Idaho National Laboratory

INL

RELAP5-3D Coolability Calculation for Irradiated, Dried Np/Pu Targets in Proposed Storage Rack Configuration

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2006 RELAP5 International Users Seminar

West Yellowstone, Montana

August 16-18, 2006

Pu-238 Consolidation Project

- ***Produce 5 Kg per year of Pu-238 Isotope***
- ***Fabricate Np-237 Targets for Irradiation in ATR***
- ***Ship Unirradiated Targets to and Receive Irradiated Targets from ATR***
- ***Dissolve Targets and Chemically Separate Np and Pu***
- ***Recover Np for Target Fabrication***
- ***Process Pu into Powder for shipment to LANL or a New Co-located Heat Source Fabrication Facility***
- ***Process Wastes into Form Suitable for Ultimate Disposal***

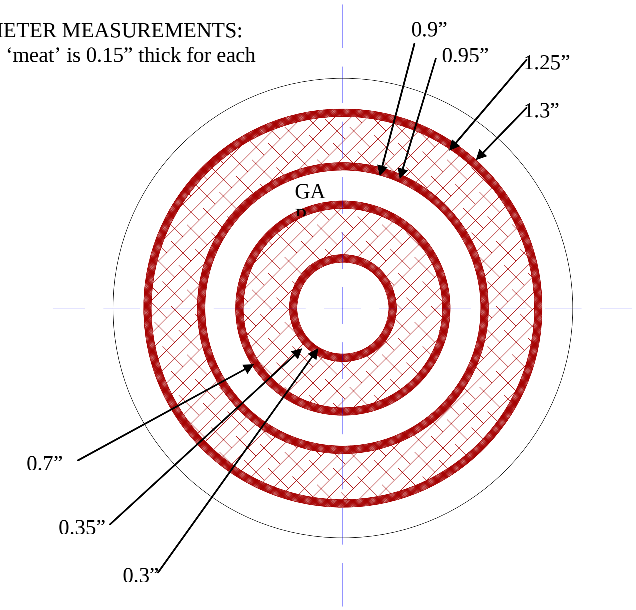
Purpose of Present Analysis

- ***Analysis Performed for Irradiated Targets***
- ***Targets Reside in Storage Rack in Hot Cell Awaiting Dissolution Process***
- ***Identify Storage Rack Cooling Requirements***
- ***Determine Whether Special Storage Rack Ventilation System Is Required***

Target Configuration

- ***Annular Target Concept***
- ***One- or Two-Ring Annular Targets***
- ***Three 16-inch Segments Stacked in ATR to 48-inch Total Length***
- ***26 watts/ft***
  - ***9 watts/ft (inner target)***
  - ***17 watts/ft (outer target)***

DIAMETER MEASUREMENTS:
So the 'meat' is 0.15" thick for each ring.



Outer Ring:
OD=1.3"; ID=0.9"; 0.025" wall inside and out
Inner Ring:
OD=0.7"; ID=0.3"; 0.025" wall inside and out

