MSIP®, A PROVEN TECHNIQUE TO ENHANCE LEAK BEFORE BREAK IN SUSCEPTIBLE REACTOR VESSEL NOZZLE WELDS

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MECHANICAL STRESS IMPROVEMENT PROCESS (MSIP®)

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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.

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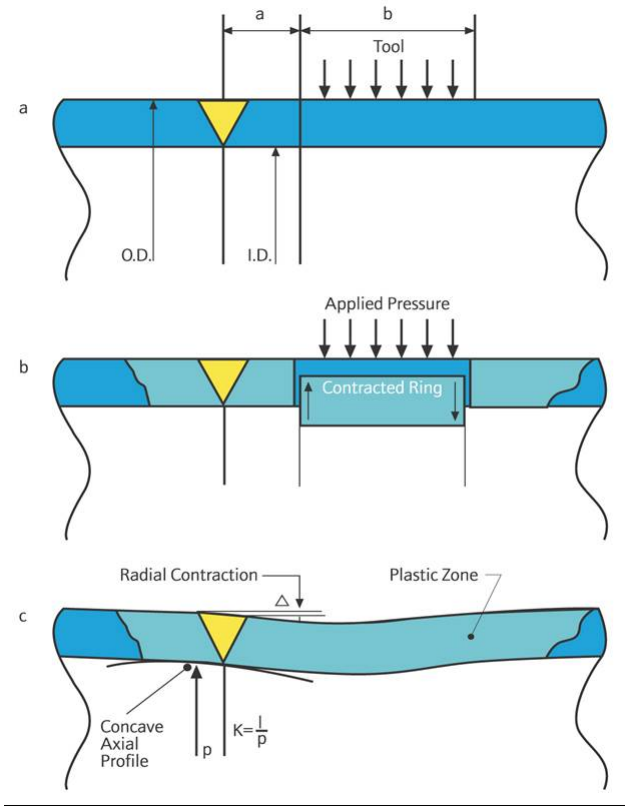
Basic Concept of MSIP®

a. MSIP® Tool Placement

b. Application of Pressure to Contract Pipe

c. Mechanism of Compression Generation in Axial and Hoop Directions



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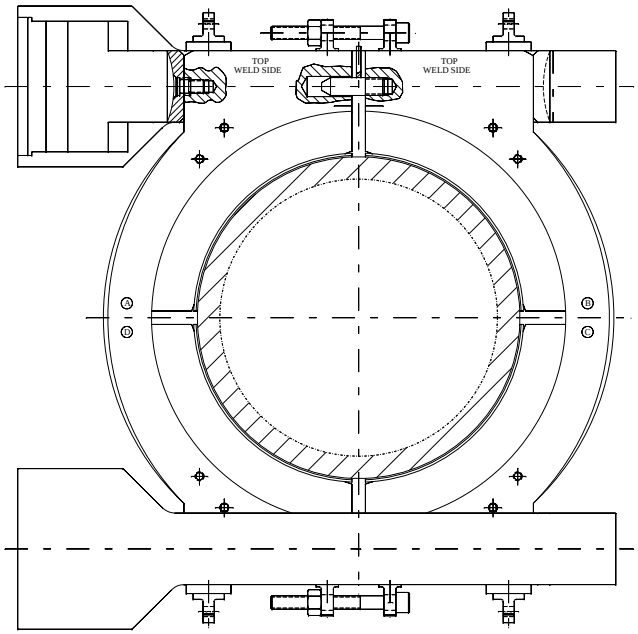
MSIP® TOOL WITH BOX PRESSES



Displacement Controlled – Physically verifiable by measuring change in circumference.

