BWXT™

BWX Technologies, Inc.

Integrated System Test Facility

Miller/Martin

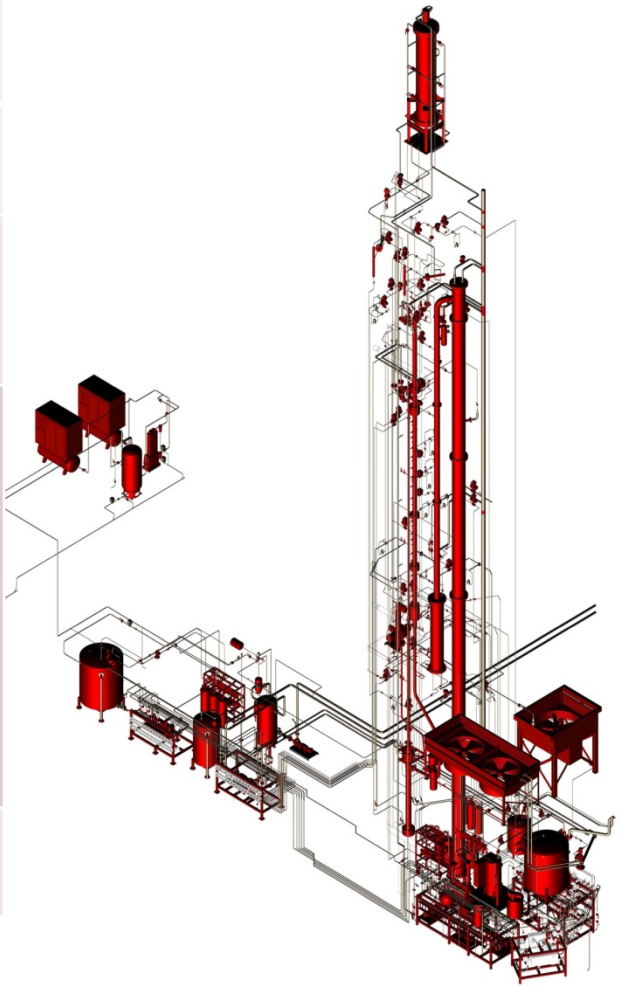
IST Overview Video

IST Objectives

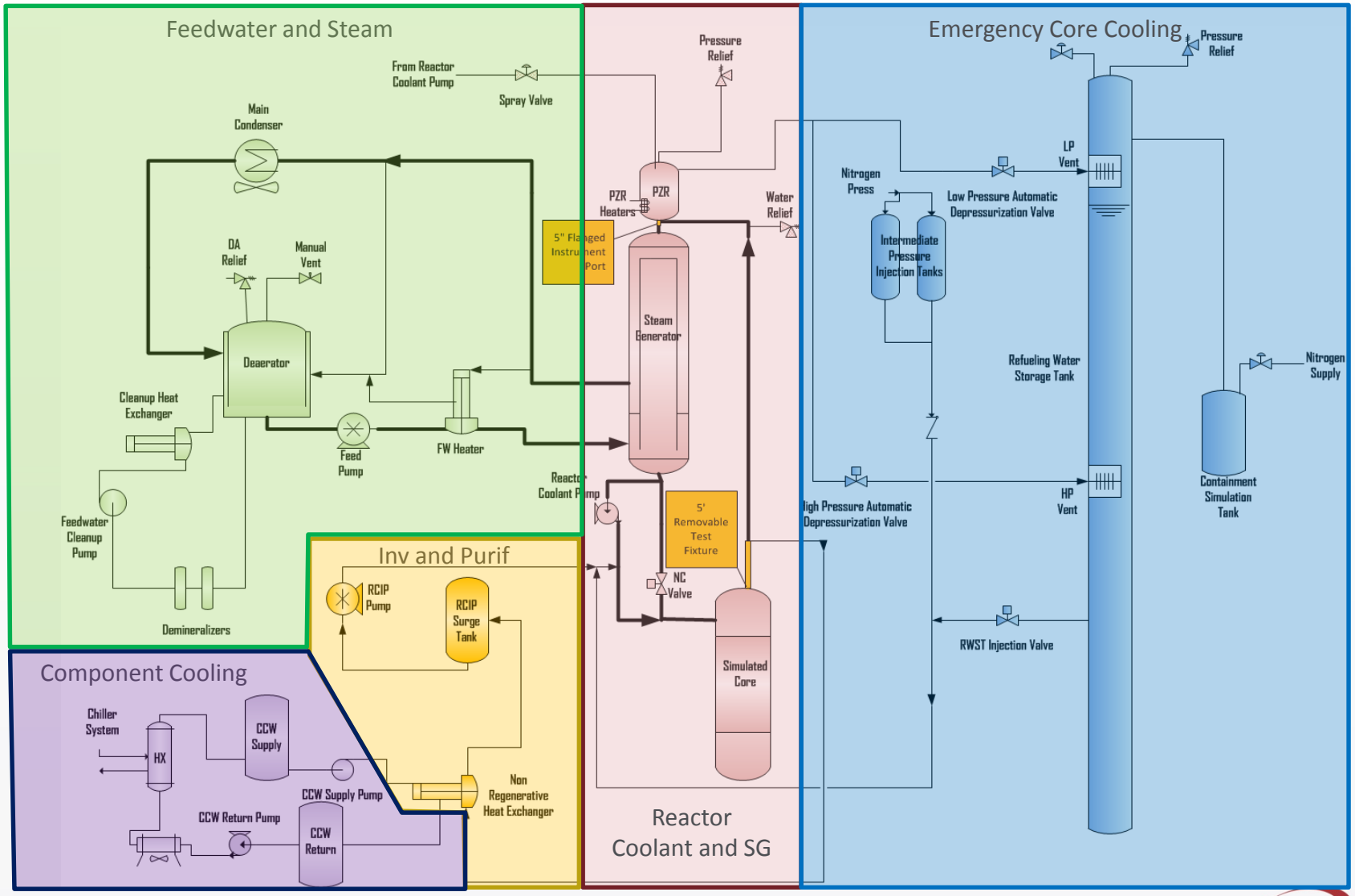
- Integrated system performance
- Evaluation model development support
- Licensing support (ASME NQA-1 Compliant)
- Insights
  - Operational evaluations
  - Design basis event data using configuration controlled systems and certified data acquisition system
  - Natural Circulation (one or two phase)
  - Fuel pin dry-out, pre-cursor to DNB under various flow regimes
  - Control and protection systems development
- Flexible and adaptable platform for broad testing applications
- Concurrent testing capabilities serving multiple stakeholders