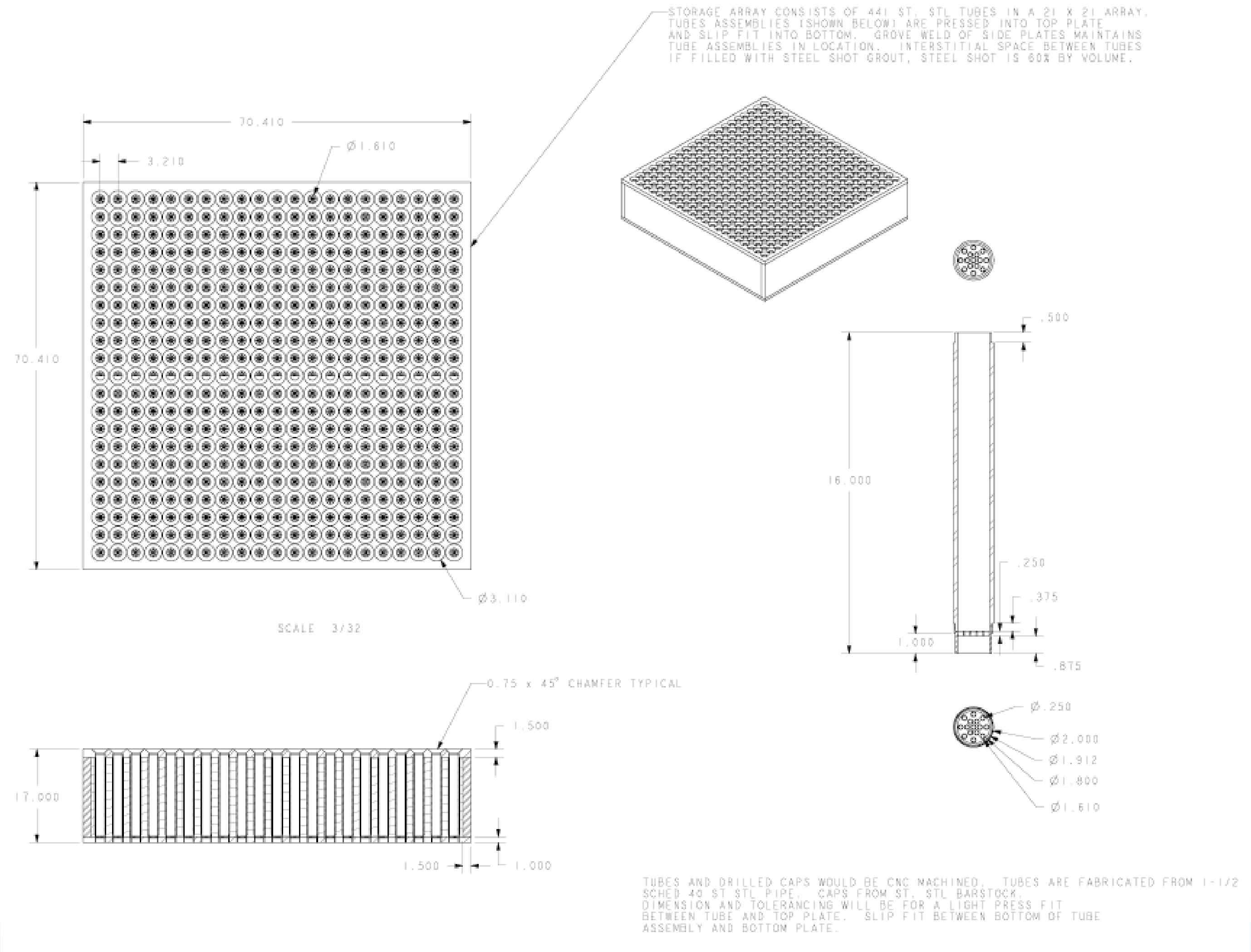
Material Properties

- ***"Meat" is Composite of NpO_2 Microspheres in Aluminum Matrix***
- ***Assumed Properties Similar to Presently-Used ATR Plate Fuel***
- ***Target Cladding is T6061 Aluminum***

Storage Rack Configuration

- ***Square Array of 31x31 Tubes***
- ***Tube-to-Tube Pitch = 3.21 inches***
- ***Tube OD = 2.0 inches***
- ***0.195-inch Wall***
- ***Drilled Bottom Cap***
  - ***15 Holes***
  - ***0.25-inch Diameter***
- ***Each Position Occupied by Either an Inner or an Outer Target (but not both)***
- ***Steel Shot Grout Occupies Interstitial Space Between Tubes***
  - ***Packing Specification is 60% Steel Shot by Volume***

Storage Rack Array Preliminary Design



Cooling Requirement

- ***Nominal Heat Load (Inner and outer targets divided equally among storage positions)***

$$Q_{total} = \frac{9W/ft + 17W/ft}{2\ positions} \cdot 1.33\,ft \cdot 961\,positions = 16.6\,KW$$

$$16.6\,KW \times 3.4121 \frac{Btu}{W \cdot Hr} = 56{,}700 \frac{Btu}{hr} \times \frac{1\,refrigeration - ton}{12{,}000\,Btu/hr} = 4.7\,refrigeration - ton$$

- ***Maximum Heat Load (All storage positions occupied by outer targets)***

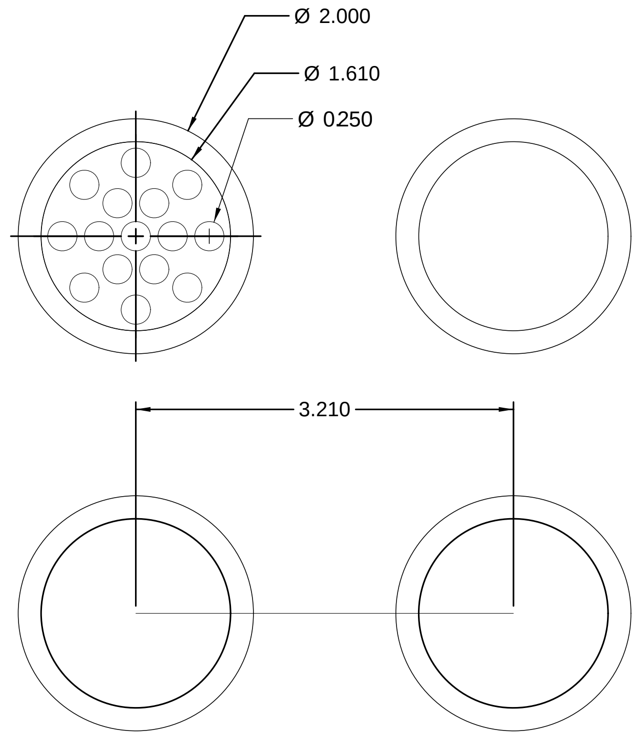
$$Q_{total} = \frac{17W/ft}{position} \cdot 1.33\,ft \cdot 961\,positions = 21.7\,KW$$

$$21.7\,KW \times 3.4121 \frac{Btu}{W \cdot Hr} = 74{,}100 \frac{Btu}{hr} \times \frac{1\,refrigeration - ton}{12{,}000\,Btu/hr} = 6.2\,refrigeration - ton$$

Np/Pu Target Thermal Limits

- ***Guideline Maximum Temperature 700 °F***
  - ***No Blistering Expected to Occur in Low-burnup ATR Fuel***
- ***Aluminum Melting Temperature 1180 °F***

