AREVA's Activities Related to VHTR Thermal-Hydraulic Analysis Using RELAP5-3D

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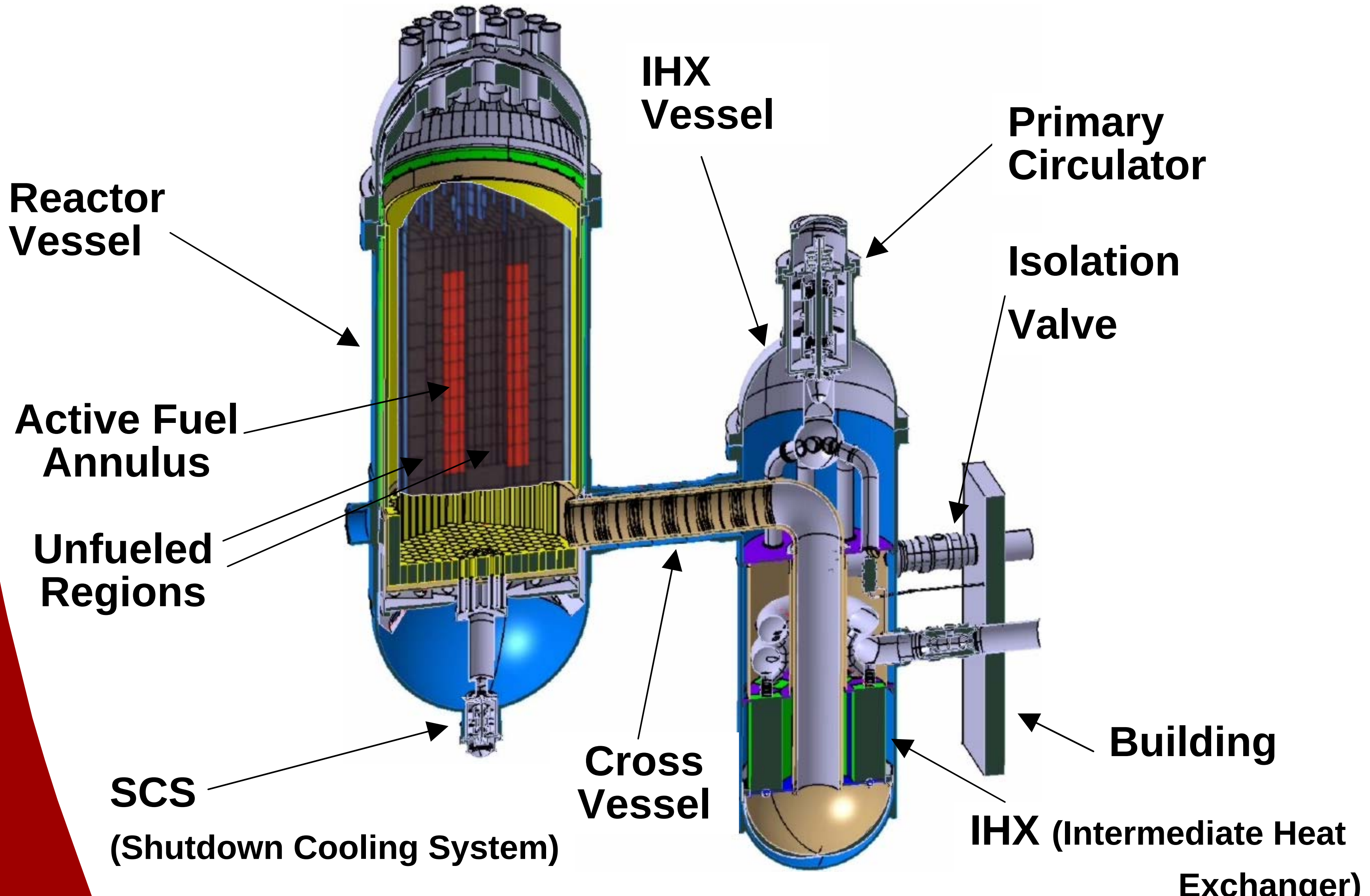
Introduction & Objectives

- **Tasks:**
  - **Evaluate RELAP5-3D for VHTR Analyses**
  - **Provide backup/validation tool for MANTA**
- **Pursuing CSAU-like methodology approach**
  - **Develop analysis-based PIRTs (Nov. 2004).**
    - starting from Wilson, et. al., NED, 1992.
  - **Confirm adequate models and modelling necessary to capture dominant TH phenomena**
  - **Identify models/methods necessary to complete VHTR analysis, Recent meeting July 2006**

Design Description

- **_Prismatic core_**
  - **_Graphic moderator_**
  - **_Stacked fuel/graphic compact (no metal)_**
  - **_Low Power Density_**
  - **_1000 C outlet temperature (600 C core delta)_**
- **_Indirect cycle_**
  - **_Brayton cycle_**
  - **_Cogeneration for hydrogen production_**