IST Design

Design	Local Architectural and Engineering Firm
Material	Standard SST pipe and fittings wherever possible
Standards	ASME Section I & VIII as required and B31.1 test system piping
Components Accommodated	• Integral reactor loop consisting of reactor vessel, steam generator, reactor coolant pump, and pressurizer • Reactor Vessel with 60 pin heater array capable of 1.8 MW (mPower optimized) • Integral economizer once through steam generator • Pressurizer vessel with 6kW heater • ECC system consisting of automatic depressurization trains and LOCA line
Design Conditions	• 650°F • 2500 psig

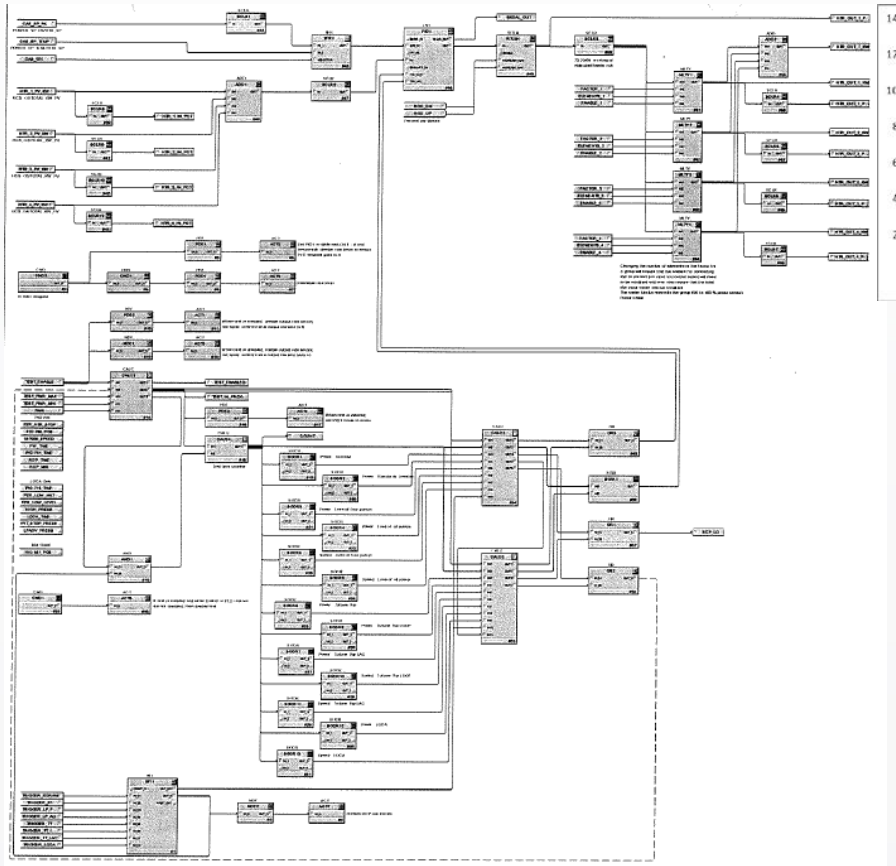


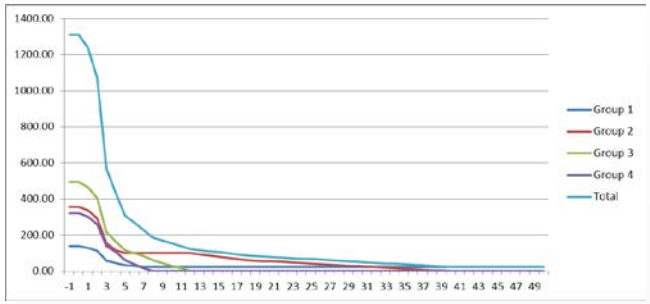
IST Arrangement

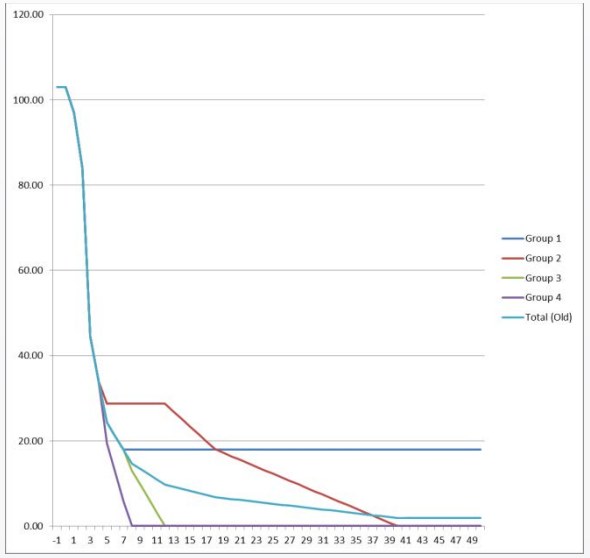


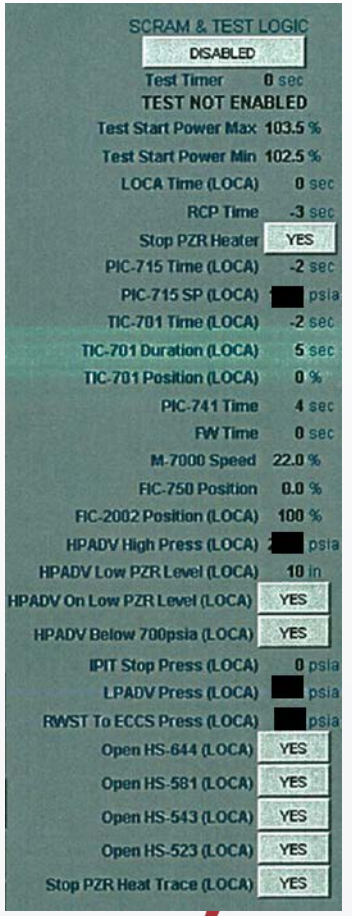
Control Logic

- Readily adaptable control Logic designed to operate valves, pumps, heaters, control boundary conditions providing for high fidelity, highly repeatability tests.