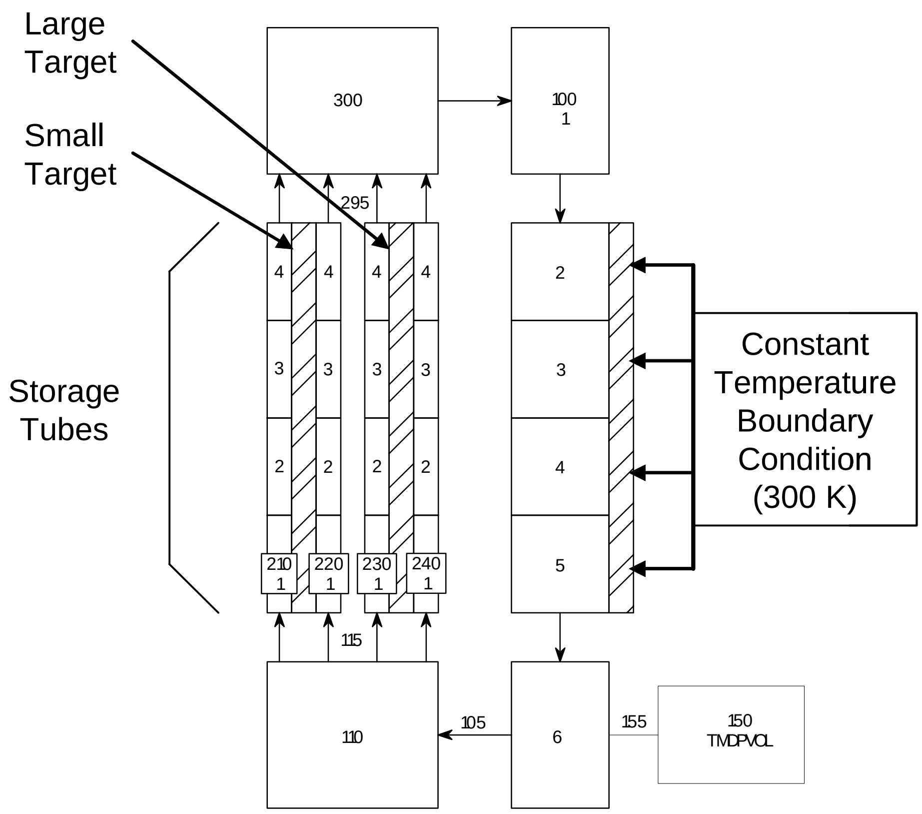
Arrangement of Four Storage Rack Tubes



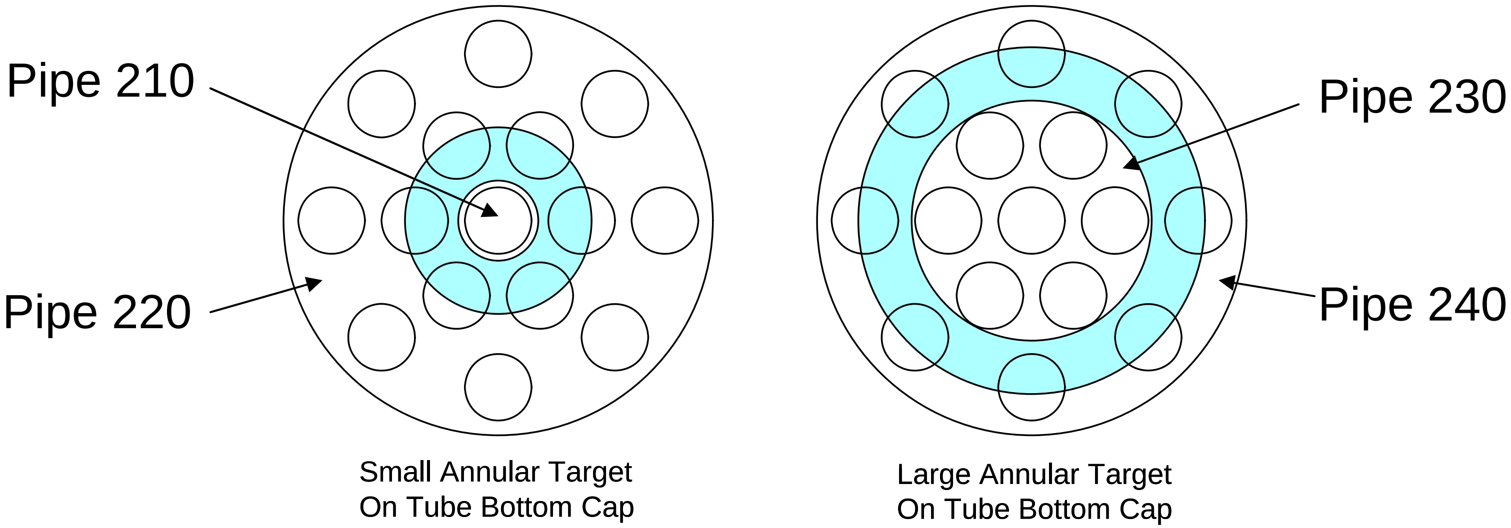
RELAP5 Modeling Assumptions

- *Rack Does Not Rest On Floor*
  - *Space Available Beneath Rack for Air to Enter Reasonably Unobstructed*
- *Two Storage Positions Represented*
  - *Small (inner) Annular Target*
  - *Large (outer) Annular Target*
  - *2 x 2 Parallel Flow Paths*
    - *Inner Cylindrical Channel*
    - *Outer Annular Channel*
- *Cooling Mechanism is Natural Convection in Air*
  - *No credit for Radiation/Convection to Storage Tube or External Cooling of Storage Tube Via Cooling of Steel Shot Grout*

