MSIP® OVERVIEW

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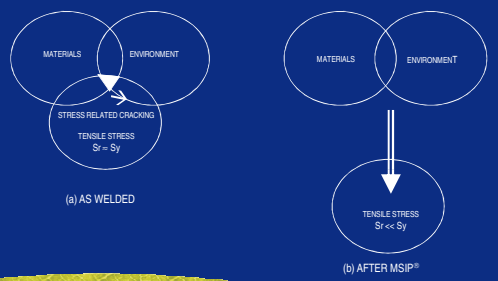
Mechanical Stress Improvement Process (MSIP®)

- *MSIP® BACKGROUND*
  - Invented, developed and first used in 1986
  - Permanently mitigates stress related cracking in nuclear reactor plant piping weldments
  - Redistributes 'as-welded' tensile residual stresses generating axial and hoop compression through ~50% wall in inner weld region.
  - Qualified and verified by EPRI and ANL (for USNRC).
  - Over 20 years of successful operating experience with more than 3000 welds treated worldwide.

MSIP® Principle



Removal of Tension Provides Permanent Protection of Weldments Against Stress Related Cracking

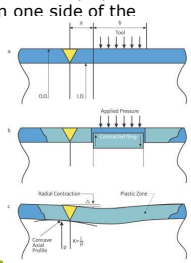
Basic Concept of MSIP®

Displacement Controlled – Uses a hydraulically operated mechanical clamp to contract pipe on one side of the weld.

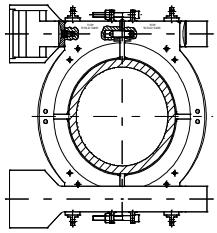
a. MSIP® Tool Placement

b. Application of Pressure to Contract Pipe

c. Mechanism of Compression Generation in Axial and Hoop Directions



MSIP® Tool with Box Presses



MSIP® QUALIFICATION TESTS

TOOL: EACH TOOL PRODUCED WAS TESTED FOR APPLICABLE WELDED JOINT GEOMETRY (4 TO 33 INCHES)

PROCESS:

BWR & PWR Applications Have Similar D/t

10" PIPE TO PIPE	NUVISION ENGINEERING, INC.
12" PIPE TO PIPE	NUVISION ENGINEERING, INC.
12" PIPE TO ELBOW	NUVISION ENGINEERING, INC.
12" PIPE TO NOZZLE	NUVISION ENGINEERING, INC.
14" PIPE TO ELBOW	NUVISION ENGINEERING, INC.
28" PIPE TO PIPE	NUVISION ENGINEERING, INC.
12" PIPE TO PIPE ($MgCl_2$)	EPRI
12" PIPE TO PIPE	*ARGONNE NATIONAL LAB/NRC*
28" PIPE TO ELBOW	*ARGONNE NATIONAL LAB/NRC*
28" PIPE TO ELBOW (PRE-CRACKED)	*EPRI*
12" NOZZLE TO SAFE-END (W/CRACKS)	*EPRI*
12" PIPE TO PIPE	EPRI/ROSENERGOATOM
14" NOZZLE TO SAFE-END (PWR-PZR SL)	NVE-WESTINGHOUSE-TRACTEBEL
2" DRAIN NOZZLE TO SAFE END (PWR)	NVE-WESTINGHOUSE
4" SPRAY NOZZLE TO SAFE END (PWR)	NVE-WESTINGHOUSE
6" SAFETY/RELIEF NOZZLE TO SAFE END (PWR)	NVE-WESTINGHOUSE
12" SURGE NOZZLE TO SAFE END (PWR)	NVE-WESTINGHOUSE