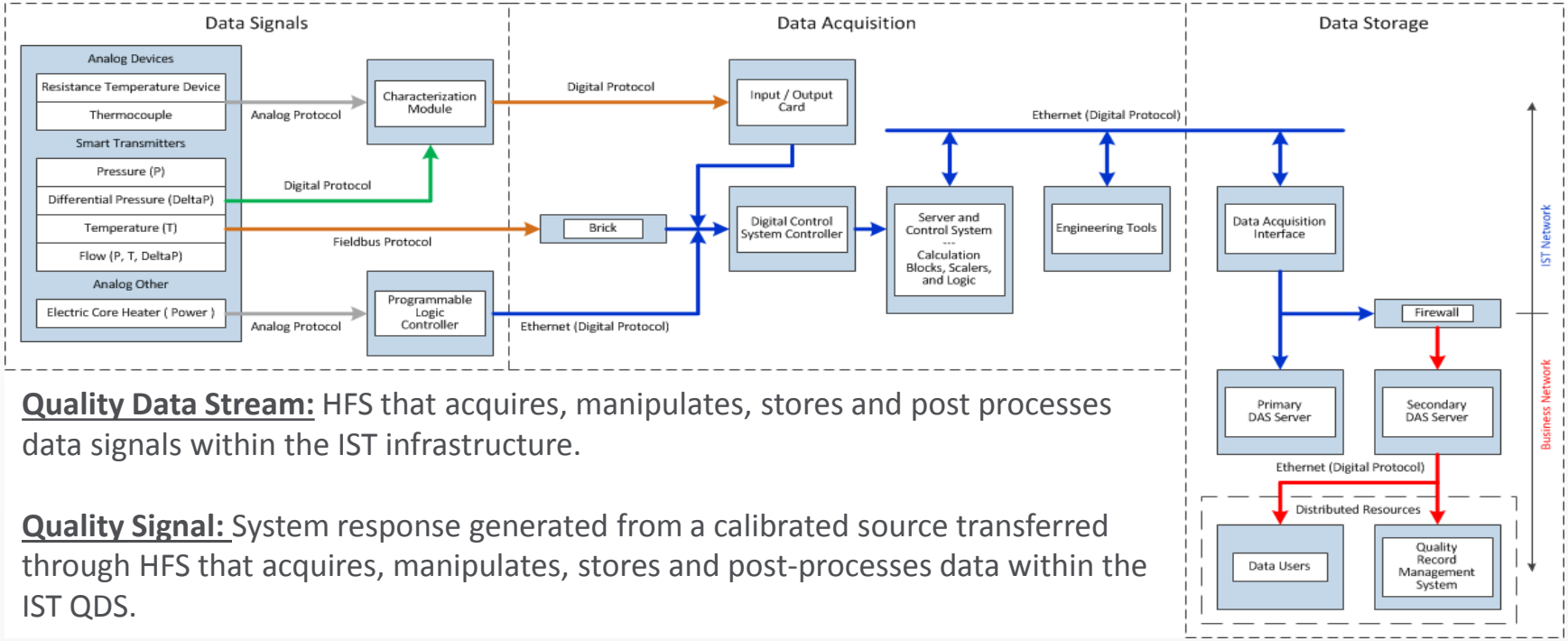








10 CFR 50 (Appendix B) / NQA-1 Quality Program

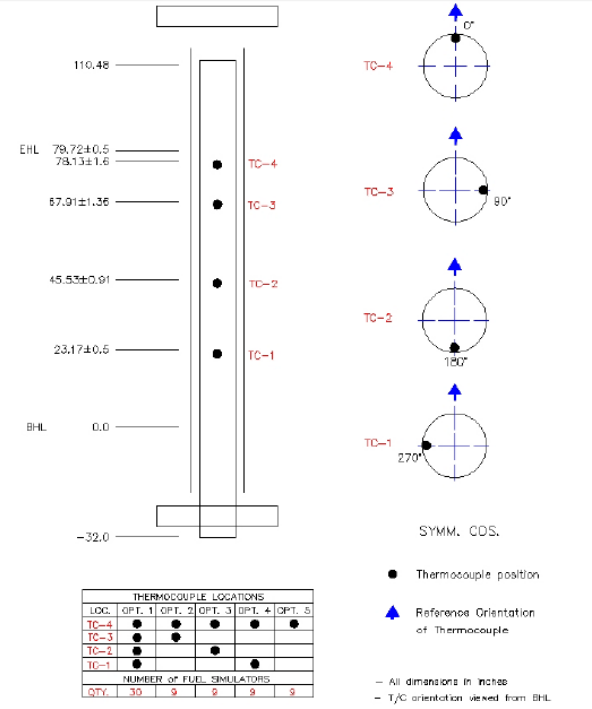


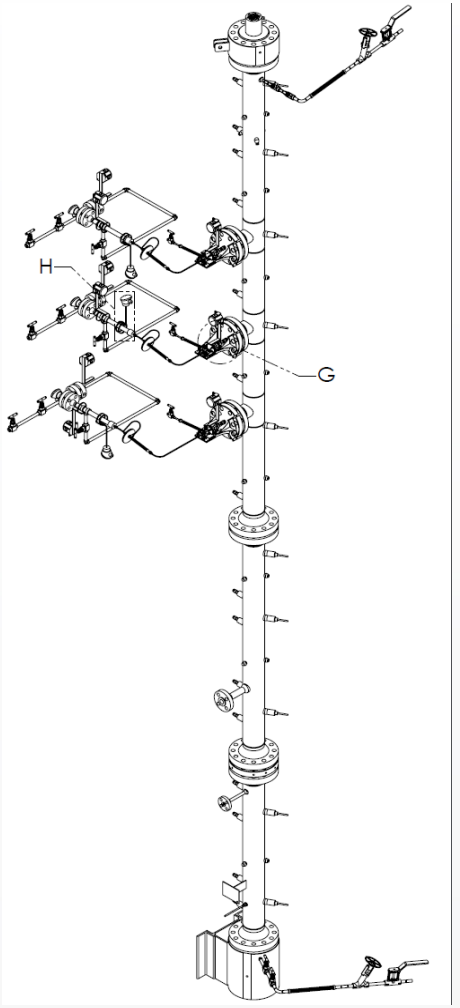
Quality Data Stream: HFS that acquires, manipulates, stores and post processes data signals within the IST infrastructure.

Quality Signal: System response generated from a calibrated source transferred through HFS that acquires, manipulates, stores and post-processes data within the IST QDS.

