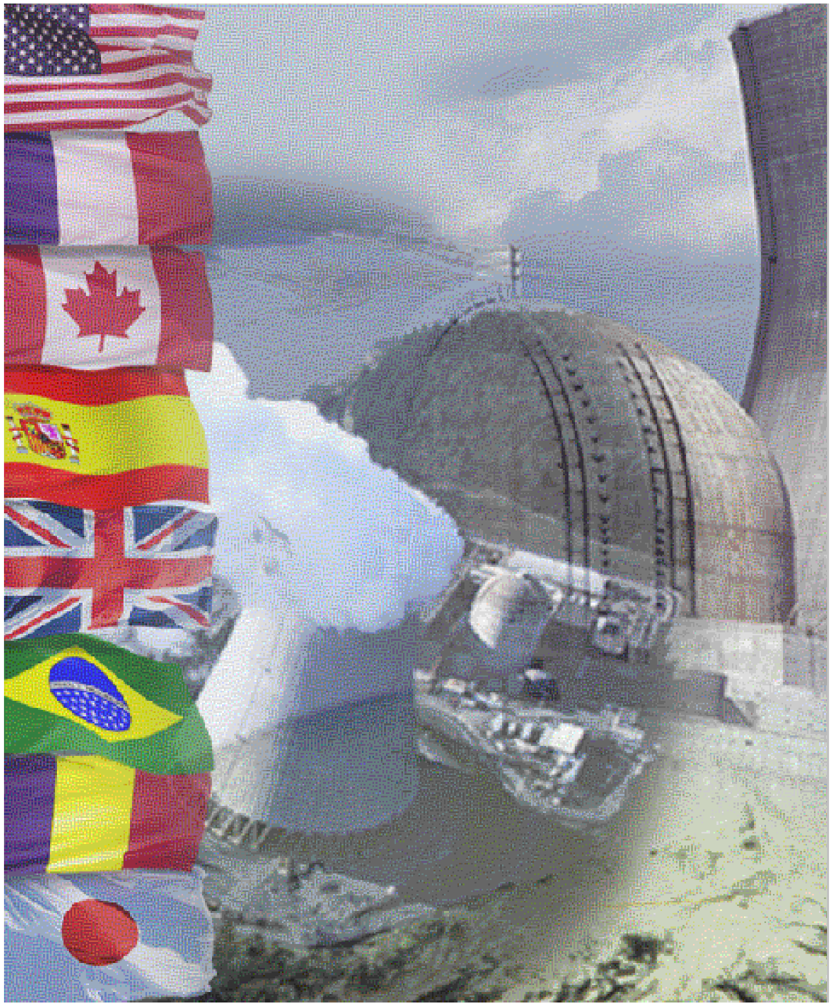

Final Results of SIPC Impact Study

NRC Meeting
Rockville, MD
November 10, 2004

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EPRI

Outline of Presentation

- Purposes of the SIPC impact study
- The revised SIPC
- SIPC technical tasks in Phase II
- How revised SIPC is being implemented
- Resolution of SIPC issues
- Test results and burst pressure model
- Results of impact study/examples
- Interim Guidance

Purposes of the SIPC Impact Study

- Determine the impact of the revised version of the SIPC that will be included in the Generic Licensing Change Package (GLCP).
- Support the Catawba submittal as the lead plant.
- Provide a methodology for evaluating the effects of loads other than pressure on structural limits.
- Provide guidance for implementing the revised SIPC.

Revised Definition of the SIPC

All inservice steam generator tubes shall retain structural integrity over the full range of normal operating conditions (including startup, operation in the power range, hot standby, and cooldown and all anticipated transients included in the design specification) and design basis accidents. This includes retaining a safety factor of 3.0 against burst under normal steady state full power operation primary-to-secondary pressure differential and a safety factor of 1.4 against burst applied to the design basis accident primary-to-secondary pressure differentials. Apart from the above requirements, additional loading conditions associated with the design basis accidents, or combination of accidents in accordance with the design and licensing basis, shall also be evaluated to determine if the associated loads contribute significantly to burst or collapse. In the assessment of tube integrity, those loads that do significantly affect burst or collapse shall be determined and assessed in combination with the loads due to pressure with a safety factor of 1.2 on the combined primary loads and 1.0 on axial secondary loads.

