



Information Systems Laboratories, Inc.

Steam Generator Modeling Considerations

Information Systems Laboratories, Inc.

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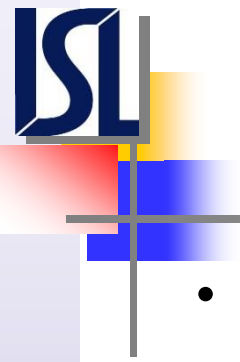
Objective

- Discuss and illustrate issues affecting development of acceptable TRACE steam generator models



Outline

- Principal parameters influencing SG behavior
- Discussion of SG model balancing methods
- SG model rebalancing exercise



Steam Generator Balancing

- Balancing the steam generator system
 - Adjusts steam generator controls to achieve targets
 - Obtain satisfactory agreement of key parameters between TRACE-calculated and target values
 - Represents a significant part of the effort needed to develop a new plant model or revise an existing plant model
- SG system is often balanced separately from plant model
 - Highly recommended approach
 - SG system is integrated into the model when acceptable performance is obtained
- Rebalancing of existing SG models is frequently needed
 - TRACE code revisions since the SG model was last used
 - Revisions in the target SG conditions (power plant uprate, etc.)



Steam Generator Balancing

- What are the key system parameters that we need to target?
 - Are there different concerns for steady-state or transients?
- What are the “knobs” that we can safely adjust without significantly affecting the system or accuracy of the results?



Important Parameters for Steady-State

- Primary System
 - Hot leg fluid temperature
 - Cold leg fluid temperature
 - Coolant loop flow rate
 - Power removed from the primary coolant system
- Secondary System
 - Main feedwater liquid temperature
 - Main feedwater/main steam flow rate
 - SG Pressure
 - Determines SG tube secondary side heat sink temperature
 - Significantly influences SG tube heat transfer rate
 - Significantly influences SG power



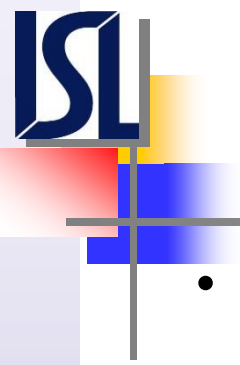
Important Parameters for Transients

- Secondary side liquid mass
 - Why is this important for transients?
- Downcomer level
 - Why is this important?
- Recirculation ratio
 - Mass flow rate from separator into downcomer divided by main feedwater/main steam flow rate.
 - Why is this important?



Successful Balancing = Compromise

- Most, but (usually) not all parameter values match desired conditions
- Code and plant models are limited in ability to predict complex flow in the SG boiler region
 - Code limited to 1-D modeling
 - Swirling axial and cross-flows in the tube bundle
 - Local effects near tube support plates are difficult to model



Successful Balancing = Compromise

- Inconsistencies and uncertainties in steady-state desired conditions
 - Basis for desired loop mass flow rate is typically not clear
 - Generally small uncertainties
 - Primary system pressures
 - Primary system temperatures
 - SG power
 - Generally moderate uncertainties
 - Secondary system pressure
 - Downcomer level
 - Main feedwater temperature
 - Main feedwater flow rate
 - Steam flow rate
 - Generally large uncertainties
 - Secondary system mass
 - Recirculation Ratio



Parameters to Compromise

- Based on principal application of plant system model
- What are “must-get-rights” for:
 - LOCA?
 - Station blackout?
 - Main steam line break?
 - Steam generator tube rupture?
- Since the acceptable compromises are somewhat use-dependent, might need more than one model to address all applications



Rebalancing Exercise

- Start with SG-1.med file in the SteamGeneratorExercise folder.
- Run model as-is, and note resulting values for the important SG parameters
- After the completion of each TRACE calculation, we will discuss the results
 - While some of you may be able to complete the exercise without further discussion, part of the objective is to outline a thought process for steam generator rebalancing
- The rest of the exercise re-balances the SG model to new target conditions
 - Similar changes to what would be needed for a power uprate