RELAP5 Model of Two Storage Rack Tubes



Partial Inlet Flow Obstruction At Storage Tube Bottom Cap

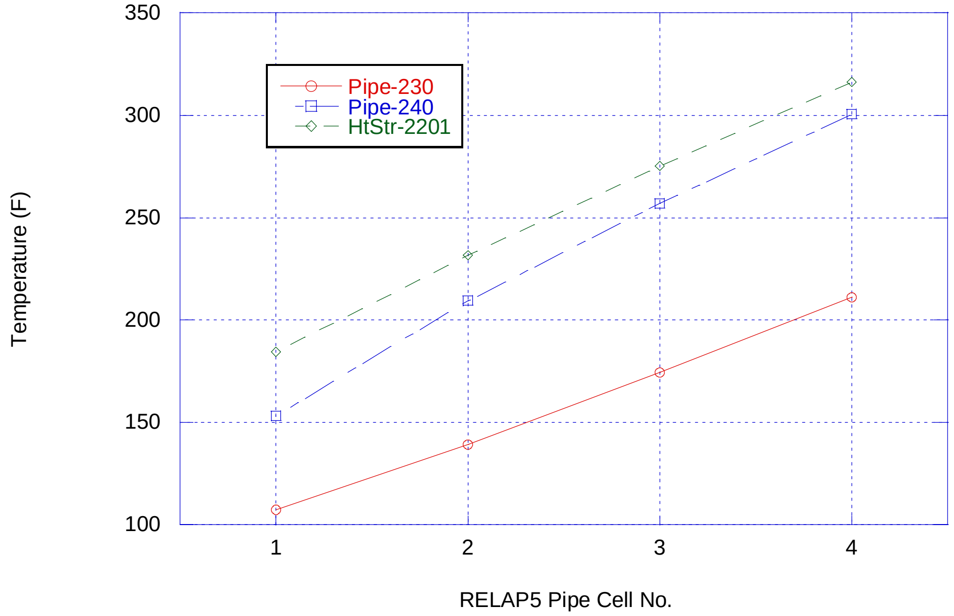


Pathway	Effective Number of Holes Contributing to Available Flow Area
Inner Channel Small Target	1
Outer Channel Small Target	8
Inner Channel Large Target	7
Outer Channel Large Target	3

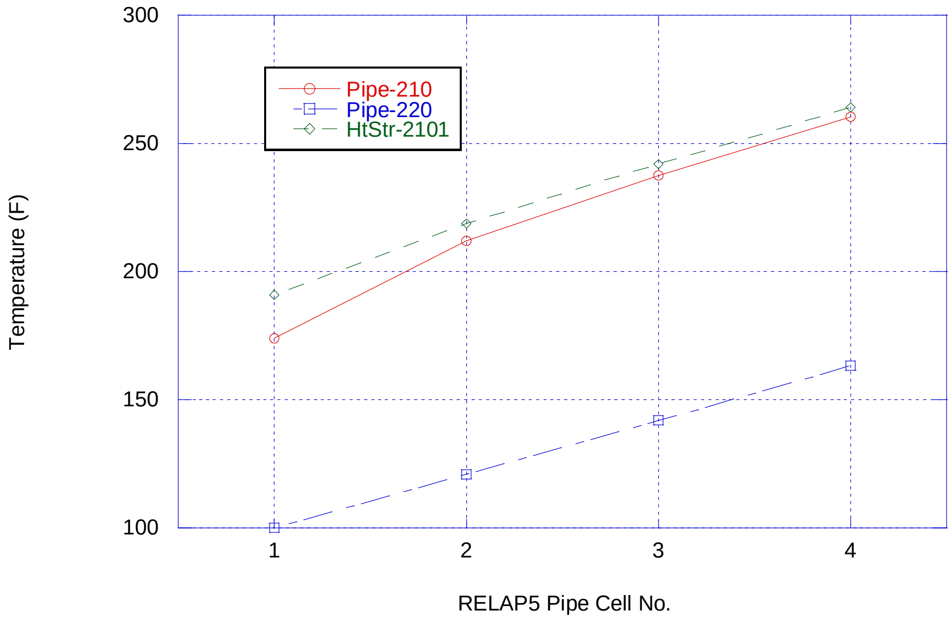
Initial RELAP5 Calculation Used Default RELAP5 Convection Heat Transfer Logic

- ***Forced Turbulent Convection***
  - ***Dittus-Boelter***
- ***Forced Laminar Convection***
  - ***Sellars, Tribus, Klein (Nu = 4.36)***
- ***Natural Convection***
  - ***Churchill-Chu (vertical geometry)***
- ***Code Uses Maximum of the Three***

