Center for Advanced Energy Studies

ANSG Advanced Nuclear Systems Group

Qualitative and Quantitative Evaluation of Coupling Approaches for Coupling of RELAP5 and LabVIEW

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College of Engineering

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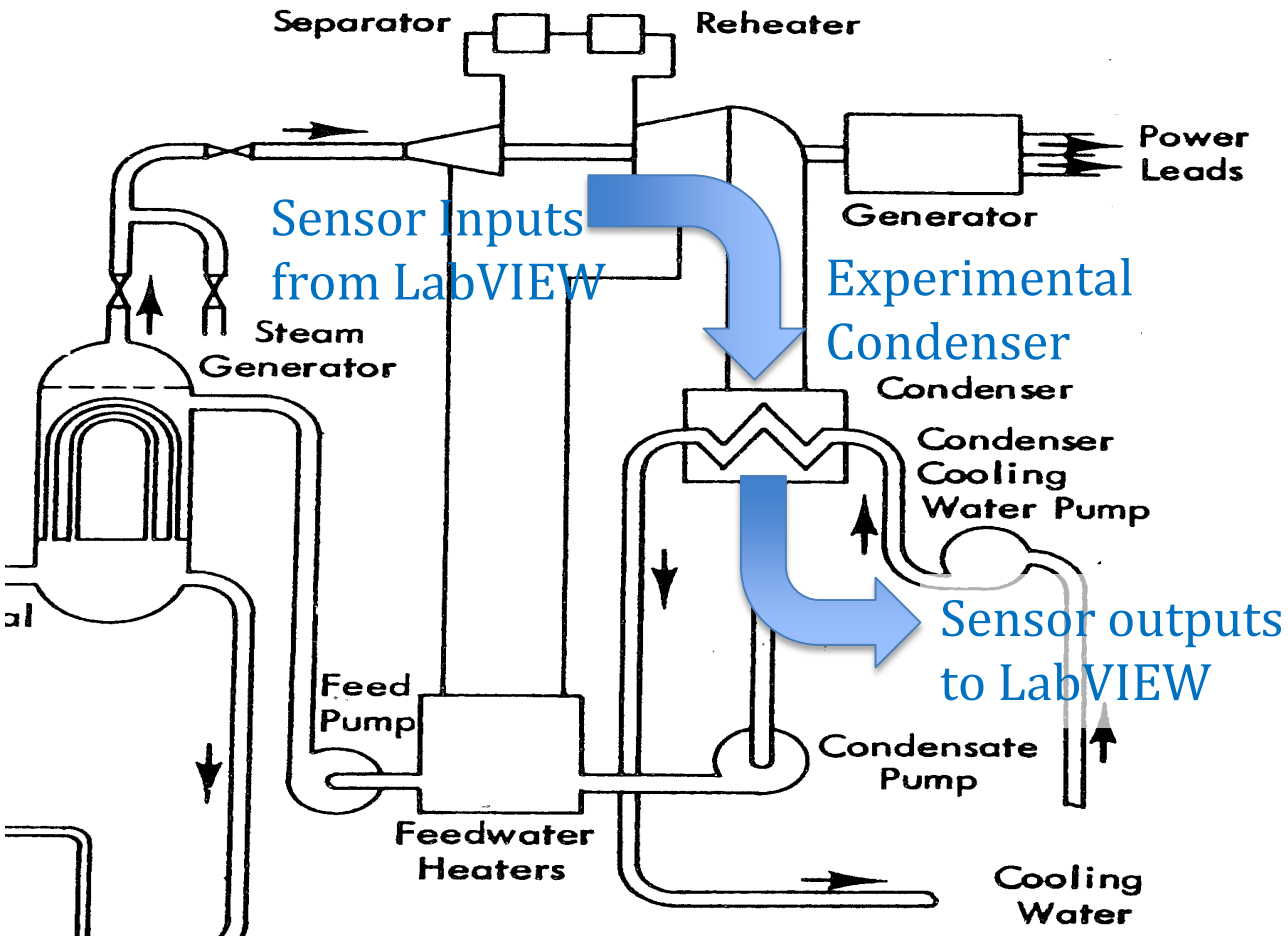
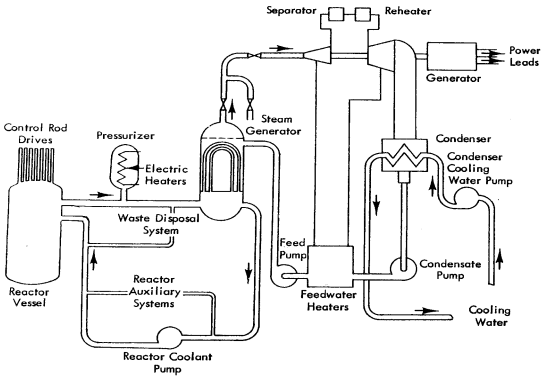
Outline

- Main Motivation
- Background
- LabVIEW
  - Main Secondary Loop Components modeled in LabVIEW
  - LabVIEW models
- RELAP5
- Simulation Results
- Conclusion

