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Terry Turbopump Expanded Operating Band Program
Sandia Modeling Efforts – FY17 Update

Douglas M. Osborn, PhD.

Sandia National Laboratories

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Terry Turbine CFD Efforts

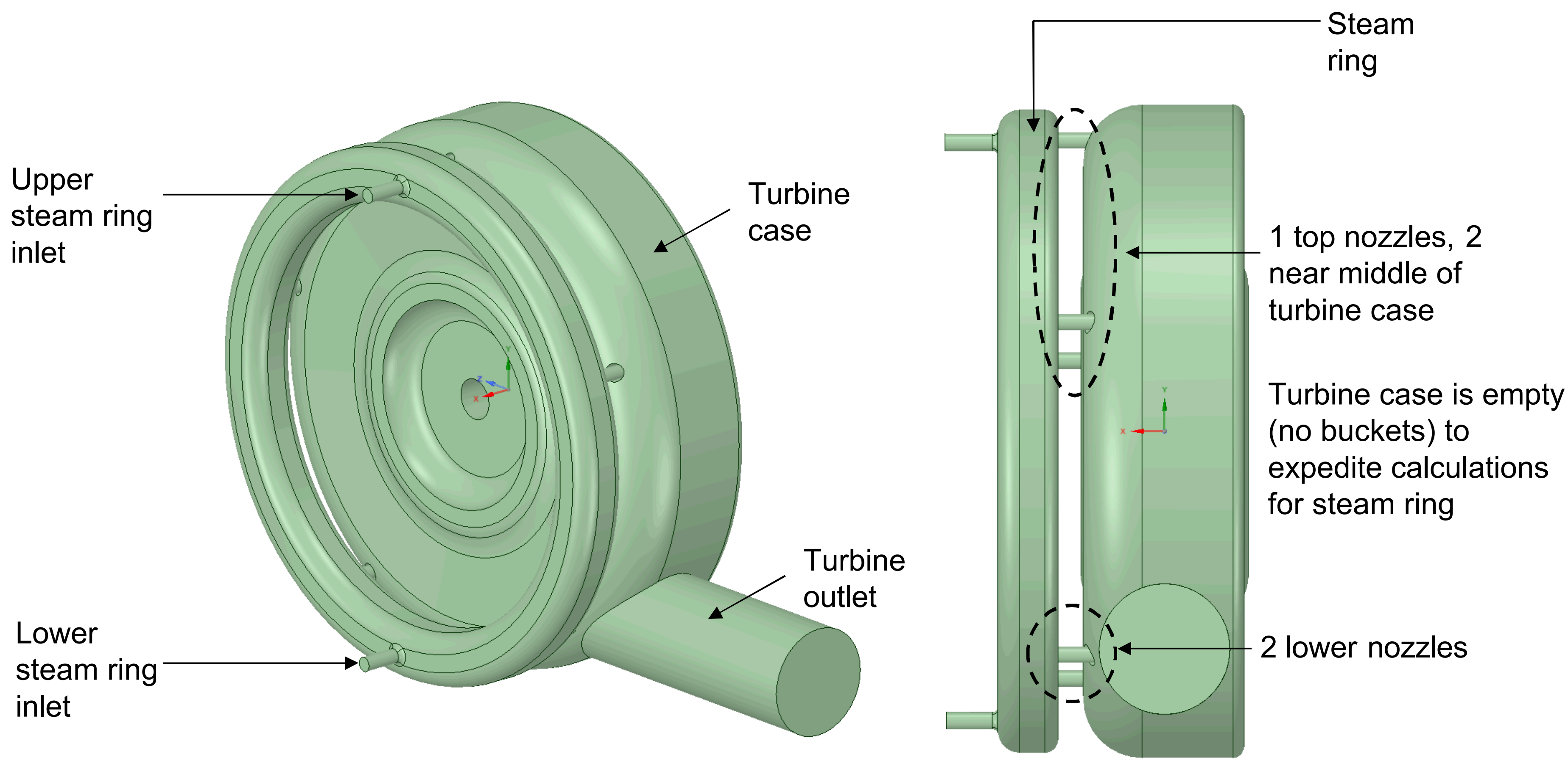
- Corroborate, complement, and inform the experimental and system-modeling efforts

- Using 3D, two-phase, turbulent, compressible, Fluent calculations of key RCIC system components to answer key questions including:
  - RCIC steam ring: does water accumulate and flood?
  - Governor valve: what are the flow characteristics and what is its C_v?
  - Nozzles and buckets: obtain bucket inlet and outlet velocities for lower steam pressures and for air to support RCIC experiments
  - Turbine wheel windage: does water accumulate around the wheel and retard turbine-pump speed?

