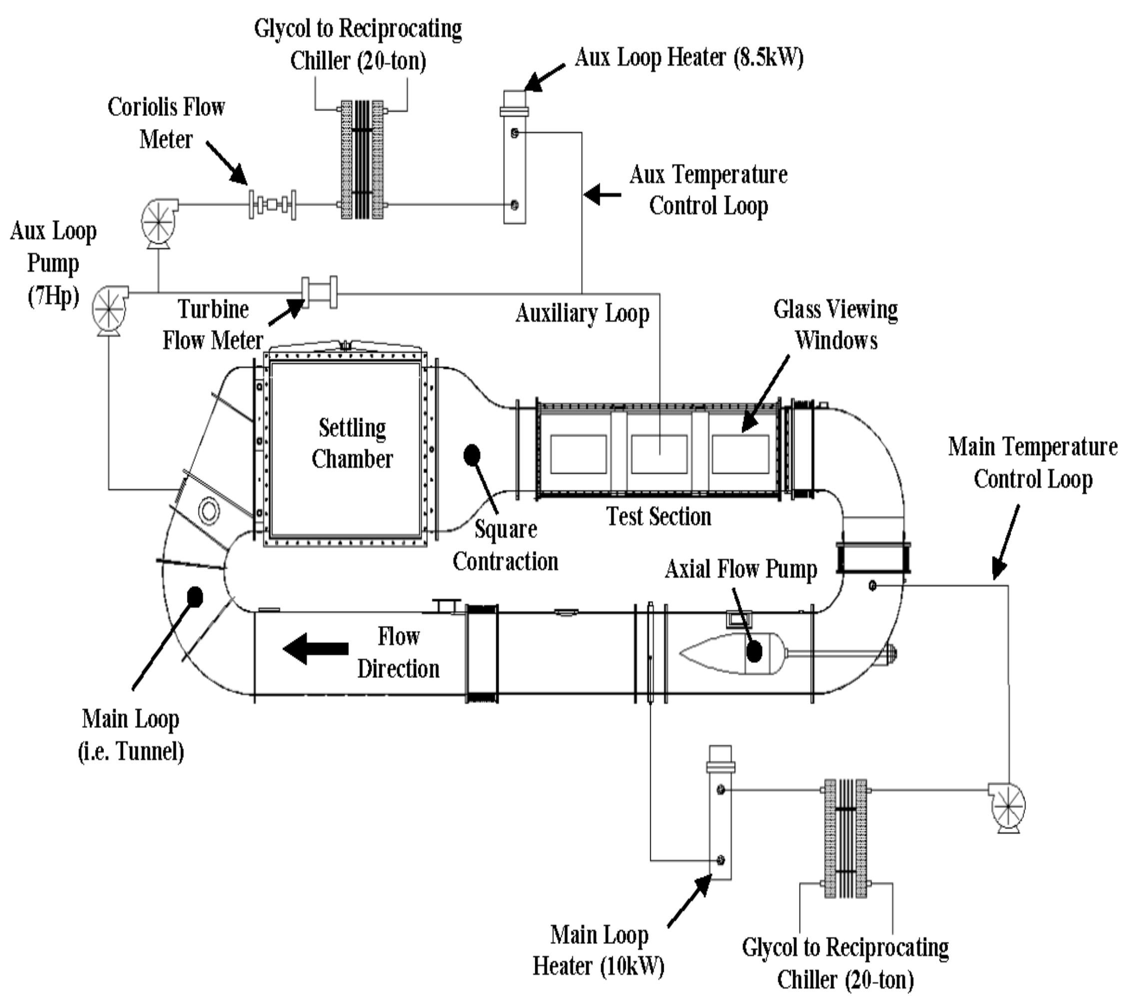
- Match Index of Refraction Facility
- Particle Image Velocimetry

- Bypass Flow Experiment (CFD under predicted the flow through the gap)
  - complex flow geometry
  - experimental results needed for CFD analysis



- To measure entropy generation rate within the bypass transitional region of the boundary layer (‘bypass’ is bypassing the Tollmein Schlichting waves of transition in quite laminar flow by introducing high turbulence in the freestream away from the plate)

Technical Specifications



Characteristic	Specification
Test Section Cross Section	0.61 m × 0.61 m (24 in × 24 in)
Test Section Length	2.44 M (8 FT)
Contraction Ratio	4:1
Working Fluid	Drakeol #5 Light Mineral Oil
Index-Matching Temperature (ºC)	Laser Wavelength Dependent
Mineral Oil Density	Matching Temperature Dependent
Refractive Index of Mineral Oil and Fused Quartz	Matching Temperature Dependent
Mineral Oil Kinematic Viscosity	Matching Temperature Dependent
Temperature Control	External
Maximum Inlet Velocity	1.9 m/s (6.2 ft/s)
Inlet Turbulence Intensity	0.5%–15%

Data from old experiments

- Experimental guided models for validation
- Assess new safety measures:
  - Passive decay heat removal
  - Natural circulation
- Uncertainty quantification

Conduct new experiments

Develop new instrumentation techniques (if required)

Demonstrate new reactor concept features and improved correlations

Conclusions

- Exciting challenges ahead!
- Innovative ideas needed to drive down costs.
- Successful demonstration are needed to gain utility, regulator, and public confidence.

Thanks…!

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