Design Schematic - Pressure Vessels

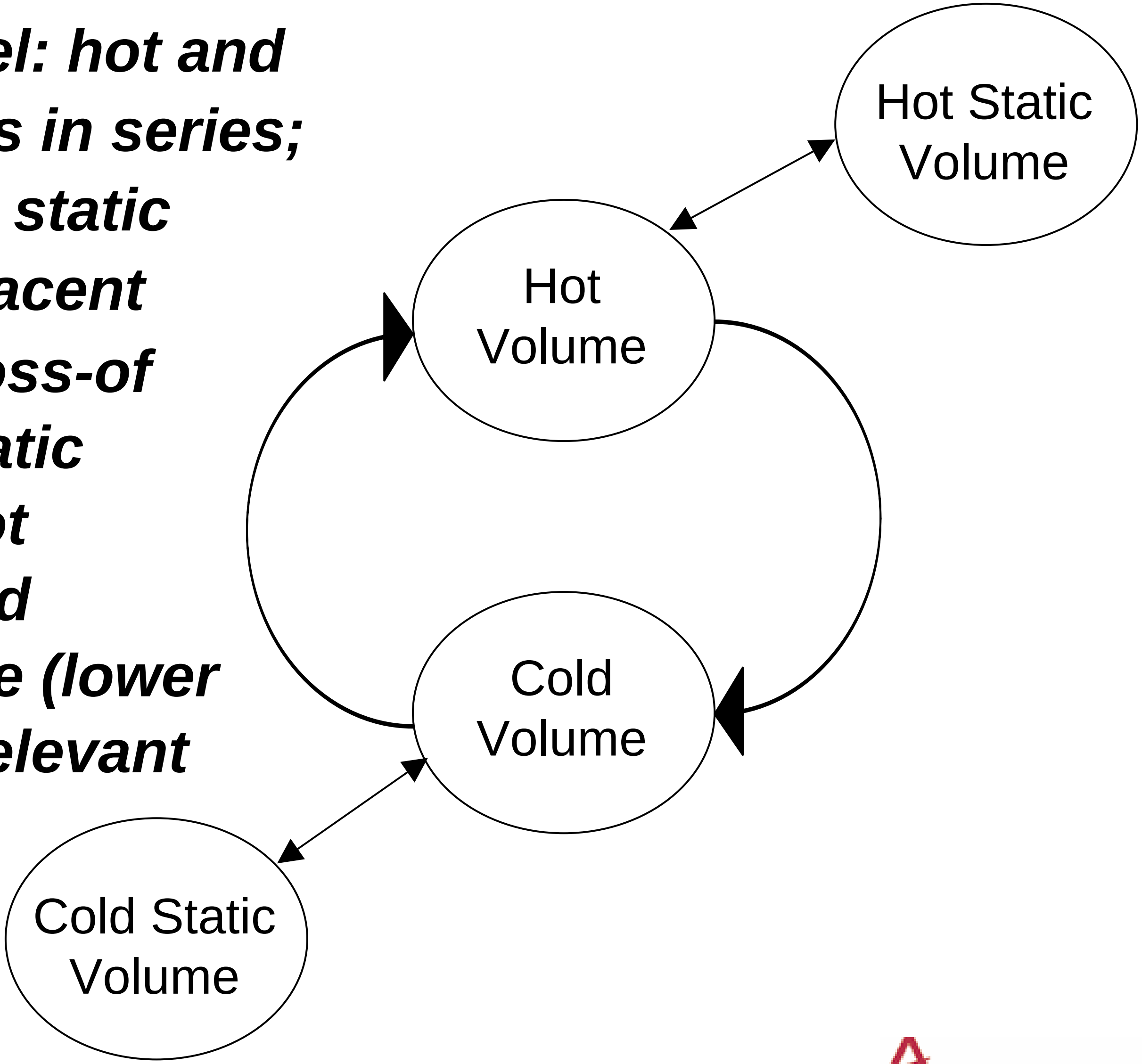


Model Development
Primary Circuit Only

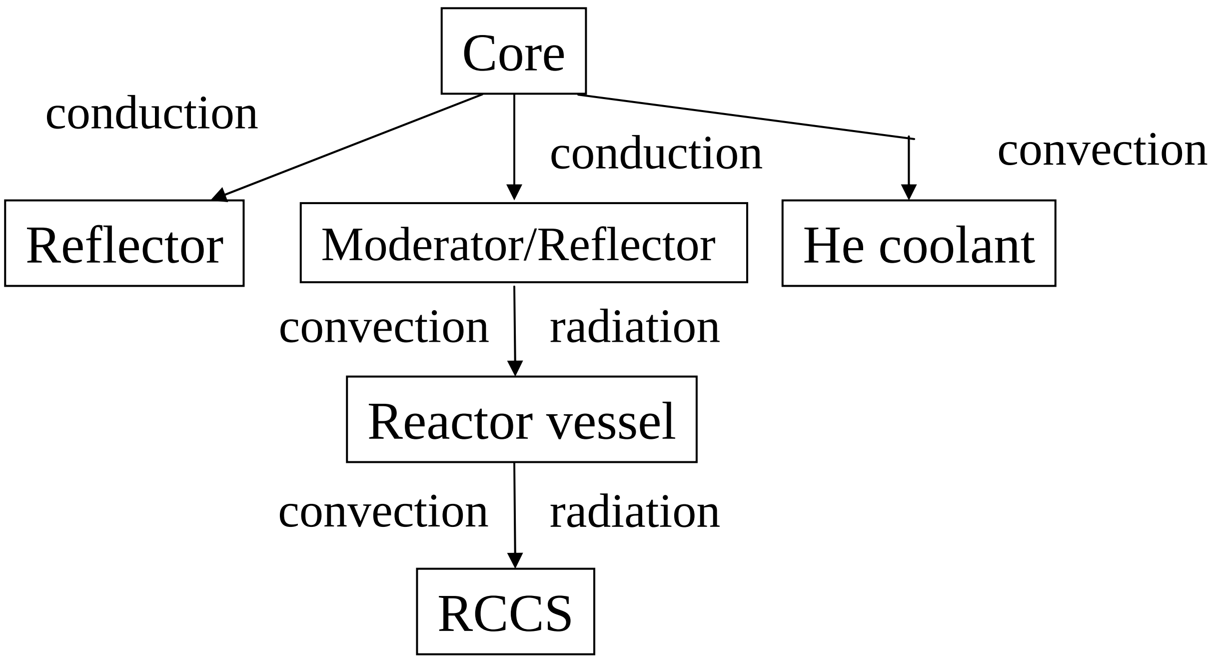
- **Follow CSAU step 8**
  - ***Primary Circuit only for most studies***
  - ***Secondary and Tertiary loops late 2005***
  - ***Main objectives***
    - ***Support NPP characteristics***
    - ***Preserve dominant phenomena***
    - ***Minimize code uncertainty***

Basic Conceptual Model

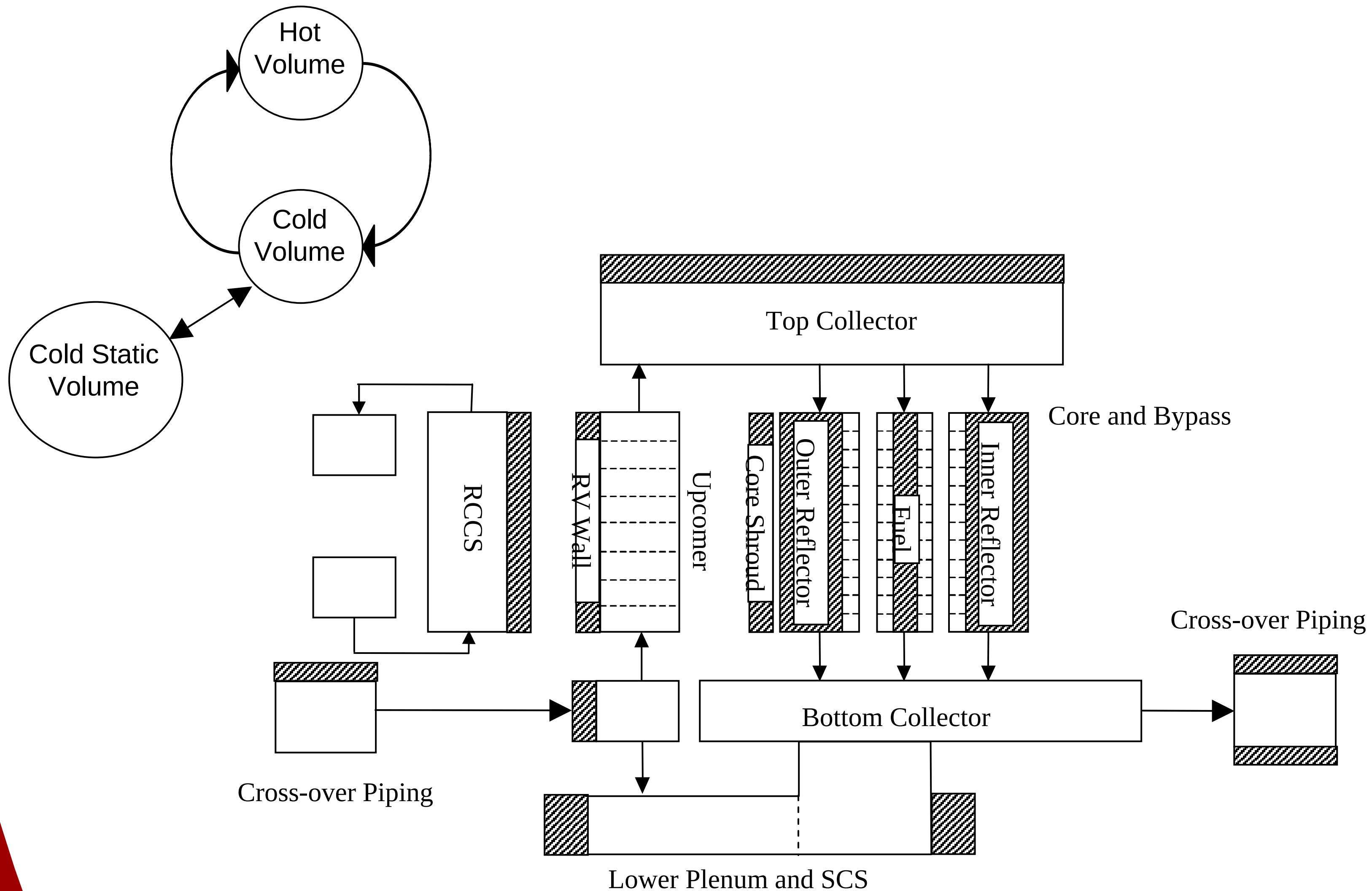
- ***Simple model: hot and cold volumes in series; hot and cold static volumes adjacent***
- ***For VHTR Loss-of Load, hot static volume is not relevant; cold static volume (lower plenum) is relevant***



