Steam Generator Issues

Generic Implications of TMI Tube Sever Event

January 31, 2002

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Presentation Outline

- Update TMI and Oconee Inspection Results
- Industry Assessment
- Industry Actions to Date
- Industry Action Plan
- Response to NRC Questions
- Conclusions
- Next Meeting

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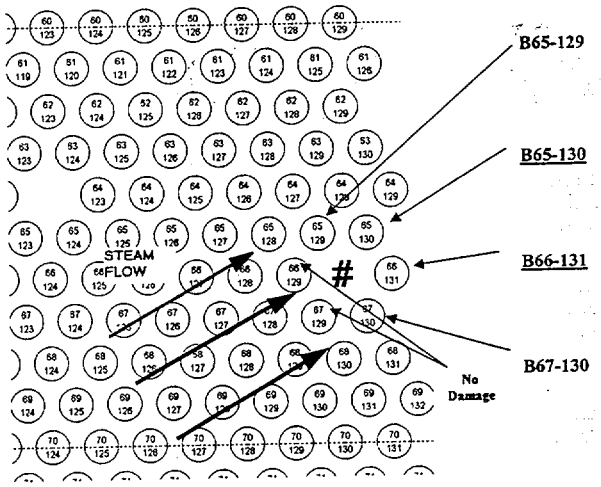
TMI Results

- Inspection Results
  - 870 tubes de-plugged
  - 263 tubes contained water
  - No tubes with original Alloy 690 plugs (87) contained water or any evidence of swelling
  - 29 tubes have swelling present:
    - Westinghouse Alloy 600 re-rolled plugs (23) top and bottom
    - Framatome Alloy 600 rolled plugs (6) replaced with Framatome Alloy 690 rolled plugs on top and Framatome ribbed plugs bottom

TMI Results

- Two severed tubes
  - B66-130, Severed at UTSF
    - Impacted 4 surrounding tubes
    - Original UTS Alloy 600 rolled plug replaced in 1997 with Alloy 690 (ribbed A-600 at bottom)
  - A2-24, Severed at 15th TSP
    - No impact on surrounding tubes
    - Westinghouse Alloy 600 rolled plugs top and bottom, re-rolled after hot functional testing
- One axial burst
  - B150-14, Opening in Top Span
    - Original UTS Alloy 600 rolled plug replaced in 1997 with Alloy 690 (ribbed A-600 at bottom)

Tubes With Damage Surrounding B66-130



TMI Root Cause Assessment

- Failure scenario for B66-130
  - Tube swelled during heatup due to trapped water
  - Tube became restrained at top TSP and UTS
  - Restraint isolated top span & decreased damping
  - Tube severed due to high cycle fatigue caused by flow-induced vibration at area of high cross flow
    - Initiated at shallow OD IGA patch
- Populations with observed swelling at TMI
  - Locations where plugs were repaired without de-watering
    - Westinghouse A-600 roll plugs re-rolled in place
    - Framatome A-600 UTS roll plugs removed & replaced

ONS-3 Plugged Tube Inspection

- 108 UTS rolled plugs removed, tube inspected
  - All locations (73) where either UTS or LTS plugs were removed and replaced
  - Older Alloy 600 plug locations (35)
- Results
  - 22 tubes contained water
    - One through-wall leak at site of original tube defect
  - 8 tubes >50% filled with water (6 tubes > 70%)
  - No swollen, severed, or burst tubes

Comparison of TMI-1 and Oconee-3 Results

- Difference can be explained by relative numbers of plugged tubes most susceptible to swelling:
  - Westinghouse re-rolled A-600 plugs
    - TMI - 484 tubes, 23 were swollen (5%)
    - ONS - 0 tubes
  - Removed / replaced UTS Framatome A-600 rolled plugs
    - TMI - 248 tubes, 6 were swollen (2%)
    - ONS - 37 tubes, 0 swollen
      - Would expect <1 swollen tube based on percent affected at TMI-1

Comparison of TMI-1 and Oconee-3 Results

- TMI had a larger population of the plugged tubes susceptible to severance from swelling:
  - 546 total at OTSGs
    - 492 inspected at TMI-1
    - 11 inspected at ONS-3
    - 43 elsewhere:

ANO-1, 8 (Fall 2002)	ONS-1, 18 (Spring 2002)
CR-3, 1 (Fall 2003)	ONS-2, 11 (Fall 2002)
Davis Besse, 1 (Spring 2002)	ONS-3, 4 (Spring 2003)