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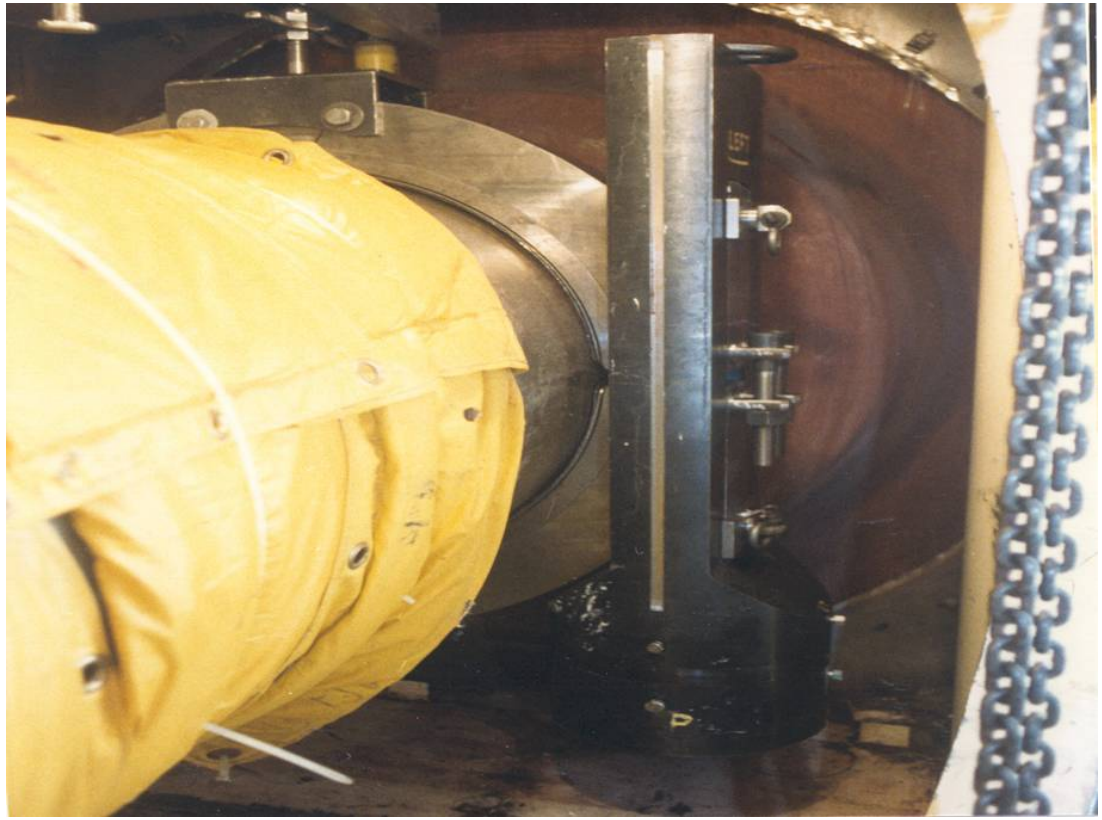
MSIP® APPLICATION TO NOZZLE/SAFE END WELD