Heat Transfer Modeling for Short-term transients



VHTR Vessel Hydraulic Nodalization
Base Nodalization



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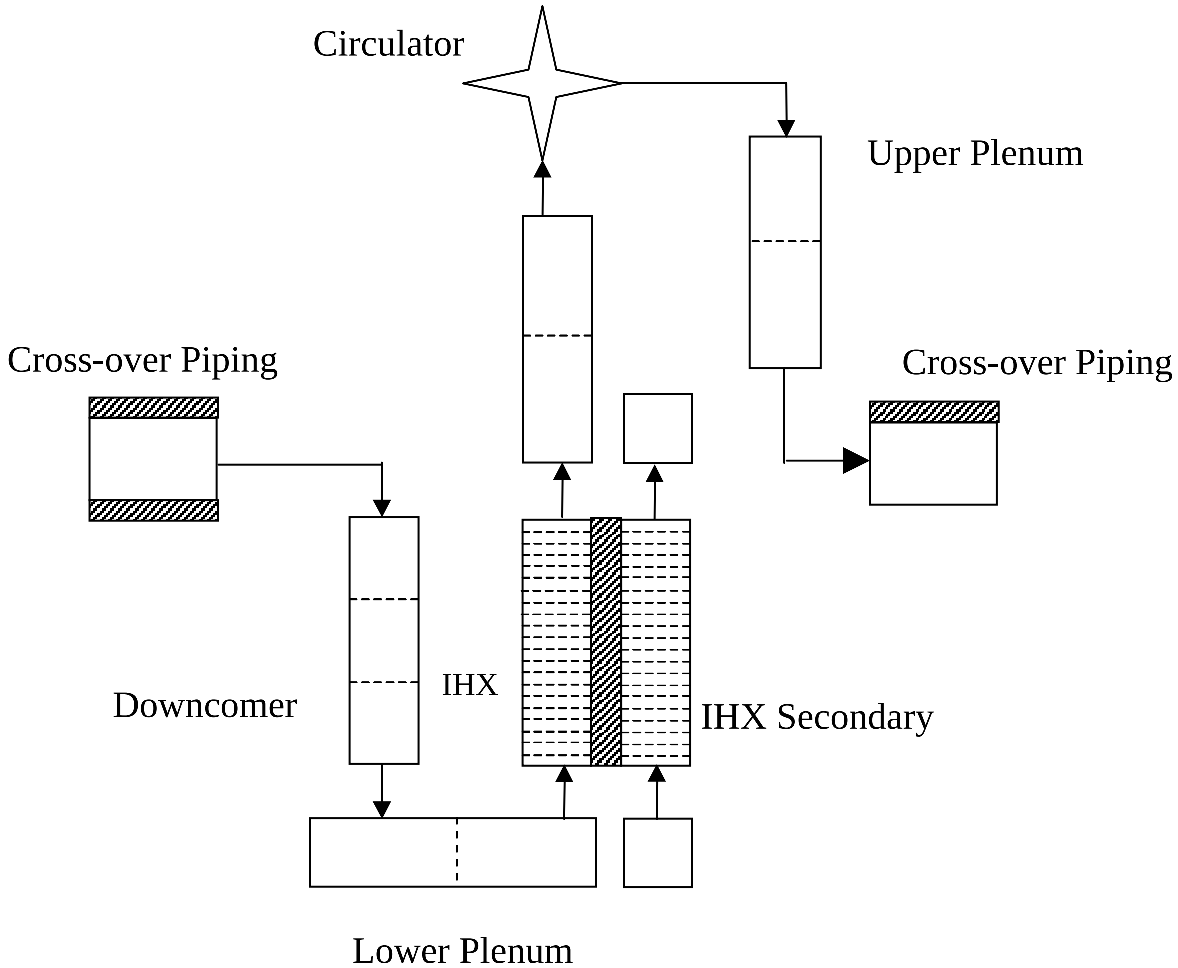
VHTR IHX Nodalization



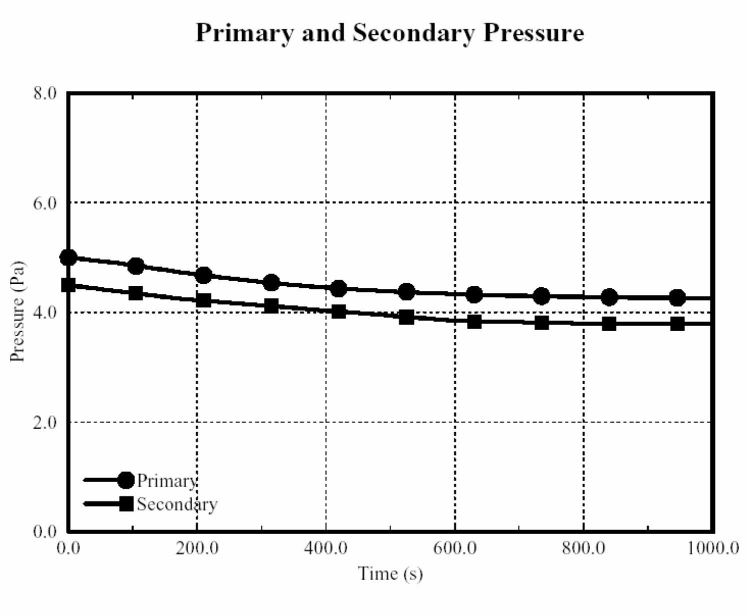
Scoping Studies

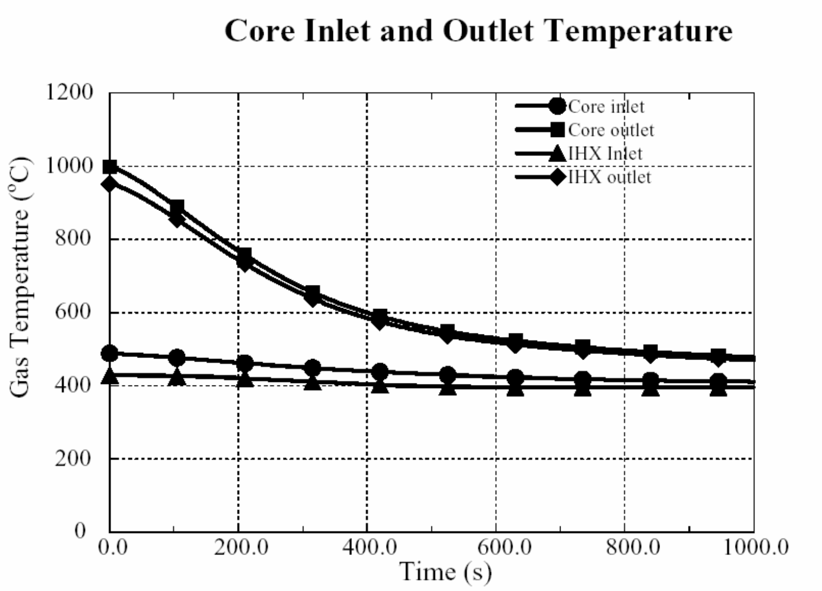
- **Currently for model shakedown activities**
  - **Steady-state**
  - **Null Transient/Reactor Trip**
  - **Loss of Load**
- **Benchmark vs. MANTA**

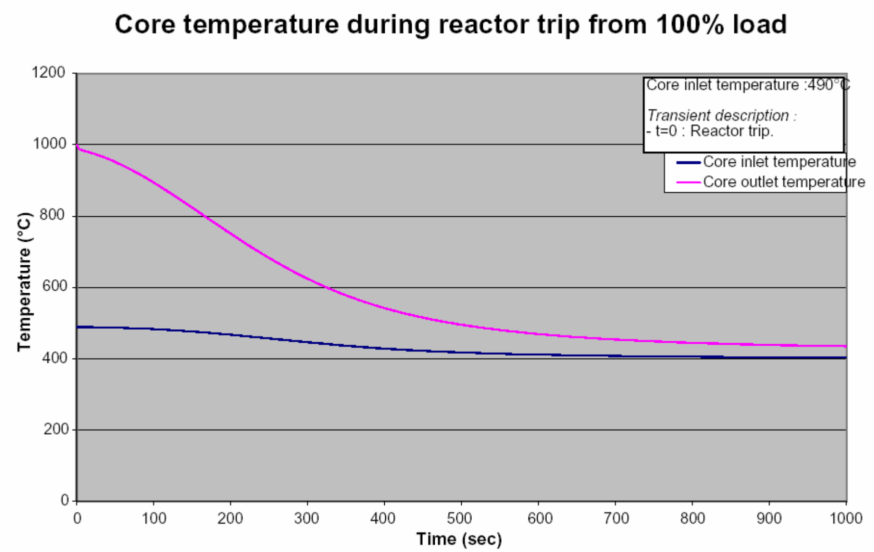
Steady-state

Parameter	Target	RELAP5
Power (MW)	600	600
Rx Outlet Temp (°C)	1000	1000
Rx Inlet Temp (°C)	490	489
Primary Flow Rate (kg/s)	226	226
Primary Pressure (MPa)	5	5.01
Max Fuel Temp. (°C)	1300	1080
IHX Sec. Inlet Temp (°C)	431	434
IHX Sec. Outlet Temp (°C)	950	950

