Analysis of a Proposed Gas Test Loop Concept

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Outline of Presentation

- Gas Test Loop concept and configuration
- Objective of thermal hydraulic analysis
- Construction of RELAP5 model
  - General approach
  - System components
- Results
- Conclusions

Gas Test Loop (GTL) Concept

Provide high intensity fast-flux irradiation environment for testing fuels and materials for advanced concept nuclear reactors

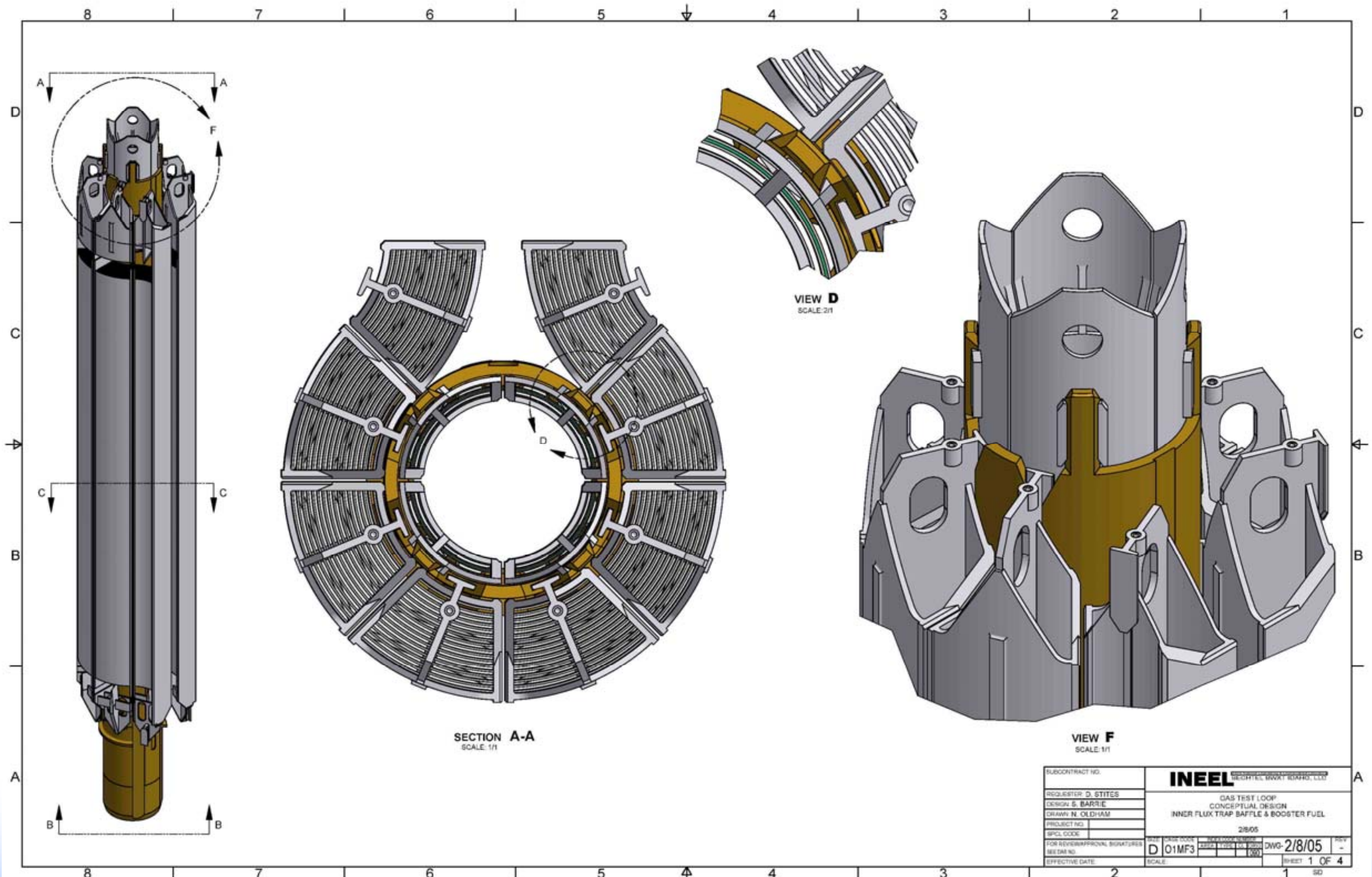
- Minimum neutron flux = 10^{15} n/cm^2·s
- Fast-to-thermal neutron ratio > 15