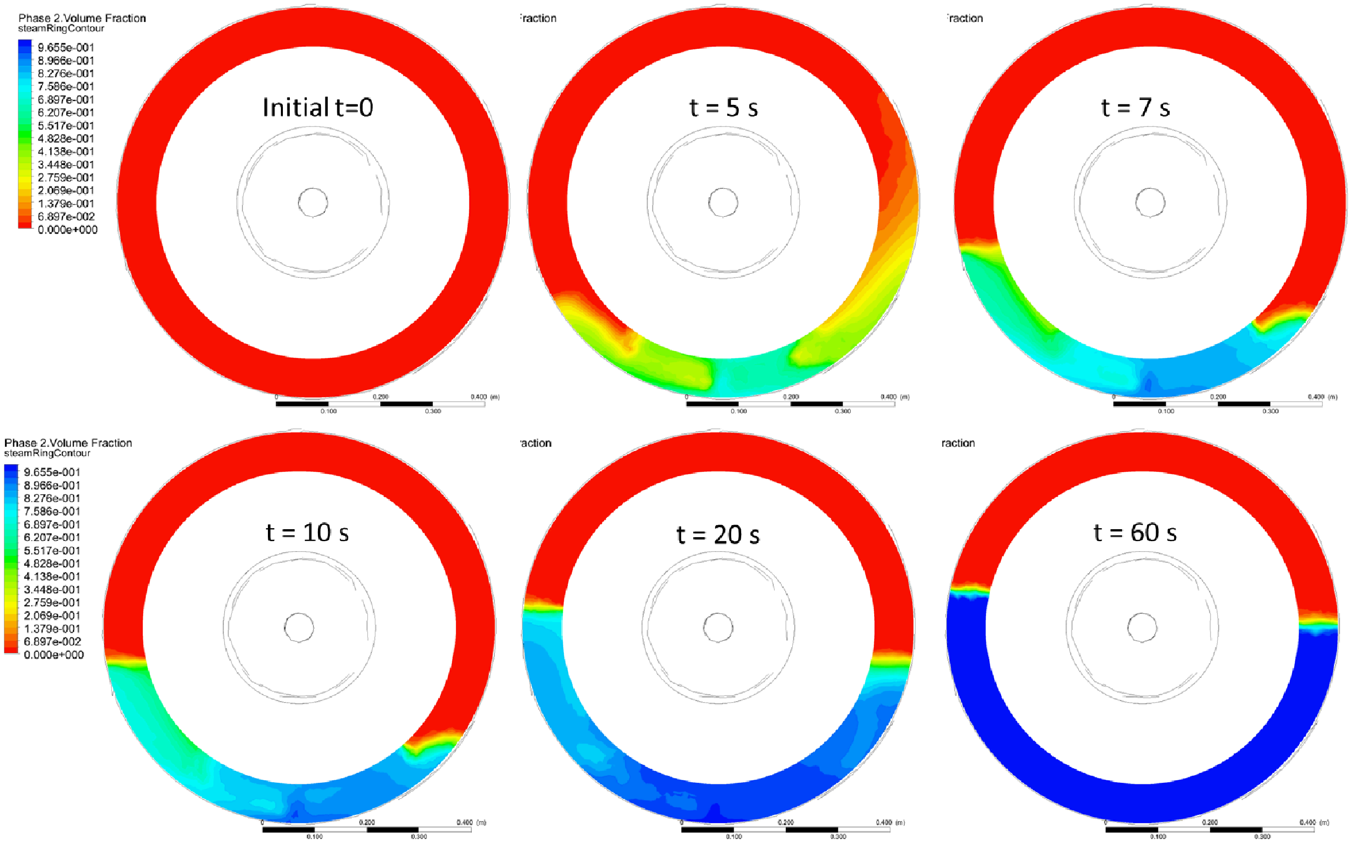
Steam ring analyses

- For a range of pressures and 2-phase conditions (i.e. void fraction), examine flow regime inside steam ring – between governor valve and nozzles
- Calculations largely corroborate system-level assumption concerning flooded nozzles in the lower part of the turbine
  - Water appears to quickly accumulate and result in stratified flow – flooding the lower nozzles – particularly for high liquid content (> 50% volume frac.)
  - Lower liquid content (< 5%) results in a two-phase mixture covering the lower nozzles
  - Often upper nozzle flow is still 2-phase, but predominately steam
- Transient analyses were performed for a representative steam ring with two inlets and five nozzle
  - Additional calculations could make use of expanded geometry information for the steam ring, particularly the details of its inlets from the governor

Steam ring geometry



Steam ring results



- Mid-plane slice of steam ring – contour of liquid volume fraction (1.0 = all liquid)
- 300 psig inlets
- Top steam ring inlet: 100% steam
- Bottom inlet: 100% liquid
- Saturated vapor-liquid properties assuming no mass/energy transfer between phases
- Fluent's Euler multiphase model (code's most rigorous option)

More steam ring results

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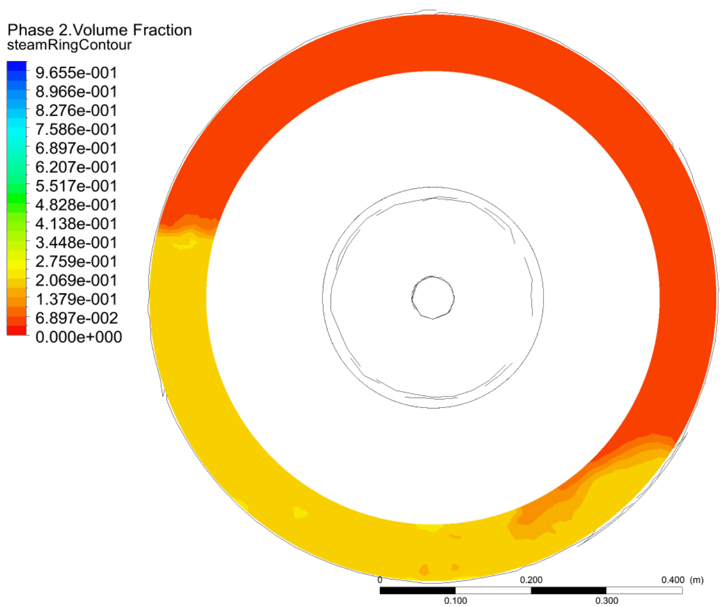
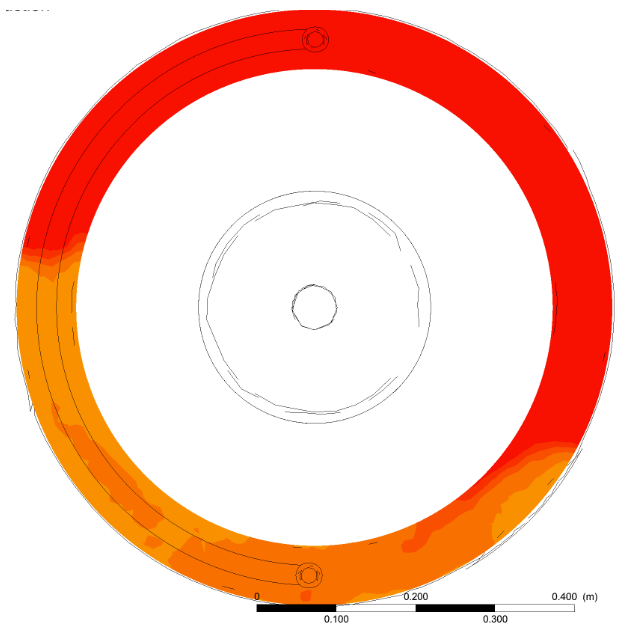
10% avg. liquid volume fraction across inlets