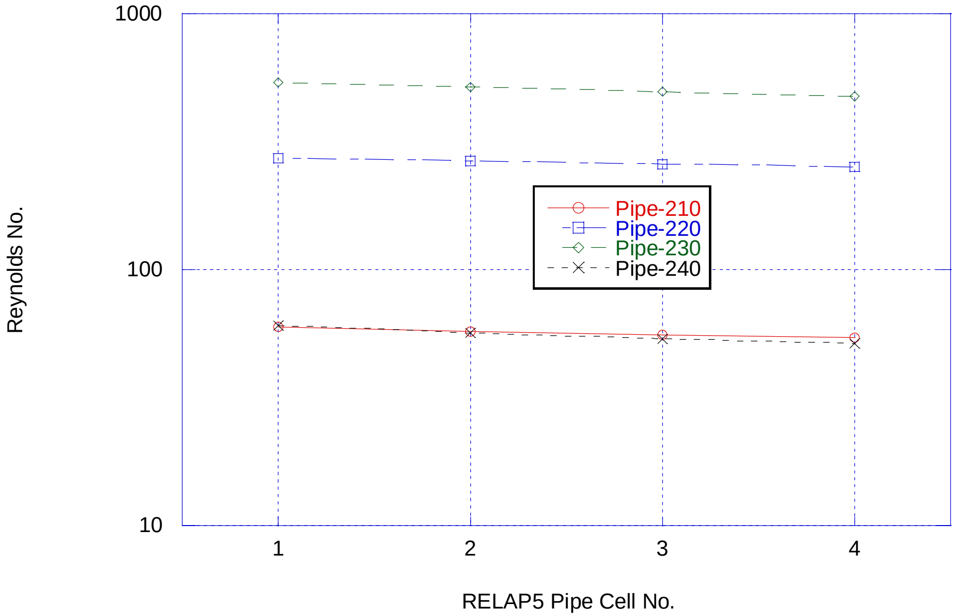
Axial Temperature Along Channel with Large Annular Target (Initial Calculation)



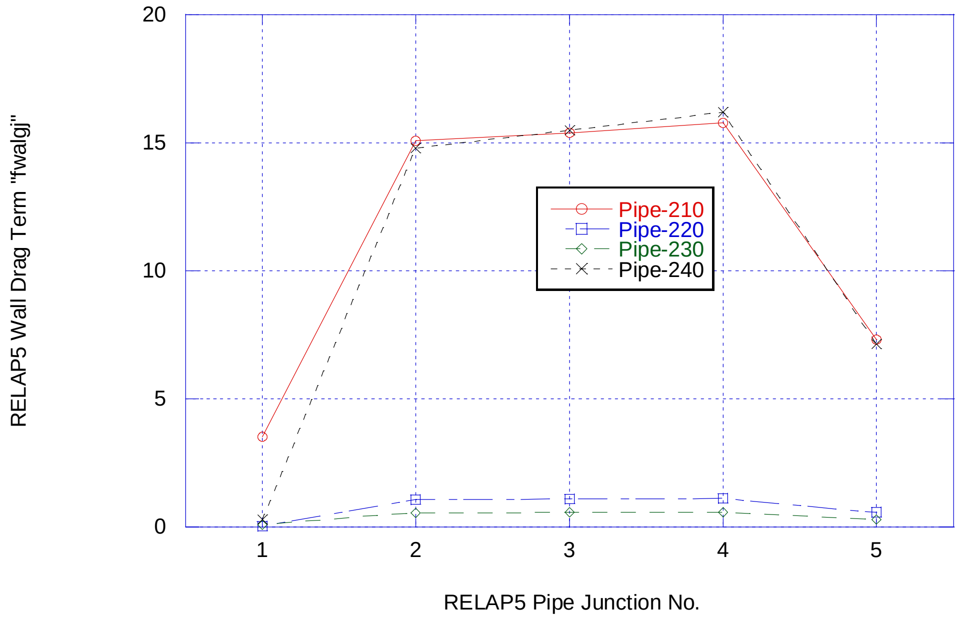
Temperatures Along Channel With Small Annular Target (Initial Calculation)



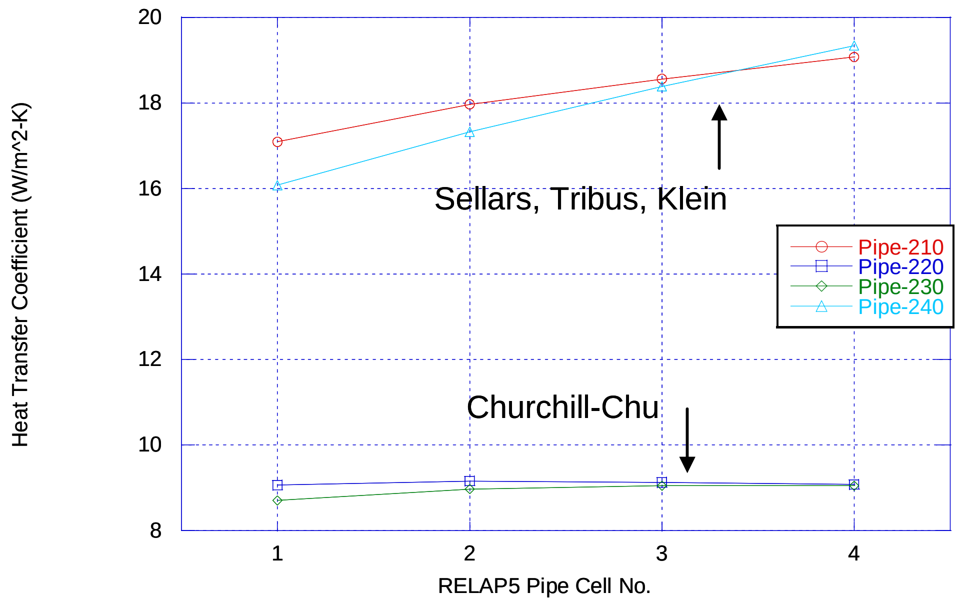
Reynolds Numbers Along RELAP5 Channels (Initial Calculation)