The Revised Structural Integrity Performance Criterion (SIPC)

Major SIPC Revisions

- The safety factor of 3.0 against burst under normal steady-state full power operation remains as before.
- Safety factor of 1.4 against burst applied to pressure differentials from Level C and D events.
  - Historically, Level D (faulted) conditions have been used for evaluation of limiting design basis accidents by regulatory precedence.
- Additional accident loads shall be evaluated to determine whether they contribute significantly to tube burst or collapse.
  - If so, they should be assessed in combination with loads due to pressure with a factor of 1.2 on the combined primary loads and 1.0 on axial secondary loads.

SIPC Technical Tasks

- Carry out burst and collapse tests to validate a burst model for circumferential degradation that combines membrane and bending loads, and to determine the tube conditions for collapse.
  - Straight tube tests
  - Small- and large-radius U-bend tube tests
- Improve understanding of existing design basis information.
- Develop and illustrate methods for evaluating contributing loads and assessing their significance to tube integrity.
- Provide screening limits for bending loads such that plants with limited design information can apply criterion with minimal impact.
- Recommend criteria for in situ pressure testing when contributing loads are significant and lead to reduced structural limits.

How the Revised SIPC is Being Implemented

- EPRI Technical Report 1009541 to be published in November 2004 to document the technical basis.
  - Main summary report.
  - Appendices include a white paper and supporting vendor reports.
- Interim Guidance is being issued for use prior to publication of Revision 2 of Steam Generator Integrity assessment Guidelines.
- A workshop to facilitate implementation is scheduled for December 9-10, 2004.
- Final implementation of SIPC will be through revisions of NEI 97-06 and the Steam Generator Integrity Assessment Guidelines.

Resolution of SIPC Issues

Tube Collapse Condition

- Collapse tests show collapse condition not reached even at loads exceeding design. Similar observation for straight tube collapse tests.
- Combined pressure plus bending load burst tests indicate burst condition precedes condition for tube collapse.
- Tube collapse is not a credible failure mode, but Industry included collapse in revised SIPC nevertheless.

Definition of Collapse: For the load displacement curve for a given structure, collapse occurs at the top of the load versus displacement curve where the slope of the curve becomes zero.

Resolution of SIPC Issues

Thermal Loads

- Axial tube loads are created primarily by the difference in temperature between the tube and shell and are considered as secondary loadings per ASME Code definition.
- Basic characteristic of a secondary stress is that local yielding or deformation will reduce the axial load.
- For OTSG plants axial secondary loads will be controlling for circumferential degradation.

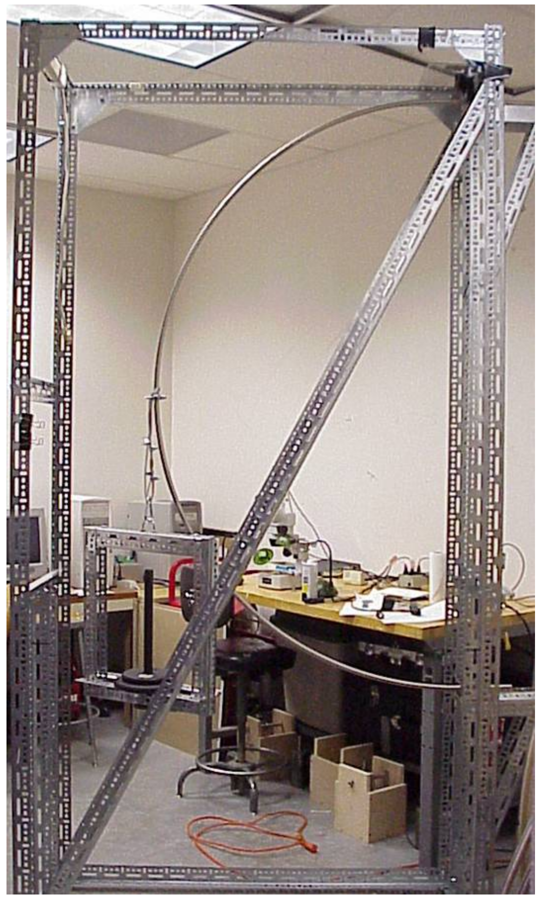
Implementation Procedure

- Perform an assessment to determine the appropriate factor of safety (1.0 or 1.2).
- Perform additional analysis if 1.2 is appropriate.