- Lower nozzles flow more water (20-30% liquid)
- Uppers nozzles flow more steam (only ~5% liquid)

5% avg. liquid volume fraction across inlets

- Lower nozzles: 5-20% liquid
- Uppers nozzles are almost fully steam flow



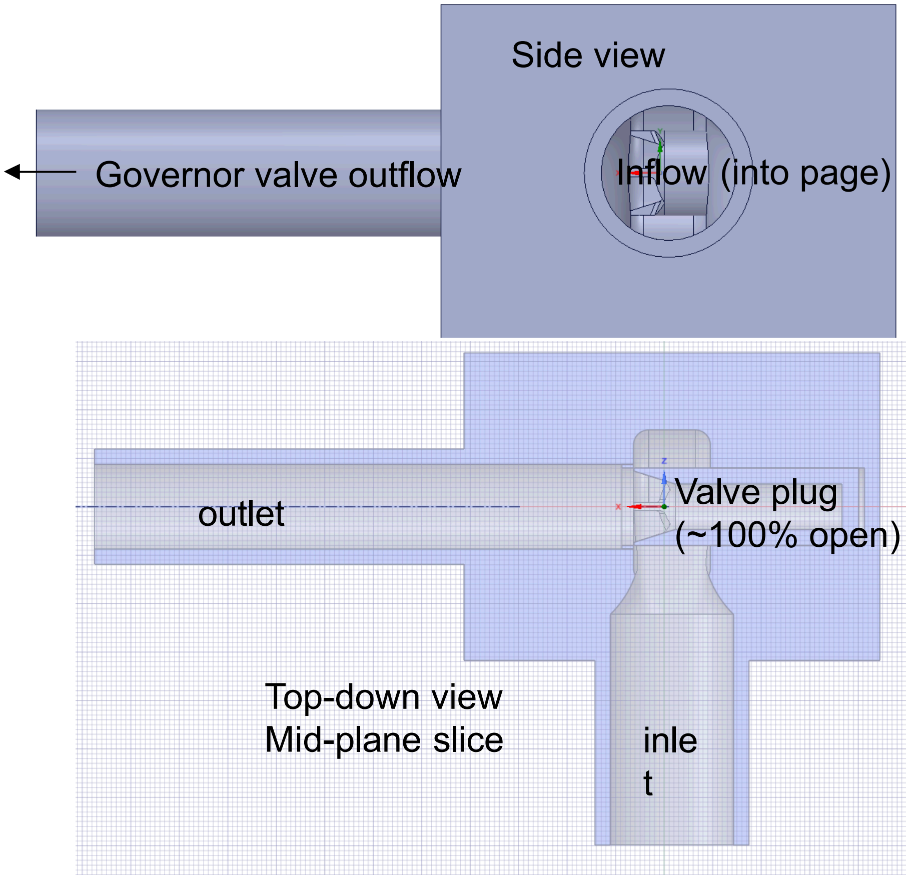


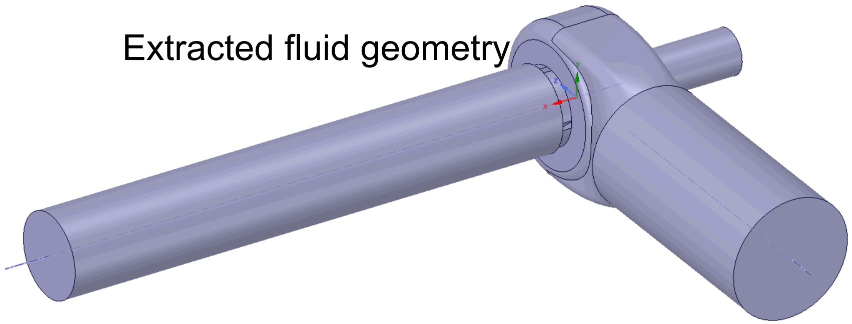
Transient calculations after 60 seconds
(initial condition is all saturated steam at 300 psig)

Governor valve calculations

- Obtain C_v information for governor valve
  - Leverage CAD/flow modeling using SolidWorks from 2016
- Examine two-phase flow characteristics
  - Expanded model may be able to inform analysis of the steam ring
  - Need piping details from governor valve to steam ring inlet(s)
- Will enable rigorous benchmarking to Unit 2 strip chart data before power was lost
  - Allows for more calibration of uncertain model inputs (multipliers, friction coefficients, etc.)
  - May increase understanding of Unit 2 avoiding overspeed trip after loss of power