Data Signals

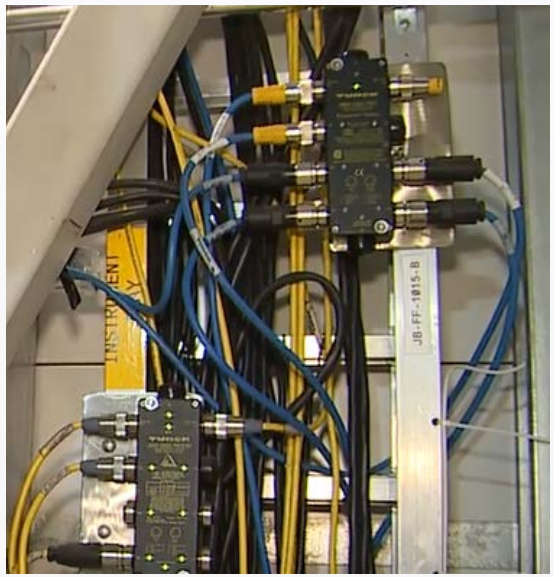
- Sensors convert process conditions (temperature, pressure, chemistry, component, etc.) to analog signals
- Analog signals are converted to digital either through onboard digital conversion or through analog to digital characterization modules





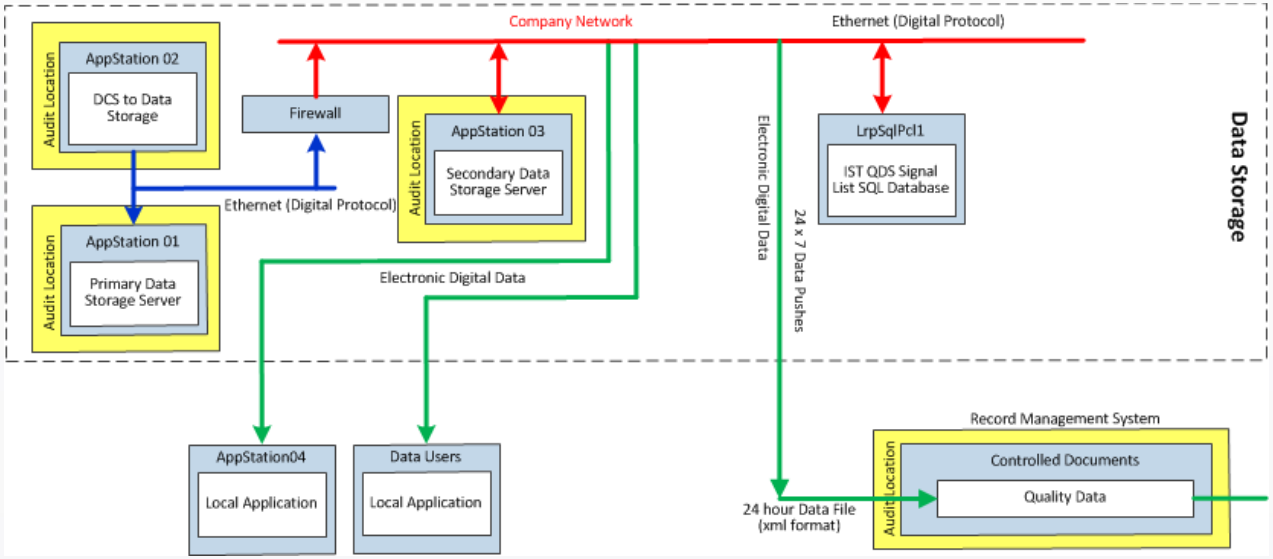
Data Acquisition

- All-digital, serial, two-way communications system
- Protocol through either High Speed Ethernet (HSE) or Foundation fieldbus protocols
- Fieldbus network includes segment system to reduce hardware requirements, reduce troubleshooting effort and organize the field network



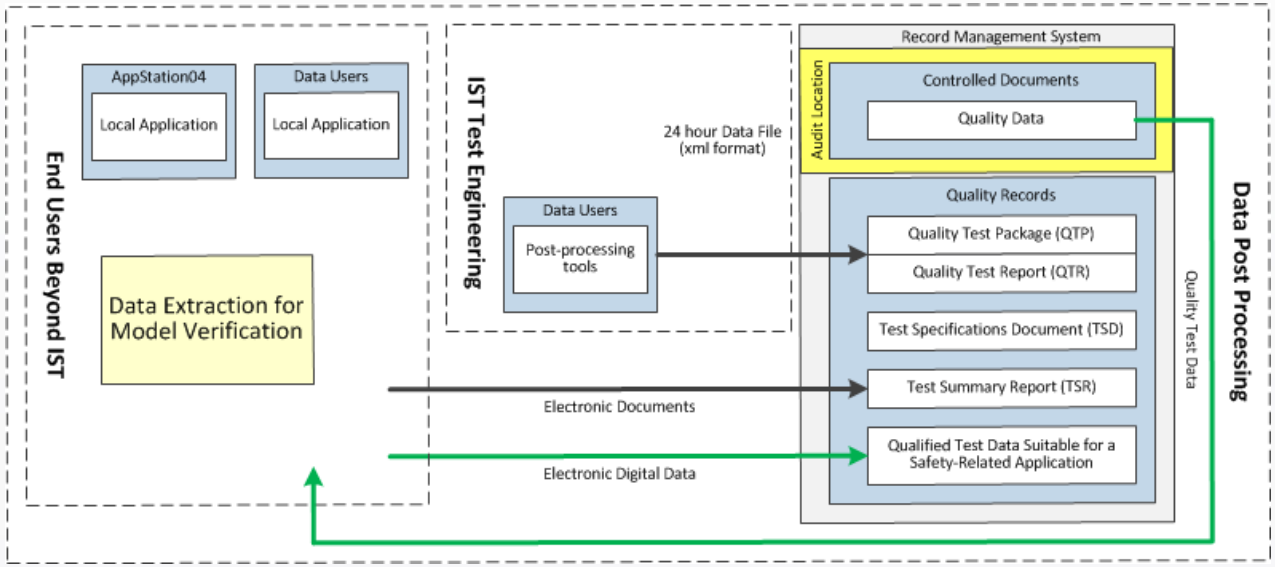
Data Integrity and Auditing

- Real-time and historical verifications of signals included in the IST quality data stream
- Data obtained prior to storage on application stations
- Audit verifies data is not compromised during signal transmission