Use existing irradiation facility

- Northwest lobe of the Advanced Test Reactor (ATR) at the Idaho National Laboratory

Potential users include Generation IV Reactor Program, Advanced Fuel Cycle Initiative, and Space Nuclear Programs

GTL in the Advanced Test Reactor



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Proposed Design

Section I – Gas Loop

- Experiment tubes, instrumentation, neutron filters, spacers, helium coolant

Section II – Structural mid-section

- Pressure tube, envelope tube

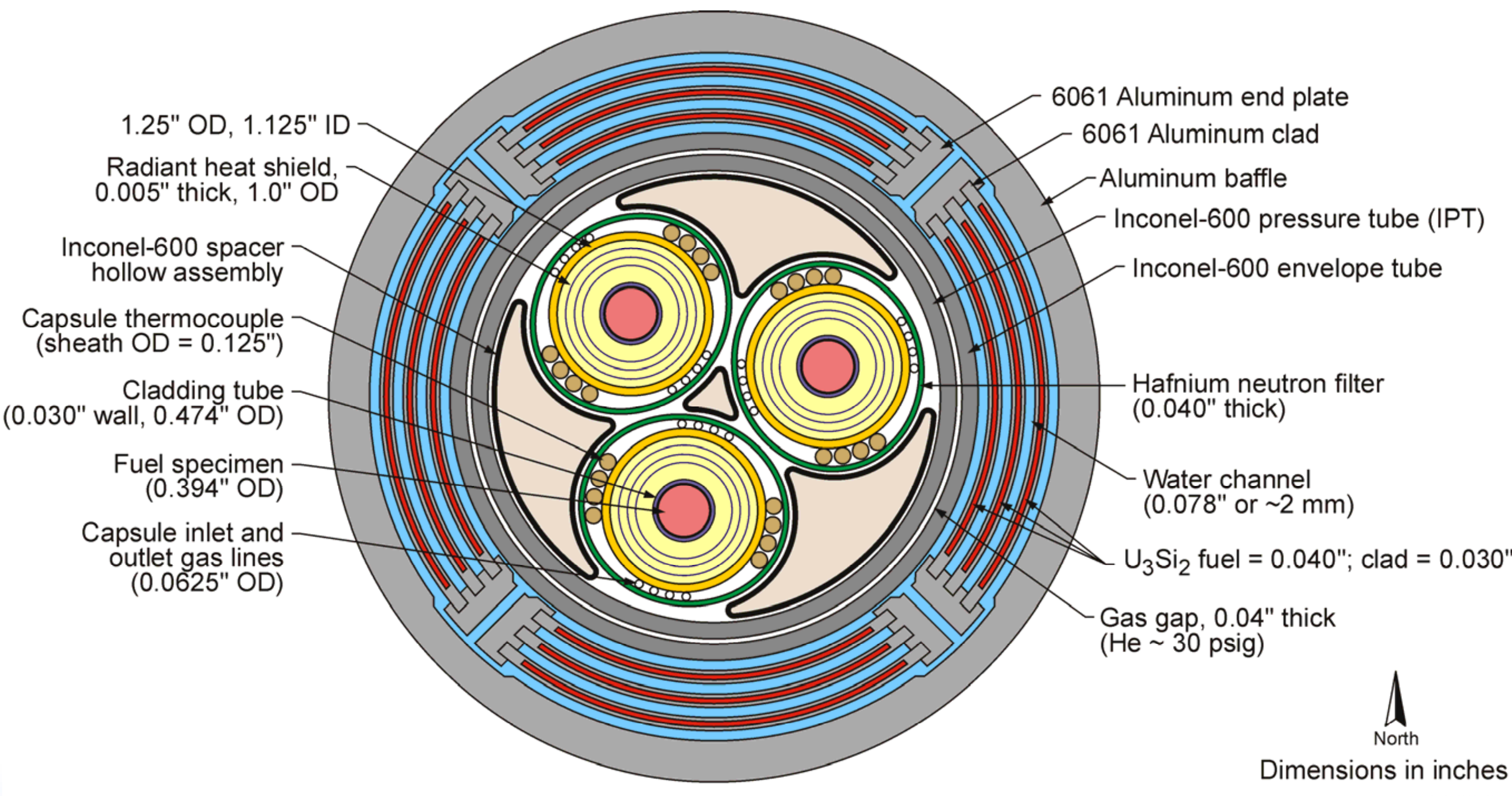
Section III – Booster fuel

- Three rings of U_3Si_2 fuel plates, water cooled

Features:

- Booster fuel to meet neutron flux requirement
- Neutron filters to attain fast-to-thermal ratio
- Gas cooling to avoid thermalizing the neutrons

Gas Test Loop Configuration



Objective of Thermal Hydraulic Analysis

Determine steady-state operating temperatures for the GTL conceptual design

- Examine design trade-offs, sensitivities

Once conceptual design is complete, analysis will be needed for changes to ATR safety basis

- GTL is considered a “major modification” to ATR

RELAP5 Model Construction

- Sketch a nodalization diagram of the heat structures, hydrodynamic volumes and junctions
- Create a reference table listing the components
- Use PYGI to obtain initial flow conditions
- Obtain heat loads from neutronic (MCNP) analysis
- Obtain hydraulic test data (i.e., K_e, K_o, flow rate, wall friction)
- Obtain cladding oxide layer surface roughness data

Section I – Gas Loop

Two parallel flow paths for flowing helium

- **Annular regions between experiment tubes and neutron filters**
  - $A_{020} = \pi(R_o^2 - R_i^2)$
  - $D_h = 2(R_o - R_i)$
- **Region outside of neutron filters and inside the pressure tube**
  - $A_{022} = A_{test} - A_{spacers} - 3A_{filter}$
  - $D_h = 4A_{022}/\Sigma P_w$

In-Pile Tube Parametrics

	Base Case	High Inlet Temperature	Low Flow Rate	High Inlet Temperature Low Flow Rate
Gas Inlet Temperature	51.7 ºC (125 ºF)	129.5 ºC (265 ºF)	51.7 ºC (125 ºF)	129.5 ºC (265 ºF)
Gas Pressure Drop	347 kPa (50.3 psid)	347 kPa (50.3 psid)	170.4 kPa (24.7 psid)	170.4 kPa (24.7 psid)
Experiment Tube Maximum Surface Temperature	363 ºC (687 ºF)	472 ºC (881 ºF)	506 ºC (943 ºF)	626 ºC (1158 ºF)
Filter Maximum Temperature	222 ºC (432 ºF)	319 ºC (606 ºF)	304 ºC (579 ºF)	391 ºC (735 ºF)
Gas Flow Rate	0.759 kg/s (6011 lbm/hr)	0.667 kg/s (5281 lbm/hr)	0.496 kg/s (3926 lbm/hr)	0.438 kg/s (3469 lbm/hr)
Pumping Power	113 kW (152 hp)	122 kW (163 hp)	37 kW (50 hp)	40 kW (54 hp)

Neutron Filters

A thin elliptical filter surrounds each of the 3 experiment tubes

- Modeled as circular cylindrical shells

Concern over hydrogen embrittlement of hafnium at filter temperatures > 300 ºC (572 ºF)

- May have to clad neutron filters (Inconel 600)

Two filter designs modeled:

1. 40 mil hafnium shell
2. 30 mil hafnium clad with 5 mils of Inconel 600

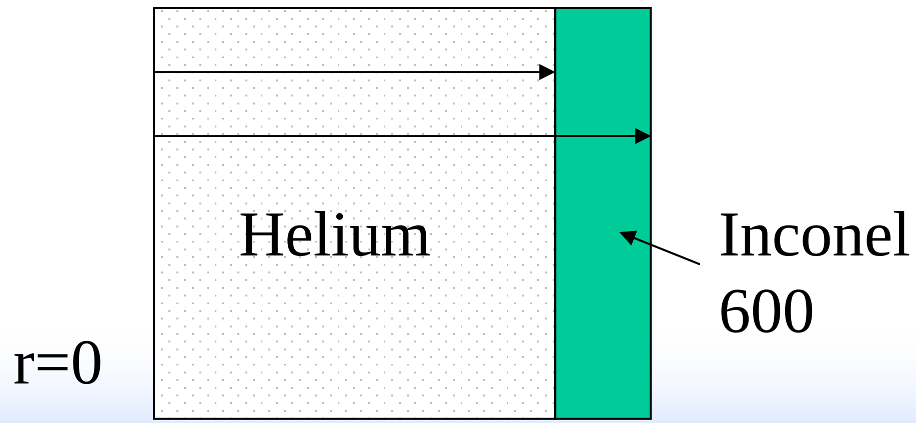
Spacers

Serve to reduce the flow area for the helium coolant

- Increase flow velocity
- Decrease volume pumped across test loop

Model as equivalent cylinders with same area

Stagnant helium inside Inconel 600 shell



Section II – Structural Mid-Section

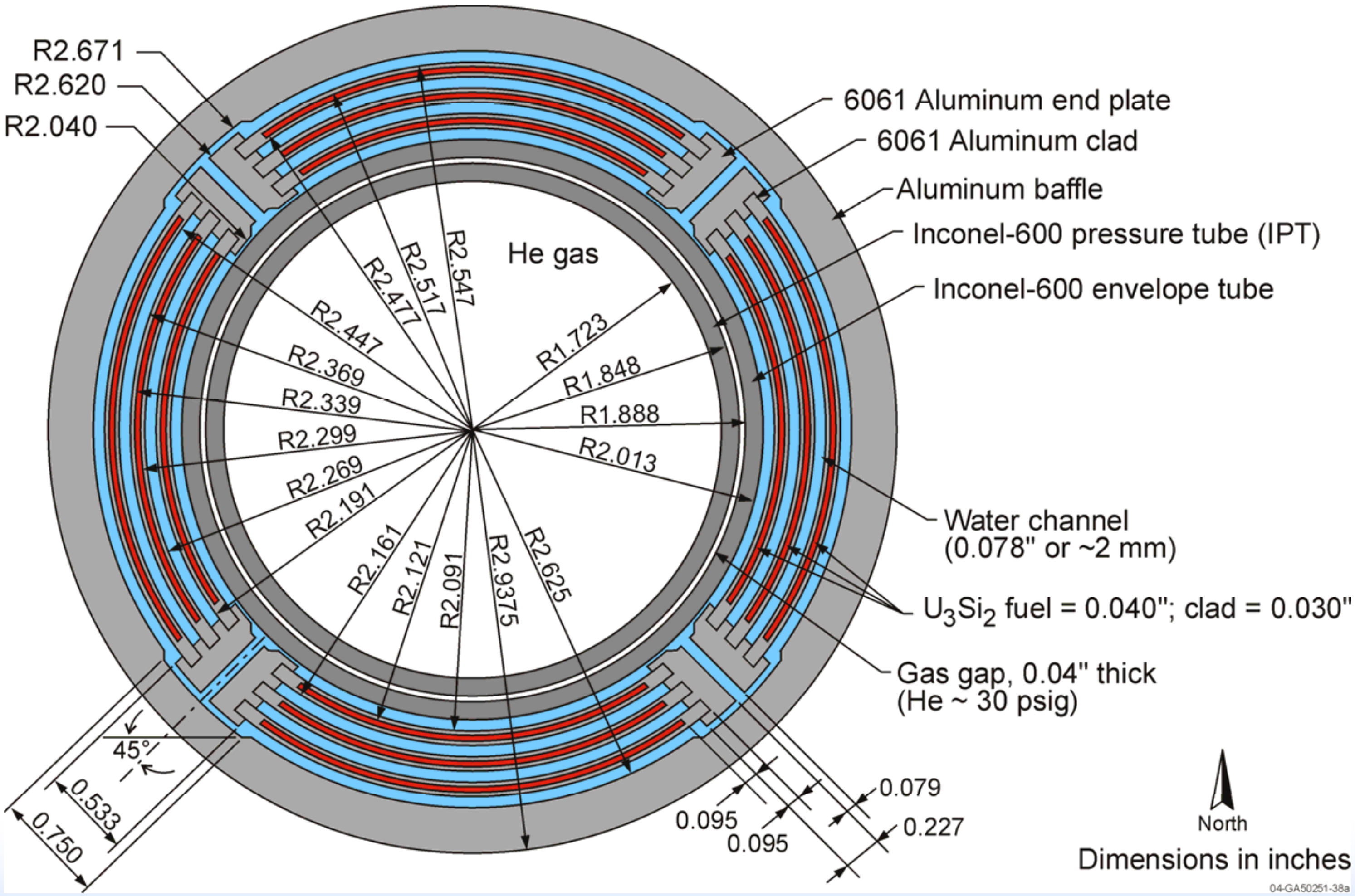
Pressure tube temperature limit is 800 ºF (ASME)

Small helium gap between pressure tube and envelope tube for leak detection monitoring