Burst Tests: Straight Tubes and U-bend Tubes (both small and large radius) with Circumferential Cracks Under Internal Pressure Loading and Single Point Bending Load

Test Rig with Load Applied to Large U-Bend

Applied load



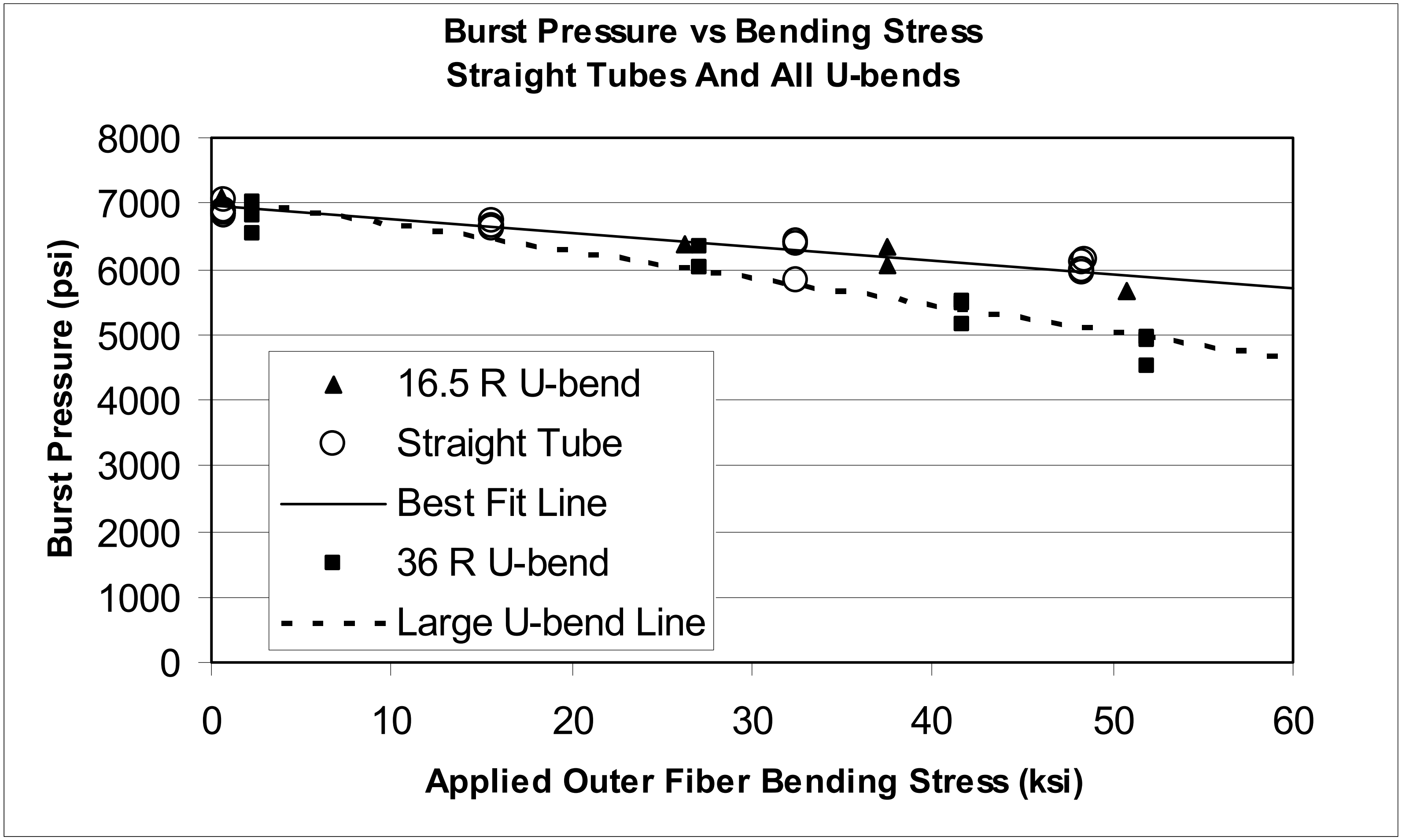
Upper U-bend support - location of tube flaw
Camera and light focused on flaw