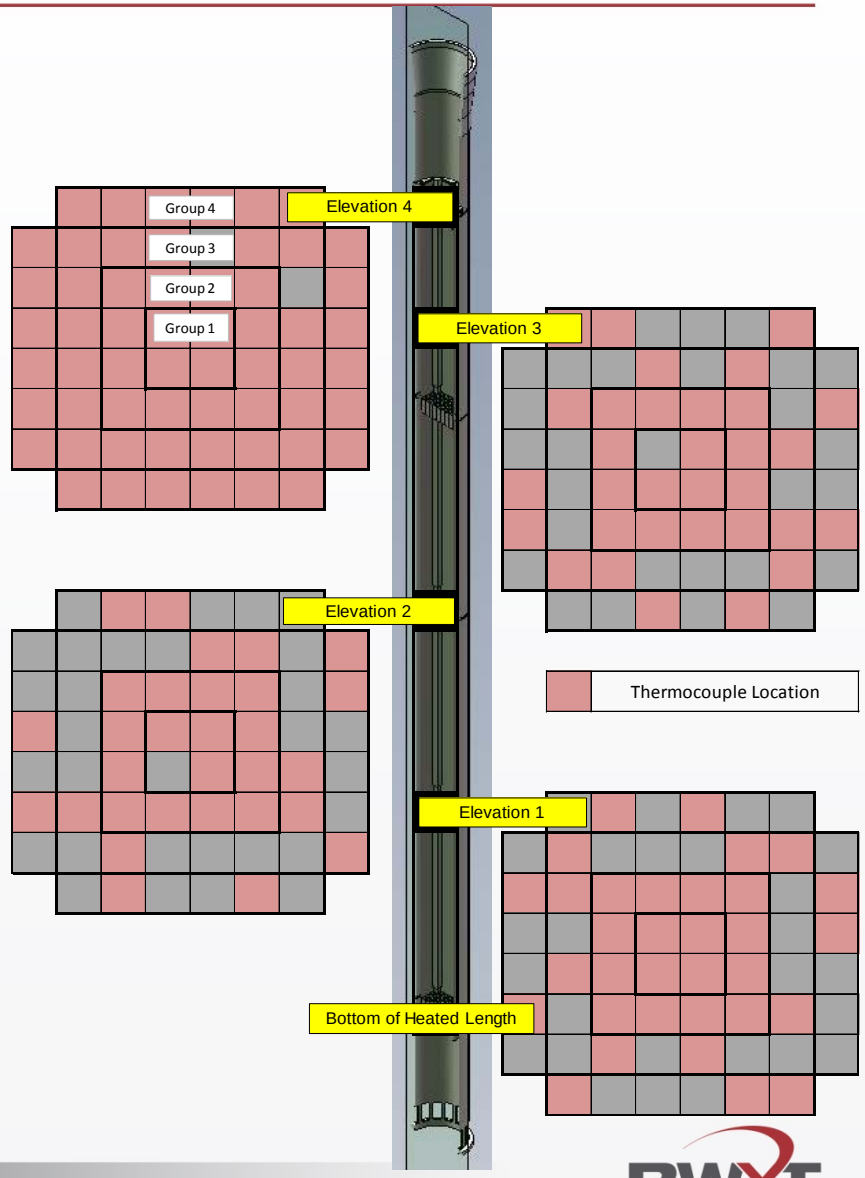
Data Storage

- Two redundant storage servers, allows access to real-time and historical data
- Quality record repository for use in safety-related processes



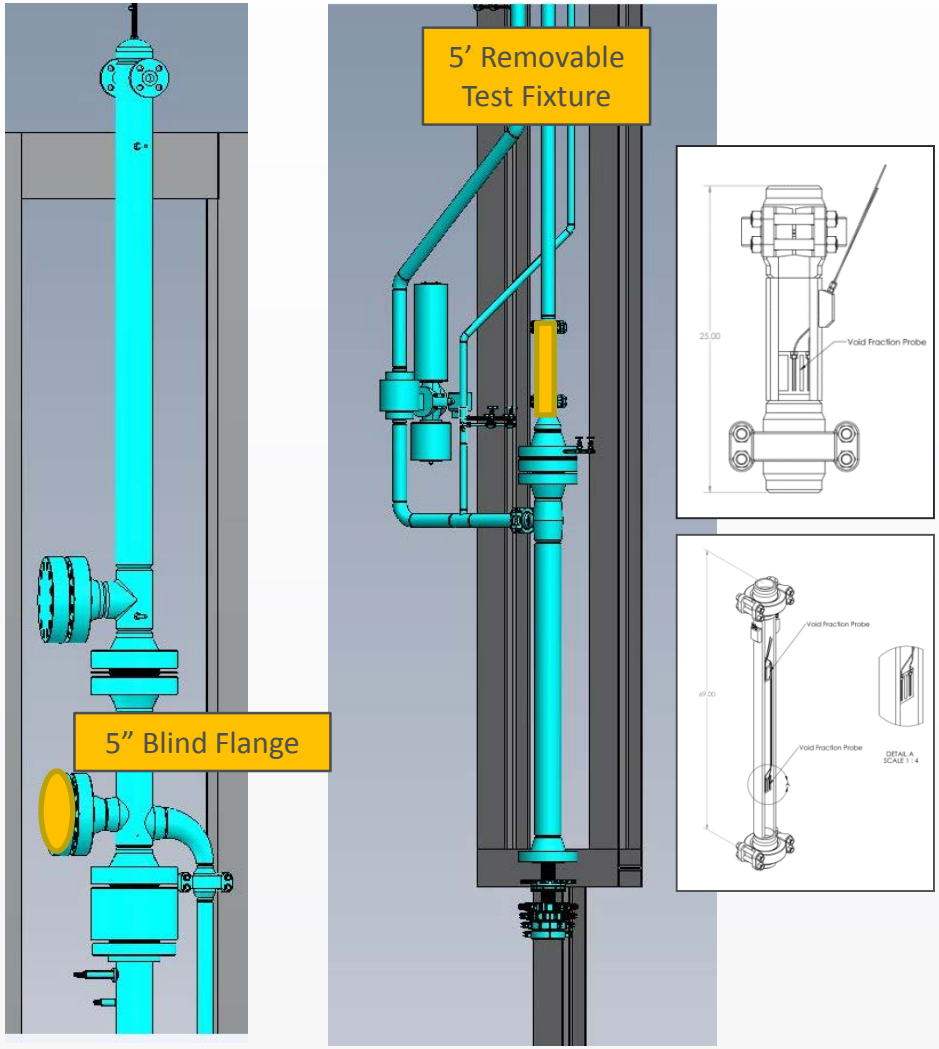
Simulated Core Heater TC Layout and Pin Array

- 1.8 MW, 4 Groups
- Adjustable radial profile
- Symmetric Cosine Axial Power Profile
- 160 Thermocouples located at 4 different elevations and 4 reference orientations