Reactor Trip – Base Model







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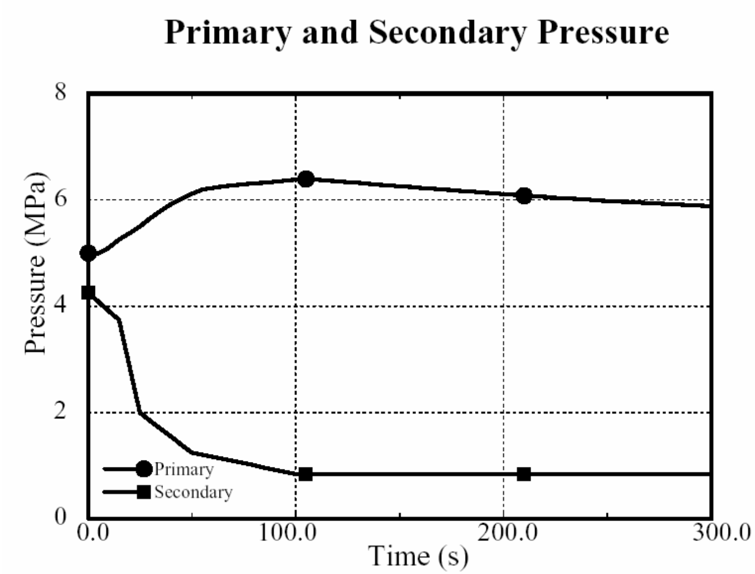
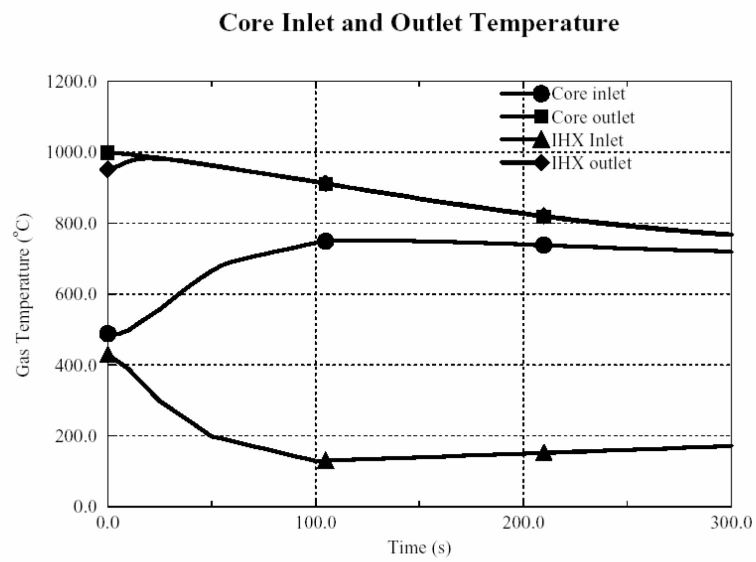
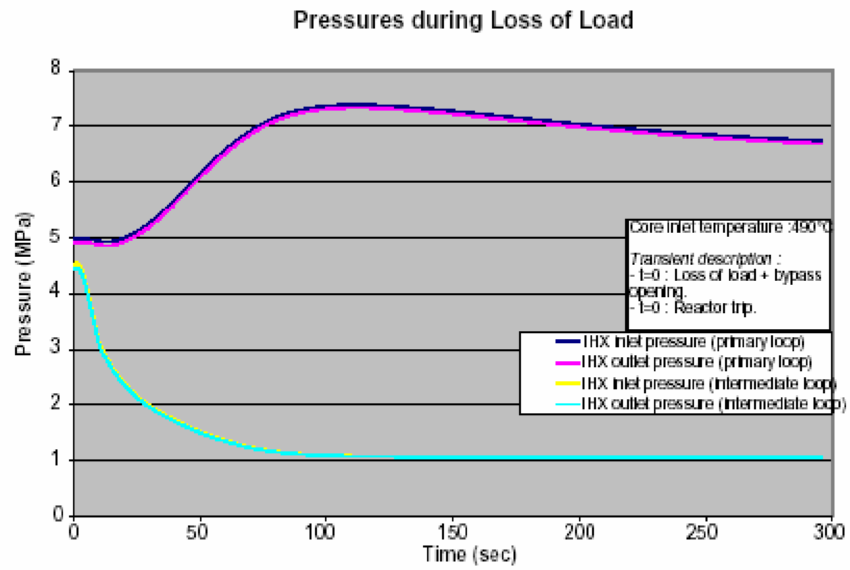
Loss of Load – Base Model