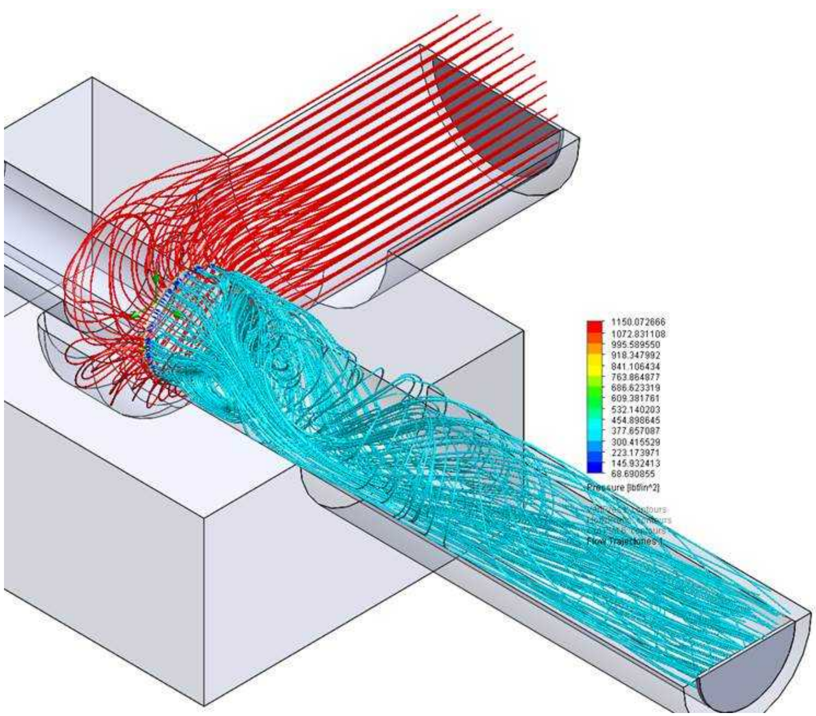
Governor valve geometry



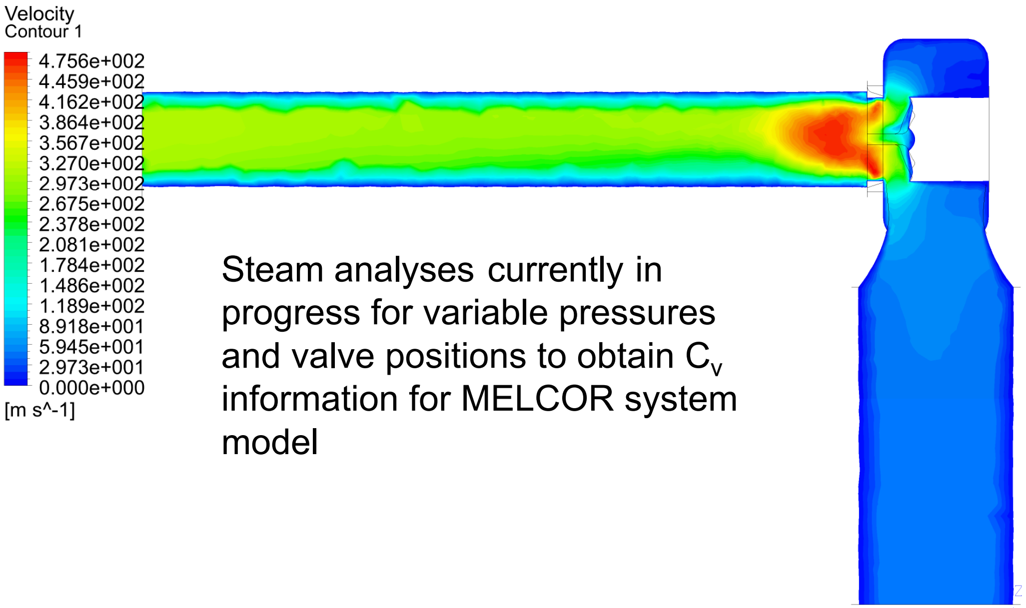


Preliminary governor valve results

From 2016 using Solidworks Flow
Streamlines with pressure contour
1100 psig inlet; 300 psig outlet



Fluent test calculation using ideal-gas steam to validate mesh and geometry
Velocity magnitude contour for 1100 psig inlet and 300 psig outlet
Valve position at about 70% open



Steam analyses currently in progress for variable pressures and valve positions to obtain C_v information for MELCOR system model

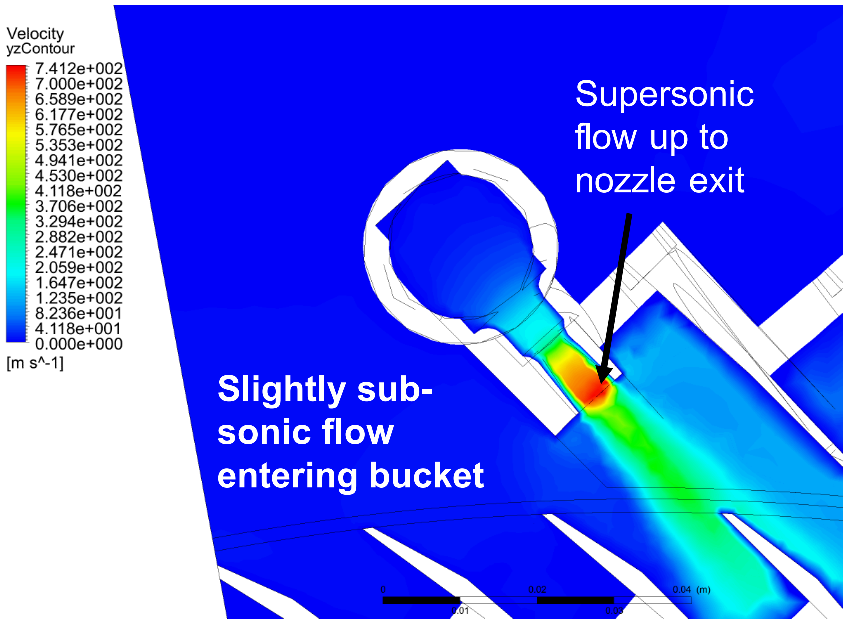
Nozzle calculations with low pressure steam