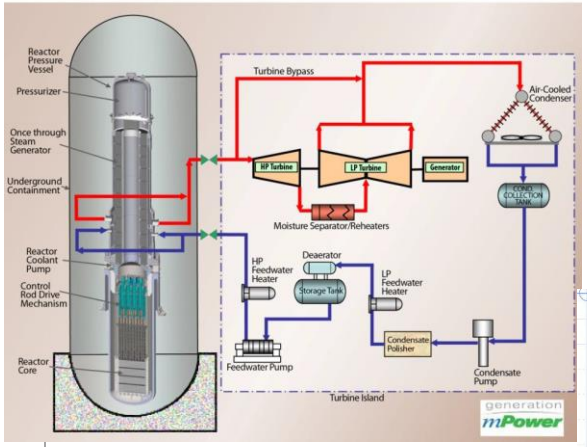
Main Motivation

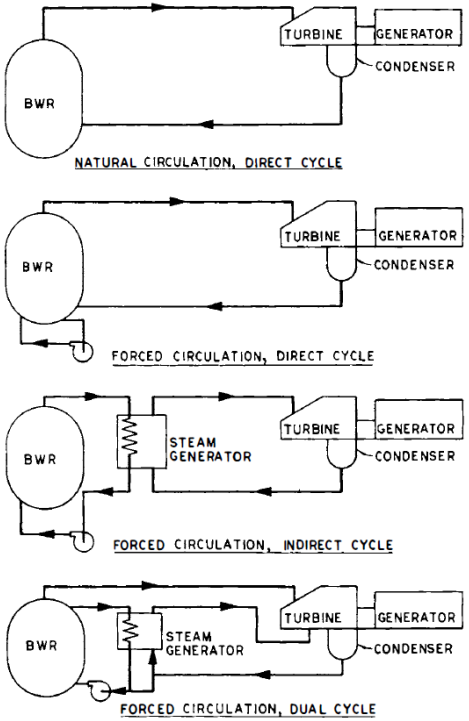


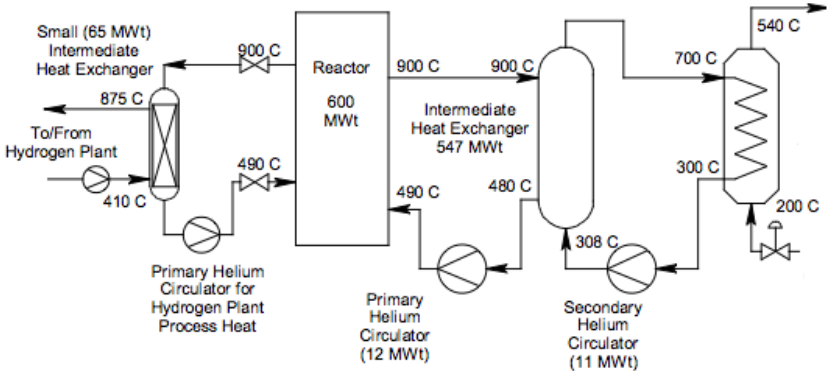
Background



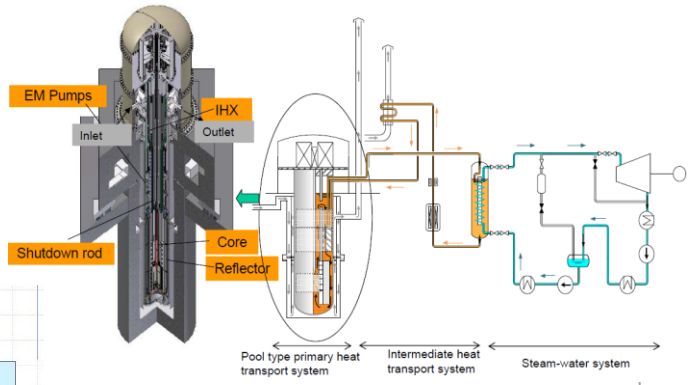
Electric Power Generation Cycle

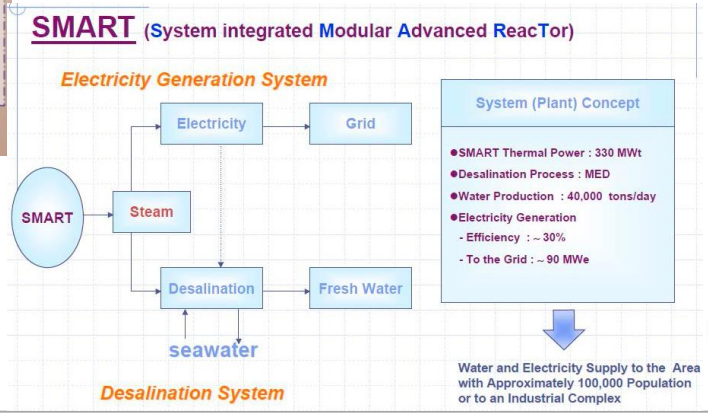






4S System Configuration





Background

- Typical Pressurized Water Reactor(PWR) contains two main coolant loops.
  - The Primary coolant loop including the reactor, pumps, Pressurizer, and the primary side of the steam generator.
  - The Secondary coolant loop contains the Secondary side of the steam generator, the turbine generator, condenser, pumps, and other feed water heaters.

Coupling Approaches

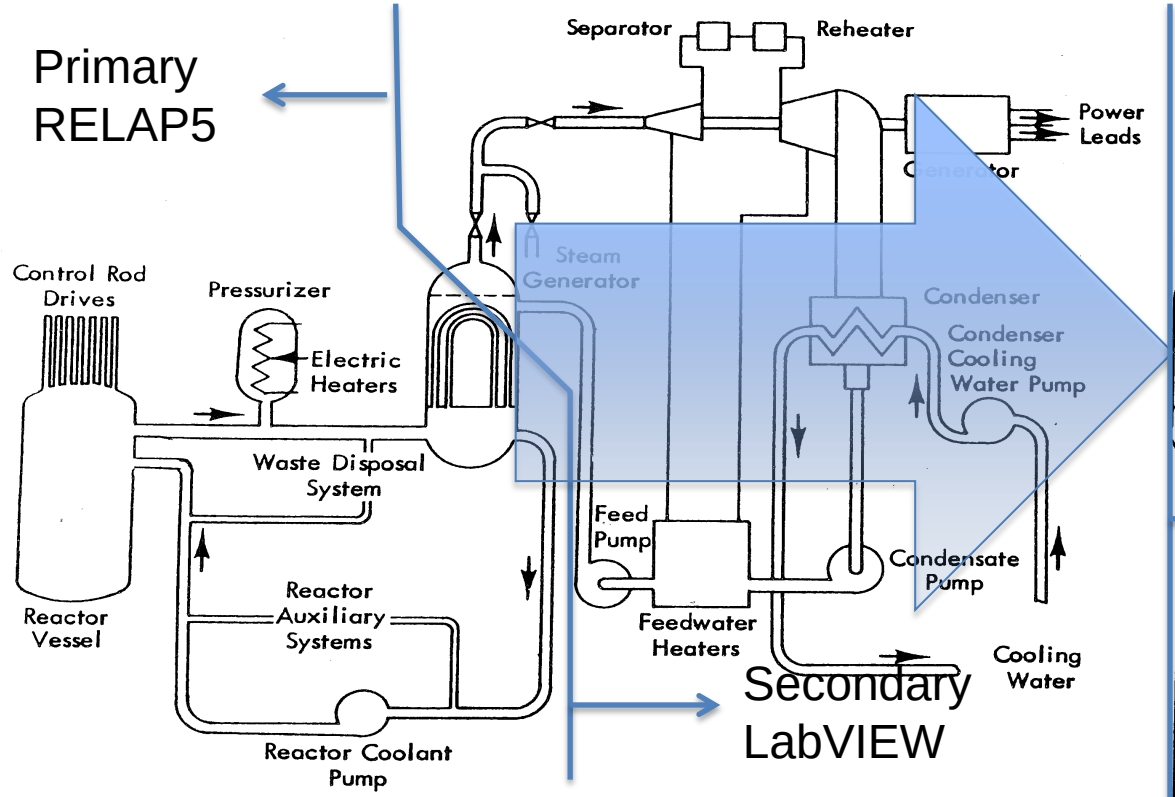
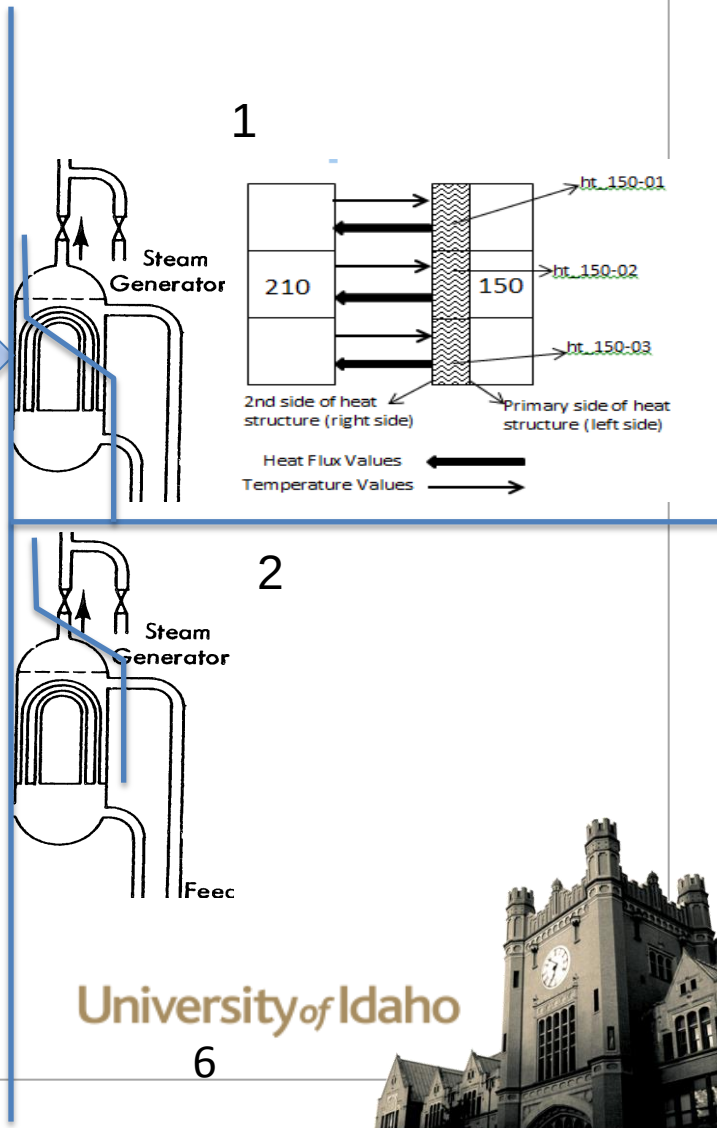


Fig. 1.1 Typical PWR system (from Ref. 1).