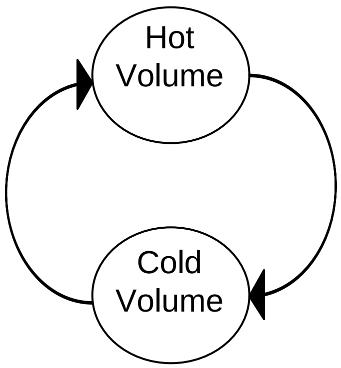


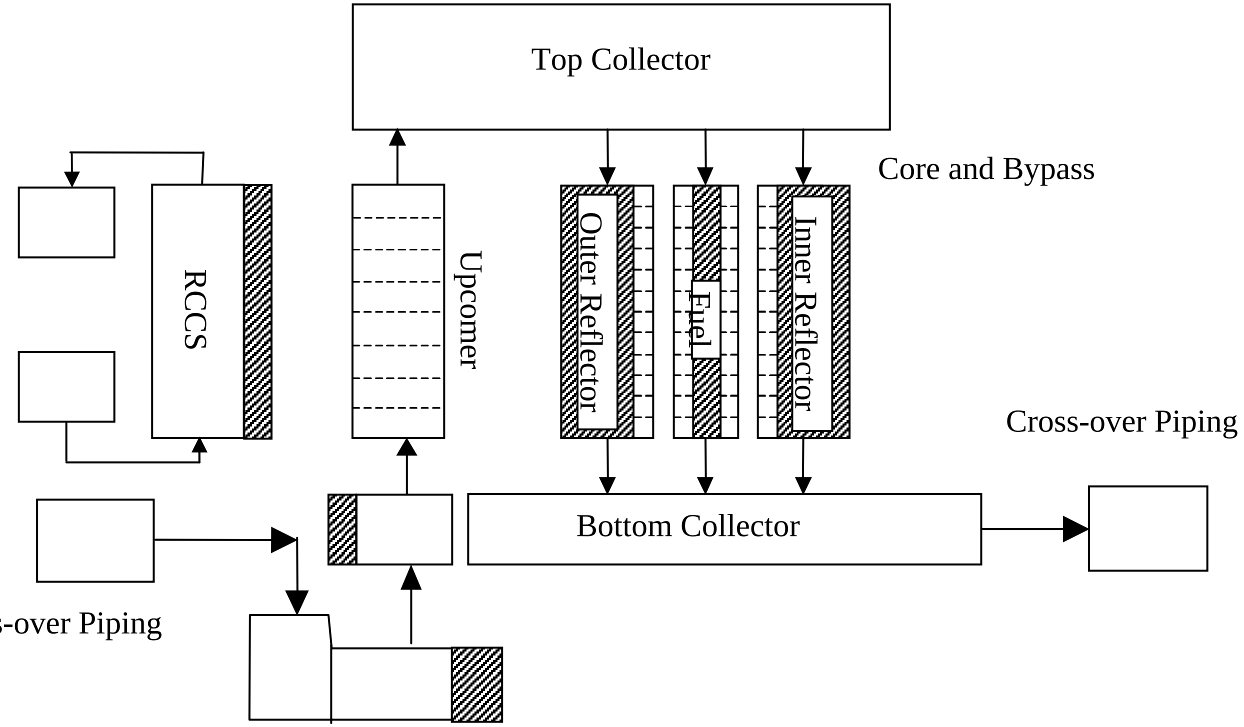


Results Assessment

Need to Explain Difference in System Pressure Response to Loss of Load

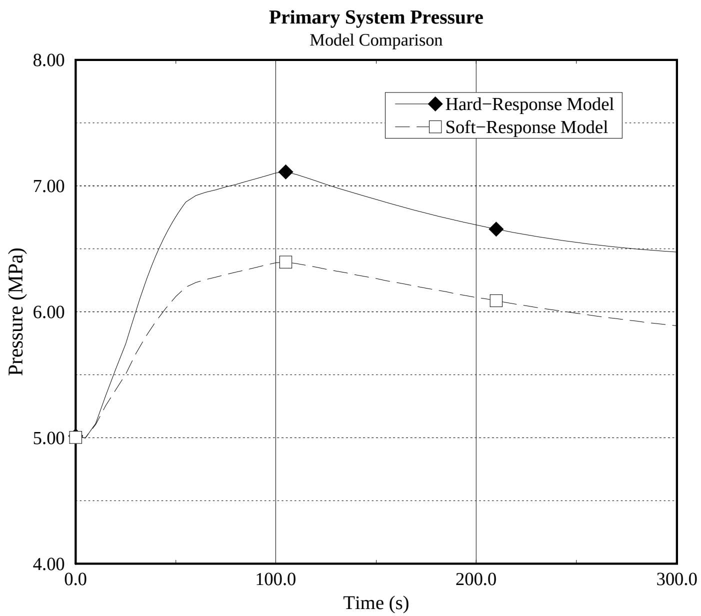
Loss of Load – Benchmark Model

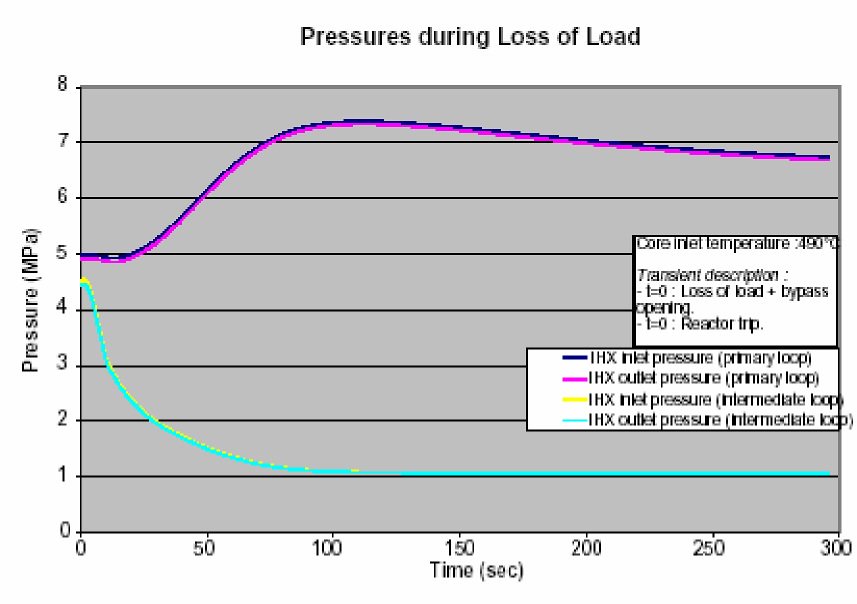




Comparison of Results

- ***Approximately 0.70 MPa difference on peak pressure***





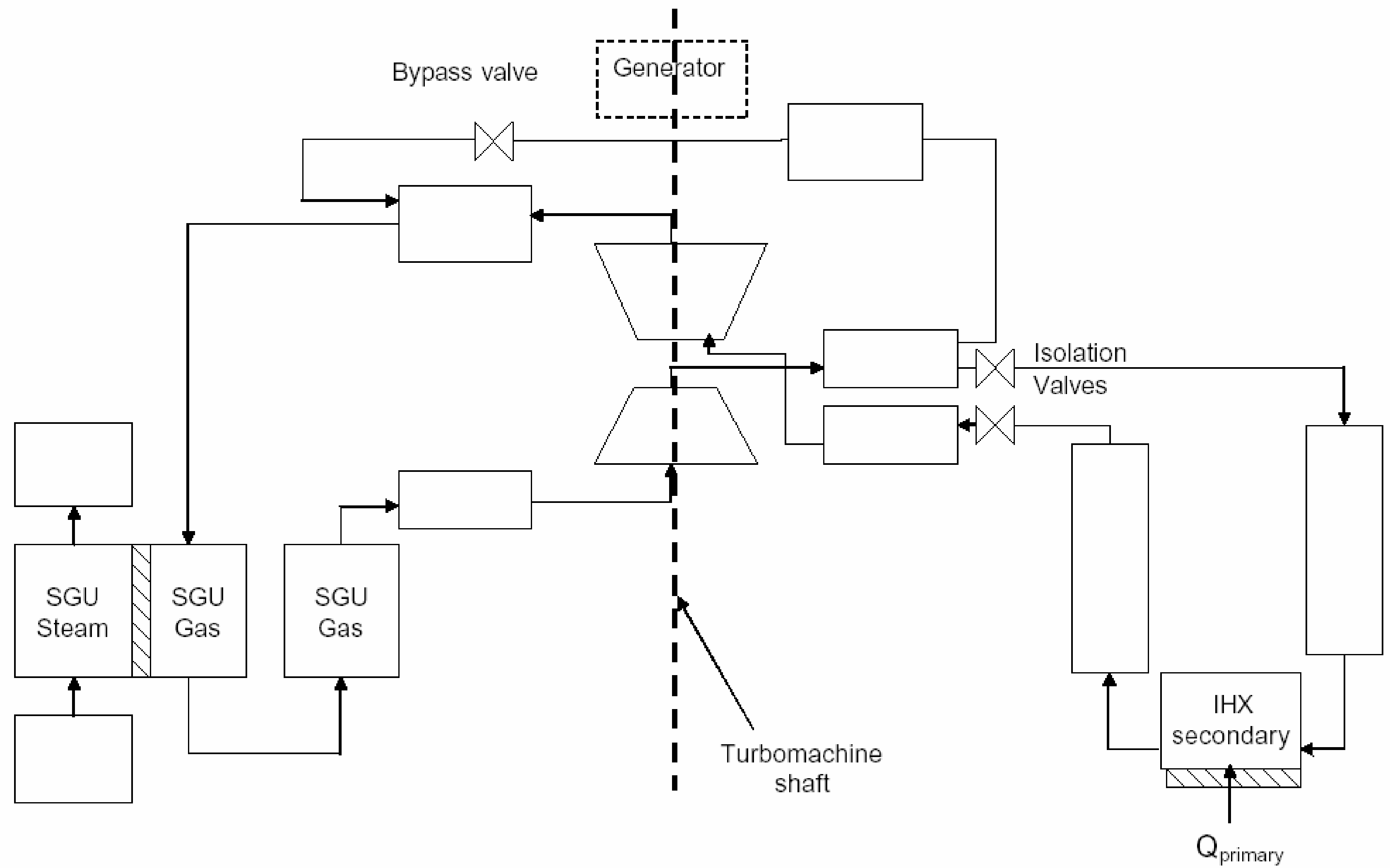
Result Assessment

- ***System Pressure is a dominant design parameter impacting large component forgings and material choices***
  - ***Mixing in the lower head/SCS region highly uncertain;***
  - ***Conservative to assume total mixing; however,***
  - ***given 0.7 MPa difference, need to examine with CFD to quantify margin***

VHTR Integrated Model

- **_Integrated model_**
  - **_Complete Secondary (turbine, heat exchanger, compressor) with Tertiary steam generator BC_**
  - **_Model corresponding to 490 °C core inlet temperature_**
  - **_Model revision necessary for IHX from a BC to a dynamically functional component_**