MSIP® Qualification - Summary of ANL Tests for NRC

- MSIP® TREATED 12" (D/t=20) AND 28" (D/t=25) WELDMENTS EXAMINED TO:
  - DETERMINE RESIDUAL STRESS STATE PRODUCED BY MSIP®
  - COMPARE MEASUREMENTS WITH FINITE ELEMENT ANALYSIS
  - INVESTIGATE POSSIBILITY OF ANY UNDESIRABLE SIDE EFFECTS
- RESIDUAL STRESSES MEASURED ON INNER SURFACE AND THROUGHWALL:
  - INNER SURFACE AXIAL AND HOOP STRESSES HIGHLY COMPRESSIVE
    - (-30 KSI TO -50 KSI IN HAZ FOR 12" AND
    - -22 KSI TO -50 KSI IN HAZ FOR 28")
  - THROUGHWALL AXIAL RESIDUAL STRESS DISTRIBUTIONS ALMOST LINEAR ACROSS THICKNESS
  - COMPRESSIVE STRESSES IN HAZ PERSIST THROUGH 50% OF PIPE WALL
- MEASUREMENTS COMPARE FAVORABLY WITH ANALYTICAL RESULTS
- NO UNDESIRABLE SIDE EFFECTS

MSIP® Qualification - EPRI Tests

- Test Mockups
  - Nozzle to Safe-end, 14" OD with 1.2" wall thickness (D/t=12)
  - Pipe-to-Elbow, 28" OD with 1.125" wall thickness (D/t=25)
- Scope of EPRI mock-up qualification tests:
  - Determine change in residual stresses
  - Determine if pre-existing cracks are extended
  - Determine if pre-existing cracks are detectable with UT after MSIP®
  - Determine if there is any work hardening due to MSIP®
  - Monitor surface strains during MSIP® application
- Flaws and repair regions inserted into mock-ups and strain gages placed to measure stress at various locations

Mockup Qualification - Conclusions

- MSIP® generated compressive stresses in the inner weld region of all mock-ups
- D/t range tested 12 – 25 and results correlated well with finite element analysis
- Inner surface maintained in compression during MSIP® application (no tensile transients)
- Cracks were not extended and were detectable by UT after MSIP® application
- No work hardening

MSIP® for PWRs

- EPRI Nozzle Qualification directly applies to PWR RV nozzles.
  - Similar Materials
    - Nozzle SA508 Cl II
    - Weld 82/182
    - Safe-end SST
  - Similar Configuration
    - Nozzle to Safe-end / Pipe Welds
  - Similar Geometry
    - Comparable D/t (typical 4 loop D/t=13, typical 3 loop D/t=14)
  - Analysis shows similar Post-MSIP® results
  - Application
    - Similar Tooling
    - Similar Procedures
    - Same Verification Parameters

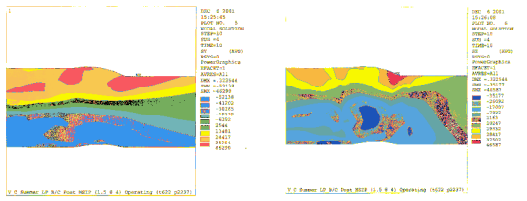
MSIP® for PWRs (continued)

- PWR specific data includes:
  - Mock-ups for Tihange pressurizer surge nozzle, C-E design drain nozzle, and pressurizer spray and safety/relief nozzles tested with strain gage measurements to confirm generation of compression
  - PWROG FEA's
  - Plant specific applications including FEA's that are correlated through pipe circumference measurements

MSIP® Nozzle FEA Validation and Final Residual Stress from MSIP® in PWR

- During the PWROG program (WCAP-16424-P), FEA analyses were performed on pilot plants using the following inputs:
  - As-designed weld, weld repair, field weld residual stresses (As-builts and actual CMTR's that were part of plant specific applications)
  - Plant operating conditions and Post-MSIP operating loads
- Results
  - Analysis verified unfavorable residual stresses along the inner region of the nozzle-to-safe end are successfully converted to compression
  - Hoop and Axial stresses remain compressive through 50% of the wall

MSIP® Nozzle FEA Validation and Final Residual Stress from MSIP® in PWR RV Outlet Nozzle



Includes operating stresses and residual stresses due to weld repair

MSIP® Nozzle FEA Validation and Final Residual Stress - Conclusions

- FEA models for PWR applications show compressive stress on inner diameter surface (~ 50% depth)
- Plant specific applications use field measurements to confirm change in pipe circumference which correlates to plant specific FEA.
  - For example, V. C. Summer had a required change in Pipe Circumference of 1.0" (min) to 1.63" (max). Field measurements confirmed a 1.38" change in pipe circumference