- Inform/support experimental efforts
  - Steam pressures from 40 to 70 psia
  - Outlet 15 psia
- Also examine air flow
  - 40 to 70 psia
  - Outlet 15 psia

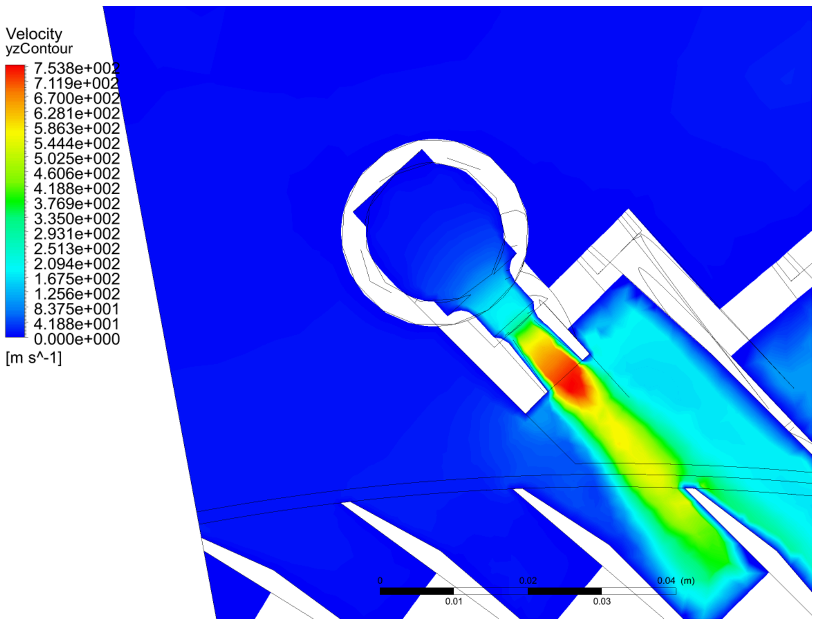
Some low steam pressure nozzle results

Such low pressure drop of the Terry nozzle typically results in shock formation near the nozzle exit plane – supersonic velocities quickly reduce to sonic speed at nozzle exit

40 psia steam inlet



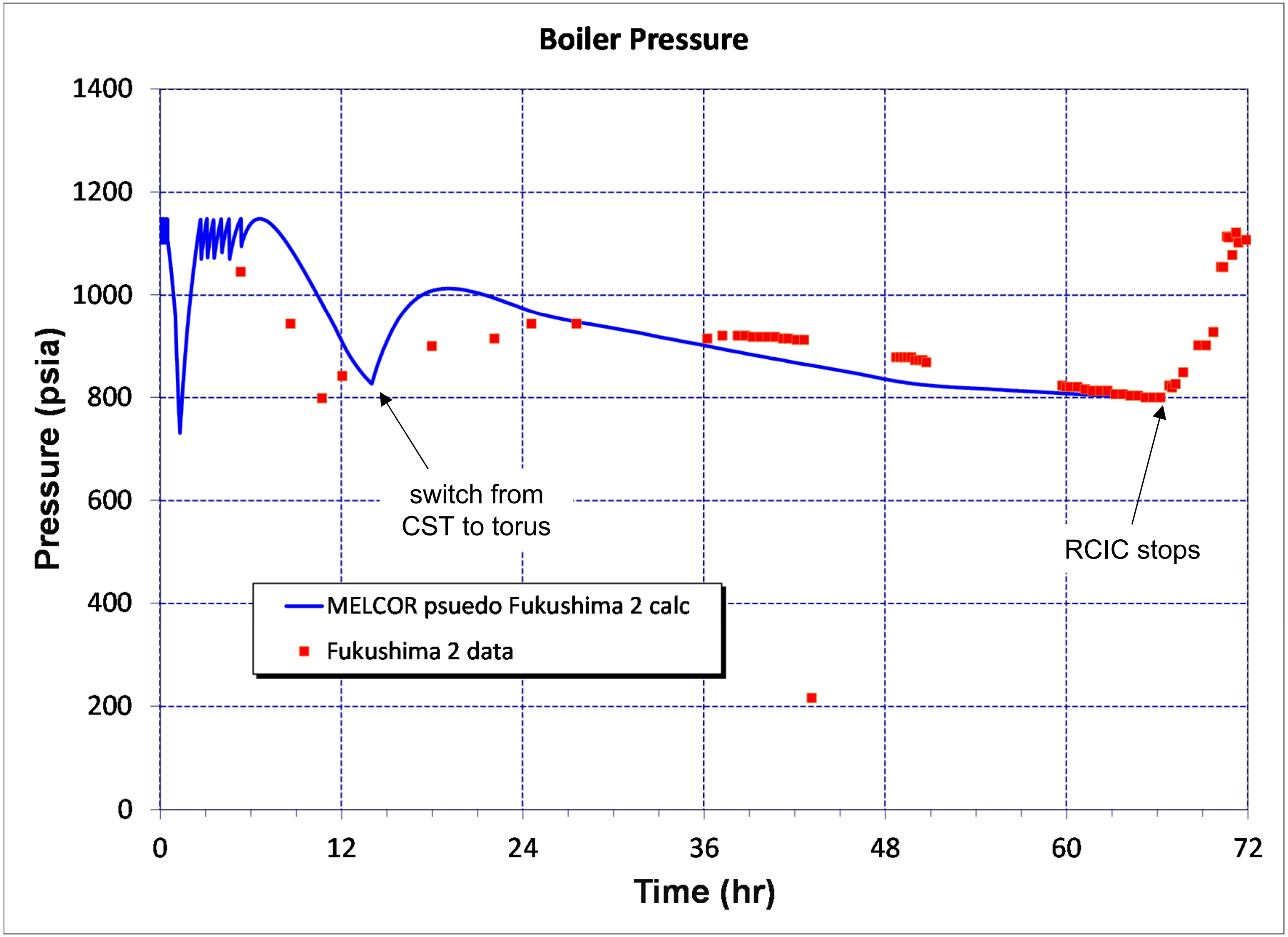
70 psia steam inlet;
higher pressure drop 'pushes' shock out of the nozzle