VHTR Secondary Nodalization



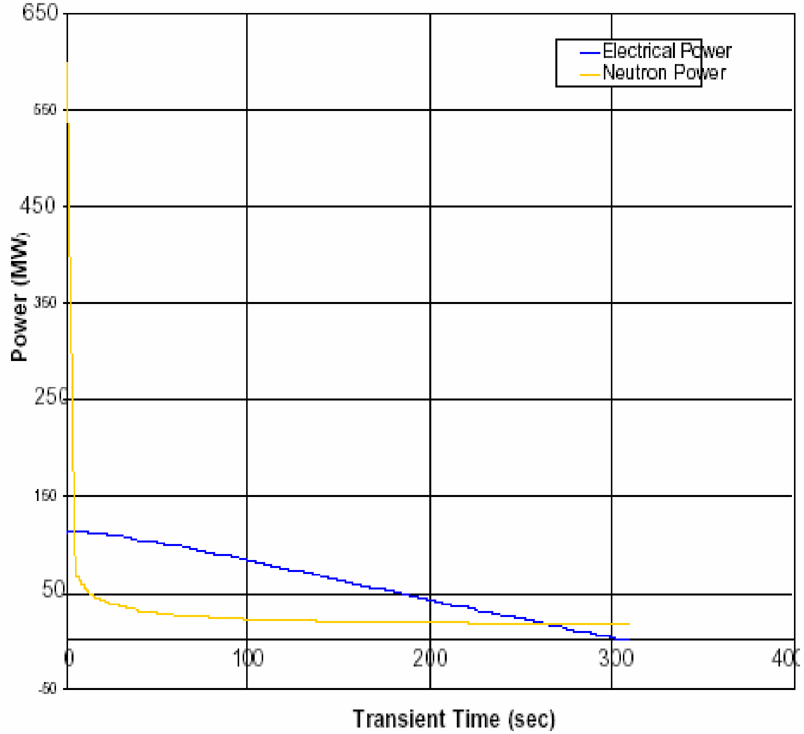
Integrated Model Steady-State Results

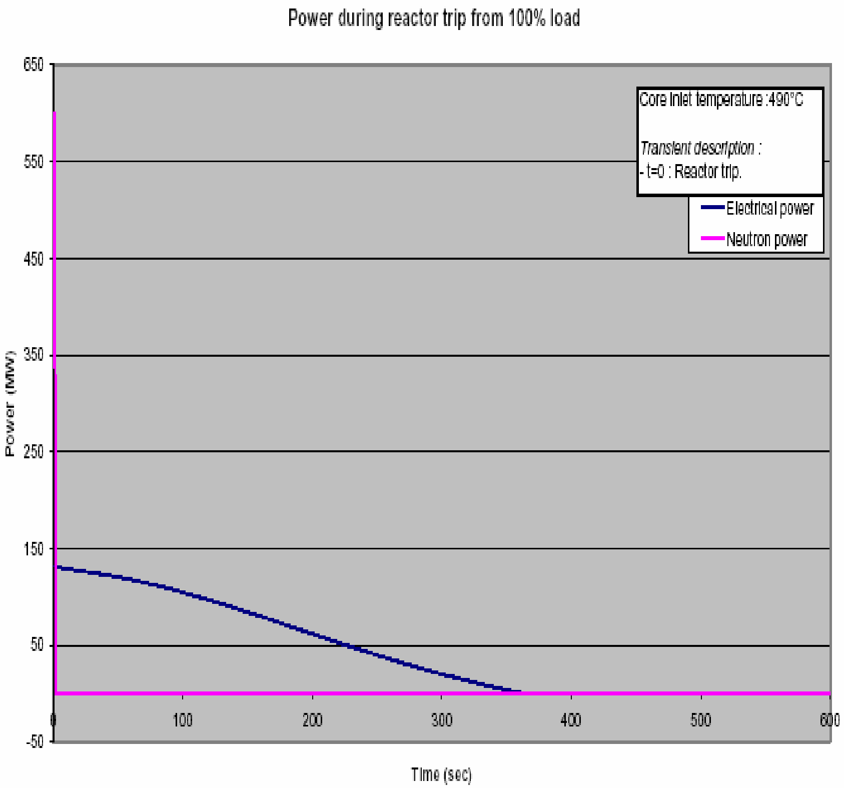
Table A.8.1-1 – Steady State Initialization to VHTR Secondary Initial Conditions corresponding to 490°C Core Inlet Temperature		
Description	Target (target values from Figure 2 of PVES DC 03 064; Reference 3)	RELAP5-3D
Core power, MW	600	600
Blower input Power, MW	9.7	9.7
Heat loss to RCCS, MW	2	2
Net reactor power, MW	607.7	607.7
IHX secondary mass flow rate, kg/sec	597.0	597.65
IHX secondary inlet/outlet temperature, °C/°C (°K/°K)	431/950 (704/1223)	430.92/951.1(703.92/1224.1)
IHX secondary ?T, °C or °K	+519	+520.2
Turbine mass flow rate, kg/sec	597.0	597.65
Turbine inlet/outlet temperatures, °C/°C (°K/°K)	950/571 (1223/844)	950.9/567.22(1223.9/840.22)
Turbine inlet/outlet pressures, MPa/MPa	4.5/1.2	4.49/1.18
SGU gas side inlet/outlet temperatures, °C/°C (°K/°K)	571/158 (844/431)	567.22/148.37(840.22/421.37)
Compressor inlet/outlet temperature C/°C (°K/°K)	158/431 (431/704)	147.3/430.82(420.3/703.82)
Compressor inlet/outlet pressures, MPa/MPa	1.2/4.5	1.18/4.58
Net gas turbomachine power, MW	126	120.8

Simulation(s)

- **Reactor Trip**
  - ***Full power, circulator not tripped, turbomachinery not tripped***
  - ***Key results***
    - ***Time scale of drop in electrical power similar***
    - ***Lower Primary-to-Secondary HT in RELAP5***
- **Loss of Load**
  - ***Code problems prevented completion***
  - ***Maximum compressor speed validated (~4000 rpm)***