LabVIEW

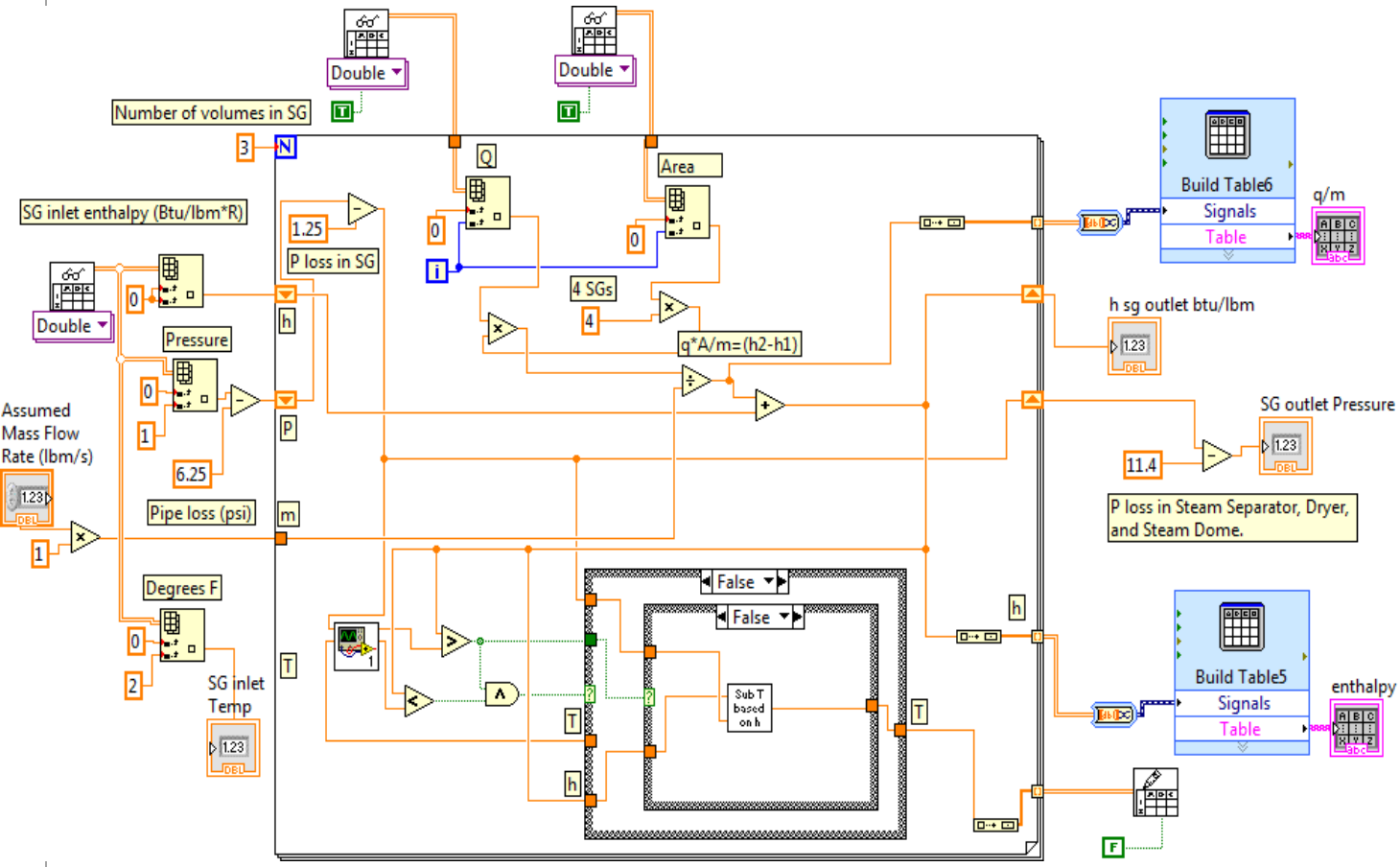
Why LabVIEW

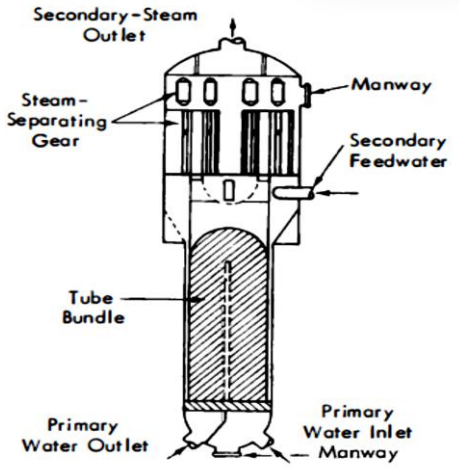
- Have a user friendly Graphical User Interface GUI
- Instrumentation analysis capabilities
- GUI based programing and display methods.
- Simple program modification to match specific systems

Components Modelled with LabVIEW

- Steam Generator
- Turbine
- Condenser
- Feed water pumps
- Feed water heaters

Secondary Loop Components
Steam Generator

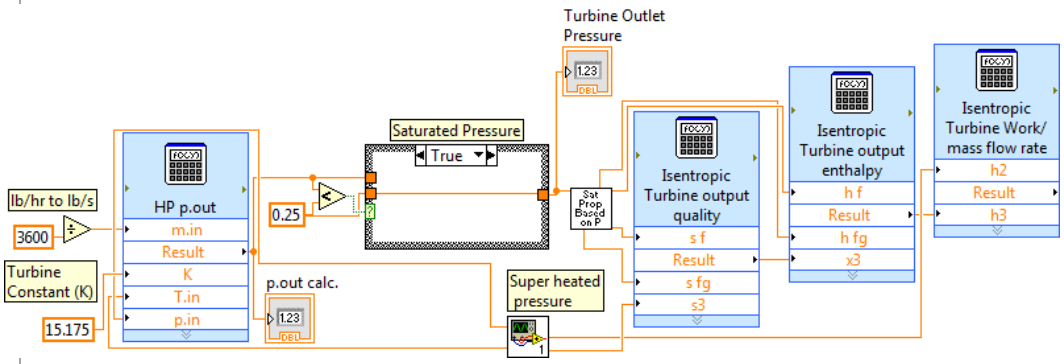


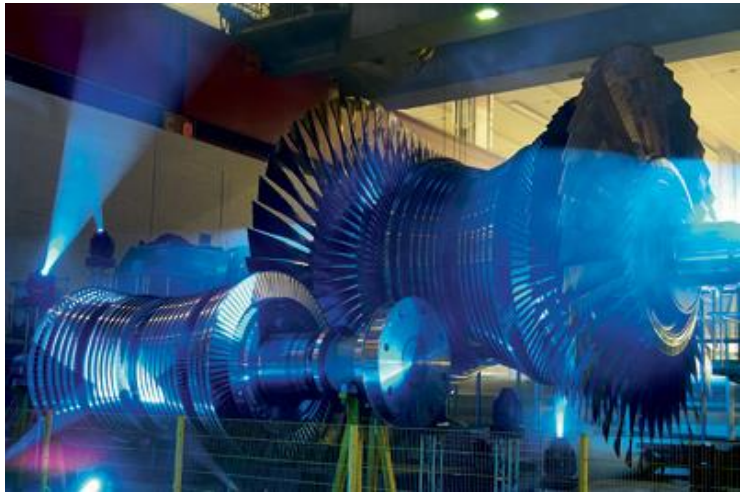


Secondary Loop Components Turbine Model

- The steam turbine model uses standard thermodynamic equations as well as:

$$\dot{m}_{in} = \frac{K}{\sqrt{T_{in}}}\sqrt{p_{in}^2 + p_{out}^2}\ *$$



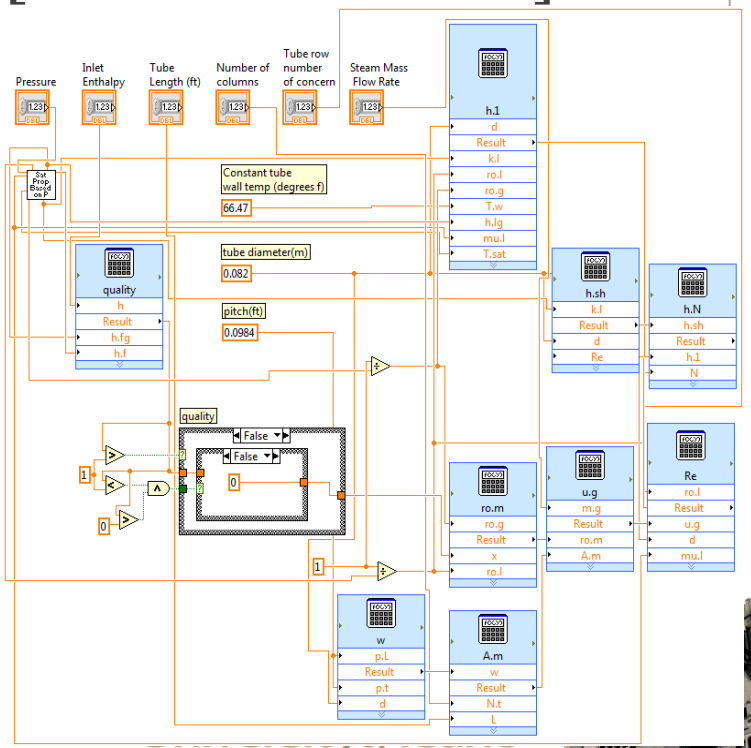


http://www.energy.siemens.com/hq/en/fossil-power-generation/steam-turbines/sst-9000.htm

*Chaibakhsh, Ali and Ghaffari, Ali. 2008. Steam Turbine Model. Simulation Modelling Practice and Theory 16 pp.1145–1162.

Secondary Loop Components: Condenser

- The heat transfer coefficient is calculated using the Butterworth* method:
- $h_N = \left[\frac{1}{2}h_{sh}^2 + \left(\frac{1}{4}h_{sh}^4 + h_l^4\right)^{1/2}\right]^{1/2} \times \left[N^{5/6} - (N-1)^{5/6}\right]$
- Where
- $h_{sh} = 0.59\frac{k_l}{d}\widetilde{Re}^{1/2}$
- $h_l = 0.728\left(\frac{k_l}{d}\right)\left[\frac{\rho_l(\rho_l - \rho_g)gh_{fg}d^3}{\mu_l(T_{sat} - T_w)k_l}\right]^{1/4}$
- $\widetilde{Re} = \frac{\rho_l u_g d}{\mu_l}$



*As demonstrated in Prof. Kakac's book of "Heat Exchangers: Selection, Rating, and Thermal Design", ISBN-13: 978-0125041904

Secondary Loop Components: Condenser

- The heat exchanger calculations are performed using the following equations from the NTU* Method

$$NTU = \frac{U_h A_h}{C_{min}}$$

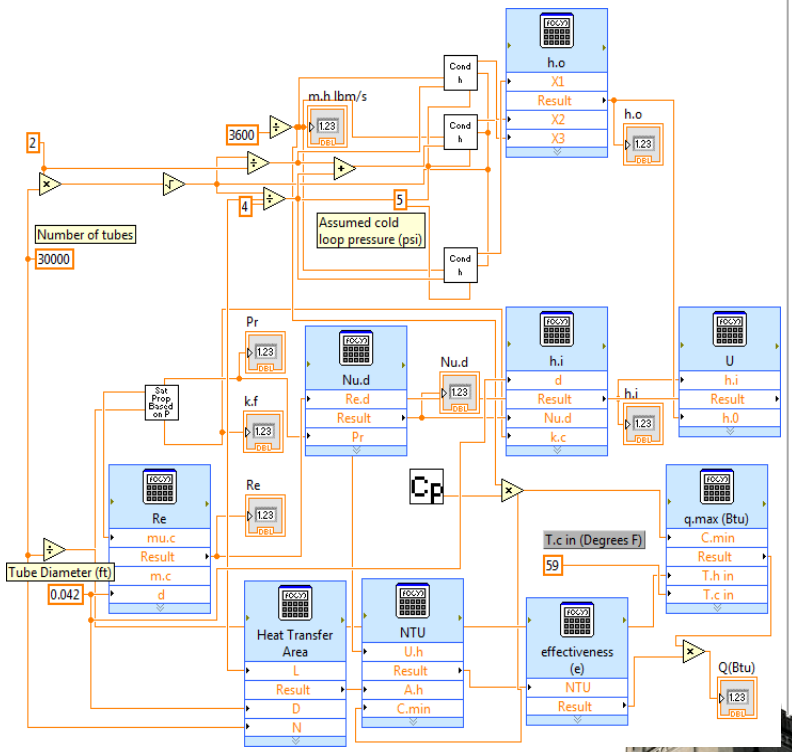
$$U_h = \frac{1}{(1/h_i)+(1/h_o)}$$

$$q_{max} = C_{min}(T_{h,i} - T_{c,i})$$

$$q = \varepsilon q_{max}$$

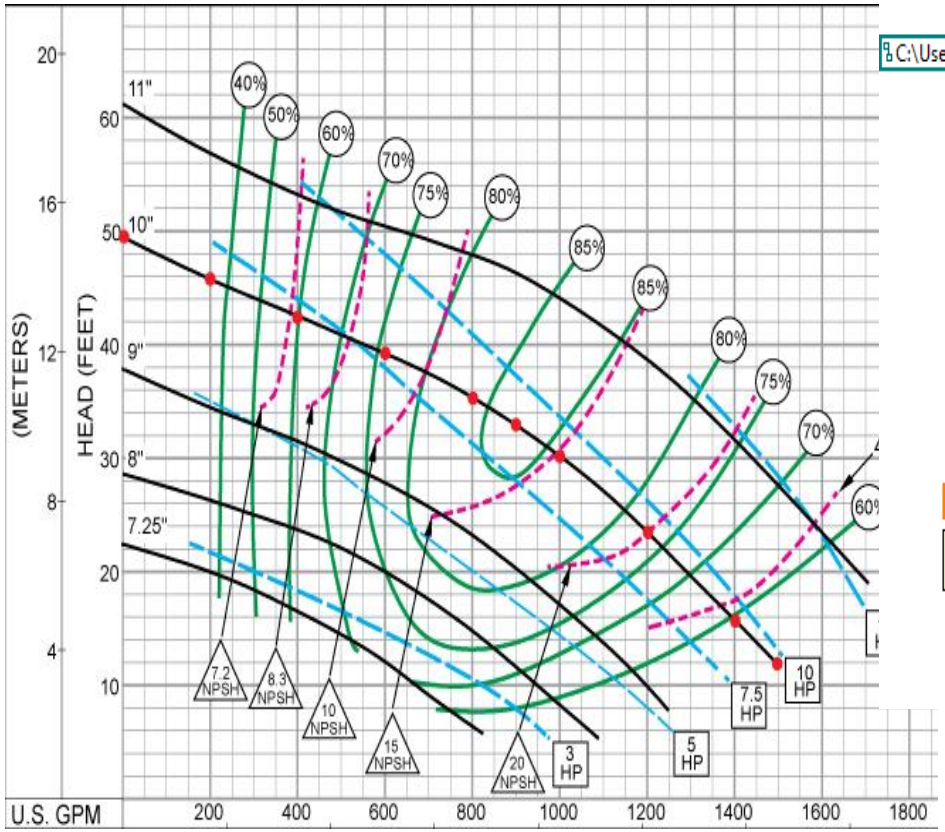
$$T_{h,o} = T_{h,i} - \frac{q}{\dot{m}_h c_{p,h}}$$