Lesson learned:

- On 1CCCG101 card, only use 1 node for heat structure mesh representing gas gap otherwise instabilities may result

Section III – Booster Fuel



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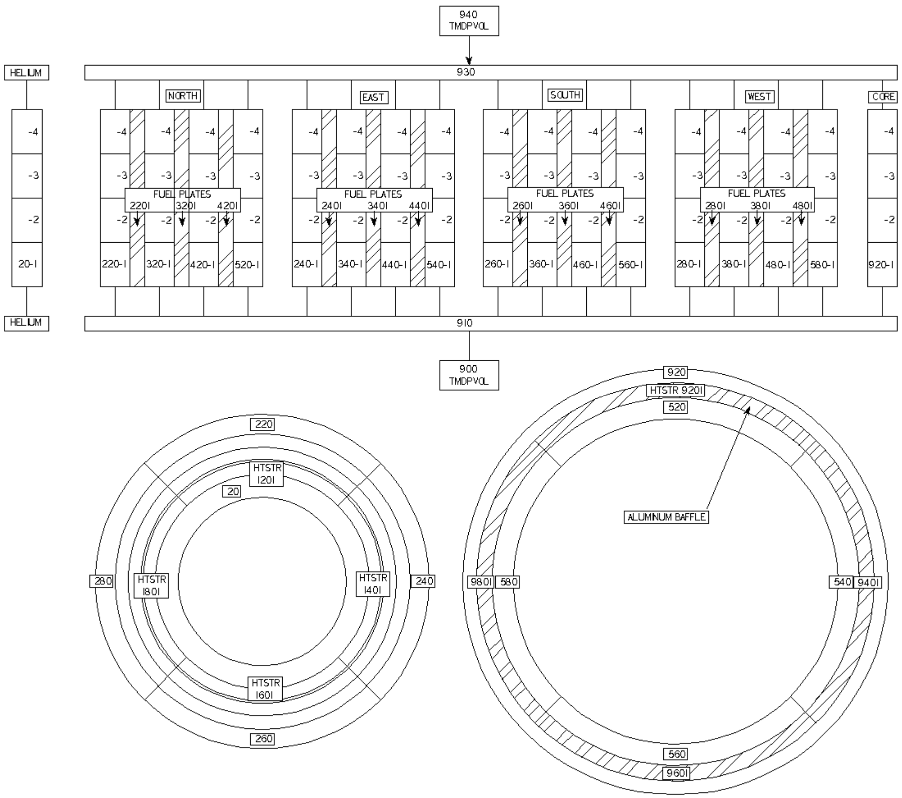
RELAP5 Nodalization

Can accommodate a non-uniform power (heat load)

- **4 axial segments**

0.165	4	flow ↓
0.315	3	
0.3275	2	
0.1925	1	



- **4 radial segments N, E, S, W**

Booster Fuel Design

Uranium silicide fuel clad with 6061 aluminum

- **Double-thick – 0.04” fuel meat/0.03” cladding**
- **4 ft long curved plates**

Model oxide layer on cladding surface

- **1.5 mils – ATR Safety Analysis**
- **2 µm – Conservative value based upon corrosion data**