Rx Trip - Electric/Neutron Power





RELAP5-3D **MANTA**

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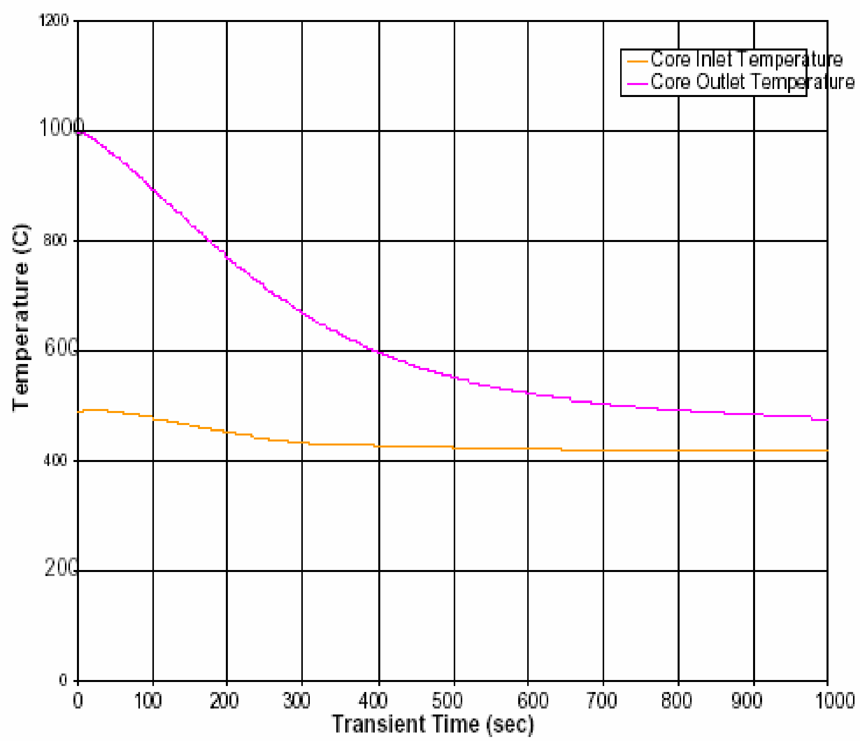
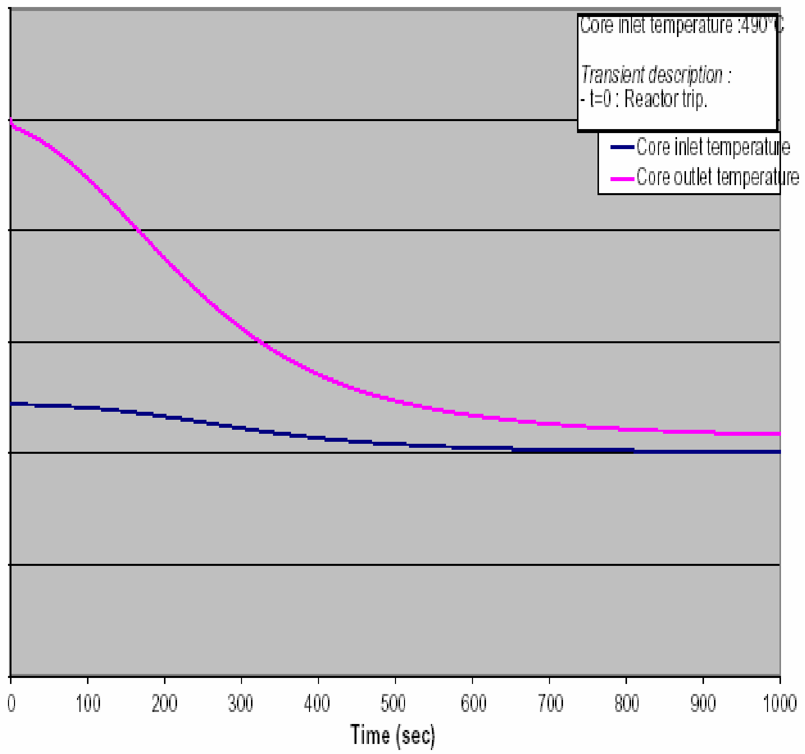
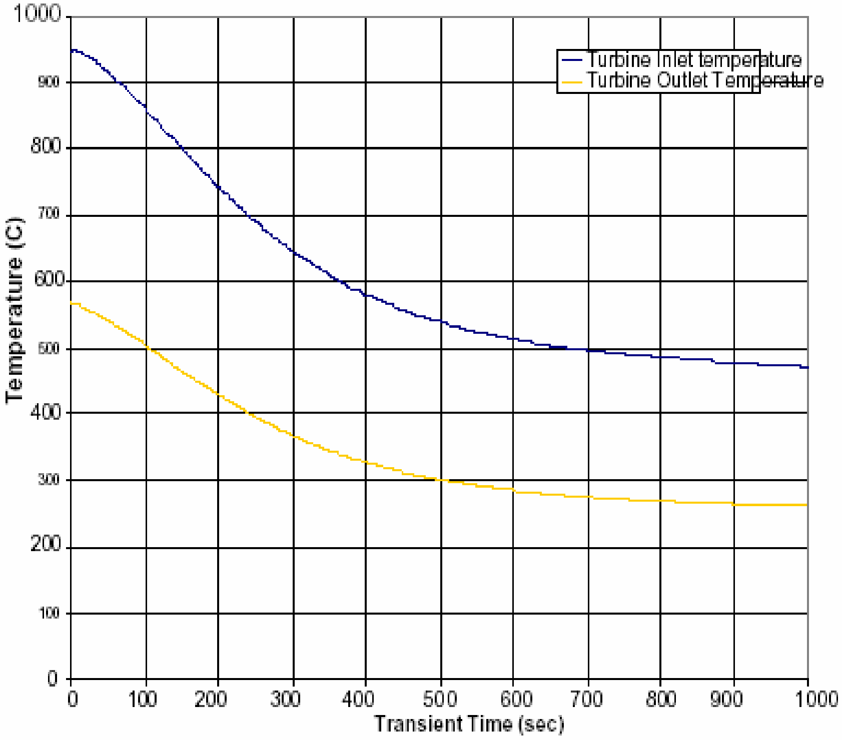
Rx Trip - Core Temperature