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Industry Actions to Date

- Senior management meeting with NRC on 11/29
- Communicated event to the industry
  - BWOG meeting week of 12/3
  - SGMP TAG meeting week of 12/10
- Developed initial assessment and submitted to NRC on December 21, 2001
- Numerous industry meetings and telecons including a meeting at NEI on January 10th

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OTSG Initial Assessment

- Time is available to take action on the susceptible plugged tubes:
  - Based on the rate of wear at TMI and the time that an affected tube could be expected to be in service in a condition that it may fail under MSLB conditions, the changes in CDF and LERF for the remaining plants would be in Region III of RG 1.174
  - The risk attributable to other plug types is inconsequential to the short term operation of the plants

RSG Initial Assessment

- Time is available to study the issue:
  - Three potential areas of high flow concern in RSGs:
    - U-bends
      - Response to NRC Bulletin 88-02 on rapidly propagating fatigue cracks in U-bends
    - Top of tube sheet
      - Operating experience and/or analysis for plants with locked tubes has identified no fluid-elastic instability problems
    - Pre-heater
      - Encompassed by actions taken in response to stability analyses performed in the early 80s
      - CE system 80 plants stabilize degraded tubes in the pre-heater region with high flow velocities

RSG Initial Assessment

- Operating experience shows that among the plug diode effects observed, only axial failures occurred which caused no damage to in-service tubes
- Unplugged hundreds of tubes – no known severed tubes
- Thousands of locked / dented tubes in the areas of highest cross flow velocity with no fatigue failures confirms analysis results
- No locations of fluid-structure coupling where fatigue failure of swollen tubes is expected

Current Status

- BWOG developed recommendations for addressing susceptible plug types to be implemented during next scheduled outage
  - May be revised based on experience and longer term study
- SGMP taking lead to address generic implications
  - Received proposals and directed scope of initial tasks
  - Developing long term plan

Initial Tasks

- Identify potential damage mechanisms that would cause plugged tubes to damage adjacent tubes
  - Include interaction effects
- Evaluate the existing level of analytical and empirical data to ensure it is sufficient to support conclusions
- Evaluate the probability of occurrence of each mechanism
- Rank mechanisms in order of importance
- Determine need and priority of additional action

Action Plan Scheduling

- Time is available to study the significance of the issue and determine appropriate actions
  - Complete initial tasks in 5 months
  - If safety significant issues are identified, follow up action will be initiated immediately and communicated to the NRC
  - Longer term actions will be addressed through the SGMP process

Response to NRC Questions

- 1) RSG operating experience on swelled and ruptured tubes
  - Visual inspections have identified ruptured tubes in row 1 and peripheral tubes
    - These are the most limiting locations from a FIV perspective
  - Frequent visual inspections of the interior are performed, but not for the purpose of identifying swelled tubes
  - Numerous interior tubes have been returned to service – no swollen or ruptured tubes have been identified
    - Sample size is comparable to TMI's deplugging campaign

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Response to NRC Questions

- 2) Probability that a plugged RSG tube may sever over the long term
  - Analyses have been performed on tubes locked at the most limiting locations from a FIV (turbulence and fluid elastic) perspective
    - Fatigue evaluations consider the maximum effect of mean stress
    - Existing analyses indicate that a significant pre-existing crack must be present to exceed the threshold for fatigue crack growth
  - Initial tasks of industry action plan will address this item further

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Response to NRC Questions

- 3) Basis for limiting OTSG tube plug types susceptible to swelling / burst
  - 12/01 letter stated that all plugged tubes are potentially susceptible to swelling
  - Short term actions focused on most susceptible tube populations
    - Joint repaired such that existing water trapped inside
    - Supported by OTSG field experience to date
      - 31 of 31 known observations fall in this category
      - Many locations in other categories inspected with no swollen tubes
  - All plug types will be evaluated as part of long term plan

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Response to NRC Questions

- 4) Total Number of Tubes Plugged in OTSGs

Plant	Number of Tubes Plugged
ANO-1	1274
CR-3	947
DB-1	540
ONS-1	2429
ONS-2	1998
ONS-3	1980
TMI-1	2064

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Response to NRC Questions

Types of Plugs Installed in OTSGs

Plug Type	Mfg	Matl	Dates Plugs Installed			Total Installed	Total Removed / Repaired	Current Pressure Boundary
Ribbed	FRA-ANP	I600	Oct-83	To	Oct-88	998	205	793
	WEST	I600	Jun-83	To	Oct-84	190	119	71
Roll Tube Plug	FRA-ANP	I600	Feb-85	To	Mar-90	974	555	419
	FRA-ANP	I690	Feb-90	To	Present	17967	471	17496
	WEST	I600	Mar-82	To	Nov-84	1021	478	543
	CE	I690	Sep-91	To	Sep-91	56		56
Roll Sleeve Plug	FRA-ANP	I600 & I690	Apr-90	To	Present	213	1	212
Explosive Welded	FRA-ANP	I600	Jan-71	To	Oct-84	1431	1117	314
Tig Welded	FRA-ANP	I600 & I690	Jan-70	To	Present	2602	43	2559
	CE	I690	Sep-91	To	Sep-91	1		1
							Total	22464