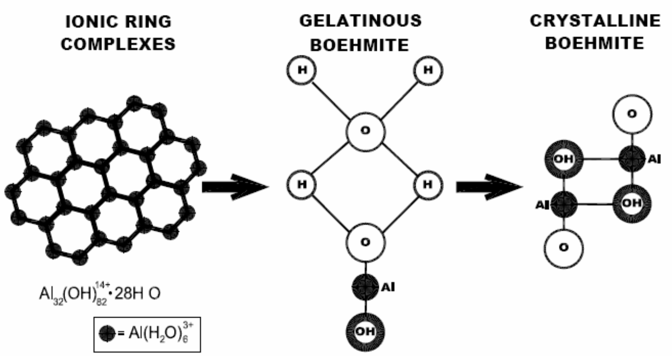
Corrosion of Aluminum Cladding

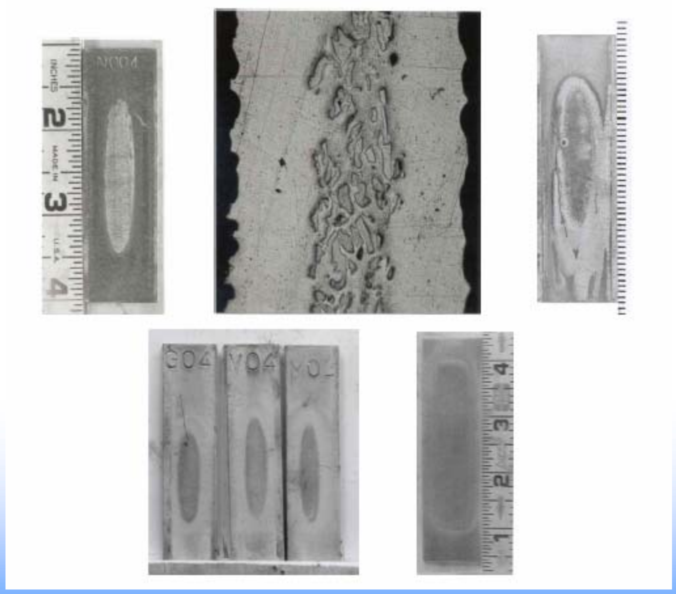
Formation of aluminum hydroxide in water

- Low thermal conductivity (2.25 W/m·K), acts as an insulator and increases fuel temperature
- Spalling of corrosion product

Pretreatment of fuel cladding with a very thin, highly crystalline layer of boehmite

- Minimizes the temperature differential across the hydroxide layer
- Eliminates spalling
- Precludes significant additional hydroxide layer growth during irradiation





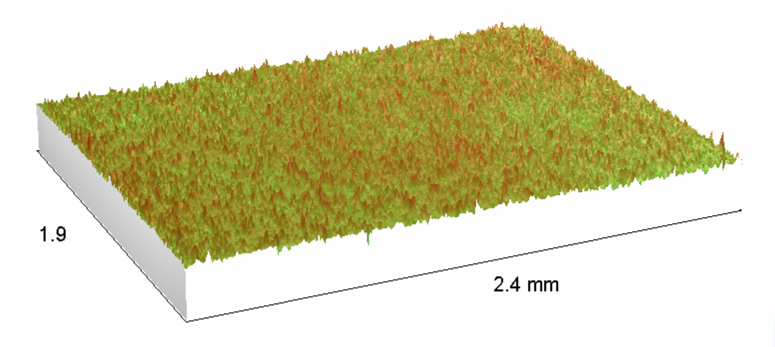
Surface Roughness of Boehmite Layer

Obtain roughness value from surface profilometry of aluminum coupon with boehmite coating

Coupon autoclaved with ATR fuel to produce coating

Coating thickness 0.00006” to 0.00030” (fuel spec)

- Wyco Model NT-1100 interferometer in VSI mode
- R_a ranges from 500 to 600 nm



Friction Factor Sensitivity Study

Compare the effects of various surface roughnesses

Use Zigrang-Sylvester correlation

material	smooth	ATR fuel	comm. steel	galv. iron
e (m)	3.96E-12	1.31E-06	4.57E-05	1.50E-04
e (ft)	1.30E-11	4.30E-06	0.00015	0.0005
e/Dh	1.00E-09	3.30E-04	0.01154	0.03786
f	0.016	0.019	0.044	0.064
Coolant temp.	385 K (233 ˚F)	388 K (240 ˚F)	417 K (291 ˚F)	439 K (330 ˚F)
Fuel centerline temp.	520 K (476 ˚F)	522 K (480 ˚F)	555 K (540 ˚F)	580 K (585 ˚F)
Fuel surface temp.	424 K (304 ˚F)	427 K (310 ˚F)	462 K (373 ˚F)	488 K (419 ˚F)
coolant velocity	14 m/s	13.3 m/s	9.3 m/s	7.3 m/s
coolant flow rate	580 gpm	552 gpm	386 gpm	303 gpm