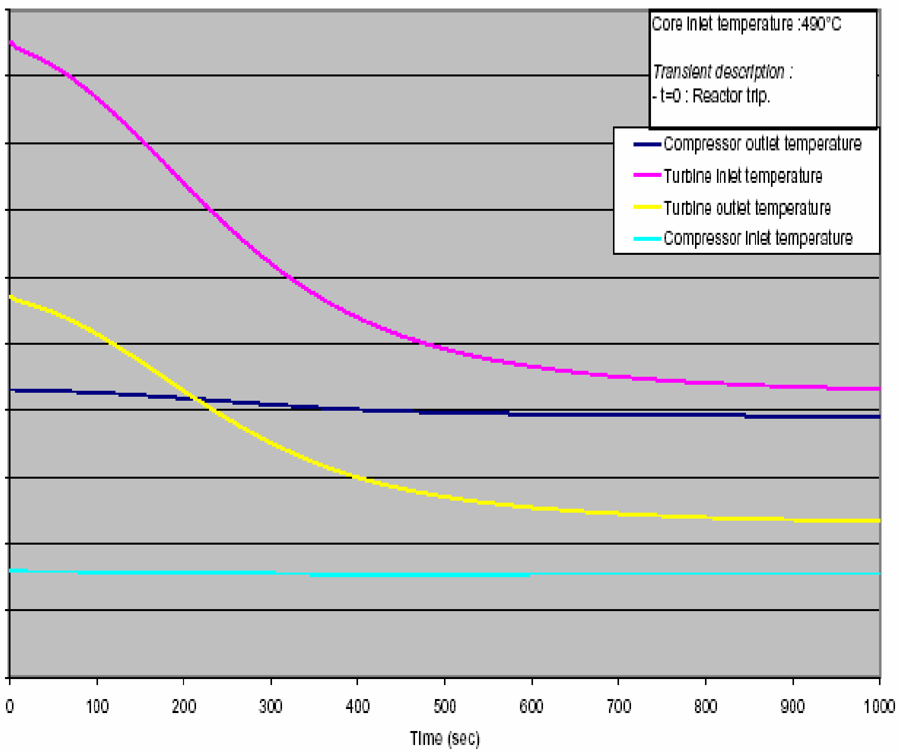




RELAP5-3D **MANTA**

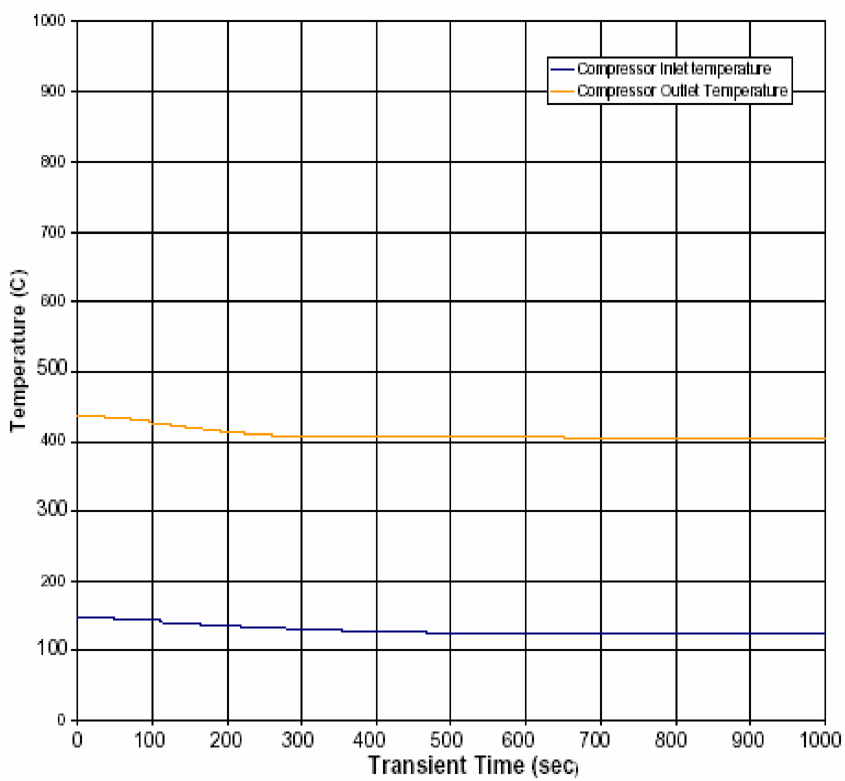
Rx Trip - Turbine Temperatures

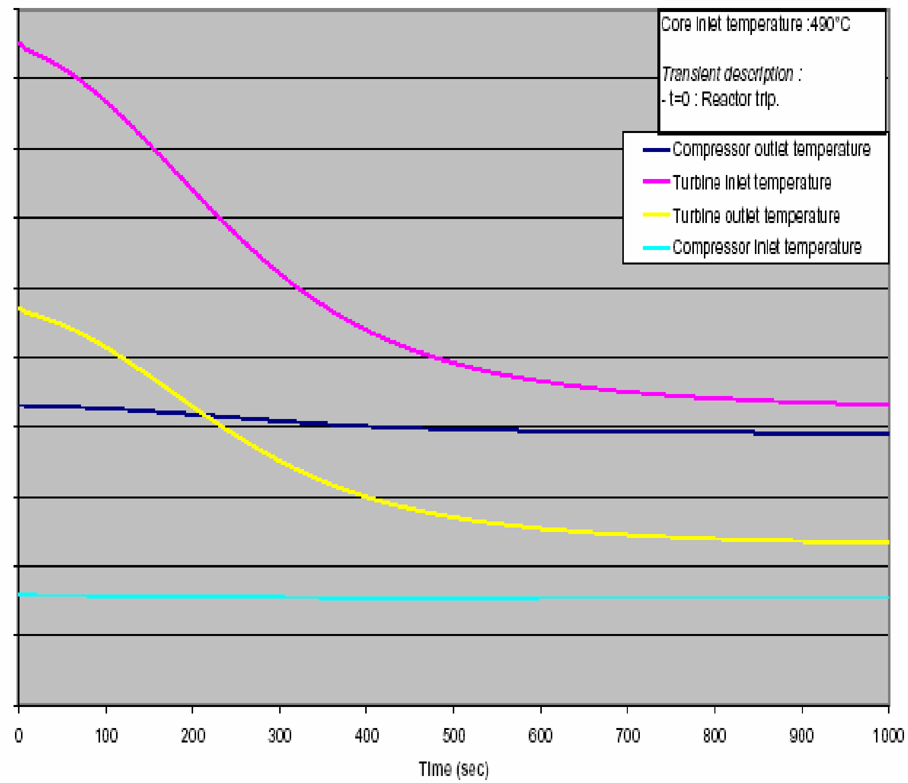




RELAP5-3D **MANTA**

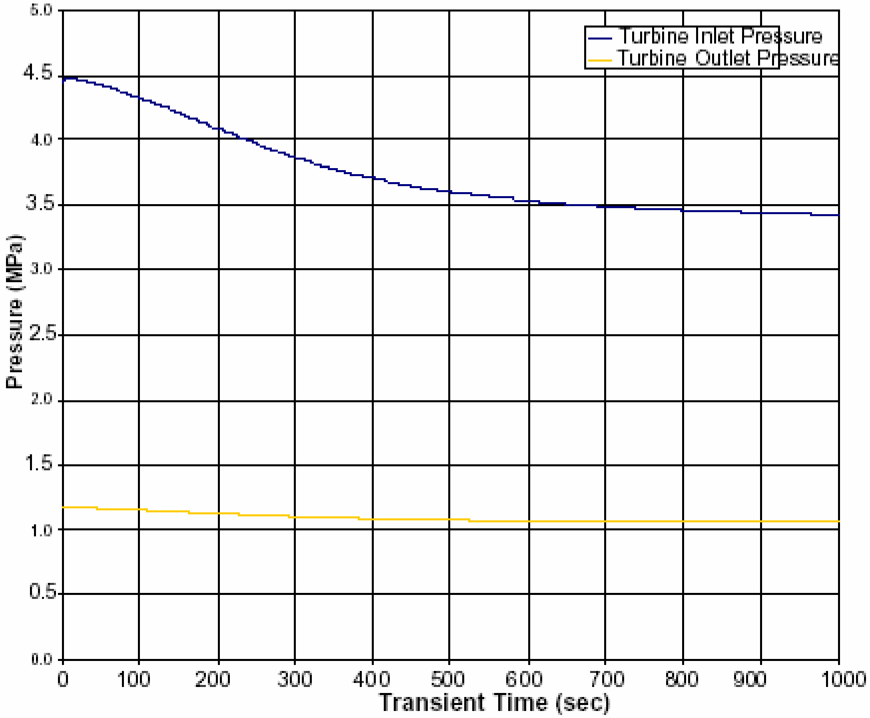
Rx Trip - Compressor Temperatures

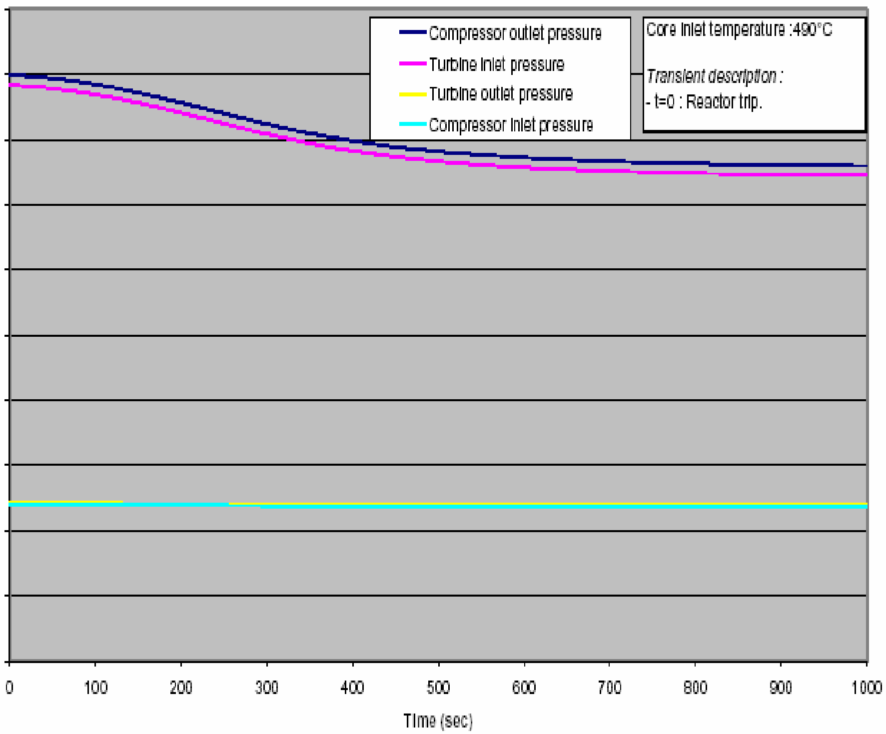




RELAP5-3D **MANTA**

Rx Trip - Turbine Pressures





RELAP5-3D **MANTA**

Reactor Trip Summary

- ***Generally good agreement***
- ***RELAP5-3D predicted quicker decrease in electrical power (310 s vs. 360 s)***
  - ***Indicative of lower HT from primary in R5 calc***
  - ***Consistent with lower secondary pressures and higher primary temperatures***
  - ***Possible the result of less dissipation of stored energy in graphic blocks***

RELAP5-3D Code Challenges

Generally, code issues were minor and quickly resolved

- Nearly Implicit Advancement Scheme
- Mass Error with He property table (required modification to property table)
- Mixed Constituent Properties on the Secondary use with Condenser (feature added)
- Turbine modeling (conservation of energy questioned)

Summary/Status

- **2005 Goals:**
  - **Complete RELAP5-3D model (w/ secondary/tertiary loops)**
  - **Analyze a suite of short-term events**
  - **Support MANTA development activities as needed**
  - **Identify Code/Model Deficiencies/Recommend Solutions**
- **2006 Goals**
  - **Apply new version…**
  - **Further studies pending review of documented preconceptual design**

VHTR Loss of Load good candidate for challenging many RELAP5-3D features

End of Presentation

Establishment of Assessment Matrix

- Code assessment shows the capability and accuracy of the codes to predict the actual phenomena
- Integral Test Programs
  - EVO (Germany)
  - HTTR (Japan)
  - Fort Saint Vrain
  - PBMR Micromodel (South Africa)
- Separate Effects
  - Internal component testing
  - Space/Fusion Rx R&D ????