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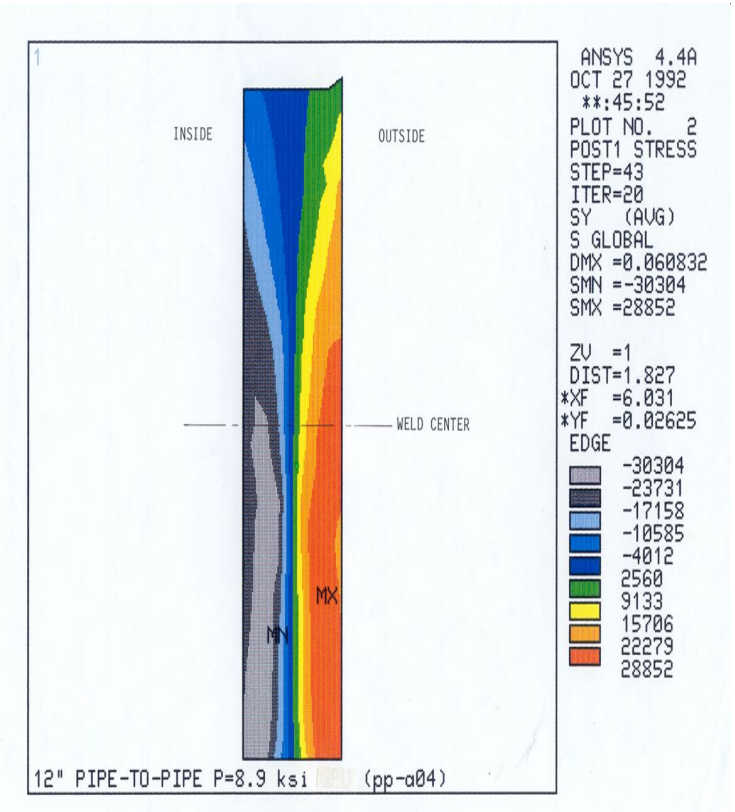
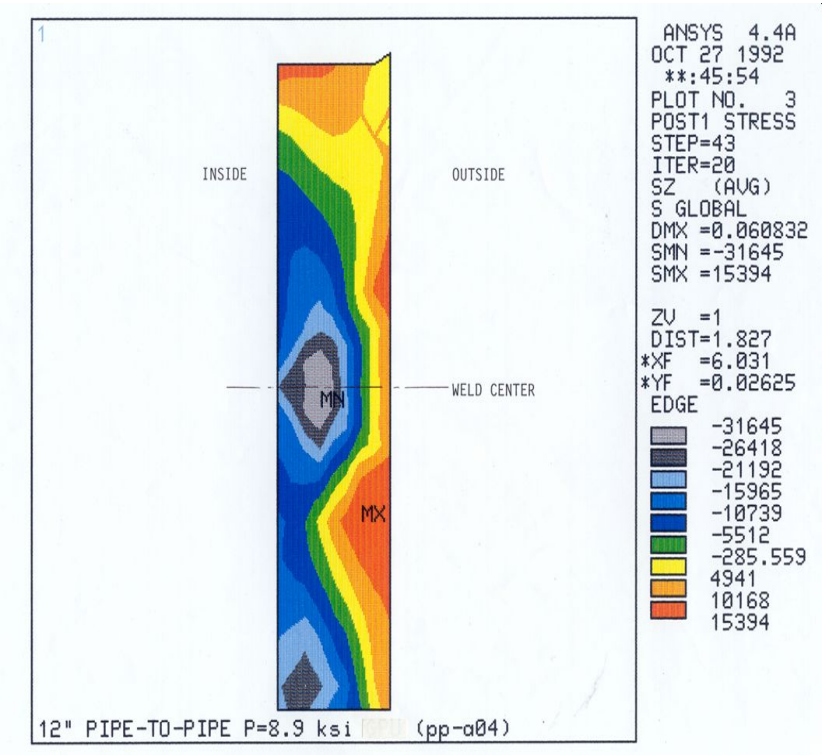
12" PIPE POST-MSIP® STRESSES



Axial Stress



Hoop Stress

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ARGONNE NATIONAL LABORATORY (for NRC) 12" AND 28" PIPE WELDMENTS

- MSIP® TREATED 12" AND 28" 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 AND ARE, IN FACT, BETTER
- NO UNDESIRABLE SIDE EFFECTS