Lower U-bend support

Conclusions from Burst and Collapse Tests

- Plastic collapse in bending is not a credible failure mode for steam generator tubing.
- Burst tests of tubing with circumferential degradation and prototypic tube supports show that applied bending loads cause a mild reduction in burst pressure.
  - For straight tubes and small radius U-bend tubes the burst pressure decreases about 1000 psi for an outer fiber bending stress of 50,000 psi.
  - Burst pressure reductions for large radius U-bends are about twice this value.
- Burst pressure reduction is not a function of flaw severity in the range of interest.
- Burst pressure reductions due to bending are not needed for PDA values less than 25.

Burst Test Results and Best Fits to Data



Burst pressure vs bending load equations (best fits to the data)

- For straight tubes and for U-bends when the bend radius–to–mean tube radius ratio is less than or equal to 52.5

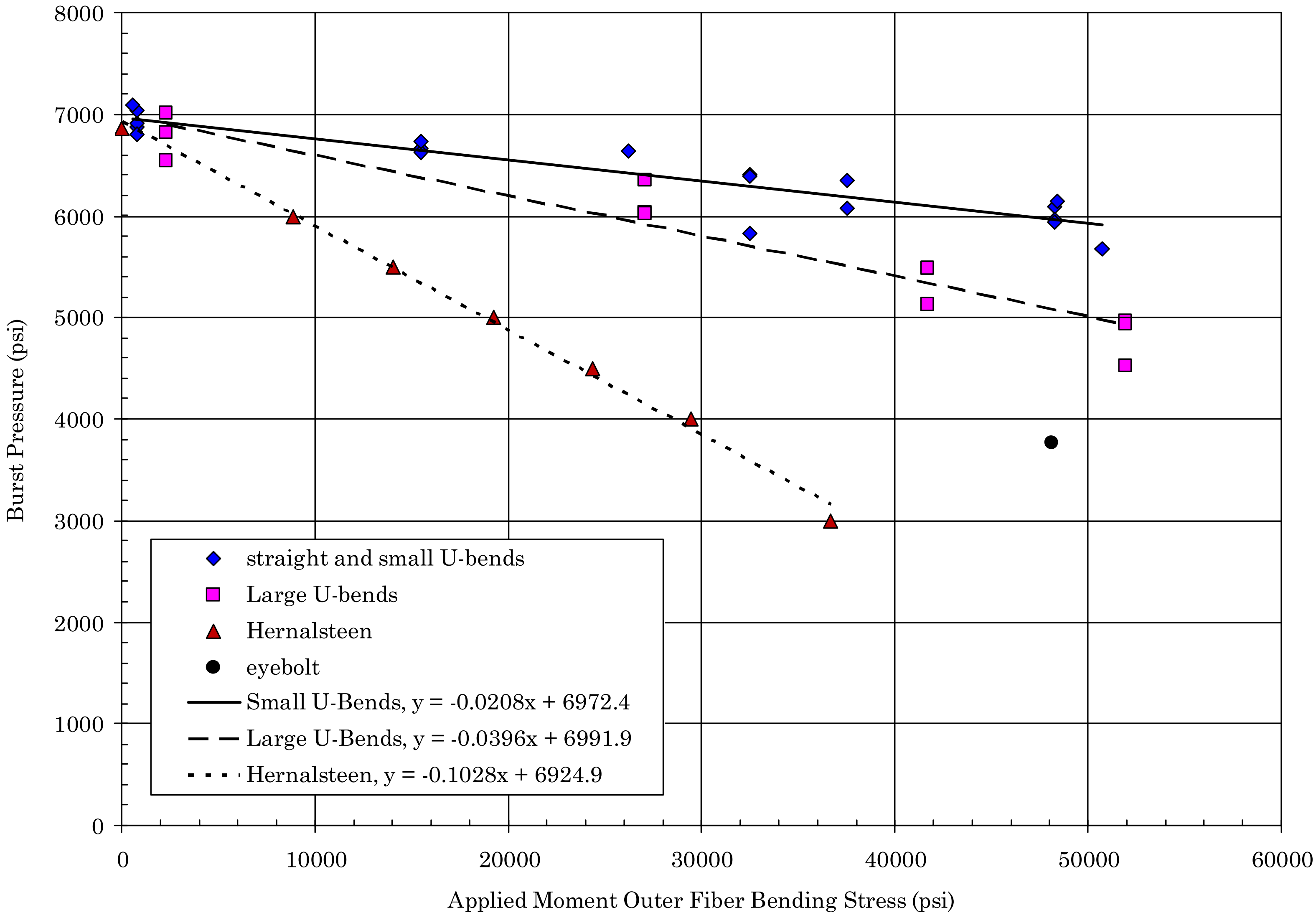
$$BP_R = 0.157 \bullet t/R_m \bullet \sigma_{OFB} + Z \bullet 1218 \bullet t/R_m$$