System-level Modeling

- These are test models and test results
- This work is explorative
- Investigating several different explanations and modeling approaches
  - The results are going to change
- The results are qualitative
  - They reproduce the general trends of Fukushima Unit 2

Fukushima 2 MELCOR Model



Quasi-Steady vs Time-Dependent Fukushima 2 MELCOR Calculations

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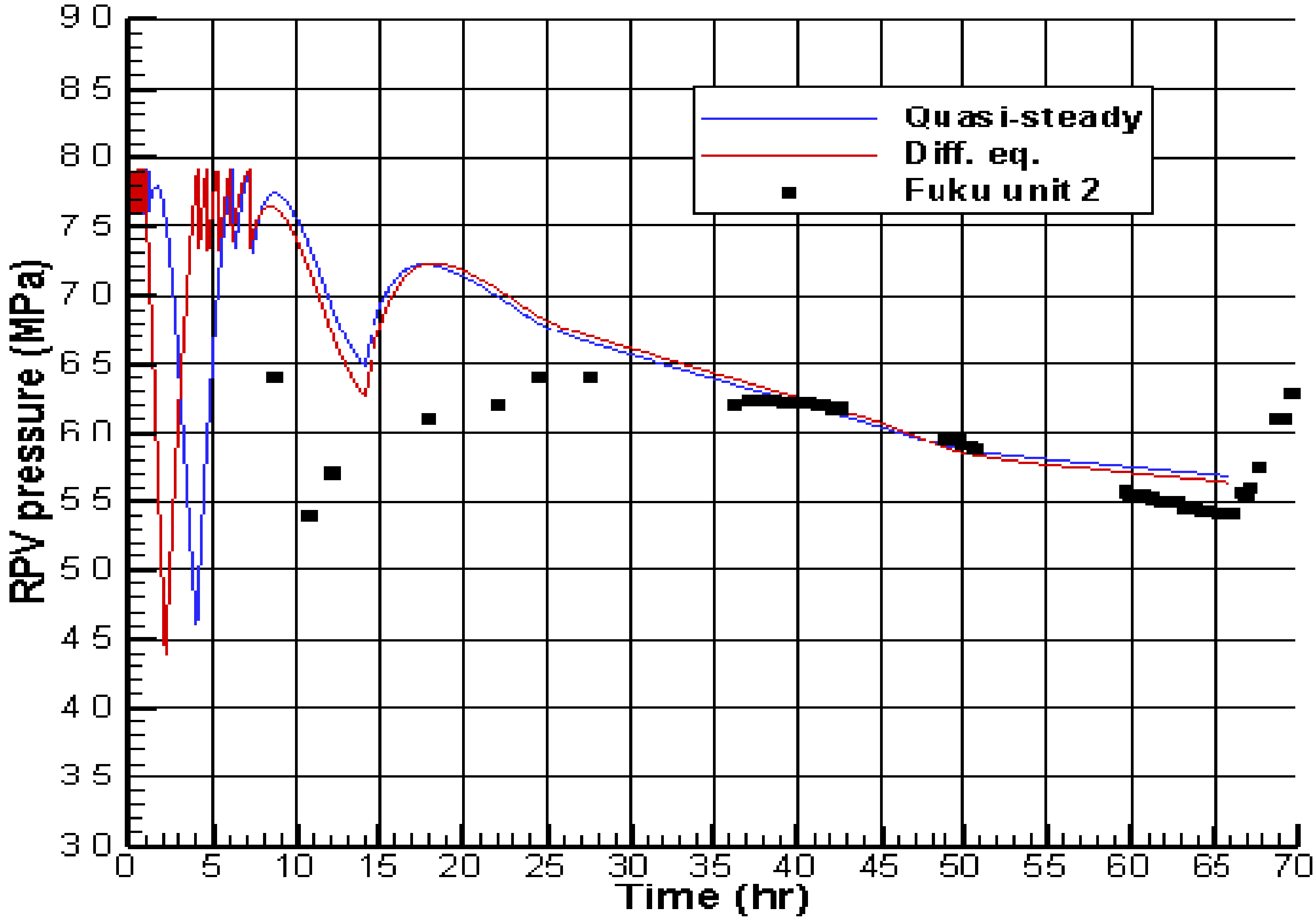
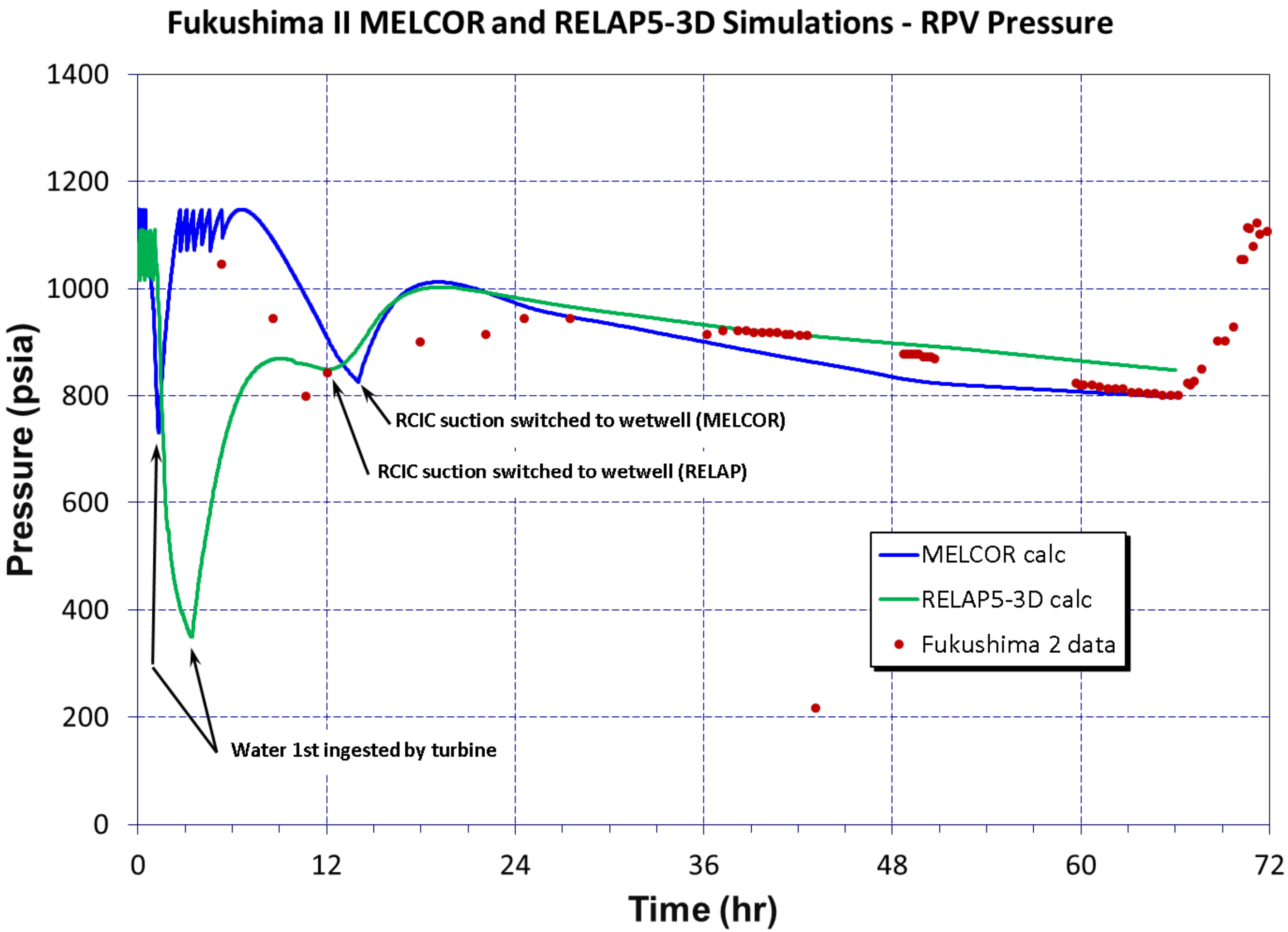