Wall Drag Applied to Junctions Along RELAP5 Channels (Initial Calculation)



Heat Transfer Coefficients Along RELAP5 Channels (Initial Calculation)



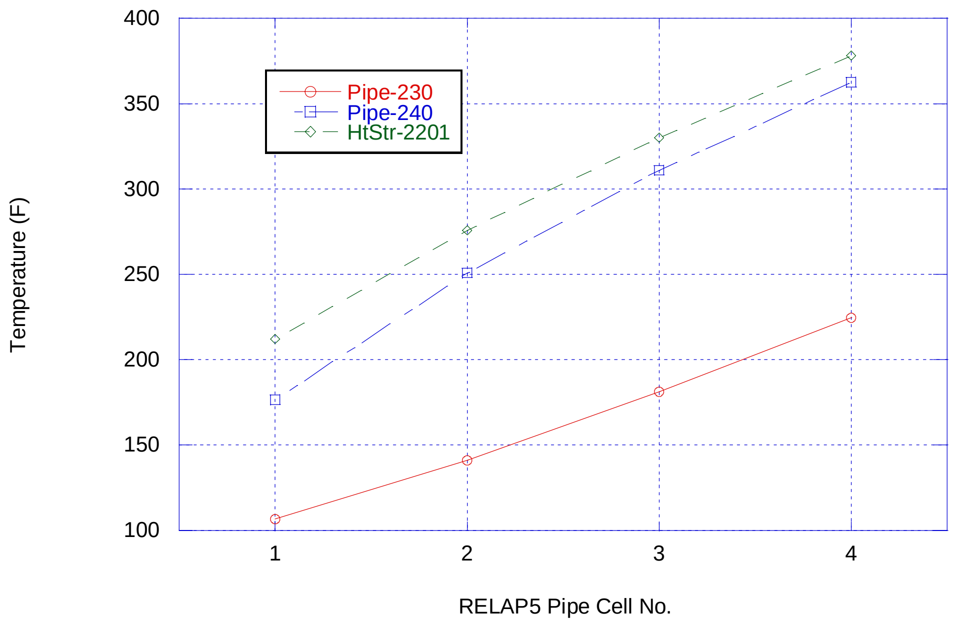
Results of Initial RELAP5 Calculation (1 of 2)

- Hydraulic Diameter of Large Channels ~0.023 m
- Hydraulic Diameter of Small channels ~0.007 m
  - Higher Wall Friction
  - Lower Reynolds Number
- Maximum Target Temperature
  - 316 °F on Large Annular Target
  - 264 °F on Small Annular Target
  - Maximum Target Temperature Rise 236 °F Over Ambient
- Large Annular Target Heat Load Evenly Split Between Channels
  - 13.7 W (60%) to Inner Cylindrical Channel
  - 8.9 W (40%) to Outer Annular Channel
- Small Annular Target Heat Load Predominantly to Outer Channel
  - 11.2 W (93%) to Outer Annular Channel
  - 0.8 W (7%) to Inner Cylindrical Channel

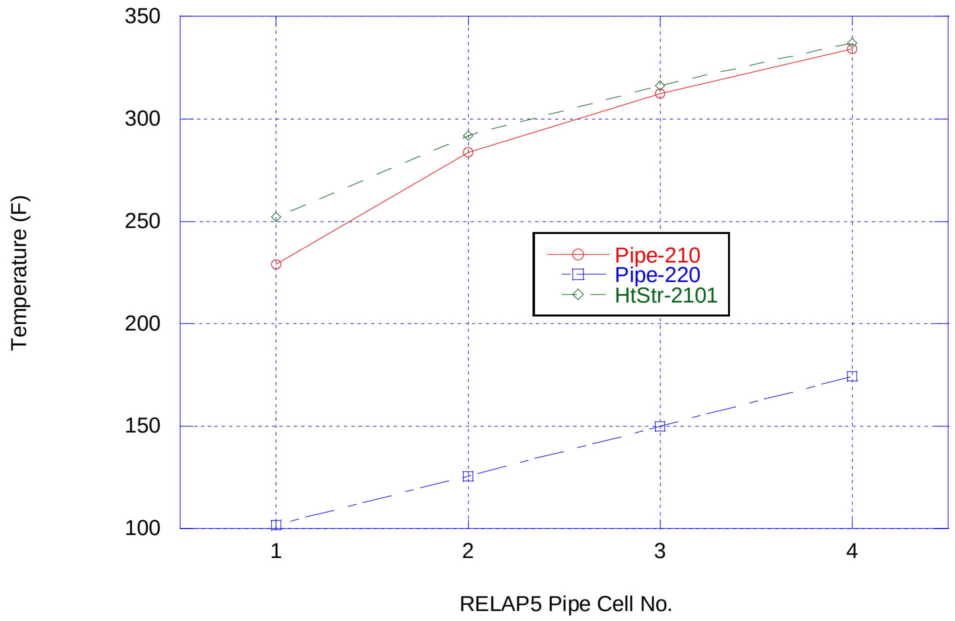
Results of Initial RELAP5 Calculation (2 0f 2)