Where the applied outer fiber bending stress is σ_{OFB}, t is tube wall thickness, R_m is mean tube radius, R_B is bend radius, and Z is the standard random normal deviate (= 0.0 for best estimate, 1.282 for 90th percentile)

- For U-bend tubes when the bend radius–to–mean tube radius ratio is greater than 52.5

$$BP_R = \left(0.0672 + 0.00171 \bullet R_B/R_m\right) \bullet t/R_m \bullet \sigma_{OFB} + Z \bullet 1876 \bullet t/R_m$$

Summary of Burst Test Data Compared to Hernalsteen Model



Determination of the Revised SIPC

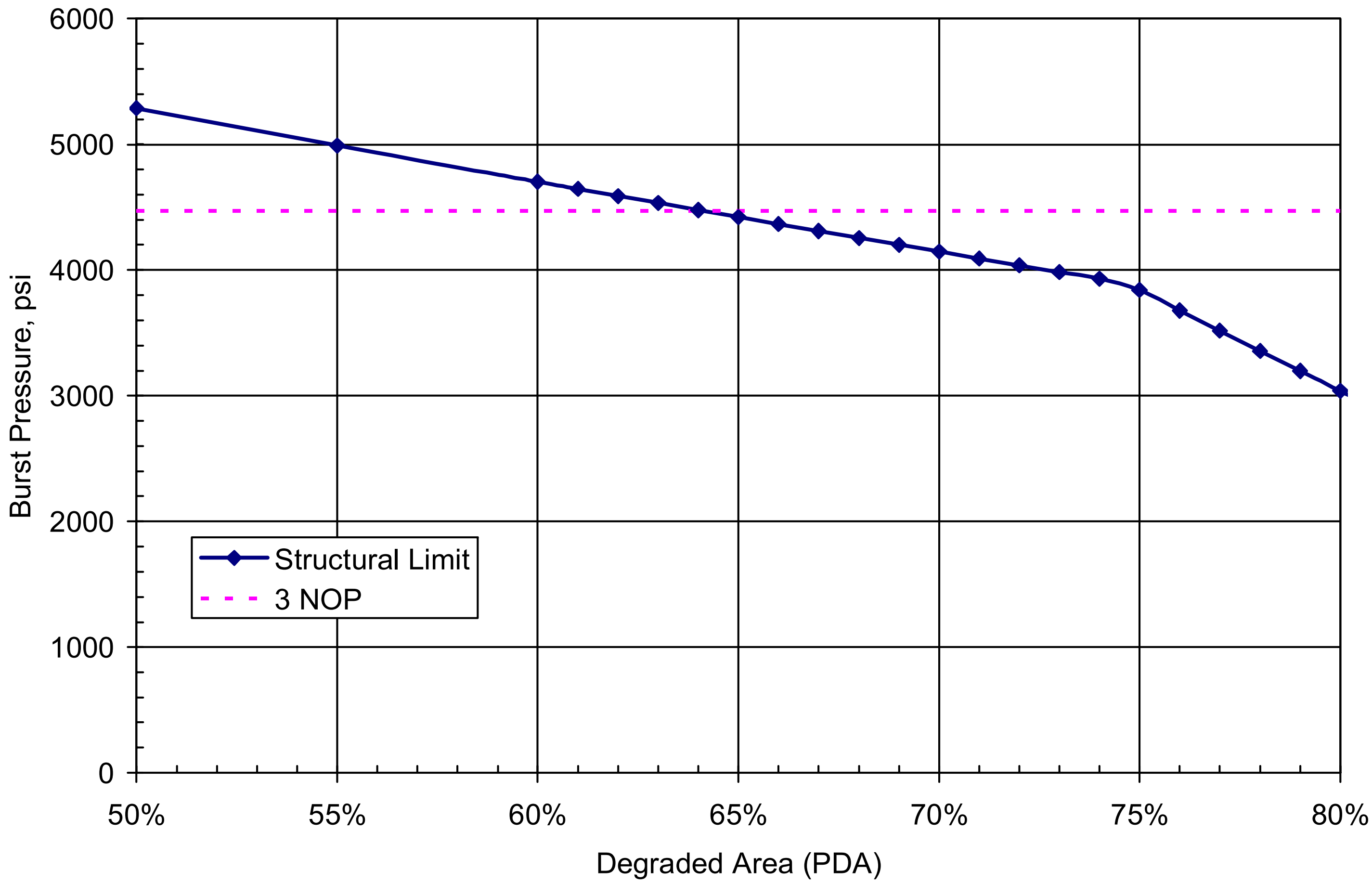
- Obtain bending and axial loads from licensing basis documents.
- Multiply the resulting load by 1.2 to account for the safety factor.
- Determine the allowable structural limit.
- Compare against the allowable structural limit for 3 x NODP or 1.4 x LAPD. Choose the smallest value.