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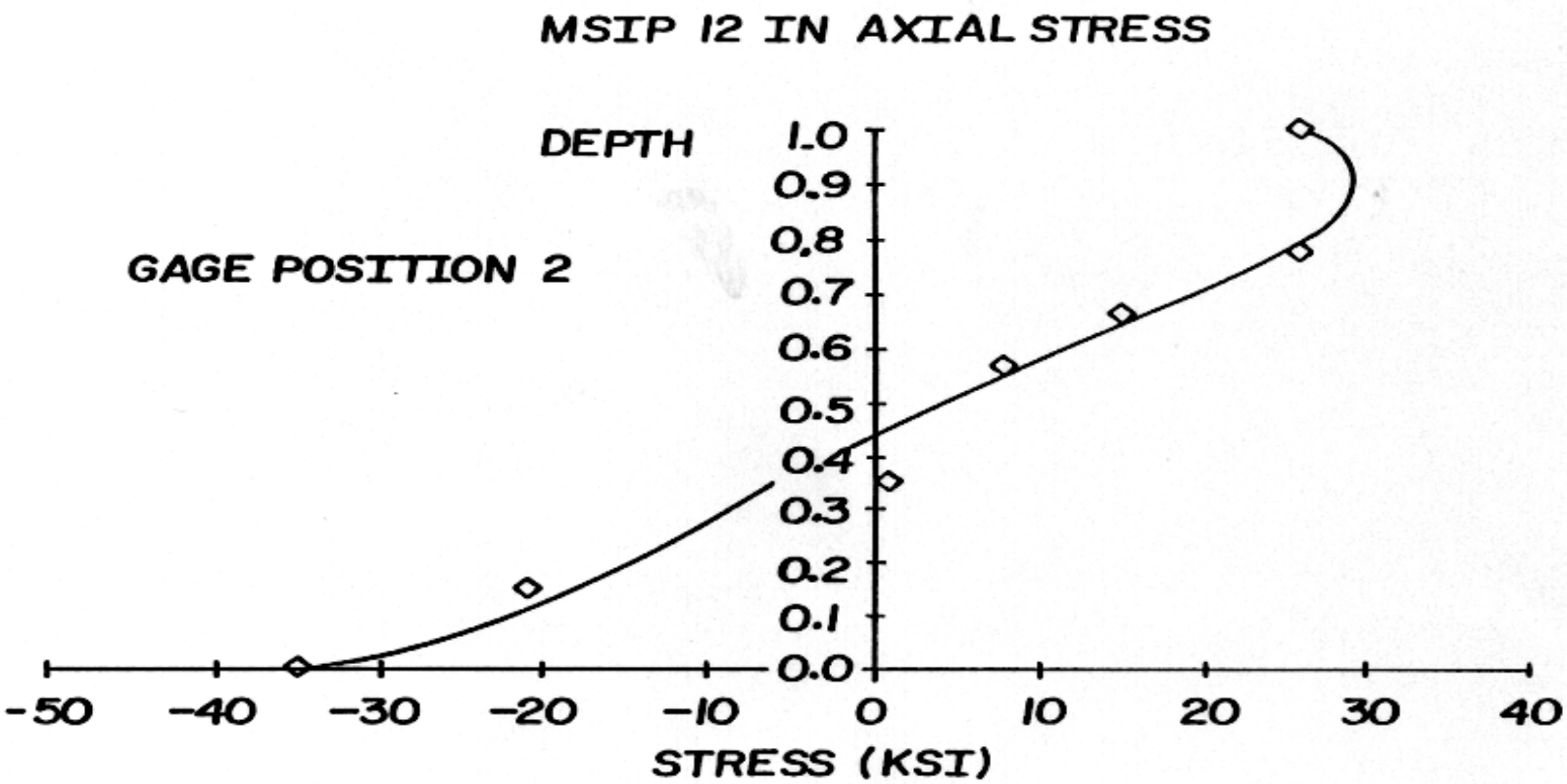
MEASURED THROUGH-THE-WALL DISTRIBUTION OF RESIDUAL AXIAL STRESS AFTER MSIP®