Run 1 Discussion

- How do your results compare to the targets?
 - Hot leg temp is too low
 - Cold leg temp is too high
 - Hot leg flow rate, feedwater temperature, steam flow rate and SG power are too low
 - Secondary pressure, recirculation ratio and secondary mass are too high
 - Controllers have achieved desired downcomer level and desired average loop temperature (CB 203 specifies 576.0 K, which is not the desired target, but it reaches the 576.0 K value)
- Some of these are boundary conditions and can be easily fixed
- Other parameters result from conditions in the steam generator and maybe more difficult to achieve



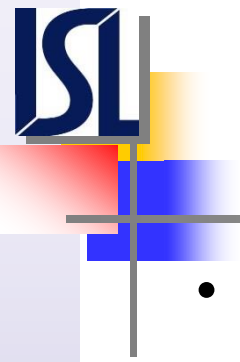
Setup Run 2

- What do you propose that we change to meet the targets better, and why?
 - FILL 1 hot leg boundary conditions should be set to desired values
 - Steam dome pressure is too high
 - Lower steam pressure boundary condition in BREAK 555 by difference in steam dome pressure and target
 - This has the effect of increasing the steam demand
 - Set the target average loop temperature in Control block 203 on the “Controls” Tab
 - Set the main feedwater temperature in FILL 21 to the new desired target value
- Return to the Exercise instructions for details



Run 2 Discussion

- How do your results compare to the targets?
 - Hot leg temp and flow are good
 - Cold leg and average loop temperatures are good
 - Downcomer level and steam pressure are good
 - Recirculation ratio and secondary mass are both high
 - Steam flow rate is high
 - SG power is high



Recirculation Ratio

- Mass flow of water returning to downcomer from the separators is greater than the feedwater mass flow
- With inadequate circulation, heat transfer surfaces can be blanketed with steam (reducing heat transfer)
- Recirculation pre-heats the incoming feedwater, which minimizes thermal stresses on the tube sheet and U-tubes
- What factors affect the recirculation ratio?
 - Weight difference between downcomer water and the riser steam/water mixture
 - Head loss from water flow through structures
 - Change in rate of heat transfer
 - Change in steam generator pressure



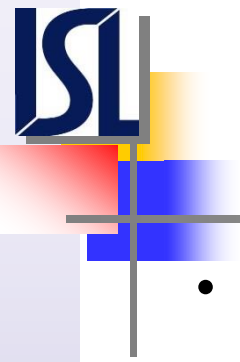
Recirculation Ratio

- Increases in power increase the rate of heat transfer and produce more steam
- What happens to recirculation ratio?
 - Density and weight of steam/water is reduced, increasing the driving head
 - Losses increase faster
 - Recirculation rate increases with power increases at low power levels (<50%), remains the same at higher power
- Steam generator pressure change (increase in steam demand) is similar to an increase in power



Setup Run 3

- What do you propose that we change to meet the targets better, and why?
 - Reduce flow area fraction in the connection between the bottom downcomer and boiler
 - These fractions/losses are generally not well understood within steam generators
 - Reduce the flow area fraction in the connection between the boiler and separator
 - These fractions/losses are generally not well understood within steam generators
- (Continued next slide)



Setup Run 3

- What do you propose that we change to meet the targets better, and why?
 - Reduce the flow area fraction in the connection between the boiler and separator
 - These fractions/losses are generally not well understood within steam generators
 - Adjust reactor power (Primary temperature and/or flow rate)
 - This is a high power case, so we would not expect a change to recirculation ratio
 - Would probably miss power targets
 - May be acceptable if running a secondary-specific transient, since primary conditions are less important
 - Adjust downcomer level
 - Change the secondary system mass
 - If scenario is primary-system based, this might be acceptable
- Return to the Exercise instructions for details