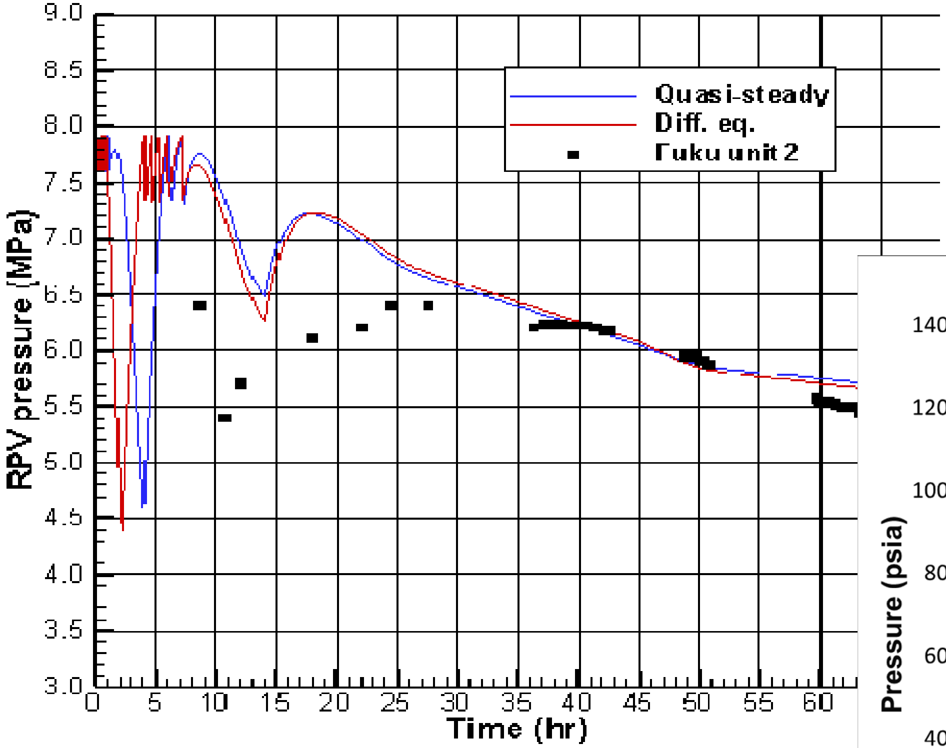
RELAP5-3D Modeling

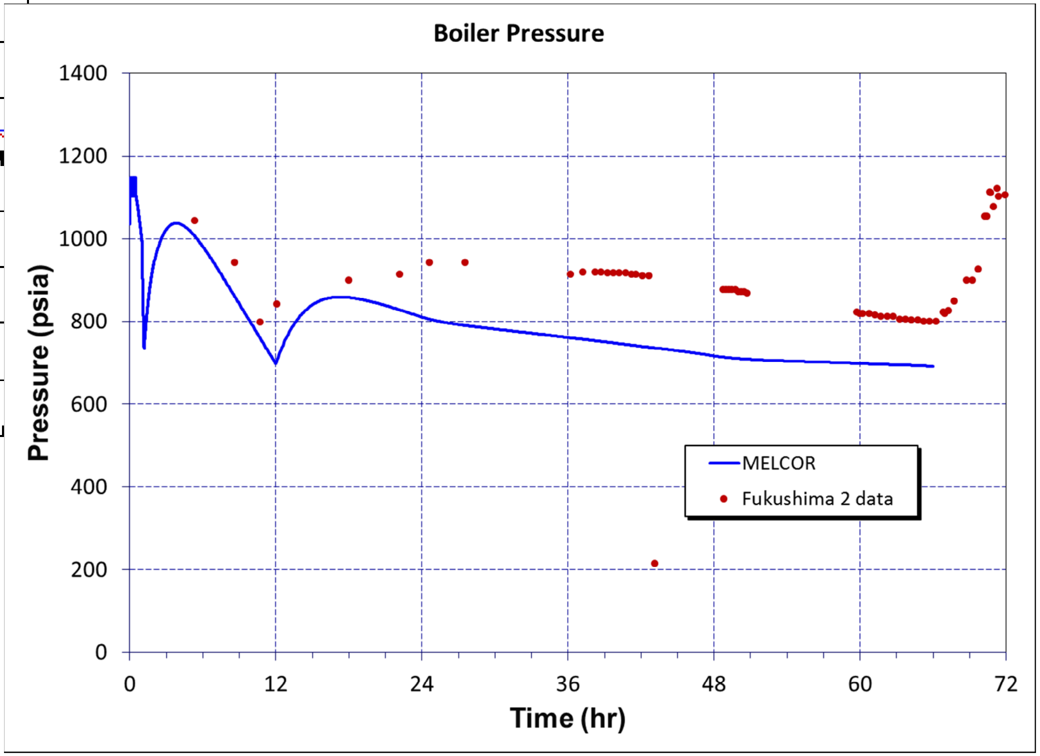


Similar results – a wide open governor & nozzle size seem critical

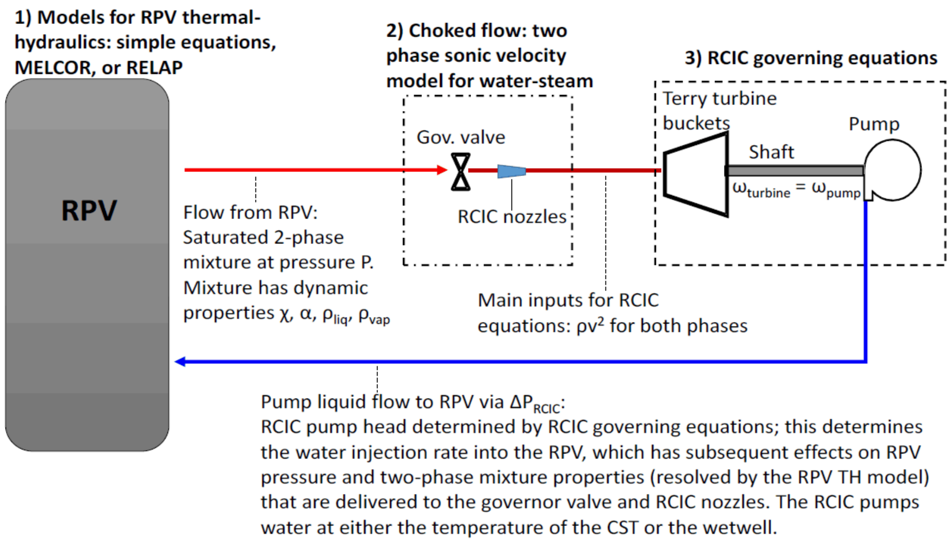
Homologous Pump Curve Result