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Response to NRC Questions

- 5) Basis for OTSG 50% fill information
  - TMI-1 Tubes de-watered by inserting eddy current sheath into tube
    - Displaced approximately 1/2 of tube volume
    - Displacement of water onto tubesheet indicates tube >50% full
      - Actual volume of water not recorded
  - Pressurization can occur during heatup when tube >70% full at room temperature
    - Based on ratio of specific volume of water at hot conditions to cold conditions

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Response to NRC Questions

- 6) Basis for OTSG not de-plugging and inspecting A-690 rolled plugs
  - Initial focus on most susceptible locations, as determined by field observations
    - Locations where plugs repaired w/o de-watering
      - UTS plug removed / replaced
      - Plugs re-rolled after pressurization cycle
  - Alloy 690 roll plugs benefit from improved installation techniques
    - Much better control of installation torque
    - Better sealing at temperature (up to factor of 10)
    - Field observations at TMI and Oconee-3 show that originally installed A-600 and A-690 roll plugs generally have low leakage in service

Response to NRC Questions

- 7a) Flow stability margin at TMI tubes B66-130 and A2-24
  - These tubes are less than 1" from periphery.
  - Difference in T/H parameters between the outermost tubes and these tubes is insignificant
    - Therefore FSM = 1.1 applies to these tubes as well

Response to NRC Questions

- 7.a.1) OTSG Performance Near 1.0 Flow Stability Margin
  - For flow velocity well below critical velocity
    - Coupling between the tube bundle and fluid flow is negligible
  - For flow velocity near the critical velocity
    - Coupling force plays larger role in response resulting in a significant increase in vibration amplitude
  - Standard approach recommended by ASME code is based on "joint acceptance" method
    - Does not include coupling between tube bundle and fluid flow
    - Underestimates vibration amplitudes when flow velocity is near critical

Response to NRC Questions

- 7.a.2) Basis for screening criteria for determining OTSG tubes susceptible to FIV if severed tubes have FSM >1.0
  - Fatigue analysis not based on fluid-elastic instability (Connors' equation)
    - This determines only if tube is stable
  - Fatigue analysis for tubes in flows close to critical velocity requires a more exact method
    - Non-linear structural dynamics
    - Direct time domain solution
      - Strictly model fluid-structure interaction force
  - An acceptance criteria based only on FSM is not appropriate.
  - Susceptible populations in OTSGs have been preliminarily identified. Any changes to the threshold for tube sever concerns would be addressed as part of the long term plan.

Response to NRC Questions

- 7.a.3) OTSG flow stability margin prediction model conservatism re: FSM prediction using lower bound damping
  - Predicted FSM is consistent with field observations
    - No mid-span impacting of B66-130 on adjacent tubes - tube was stable prior to severance
  - Only 2 of 26 swollen tubes in the periphery were severed
  - Use of nominal damping would increase FSM to ~1.3

Response to NRC Questions

- 8) OTSG risk assessment of generic implications of tube sever / wear
  - SGTR is an analyzed event and is modeled in PRAs
  - Typical initiating event frequency for SGTR is between 5e-3 and 1e-2/year
  - Bounding increase in SGTR probability is ≤ 1e-2
    - TMI precursor frequency: <1 SGTR per 492 susceptible tubes (assume one fuel cycle) = 0.0014 /tube-year
    - Bounding B&WOG plant has 11 susceptible tubes and 8 months until next outage
    - 0.0014/tube-year x 11 Tubes x 8 Months = 1e-2

Response to NRC Questions

- 8) OTSG risk assessment of generic implications of tube sever / wear
  - SGTR is typically a small percentage of plant CDF and LERF
  - Based on B&WOG PRA
    - Conditional core damage probability given SGTR is about 1e-4
    - Conditional large early release probability given SGTR is about 1e-5
  - Therefore, one-time increase in core damage probability is ≤ 1e-6 and large early release probability ≤ 1e-7

Summary and Conclusions

- SGMP is taking the lead
- An action plan is being developed and initial tasks are underway
- Meet with staff after initial tasks are completed
- Plants are operating safely and time is available to complete actions