Removable Test Sections

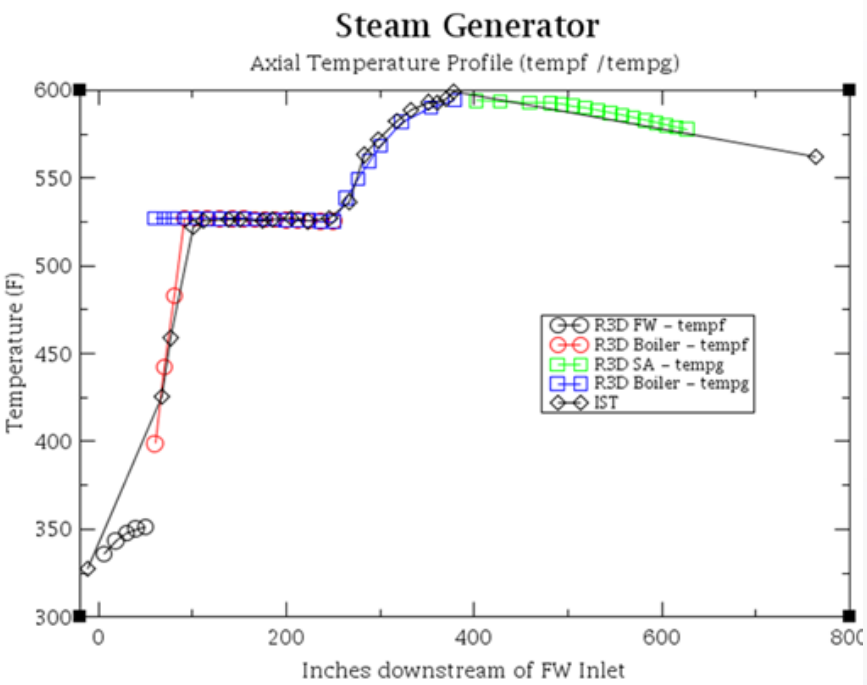
- 5’ above core, 4” Schedule 160 Stainless Steel Pipe
- 5” blind flange in the spillover region between steam generator, pressurizer, and riser.
- Convenient location for a variety of testing measurements or material investigations
- Steam test sections available throughout the steam system. Saturated through 80°F of superheat available depending on flow rate



IST Testing: SG & NC

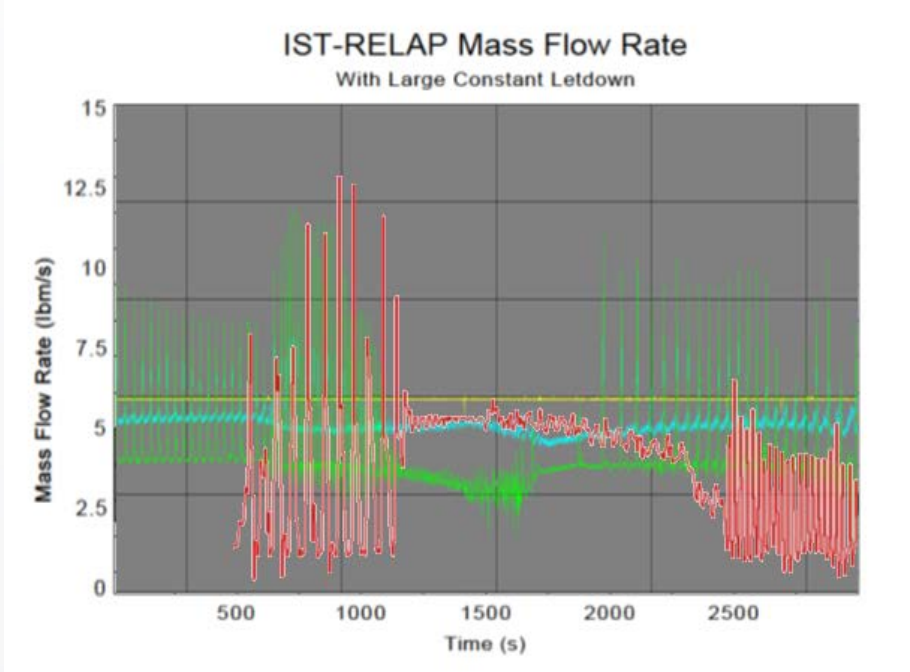
Steam generator heat transfer testing

- Plateaus from 20% to 120%
- Focus on superheat and shroud heat transfer
- IST RELAP 3D modeling of feed and steam temperatures



Natural circulation testing

- Steam created in core – carried over to IEOSTG – Condensed in SG tube.
- Water level reduced over time to show flow signature
- RCS flow: IST vs RELAP5



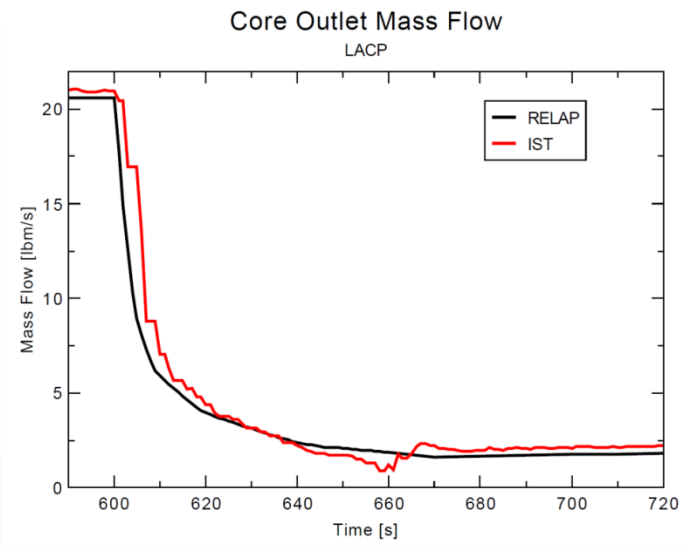
LWR/SMR Design Basis Events

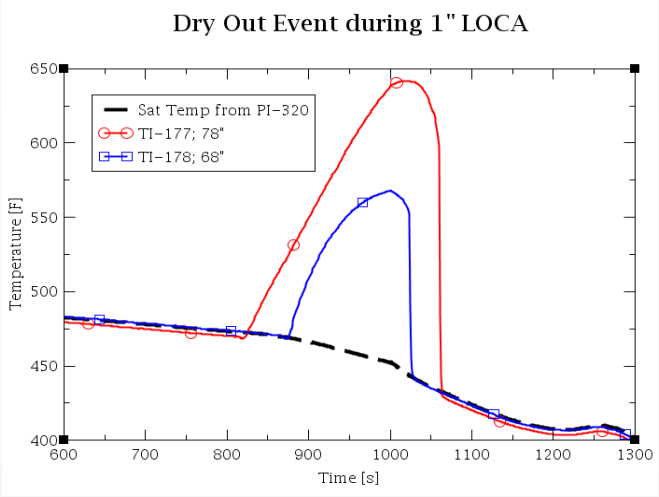
Loss of AC Power

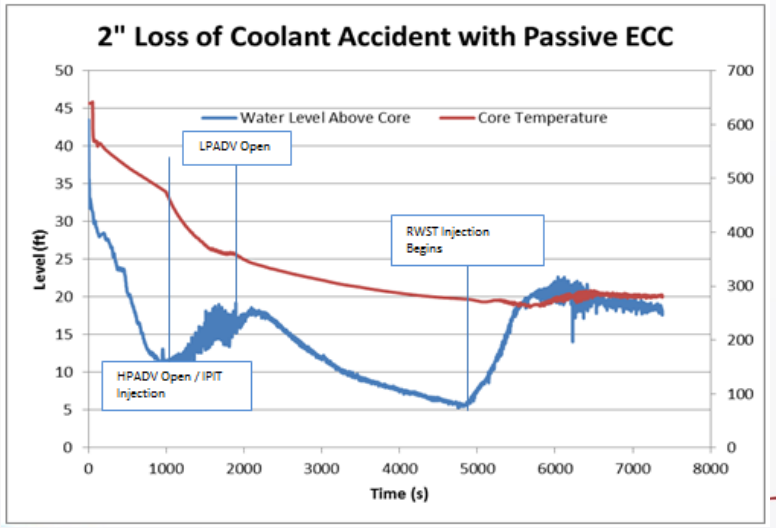
- IST reactor coolant pump variable frequency drive set to create flow coast down signal expected during a pump trip.