- ***Sellars, Tribus, Klein Selected by Code for Pipes 210 and 240 (Small Flow Area Channels)***
  - *Sellars, Tribus, Klein Heat Transfer Coefficient ~16-19 W/m^2/K*
- ***Churchill-Chu Selected by Code for Pipes 220 and 230 (Large Flow Area Channels)***
  - *Sellars, Tribus, Klein Heat Transfer Coefficient ~5 W/m^2/K*
  - *Churchill-Chu Heat Transfer Coefficient ~9 W/m^2/K*
  - *Churchill-Chu Applicable to Vertical Flat Plate Geometry*
  - *Churchill-Chu Probably Not Applicable to Vertical Annular Geometry*
- ***Modify RELAP5 to Lock Out Churchill-Chu***

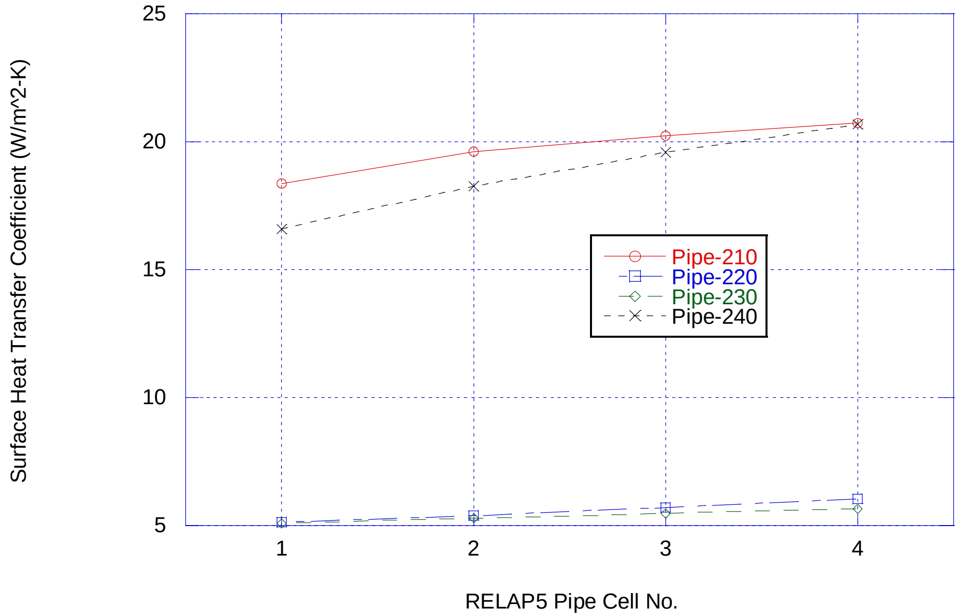
Axial Temperatures Along Channel With Large Annular Target (Modified Code)



Axial temperatures along Channel With Small Annular Target (Modified Code)



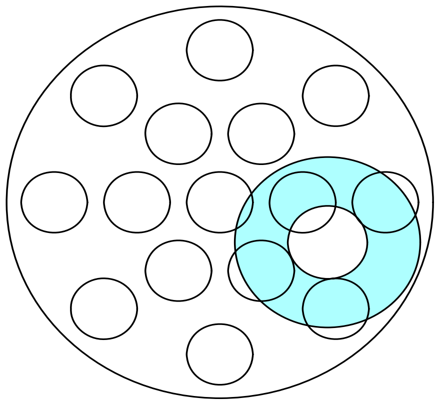
Heat Transfer Coefficients along RELAP5 Channels (Modified Code)



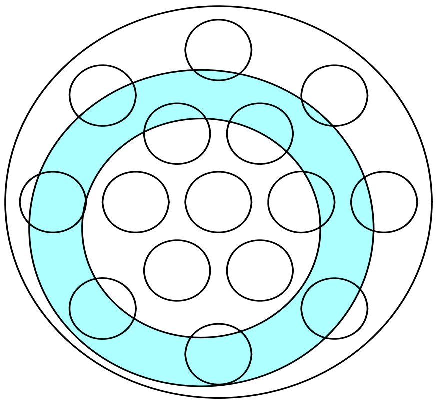
Results of Calculations With Modified Code

- ***Maximum Target Temperature***
  - *378 °F on Large Annular Target*
  - *330 °F on Small Annular Target*
  - *Maximum Target Temperature Rise 300 °F Over Ambient*
- ***Large Annular Target Heat Load Evenly Split Between Channels***
  - *13.7 W (54%) to Inner Cylindrical Channel*
  - *8.9 W (46%) to Outer Annular Channel*
- ***Small Annular Target Heat Load Predominantly to Outer Channel***
  - *11.0 W (92%) to Outer Annular Channel*
  - *1.0 W (8%) to Inner Cylindrical Channel*

Unfavorable Position of Targets over Storage Tube Bottom Cap (Assume 99% Flow Blockage of Small Target Inner Channel)