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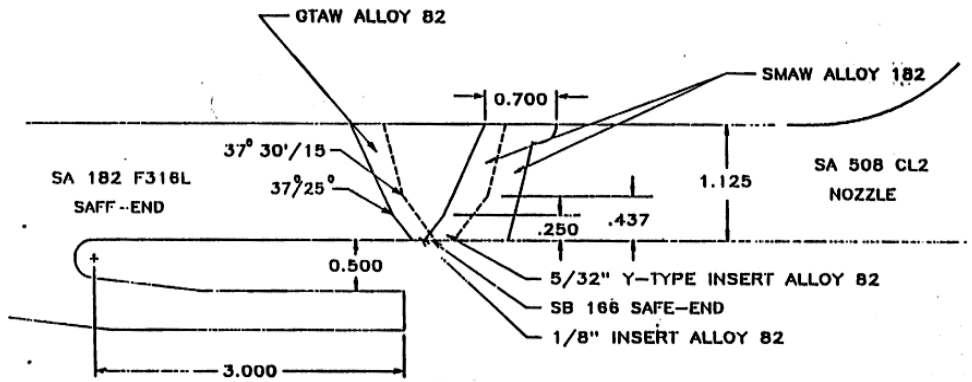
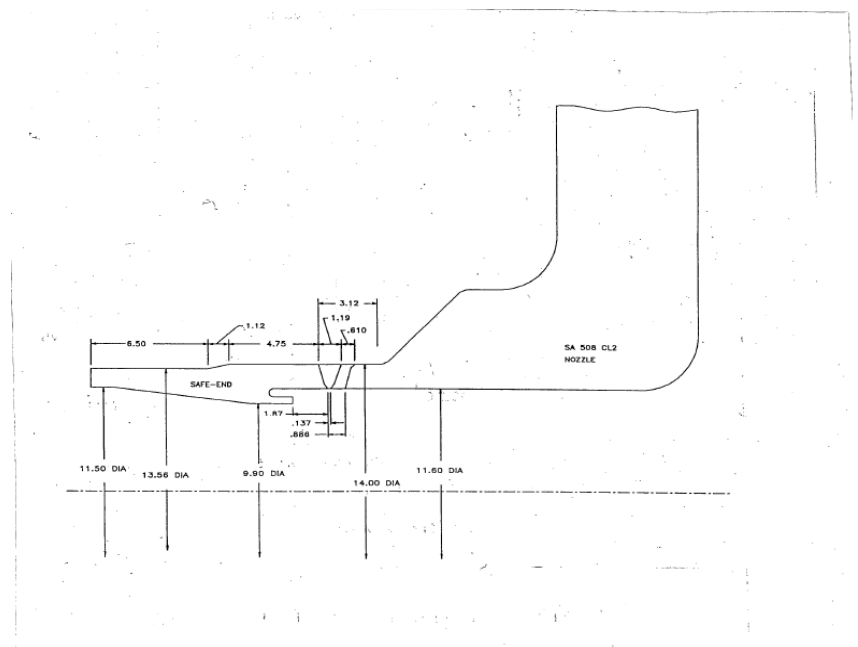
NOZZLE TO SAFE-END MOCK-UP (EPRI)



NOTES:

1. NO BUTTER ON SAFE-END
2. NO ID CLAD ON NOZZLE
3. SCALE 1:1



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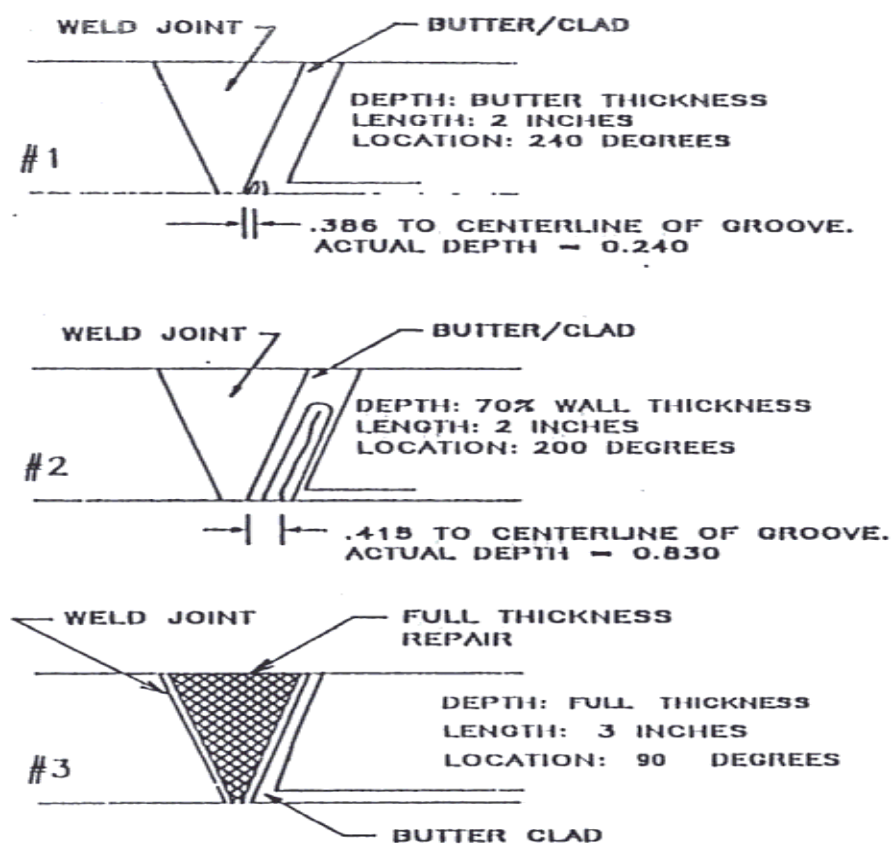
NOZZLE TO SAFE-END MOCK-UP CRACK DETAILS