Design for MSIP®

- Parameters for redistributing stress:
  - Location
  - Amount of contraction
    - *Reduce pipe 1 to 1 ½ %*
  - Width of the squeeze
- No impact on high cycle fatigue
- Few Limitations
  - Sizes 2" to 34" OD pipe in LWR's
  - No material limitations
- Flaw size
  - Compressive layer approximately 50% in depth
  - Current limit on flaws <30% in depth and <10% in circumferential length

Analysis

- Analysis
  - Considered as-designed weld residual stresses
  - Considered local weld repair residual stresses
  - Considered residual stresses from field weld
  - Considered Plant operating conditions
  - Considered Post-MSIP operating loads
- Results
  - Analysis verifies stress distribution in the nozzle-to-safe end is improved
  - Unfavorable residual stresses along the inner region of the nozzle-to-safe end are successfully converted to compression
  - Hoop and Axial stresses remain in compression through approximately 50% of the pipe wall
- Subsequent flaw evaluations are performed using the re-distributed stresses

Basis for MSIP® Application in BWR's and PWR's

- NRC Generic Letter 88-01, NRC On IGSCC in BWR Austenitic Stainless Steel Piping, Dated January 25, 1988
  - '....the following processes will upgrade non-resistant material to IGSCC category B or C'.... Mechanical Stress Improvement Process (MSIP)'
- NUREG-0313, Rev. 2, Technical Report on Material Selection and Processing Guidelines for BWR Coolant Pressure Boundary Piping, Final Report, Published January 1988
  - 'The processes considered to be qualified for providing resistance to IGSCC in BWR piping welds are:....Mechanical Stress Improvement Process (MSIP)'
- Palisades Plant Safety Evaluation of the Cracking of Inconel 600 Components, Docket No. 50-255, June 27, 1995
  - 'The process has been used in BWRs to alleviate residual stresses that cause IGSCC, a similar phenomena to PWSCC and should similarly alleviate residual stress factor contributing to PWSCC. In view of successful application of MSIP to BWRs, the use of this technique appears valid...'
- NUREG-1787, Safety Evaluation Report Related to the License Renewal of the Virgil C. Summer Nuclear Station, Docket No 50-395
  - Extracted from submittal and discussion of LBB for license extension period:
  - '....The staff finds the applicant's response acceptable because the applicant will continue its commitments made in response to PWSCC of the RCS piping into the extended operation. The applicant also states that VCSNS has implemented mechanical stress improvement activities for the two hot legs nozzle-to-piping welds that were not repaired....As discussed in this SER, the staff reviewed an analytical evaluation of applying the MSIP to the VCSNS reactor pressure vessel hot leg nozzles and agreed with the licensee's assertion that the driving force for the crack has been either removed or greatly reduced...'

Licensing and LBB: Experience with MSIP in PWR applications with LBB

- The application of MSIP® was extended to PWRs in the U.S., for mitigation of PWSCC since 1995, "Palisades Plant Safety Evaluation of the Cracking of Inconel 600 Components", Docket No 50-255, June 27, 1995
- Since that time it has been used to mitigate PWSCC in LBB piping at:
  - V. C. Summer (outlet nozzles in 2003): "Safety Evaluation Report Related to the License Renewal of the V. C. Summer Nuclear Station", Docket No. 50-395, NUREG-1787.
  - Watts Bar 1 (surge nozzle)
- All done under 50.59
- NRC consistently validated use of MSIP for mitigation of PWSCC and only additional provisions where to monitor in subsequent inspections.