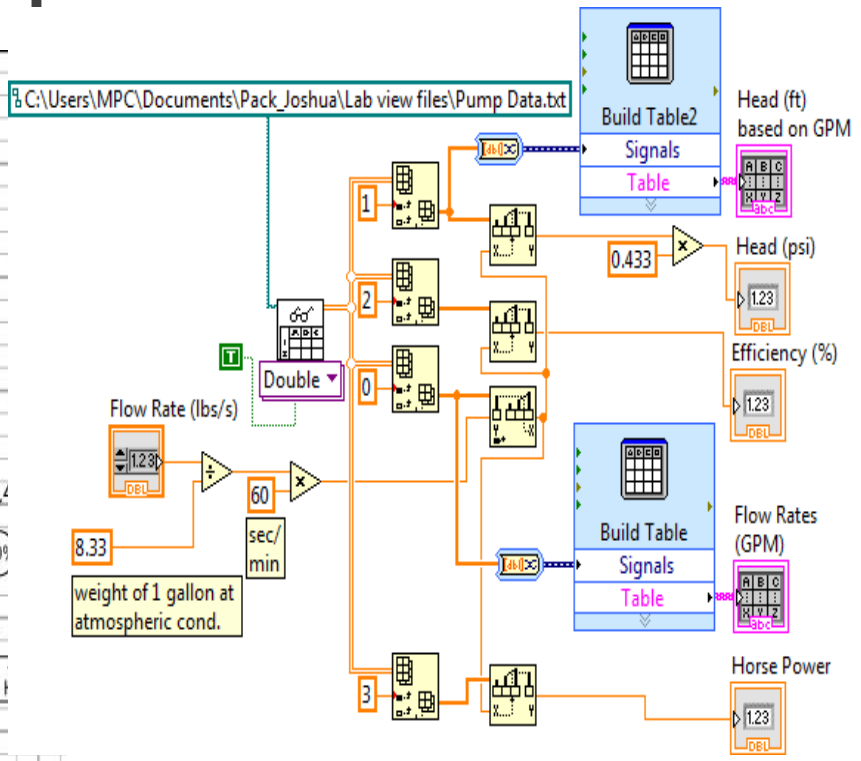
$$T_{c,o} = T_{c,i} - \frac{q}{\dot{m}_c c_{p,c}}$$



*As demonstrated in Incropera, Frank P. et al. 2011. Fundamentals of Heat and Mass Transfer 7th edition.

Secondary Loop Components: Pump



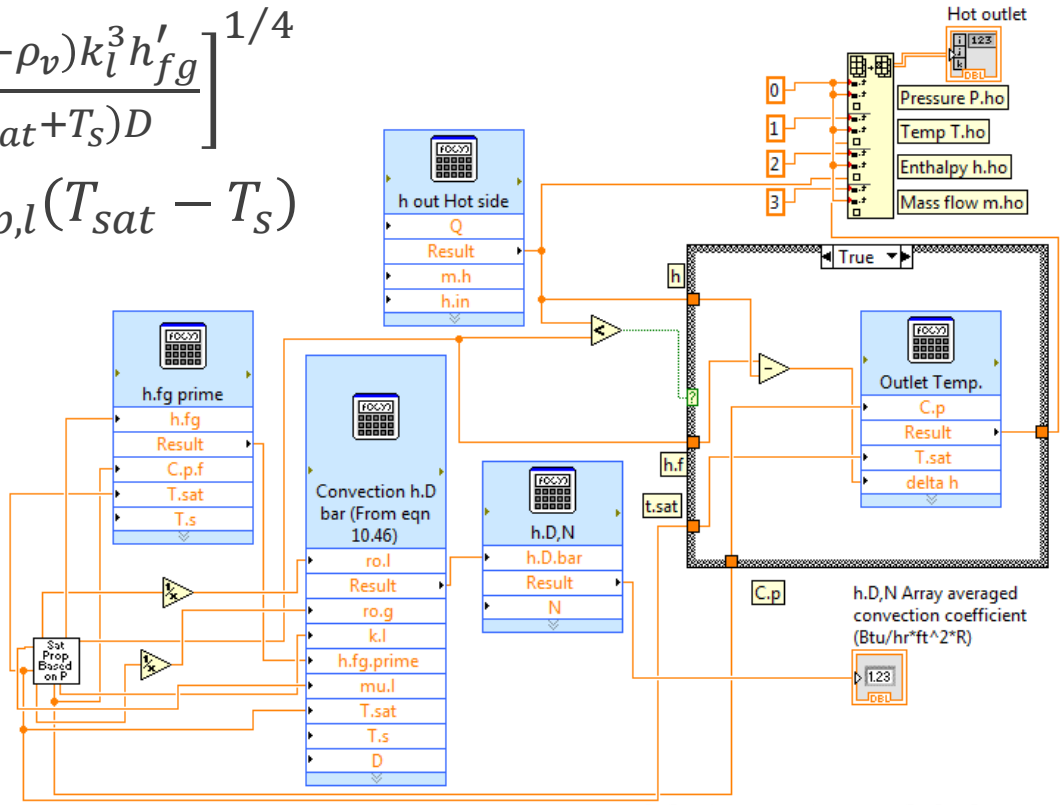


Engineered Software, Inc. 2013. "Pump Curve Accuracy."

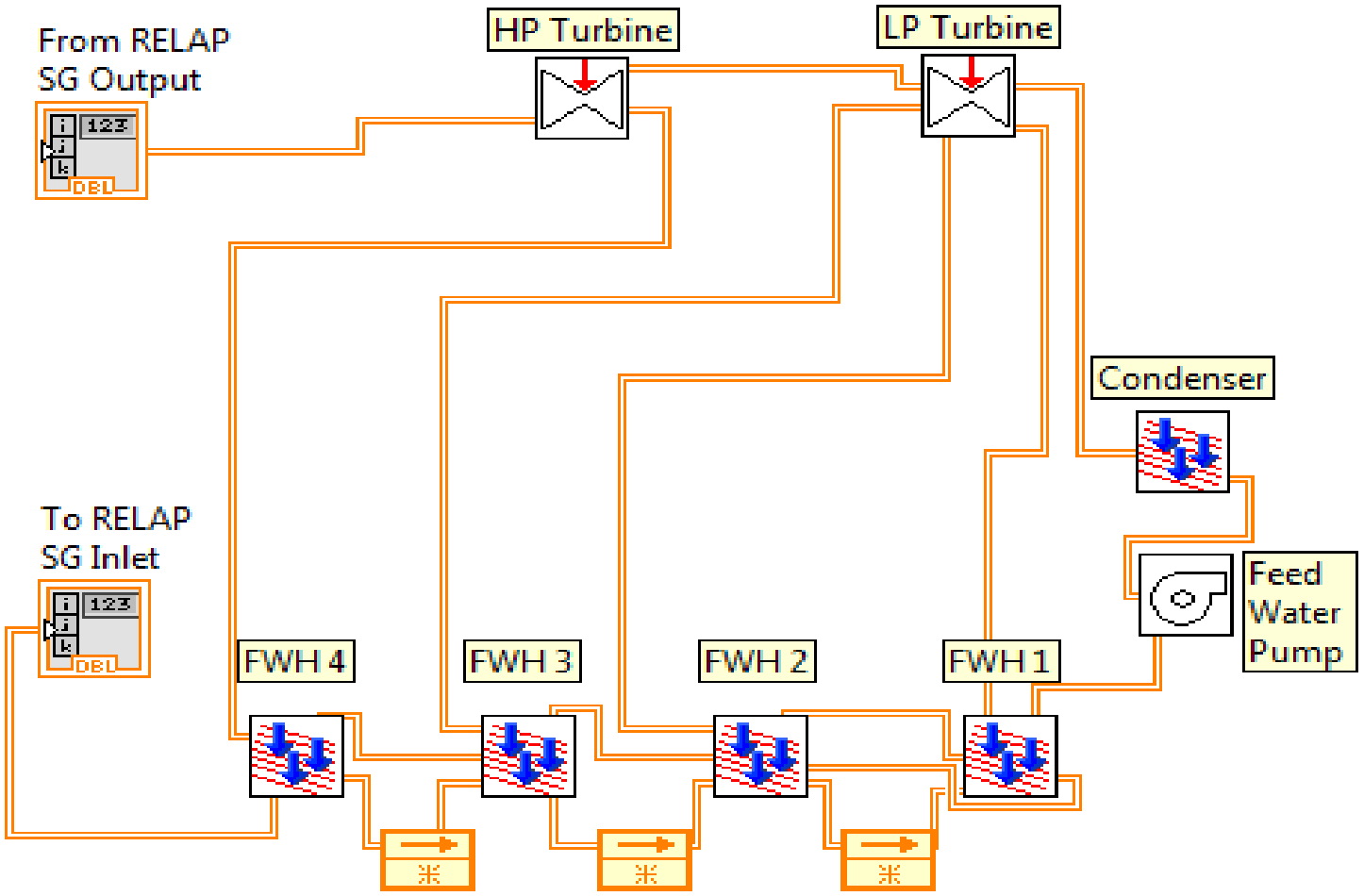
Secondary Loop Components: Feed Water Heater