Water Coolant Loop

Water coolant supplied by ATR primary coolant pumps

- **2 pump operation, ΔP=72 psi**

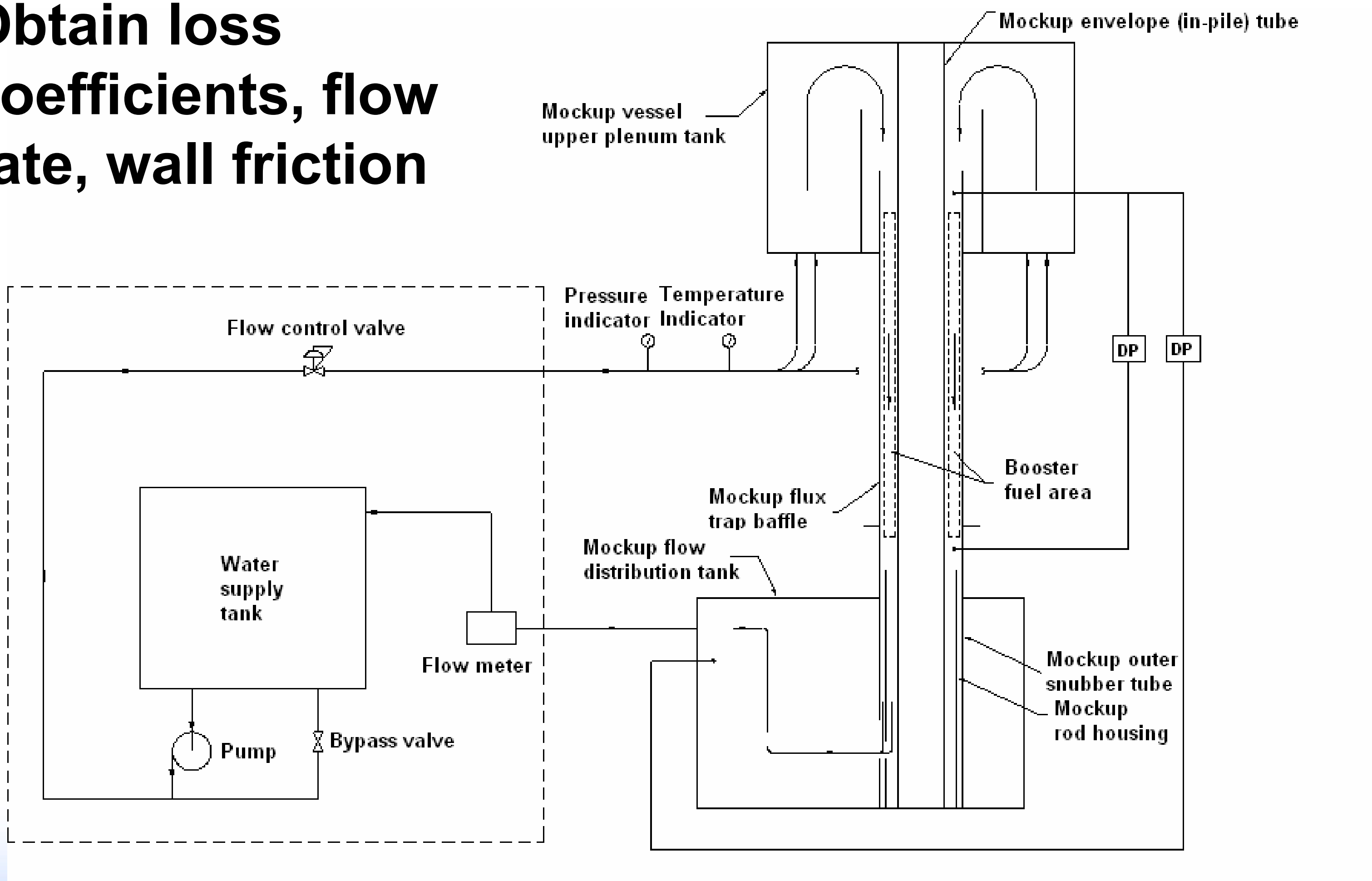
Static and dynamic instability assessed

Maintain sufficient Flow Instability Margin

$$\frac{T_{sat} - T_{inlet}}{T_{outlet} - T_{inlet}} > 2$$

GTL Flow Test Experiment

Obtain loss coefficients, flow rate, wall friction



Maximum Steady-State Temperatures

Input parameters:

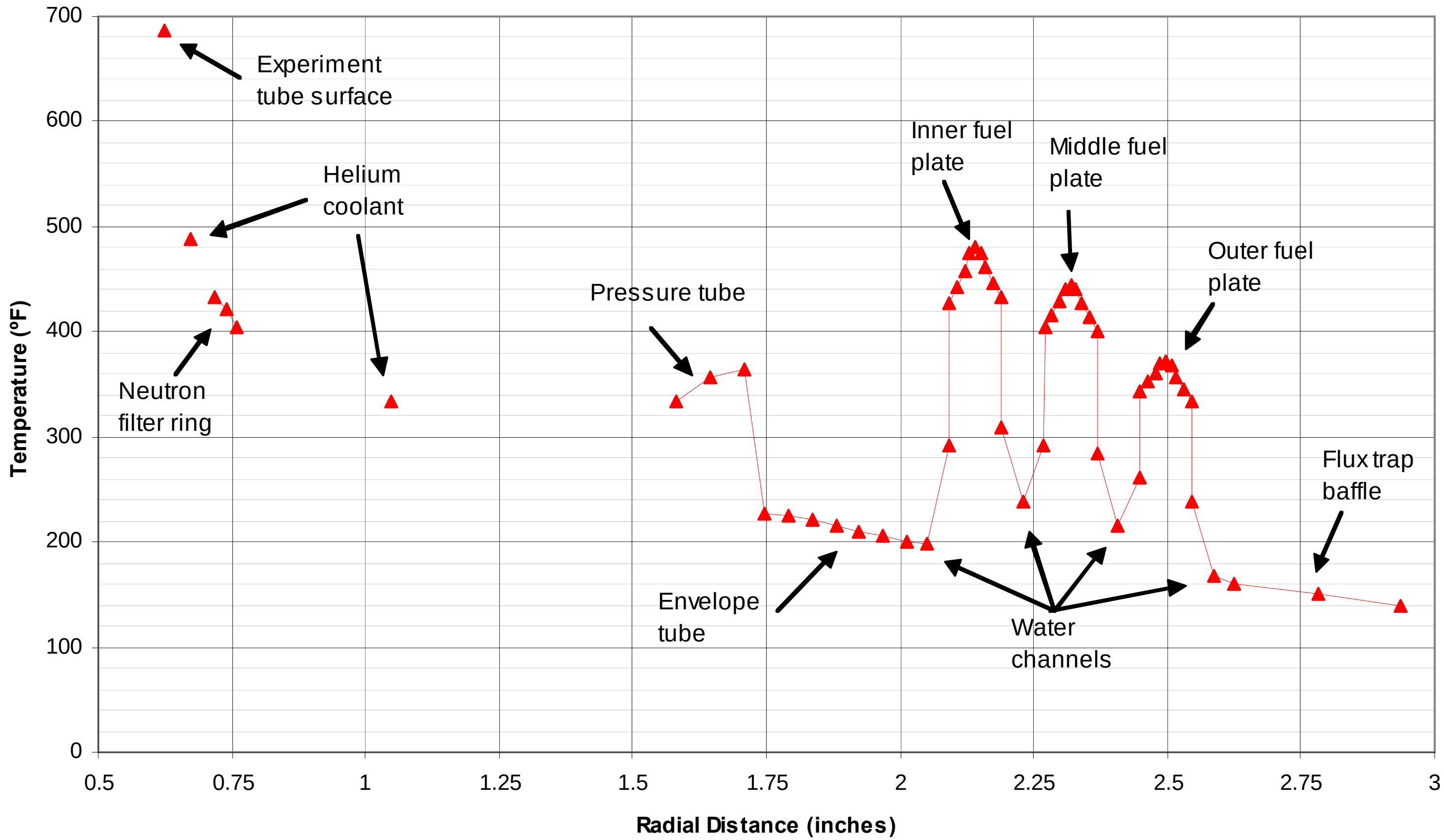
- Experiment heat load=225 kW
- 1.5 mil oxide layer
- e=1.31e-06 m
- Helium base case flow

Water coolant results:

- Highest coolant outlet temperature (388 K, 240 ºF) occurs between plates #1 and #2
- Flow instability margin = 2.7
- f_1=11 Hz, f_{fluid}=1100 Hz
- $V_{fluid} << V_{collapse}$

Heat Structure Component	Max. Temp.
Experiment Tube Surface	637 K (687 ºF)
Filler Block	429 K (313 ºF)
Neutron Filter	496 K (433 ºF)
Pressure Tube	458 K (365 ºF)
Booster Fuel	522 K (480 ºF)
Cladding Surface	427 K (310 ºF)
Baffle	346 K (163 ºF)

GTL Radial Temperature Profile



Conclusions

Proposed GTL design is feasible

- **Experiment tubes, filters and spacers can be adequately cooled by helium coolant**
- **Depending upon helium inlet conditions, neutron filters may require cladding**
- **Steady-state fuel and cladding temperatures are acceptable**
- **Static and dynamic stability of fuel plates assessed**
- **Sufficient flow instability margin**