Run 3 Discussion

- How do your results compare to the targets?
 - Recirculation ratio is good, secondary mass is reduced
 - SG power is still too high
 - Steam flow rate still high
 - Other parameters relatively unchanged
- SG power is perhaps most important parameter, since all SGs have to remove the core power



Setup Run 4

- What do you propose that we change to meet the SG power target better, and why?
 - Increase the average loop temperature
 - Will result in a smaller hot leg-to-cold leg differential temperature, which equates to a lower primary system power
 - Reduced primary system power should reduce steam generator power
- Return to the Exercise instructions for details



Run 4 Discussion

- How do your results compare to the targets?
 - Average loop temperature increased to new setpoint
 - SG power is lower, but still too high
 - Steam flow rate lower, but still high
 - Slight increase in cold leg temperature
 - Slight increase in steam dome pressure and secondary system mass



Setup Run 5

- What do you propose that we change to meet the SG power target better, and why?
 - Increase the average loop temperature even more
 - Our experience shows that this is a good “knob”
- Return to the Exercise instructions for details



Run 5 Discussion

- How do your results compare to the targets?
 - Average loop temperature increased to new setpoint
 - SG power is only slightly to high
 - Steam flow rate good
 - Cold leg temperature too high
 - Steam dome pressure too high
 - Secondary system mass high
- Do you think that the compromises are acceptable? Under what conditions?
 - Dependent upon conditions, they could be acceptable
 - Many parameters are close to desired values (including SG power)
 - Average loop temperature is 0.8 K too high, so cold leg temp and steam dome pressure are also high
 - Model limitations and/or inconsistencies in the set of target values could be the reason we have to compromise



Setup Run 6

- Examining our target parameters, which values do you anticipate are less certain?
 - Hot leg flow rate
 - SG Tube Heat transfer area
 - Steam generator losses
 - Steam generator level
 - Recirculation ratio
 - Others?
- We will attempt to correct some of the targets by adjusting the hot leg flow rate in the next run
- Return to the Exercise instructions for details

Run 6 Discussion

- How do your results compare to the targets?
 - Except for loop flow rate, all important calculated parameters are close
 - If 5% change in loop flow rate matches uncertainty of that value, then these results could be acceptable



Setup Run 7

- Recall that the steam generator tube heat transfer area is also a source of uncertainty in the model
- We will attempt to correct some of the targets by adjusting the SG Tube heat transfer area in the next run
 - TRACE variable RDX represents the number of SG tubes modeled
 - Reducing the multiplier effectively reduces the SG tube heat transfer area while not affecting the hydrodynamics portion of the model
- Return to the Exercise instructions for details



Run 7 Discussion

- How do your results compare to the targets?
 - SG power is still too high (~39 MW)
 - Little change from SG-3 Results
 - This run is the same, except for heat transfer area
 - Why didn't the reduction in area reduce the SG power?
 - Automatic steam outlet valve control adjusts the valve to keep the same loop average temperature
 - With the same loop average temperature, the hot leg-to-cold leg differential temperature and SG power stay the same
 - Recall that the SG-2 run changed the steam sink pressure in BREAK 555 – should that have worked?



Setup Run 8

- VALVE 550 is under automatic control to achieve a target primary average temperature
- Removing the controller and setting VALVE 550 manually will allow adjustment of the SG power level by changing SG thermal/hydraulic conditions
- What impacts in the SG conditions would you expect from reducing the flow area of VALVE 550?
 - Increase steam dome pressure
 - Raise secondary system temperature
 - Reduce primary-to-secondary system differential temperature
 - Reduce SG tube heat flux
- Return to the Exercise instructions for details



Run 8 Discussion

- How do your results compare to the targets?
 - Cold leg, average loop temperatures a little high
 - SG power and steam flow rate a little low
 - Steam dome pressure a little high
 - Depending on application, this agreement might be sufficient
 - SG power and steam flow are pretty well calculated
 - Average loop temperature 0.9 K high cold leg temperature 1.8 K high