- For the feed water heater the following convection coefficient method was used

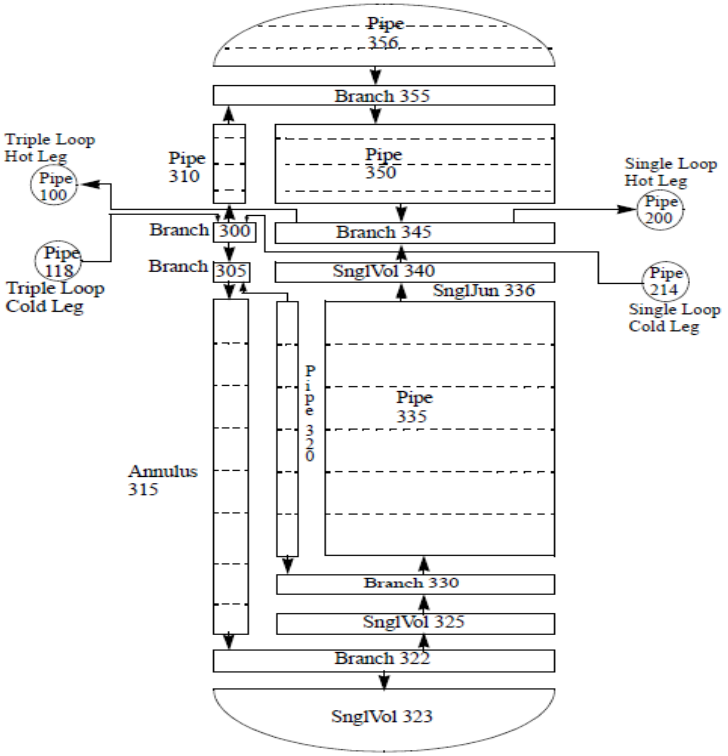
- $\bar{h}_D = 0.729\left[\frac{\rho_l g(\rho_l-\rho_v)k_l^3 h'_{fg}}{\mu_l(T_{sat}+T_s)D}\right]^{1/4}$
- $h'_{fg} = h_{fg} + 0.68c_{p,l}(T_{sat} - T_s)$
- $\bar{h}_{D,N} = \bar{h}_D N^{-1/6}$