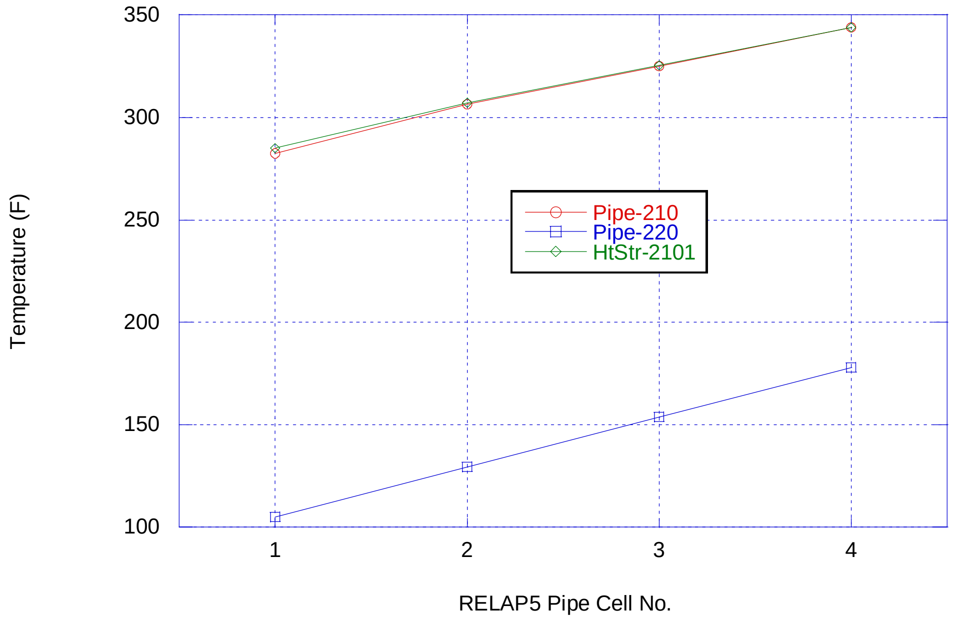


Small Annular Target
On Tube Bottom Cap



Large Annular Target
On Tube Bottom Cap

Axial Temperature Along Tube With Small Annular Target (99% Inlet Flow Blockage)



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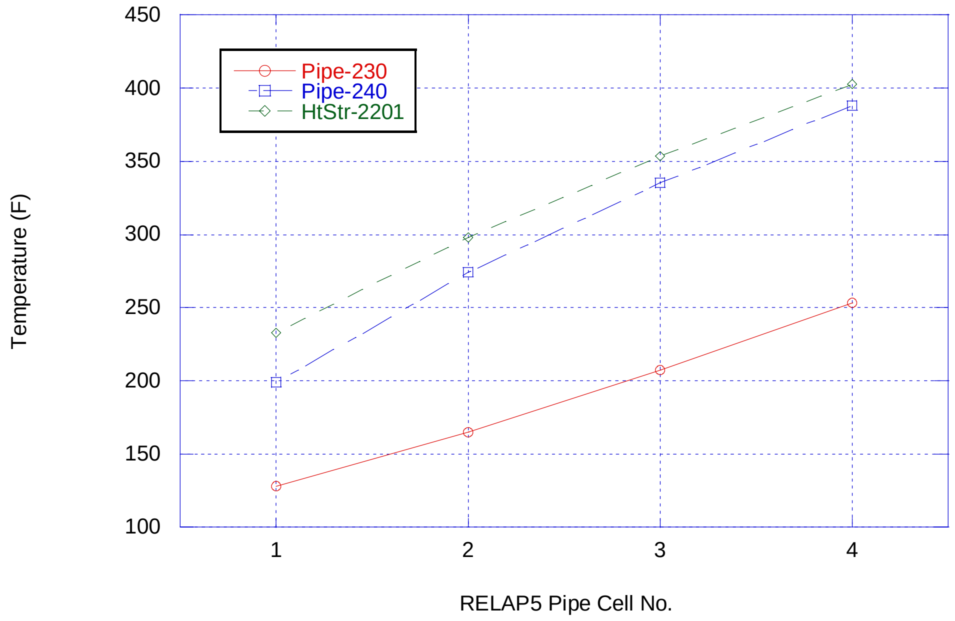
Axial Temperatures Along Channel With Large Annular Target (Modified Code And 100 ºF Ambient Temperature)



Results of Additional Sensitivity Calculations

- ***Flow Blockage of Small Annular Target Inner Channel***
  - ***12.0 W (100% of Heat Load) to Outer Annular Channel***
  - ***Maximum Target Temperature 344 °F***
- ***Significant Flow Blockage of Remaining Channels Not Credible From Geometry Considerations***
- ***Ambient Hot Cell Temperature 100 °F***
  - ***Maximum Temperature (Large Annular Target) 402 °F***

Conclusions

- ***Maximum Additional Building Heat Load 6.2 Refrigeration-Tons With Fully Loaded Storage Rack***
- ***Maximum Np/Pu Target Temperature From RELAP5***
  - *378 °F with 80 °F Room Ambient Temperature*
  - *402 °F with 100 °F Room Ambient Temperature*
  - *Temperatures Significantly Below Limits*
- ***Churchill-Chu Heat Transfer Probably Not Applicable to Vertical Annulus Geometry***
  - *Code Modified to Force Selection of Sellars, Tribus, Klein At Low Reynolds Number*
- ***Natural Circulation Cooling Adequate to Limit Target Temperatures to Within Acceptable Limits***
  - *Sufficient Space Below Rack Required For Natural Circulation*
  - *Storage Rack Ventilation System Not Required*