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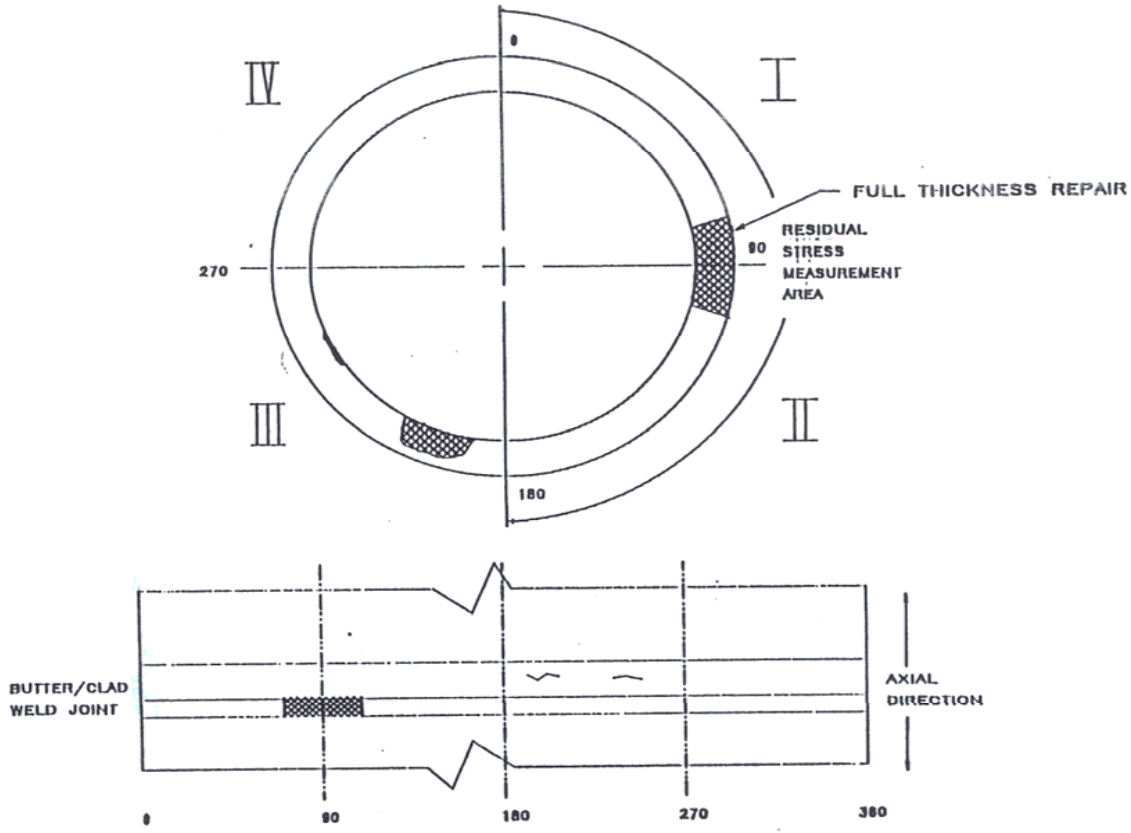
NOZZLE TO SAFE-END MOCK-UP CRACK DETAILS