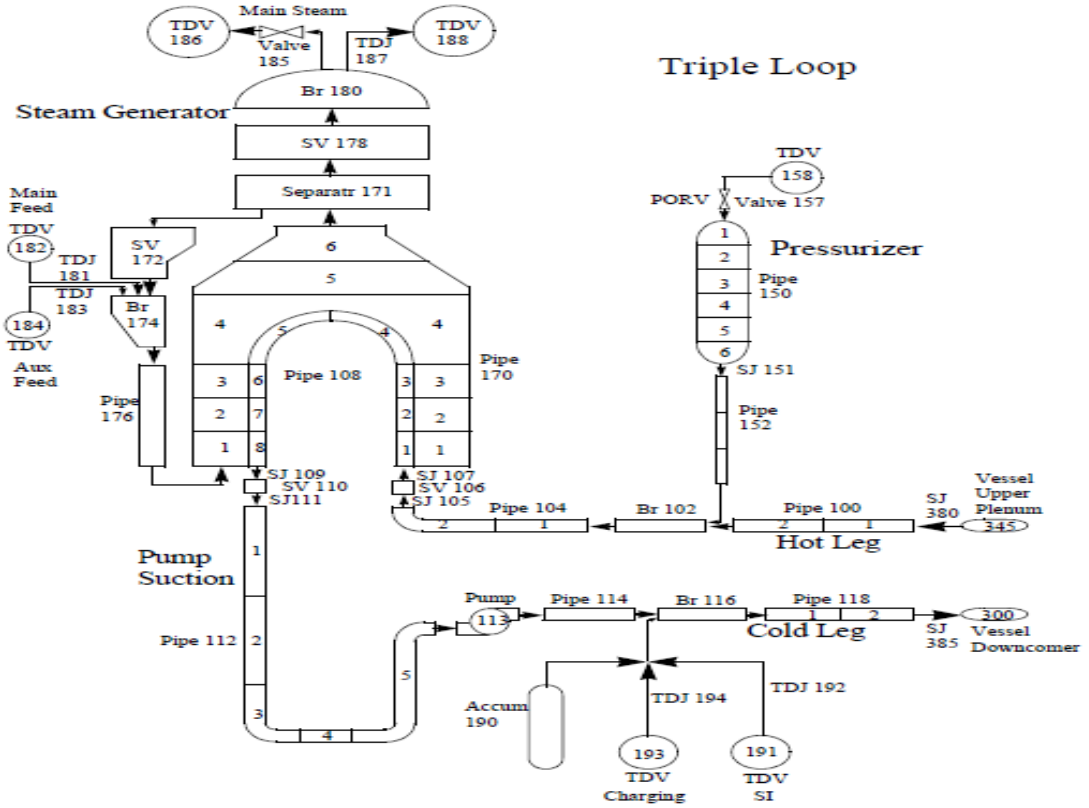


Secondary Loop LabVIEW Model



RELAP5





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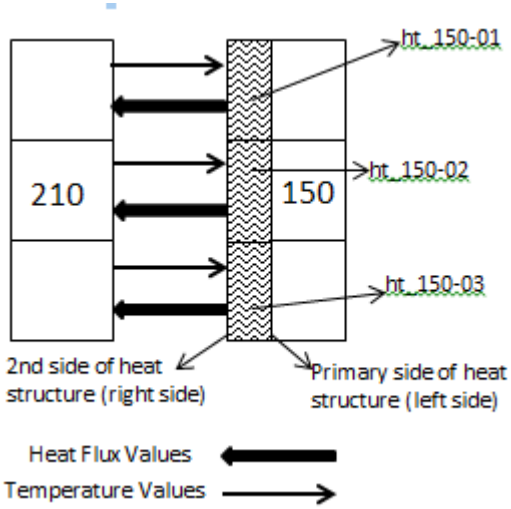
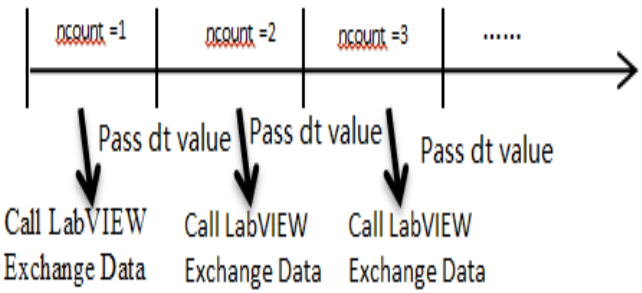
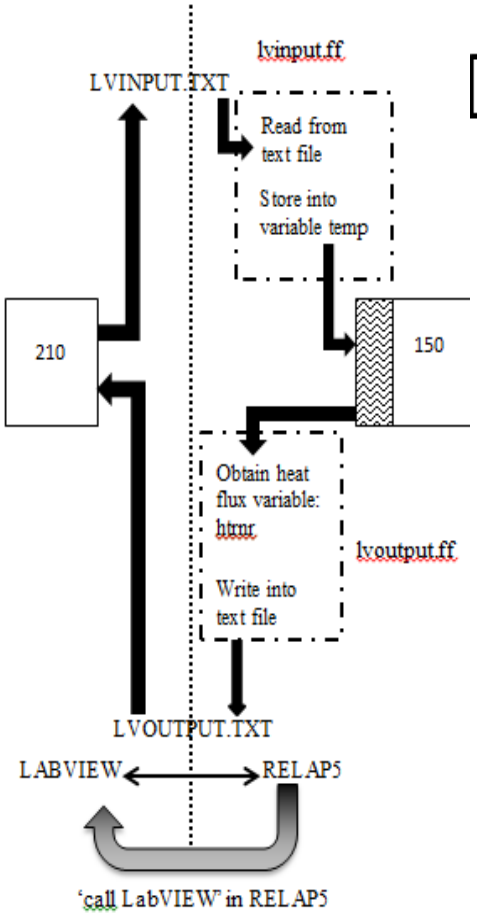
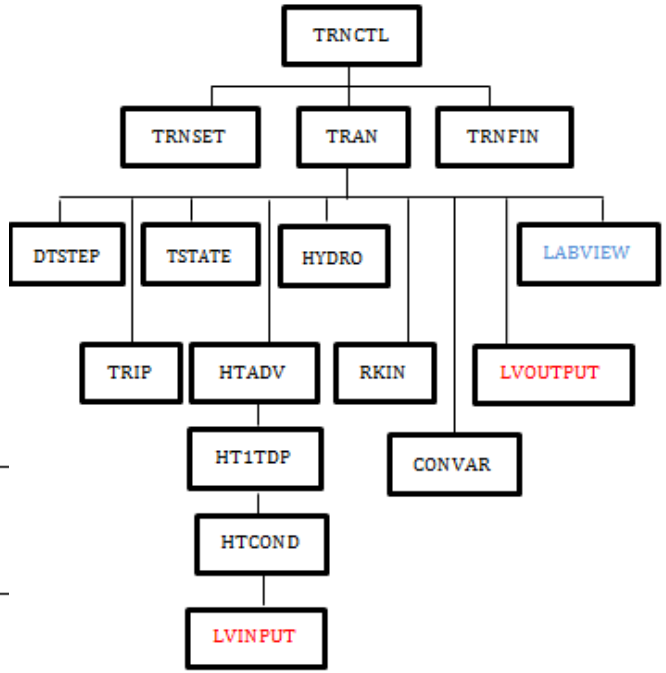
Coupling Methods