Impact Study Results and Examples

- Results bear out the general conclusions from SIPC Phase I that significant bending loads can lower the allowable structural limit.
- A number of examples are provided to illustrate how to combine the loads to obtain the allowable structural limit.
- The examples
  - Include applications to locked tubes (straight sections, small radius U-bends, and large radius U-bends
  - Consider circumferential cracks that are both through-wall and part-through-wall
  - Address both original and replacement steam generators

Structural Limit for Pressure Only (Flaw Handbook Used): Diablo Canyon Case

64% PDA at 3 X NODP



Diablo Canyon Accident Membrane and Moment Loadings: Tubes Locked

Location		Seismic Membrane (psi)	Seismic in plane Bending (psi)	LOCA in plane Bending (psi)	FLB in plane Bending (psi)	RSS LOCA +SSE Bending (psi)	RSS FLB + SSE Bending (psi)
U-Bend	R=4.75	26	297	6,054	12,500	6,061	12,504
	R=11.14	60	1,117	6,019	12,500	6,122	12,550
	R=17.55	838	19,810	5,993	12,500	20,697	23,424
	R=28.26	206	8,493	5,958	12,500	10,374	15,112
	R=45.91	242	5,153	9,543	12,500	10,845	13,520
	R=59.84	987	9,343	12,120	12,500	15,303	15,606
Top TSP	R=4.75	291	3,350	6,289	12,500	7,126	12,941
	R=11.14	619	3,346	6,508	12,500	7,318	12,940
	R=17.55	**941 (122 lbs)**	34,790	6,665	12,500	35,423	**36,967 (935 in-lbs)**
	R=28.26	1,466	15,100	6,885	12,500	16,595	19,603
	R=45.91	2,318	12,090	14,526	12,500	18,899	17,390
	R=59.84	**2,982 (386 lbs)**	14,760	20,020	12,500	**24,873 (629 in-lbs)**	19,342
Straight		4,454 (577 lbs)	5,637	0	0	5,637	5,637

These stresses can be converted back to loads and moments using:
Tube Area = 0.12959 in^2
I = 0.0110659 in^4
Pressure Area = 0.4717 in^2