Loss of Coolant Accident

- 1” - 4.56” equivalent break sizes
- Utilized IST ECC HPADV and LPADV trains, IPIT injection and RWST injection







LWR/SMR Application Domain

Primary Side Conditions

- Pressure, < 2500 psia
- Temperature, < 630°F
- Void fractions, > 0%
- Mass flux, ~1000 lbm/s-ft^2
- Vessel water levels, < 70 ft
- LHGR, < 18 kW/ft
- Subcooling, < 40 °F

Containment

- Pressure, < 60 psig
- Temperature, < 250 °F

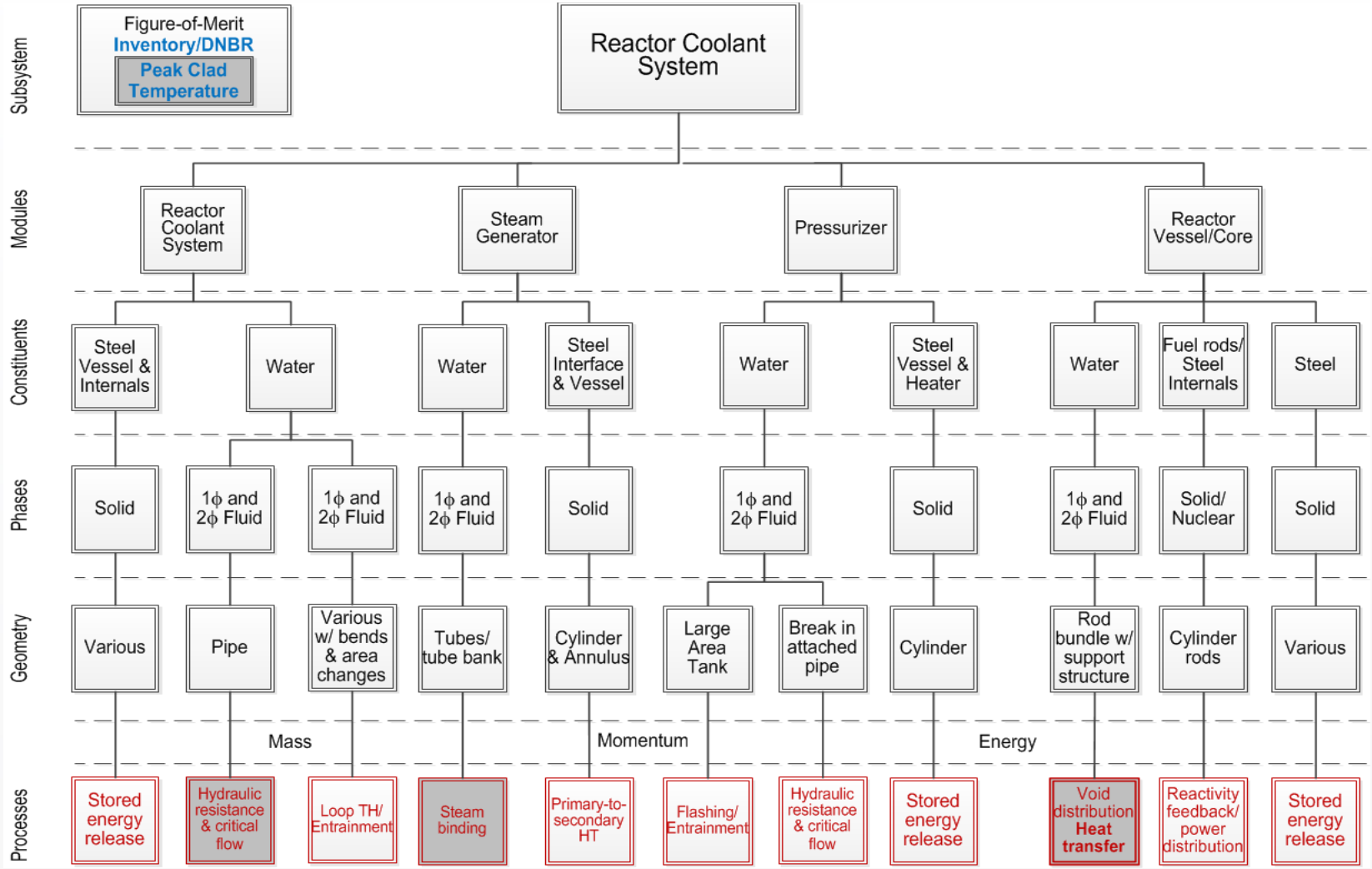
ECCS (active & passive)

- High Pressure, < 2300 psia
- Low Pressure, 15 – 650 psia
- Temperatures, 100 – 250 °F

Secondary Side Conditions

- Pressure, < 1200 psia
- Temperature, < 600°F
- Void fractions, < 100%
- Mass flux, ~100 lbm/s-ft^2
- Vessel water levels, > 0 ft
- LHGR, < 18 kW/ft
- Superheat, < 90 °F