MSIP® PWR Plant Applications

Plant	Year	Component	LBB	Inspection Requirements
Palisades	1995	2 surge nozzles 1 Shutdown Cooling	No	None – Plant volunteered to do volumetric every other RFO & VT. Currently going to 10 year ISI
V.C. Summer	2002	Hot Leg B and C	Yes	None – Plant committed to volumetric inspections, immediately following mitigation and in subsequent outages
Calvert Cliffs 1	2006	3-pressurizer nozzles 2 surge nozzles (both ends of surge line) 1 Hot Leg Drain 1 Shutdown Cooling	No	MRP-139
Calvert Cliffs 2	2007	3 pressurizer nozzles 2 surge nozzles (both ends of surge line) 1 Shutdown Cooling	No	MRP-139
Watts Bar 1	2008	5 Pressurizer nozzles 1 surge nozzle	Yes	MRP-139

Westinghouse Position on Effects of MSIP in LBB

- The MSIP® process results in permanent compressive residual stress at the inner region of the weld joints removing the driving force for future crack initiation or growth of existing undetected cracks
- For operating PWR's with LBB the only action taken following MSIP® has been to voluntarily perform inspections to monitor flaws.
  - Inspections guidance is governed by MRP-139 and future ASME Code Case N-770
- LBB is pre-existing for the plants and there is no additional safety benefit for two forms of mitigation
- The NRC's revised position, stated during January 2008 meeting, is consistent with operating experience and will require monitoring/inspection of all forms of mitigation

MSIP® has a significant benefit in reducing the potential for a through-wall flaw and also the probability of pipe rupture improving LBB defense.

Stress Relaxation and Permanence of MSIP®

- FEA and tests have shown that MSIP® permanently eliminates the tensile stress through approximately 50% of the weld/pipe wall thickness
- Permanent because there is no mechanism for relaxation of the stress:
  - High cycle fatigue is not an active mechanism on these components
  - Irradiation-induced stress relaxation is not feasible at fluence exposures $<1 \times 10^{20}$ n/cm^2
  - Thermal stress relaxation is not significant at temperatures less than half the melting point of the material (for nickel alloys no thermal relaxation at temperatures < 1200°F)
  - Operating stresses on the ID of the pipe are too low
- BWR and PWR operating experience (> 22 years) further demonstrates the permanence:
  - No cases of new crack initiation, crack growth or leaks in pipe welds treated with MSIP®
  - OE's on BWR's have shown flaws as large as 87% in depth are arrested by MSIP®

ASME Code Requirements

- MSIP® is not currently covered by ASME Code
- Code Case N-770 (draft) incorporates qualification requirements, pre-service, & in-service inspection requirements into ASME Code
  - MSIP® meets all these qualification requirements
- Pre-service inspection requirements
  - UT inspection pre & post application
  - Exception is cold leg application where core barrel must be removed
    - Post application UT and ECT inspection required to consider uncracked

ASME Code Requirements (cont'd)

- Uncracked Welds
  - Inspect 100% of welds within 10 years
  - No new cracks inspect 25% sample every 10 years
- Cracked Welds
  - Inspect 100% of welds within first or second RFO
  - No new cracks or growth of existing cracking, inspect 25% sample every 10 years
- If new cracking or growth of existing cracking detected
  - Inspect additional welds that outage
  - Inspect welds next two RFO's
  - If no growth for 3 inspections return to 25% sample inspection

Historical Inspection Data on RV Nozzles

- To date, PDI examinations of reactor vessel inlet/outlet nozzles:
  - 21 plants inspected
  - 73 outlet nozzles
  - 73 inlet nozzles
  - Indications detected at V. C. Summer
- Post-MSIP® inspection showed no significant changes in indications (i.e., flaws) from the Pre-MSIP® inspection.
  - Post-MSIP® NDE inspection was completed using ultrasonic tests (UT). One small indication not seen with UT Post-MSIP
  - Eddy current testing (ECT) was used as a complementary inspection technique and found all surface connected indications.

MSIP® Proven Technology - Conclusions

- Analyses and Tests confirm applicability for PWR nozzle welds
- MSIP® is an effective mitigation process for SCC.
  - Prevents crack initiation
  - Arrests existing cracks in the compressive zone
- MSIP® reduces both critical downtime and personnel radiation exposure

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MSIP® Proven Technology - Conclusions

- Accepted by USNRC (NUREG 0313) as a Stress Improvement method.
  - Qualified by Argonne National Labs for the USNRC
  - Independent verification by EPRI
  - Verified on thick section pipe/nozzles for PWRs Tihange pressurizer surge nozzle and Westinghouse/CE Pressurizer nozzle mockups.
- Successful Operating Experience since 1986 of over 3000 welds including 500 nozzle and safe-end welds.

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