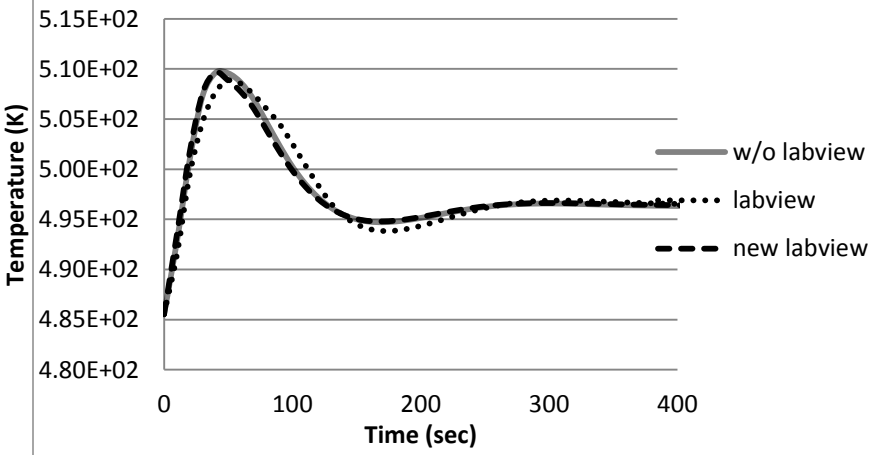




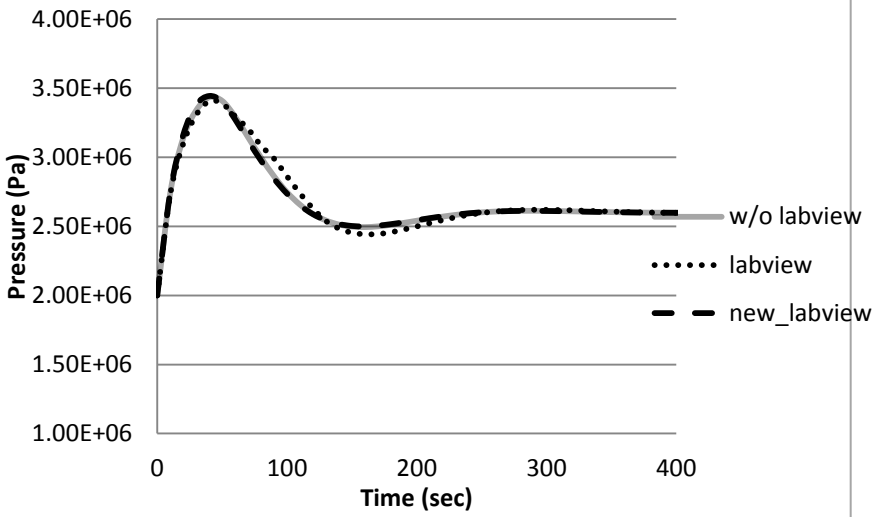


Steady State Simulation Results

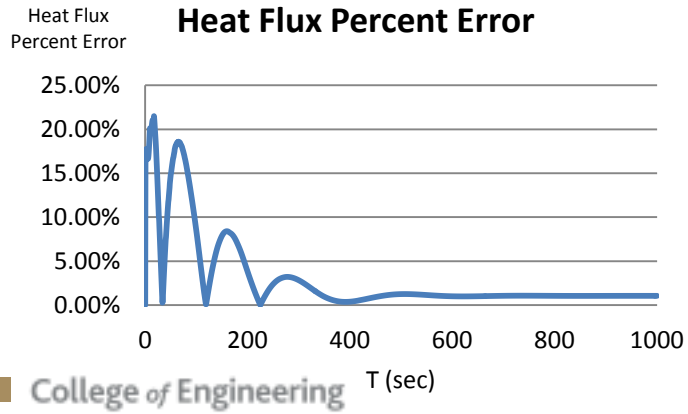
Feedwater Downcomer Liquid Temperature



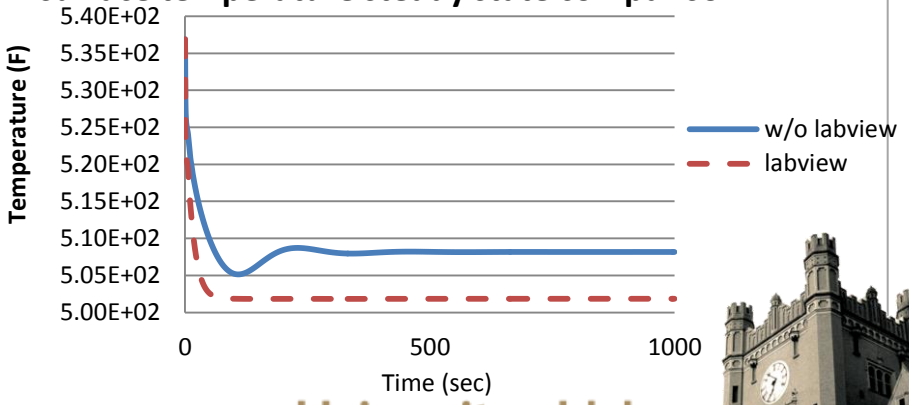
Steam Dome Pressure



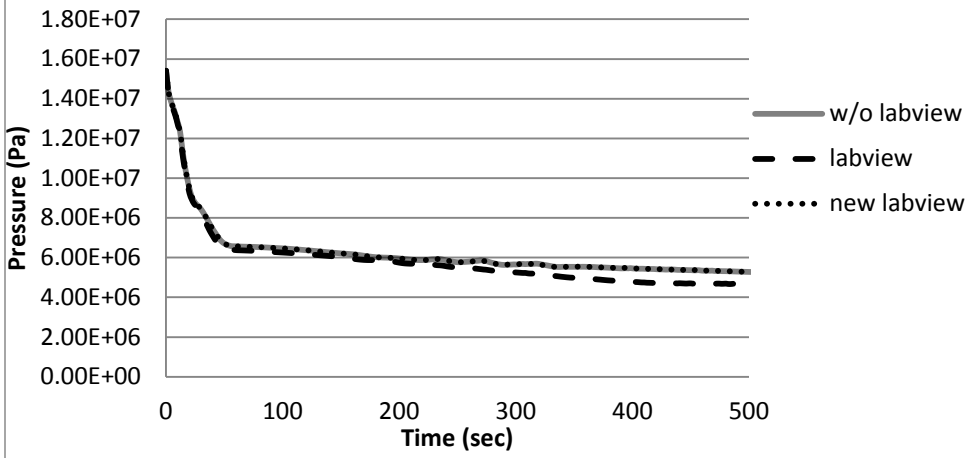
Heat Structure 150-02 Primary Side Heat Flux Percent Error



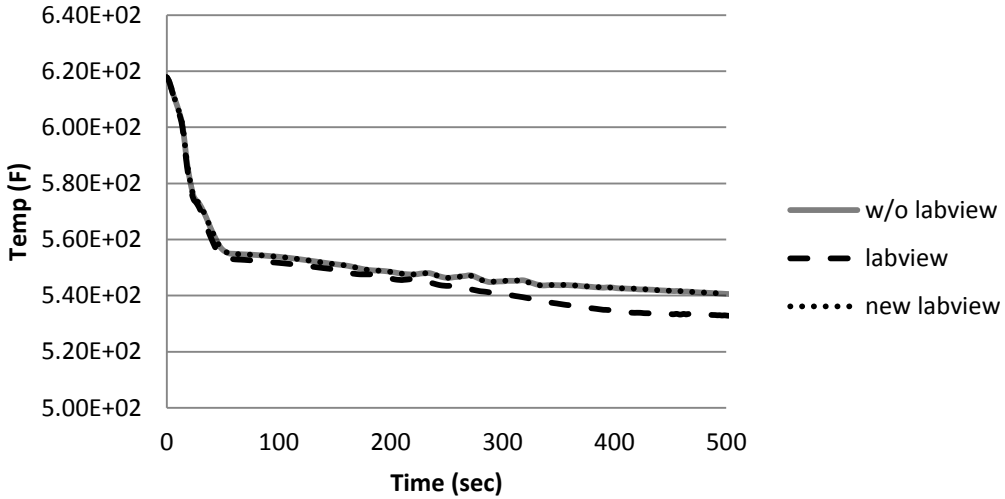
Heat structure 150-03 primary side surface temperature steady state comparison



Transient Results

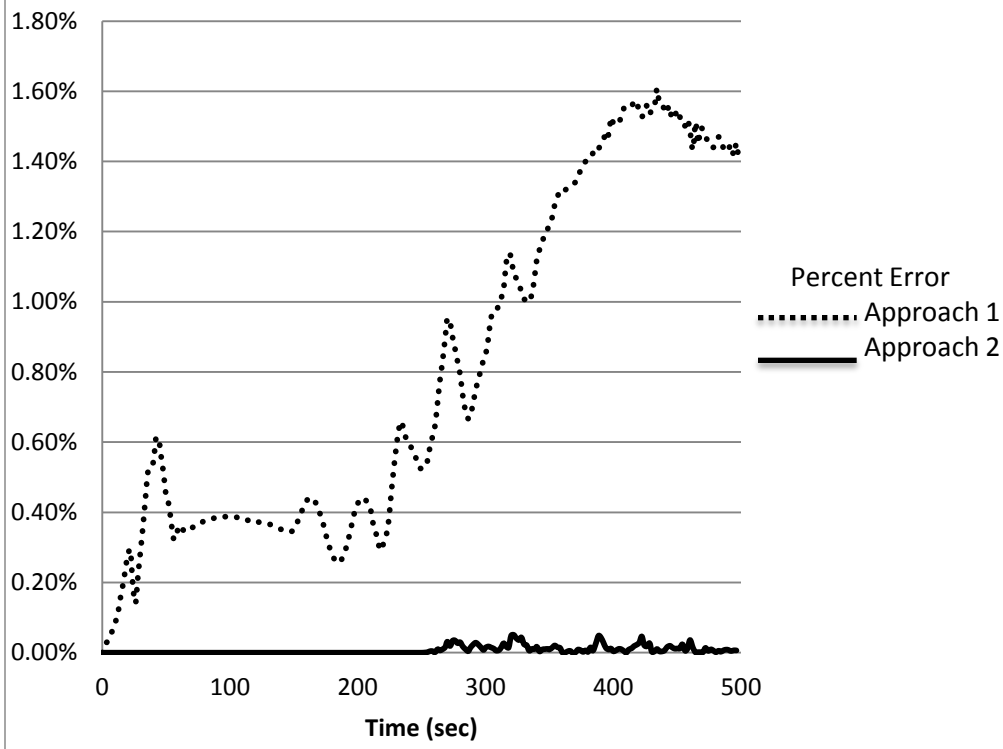


Primary system pressures during SB-LOCA

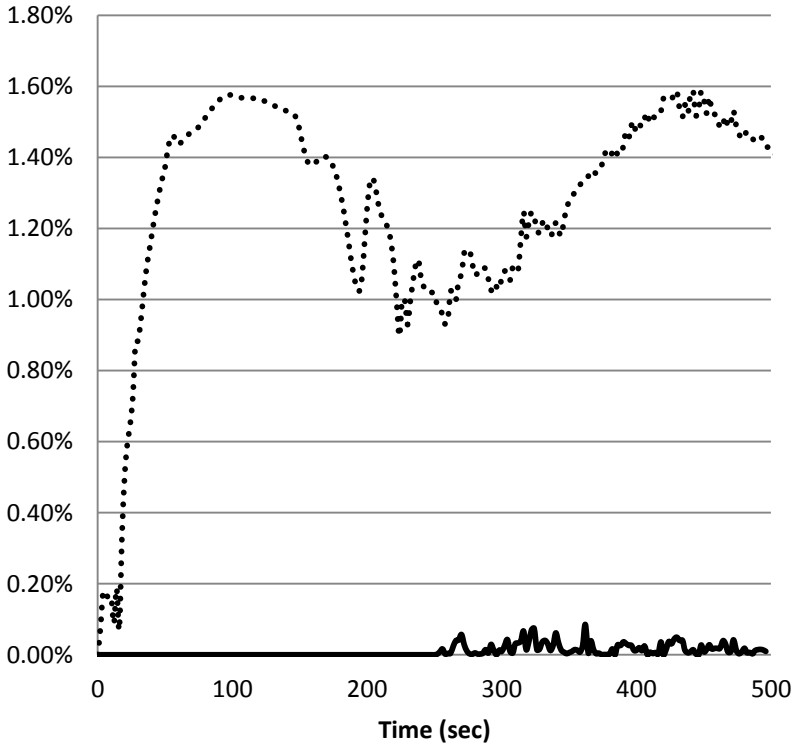


Primary system liquid temperatures during SB-LOCA

Simulation Results and Data Comparison



Primary system temperatures during LOCA



Percent difference of heat structure surface temperatures on primary side steam generator between coupling code and RELAP5 code

Conclusion

- The use of LabVIEW in the framework allows the connection of an experimental apparatus for real-time data exchange.
- Our validation results for multi-loop validation studies show that the framework works efficiently.
- Two different coupling approaches were tested.
- While both approaches are quite accurate, the coupling approach which lacks a steam generator provides results have a good agreement with RELAP5 standalone results

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Questions?