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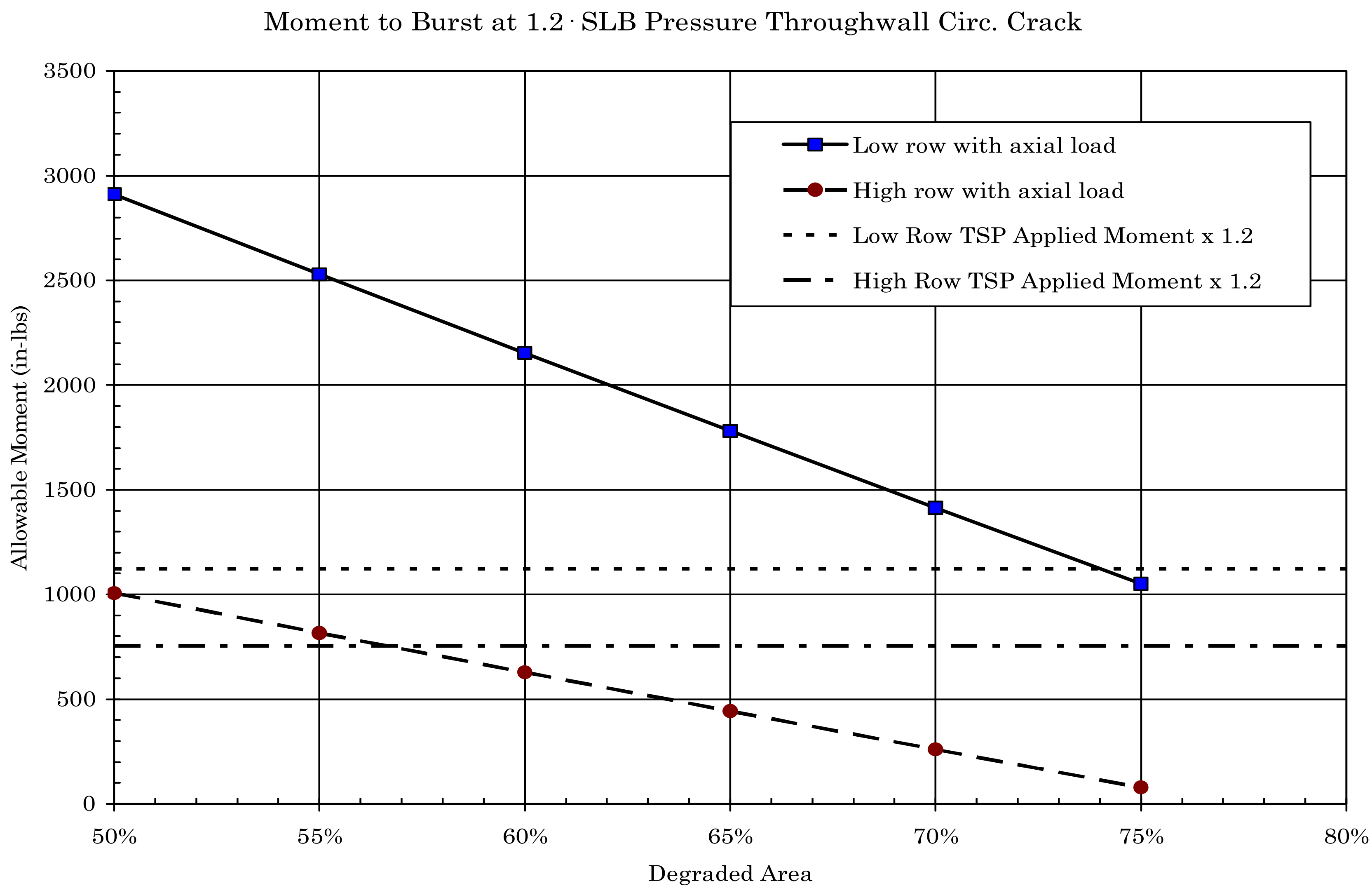
Structural Limit Considering Moment: Diablo Canyon Locked Tube Case
Test Equation Results Throughwall Crack



Example of Computation of Applied Moments (Tubes Locked, 100% Through-Wall Cracks)

- Low Row Top TSP:

  935 in-lb x 1.2 = 1122 in-lb

  Use this value when applying test equation: PDA = 74, which is greater than 64% for 3 x NODP

- High Row Top TSP:

  629 in-lb x 1.2 = 755 in-lb

  Use this value when applying test equation: PDA = 56, which is less than 64% for 3 x NODP

- The structural limit is thus a PDA of 56 for the revised SIPC.