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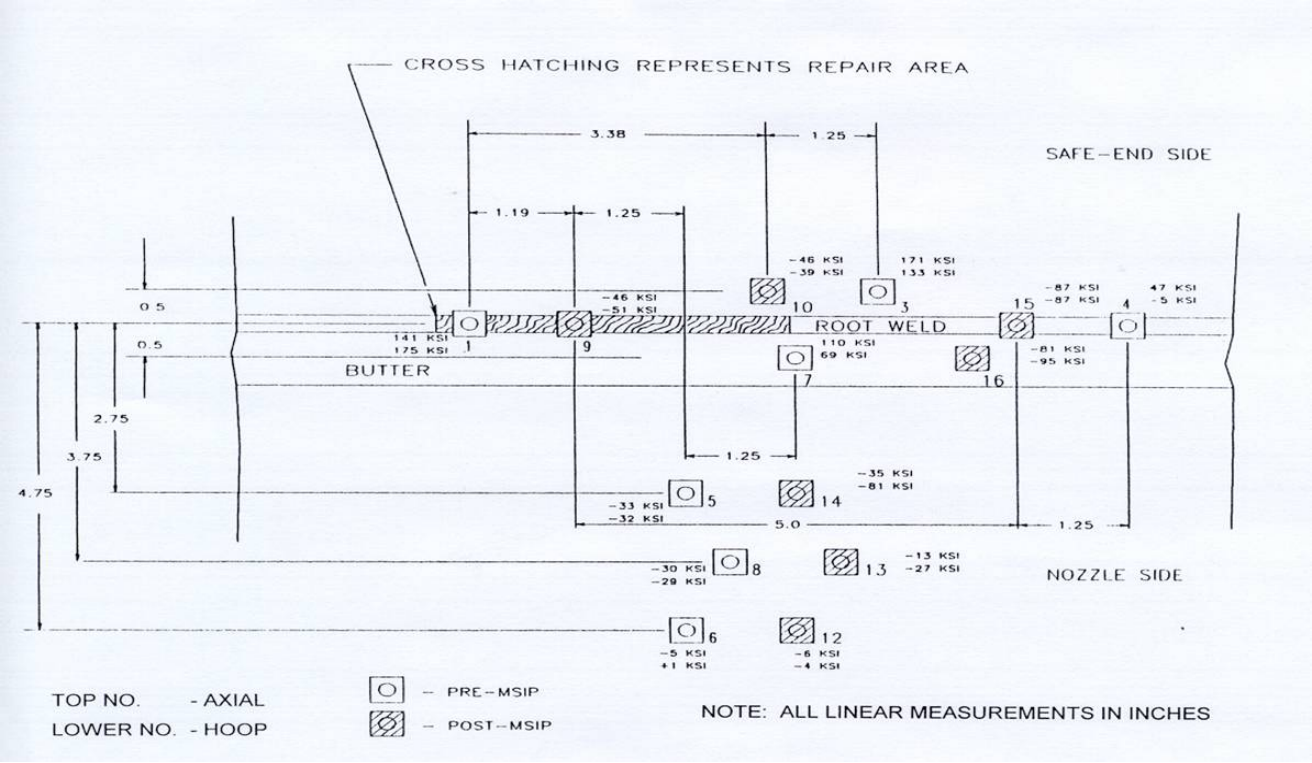
STRAIN GAGE PATTERN FOR EPRI NOZZLE-TO-SAFE-END MOCK-UP



Pre-MSIP® Stresses		
Rosette #	Axial Stress	Hoop Stress
1	141759.133	175771.367
3	171722.157	133363.746
4	47140.536	-5832.085
7	110974.927	69896.933