- Better represents the initial Unit 2 data, but not the later phase

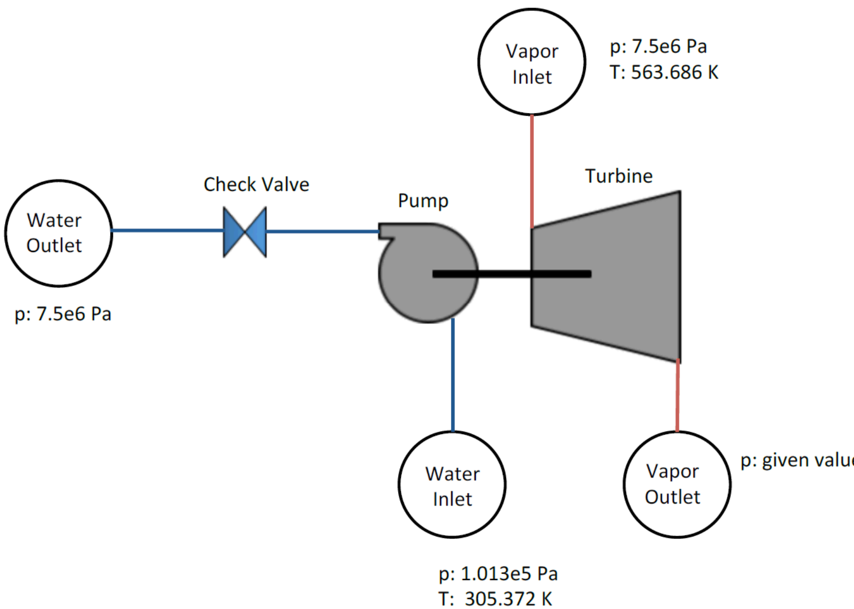




Questions



Simplified representation of physical coupling in MELCOR test model



RELAP-7 Terry turbine RCIC system test model