Major Conclusions from SIPC Impact Study

- Tube collapse is not a credible failure mode.
- Burst tests of tubing with circumferential degradation show that applied bending loads cause a reduction in burst pressure for degradation at the extrados and the intrados of the U-bend area.
- Burst pressure is not a function of flaw severity in the range of interest.
- Equations have been developed to calculate burst pressure reductions vs outer fiber bending stress for all SG tube sizes. The effect of U-bend radius on burst pressure reduction is included.
- Burst pressure reductions due to bending are not needed for PDA values less than 25.
- The largest impact of the new SIPC was found on the assessment of circumferential cracks.
- The value of the structural limit for circumferential degradation in original square-bend CE designed steam generators is not affected by non-pressure loads.

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Major Conclusions (continued)

- The determination of the impact of non-pressure loads on the structural limit would include the following tasks:
  - Verify that sufficient documentation exists to identify all accident loads that could contribute to tube burst.
    - **This information may not be readily available to the utility without consulting the NSSS OEM.**
  - Obtain the bending and axial loads and combine them as required in the licensing basis,
  - Compute the structural limit by multiplying the combined loads by 1.2 to obtain the applied moment, and determining the PDA where applying the test equation matches the applied moment.
  - If the result is lower than the structural limits for pressure only, then it becomes the revised structural limit.

Major Conclusions (continued)

- Plant-specific examples for developing the necessary data, and the evaluation of the data, were provided for Diablo Canyon, Catawba 2, Calvert Cliffs, Oconee, and Catawba 1.
- The results from a modified Hernalsteen model and from the linear fit of the benchmark test data are in general agreement, but the Hernalsteen model predictions are grossly conservative.
- It is recommended that the equations developed from the test data be used almost exclusively.
- *In situ* testing for the revised SIPC can be accomplished by increasing the test pressure consistent with current *in situ* testing guidelines. However, the expected increase in the test pressure is not expected to be large.

Interim Guidance

- No impact to structural limits for axial degradation
- Structural limits for circumferential degradation in once-through steam generators and in the U-Bend areas of recirculating steam generators may be affected by the revision of the SIPC
  - Circumferential degradation refers to any type of degradation with significant circumferential extent
    - Bending loads can contribute to burst for circumferential degradation at the intrados and extrados of the bend but will not significantly contribute to burst for degradation away from these locations
    - Volumetric degradation such as wear, cold leg thinning, impingement and volumetric IGA should be evaluated as well as cracking

Interim Guidance

- Compare technical basis for existing structural limits against the margins defined in the revised SIPC and make changes to structural limits as appropriate
- Based on specific tube loading information, evaluate which part of the SIPC is bounding
- For recirculating steam generators not experiencing circumferential degradation in the U-Bends, this evaluation is not urgent
  - Structural limits for potential circumferential cracks in the U-Bend area can be set to 25 percent degraded area
  - If steam generator replacement is planned prior to the next inspection, no evaluation is needed for the old steam generators.

Interim Guidance

- For recirculating steam generators with circumferential degradation in the U-Bends, this documentation shall be done as soon as it is expected that circumferential degradation will be identified that is greater than 25 percent degraded area (considering appropriate uncertainties)
  - It is likely that the plant will not have loading information available to them and it will be necessary to contact the OEM
- SGs originally designed by CE with “square” bends have been demonstrated to not require additional consideration with regard to bending loads.

Interim Guidance

- For plants with once through steam generators, the axial secondary load will be controlling for circumferential degradation
  - Perform an assessment to determine the appropriate factor of safety to use on loads other than pressure (1.2 or 1.0)
  - If 1.0 is deemed appropriate, the existing integrity evaluations shall remain valid.
  - If it is necessary to apply a safety factor of 1.2, additional analysis/assessment must be performed.
  - It is expected the 1.0 safety factor will be shown appropriate for most cases.