Physics Requirements By Scale



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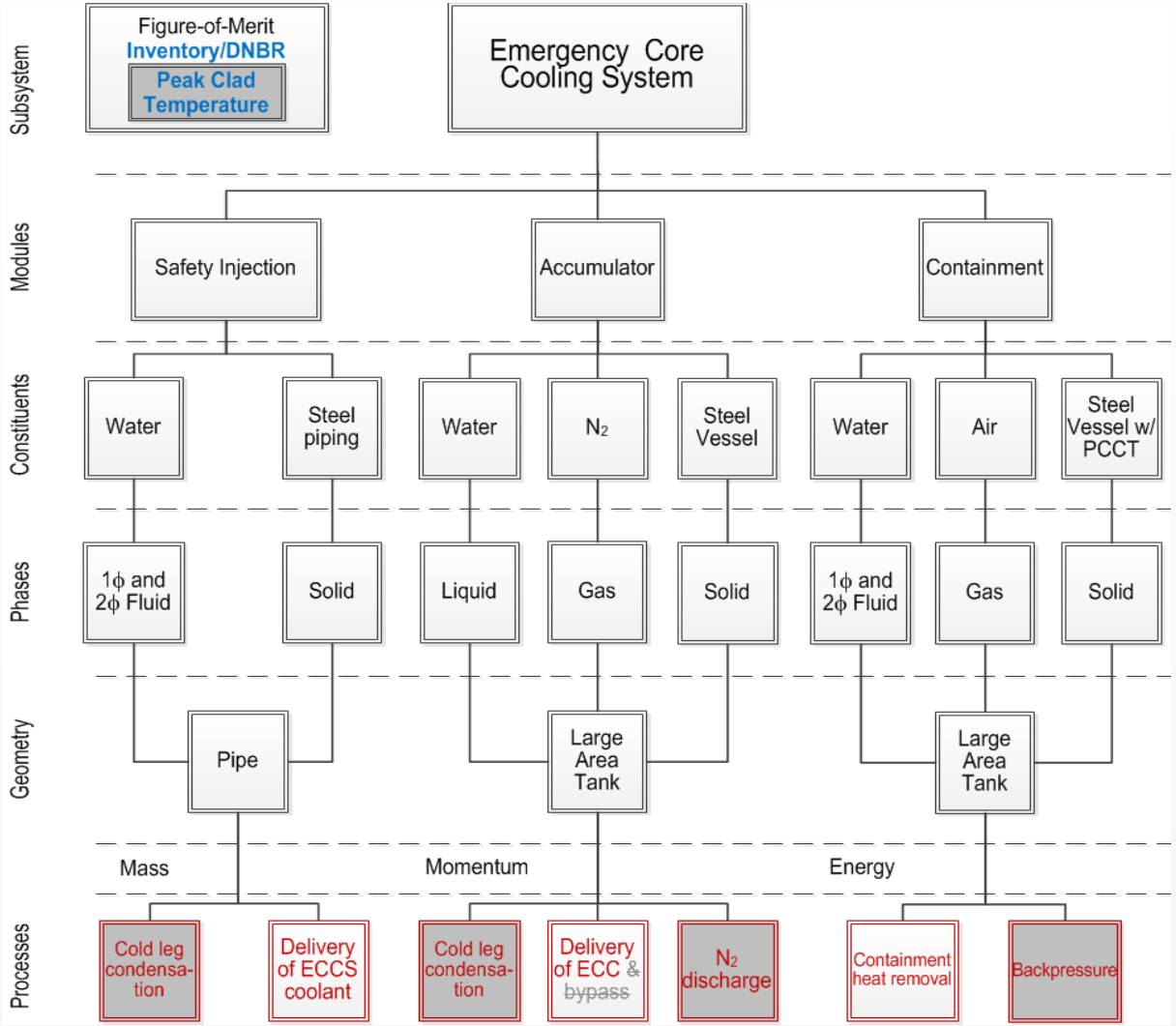

Other Process-scale Phenomena

Fluid-dynamics

- Pressure loss
- Turbulence and mixing
- Thermal stratification
- Flow instabilities
- Interfacial area
- Interphase forces
- Entrainment
- Cavitation
- Flow-induced vibration

Heat transfer

- Forced convection
- Natural convection
- Mixed convection
- Radiation
- Conduction
- Two-phase evaporation and condensation
- Boiling
- Thermal striping

Similarity Assessment

Geometry

Material

Power

Fluid

Energy Dissipation

Depressurization

Natural Circulation

Parameter	Simplified Formula (assuming matched fluid properties)
Characteristic core inlet velocity	$u_{co} = \left(\frac{\beta q_{co} L_{th} g}{\rho \cdot C_p \cdot \Pi}\right)^{1/3}$
Richardson number ratio	$Ri_R = \left($
Loop resistance scale ratio	$\Pi_{Fl_R} = \left[$
Loop energy scale ratio	$E_R = \left[\frac{(T$

Parameter	Simplified Formula (assuming matched fluid properties)
Phase change number ratio	$\Pi_{\mathrm{pch}_R} = \left(4q_o^{"} l_o\right)$
Subcooling number ratio	Π_{sub_R}
Froude number scale ratio	$Fr_R =$
Drift flux number scale ratio	$\Pi_{Nd_R} =$

Parameter	Simplified Formula (assuming matched fluid properties)
Stanton number ratio	$St_{i_R} = \left(\frac{h_{conv} l_o}{}\right.$
Conduction time number ratio	$T^*_{i_R}$
Biot number ratio	Bi_{i_R}
Heat source number ratio	$Q_{s_{i_R}}$

Parameter	Simplified Formula (assuming matched fluid properties)
Characteristic time ratio	$\Pi_{m,R} = \left[\frac{\Sigma G_{in} a_{in}}{\Sigma C_d G_{out} a_{brk}}\right]_R$
Dilation ratio	$\epsilon_{o_R} = \left\{\frac{P_o \left(\frac{\partial e}{\partial P}\right)_{v,o}}{\left[h_{out} - e + v\left(\frac{\partial e}{\partial v}\right)_P\right]_o}\right\}_R$
Energy flow ratio	$\Pi_{h,R} = \left\{\frac{\Sigma \dot{m}_{in,o}\left[h_{in} - e + v\left(\frac{\partial e}{\partial v}\right)_P\right]_o}{\Sigma \dot{m}_{out,o}\left[h_{out} - e + v\left(\frac{\partial e}{\partial v}\right)_P\right]_o}\right\}_R$
Power ratio	$\Pi_{\Gamma,R} = \left\{\frac{\dot{q}_{Net,o}}{\Sigma \dot{m}_{out,o}\left[h_{out} - e + v\left(\frac{\partial e}{\partial v}\right)_P\right]_o}\right\}_R$

Conclusions

- Preserved phenomena in the core region include:
  - Heat transfer correlations and relationships
  - Flow patterns and regimes that develop in the riser, between the riser, core bypass and core, and in the core
  - Water content of the boiling core
  - Water content in the riser above the core
  - Water level in the downcomer
- Preserved phenomena in the steam generator includes:
  - Heat transfer/Boiling effects associated with secondary water inventory
  - Condensation with and without non-condensable gases

Conclusions

- The IST is available to the DOE, NRC and industry
- IST can fulfill objectives for LWR testing and serve as a proving ground for emerging technologies
- Representative RELAP 5 3D model of the IST
- Adaptable DCS, DAS, and integral test loop for rapid changes based on testing/data requirements
- Verified data stream integrity
- Known scaling representation

Questions?

- Additional information, including contact information:

  www.caer-ist.org