Post-MSIP® Stresses		
Rosette #	Axial Stress	Hoop Stress
9	-46364.120	-31636.132
10	-46215.347	-39557.045
15	-87229.501	-87938.334
16	-81364.216	-95693.970

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NRC CONCLUSIONS AND RECOMMENDATIONS

"BASED ON THE RESULTS OF OUR RESEARCH WORK AND THE DATA AND ANALYSIS PROVIDED BY O'DONNELL & ASSOCIATES, INC., MSIP® IS JUDGED TO BE AN EFFECTIVE MEANS OF IMPROVING THE RESIDUAL STRESS STATE OF PIPING SYSTEM WELDMENTS AND SHOULD BE CONSIDERED AS EQUIVALENT TO IHSI IN TERMS OF MITIGATING SUSCEPTIBILITY TO STRESS CORROSION CRACKING. UNLIKE OTHER RESIDUAL STRESS IMPROVEMENT TECHNIQUES IT IS AS EFFECTIVE FOR LARGE DIAMETER PIPING AS SMALL DIAMETER PIPING. THE ASSOCIATED PLASTIC STRAINS ARE UNLIKELY TO HAVE DETRIMENTAL EFFECTS EITHER THROUGH THE PRODUCTION OF BRITTLE PHASE LIKE MARTENSITE OR OTHER MECHANISMS THAT INCREASE SUSCEPTIBILITY TO STRESS CORROSION CRACKING."

SOURCE:

MEMORANDUM FOR:	HAROLD R. DENTON, DIRECTOR
FROM:	OFFICE OF NUCLEAR REACTOR REGULATION ERIC S. BECKJORD, DIRECTOR OFFICE OF NUCLEAR REGULATORY RESEARCH
SUBJECT:	RESEARCH INFORMATION LETTER NO. 149, "EVALUATION OF THE MECHANICAL STRESS IMPROVEMENT PROCESS"
DATE:	FEBRUARY 12, 1987

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MSIP® APPLICATION ON PWR R.V. HOT-LEG NOZZLE WELDS

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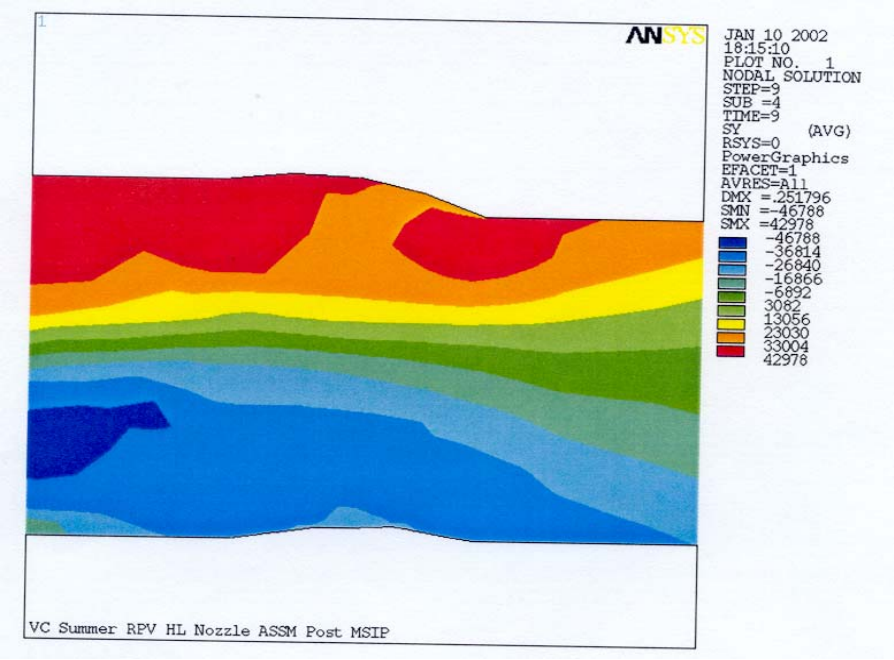
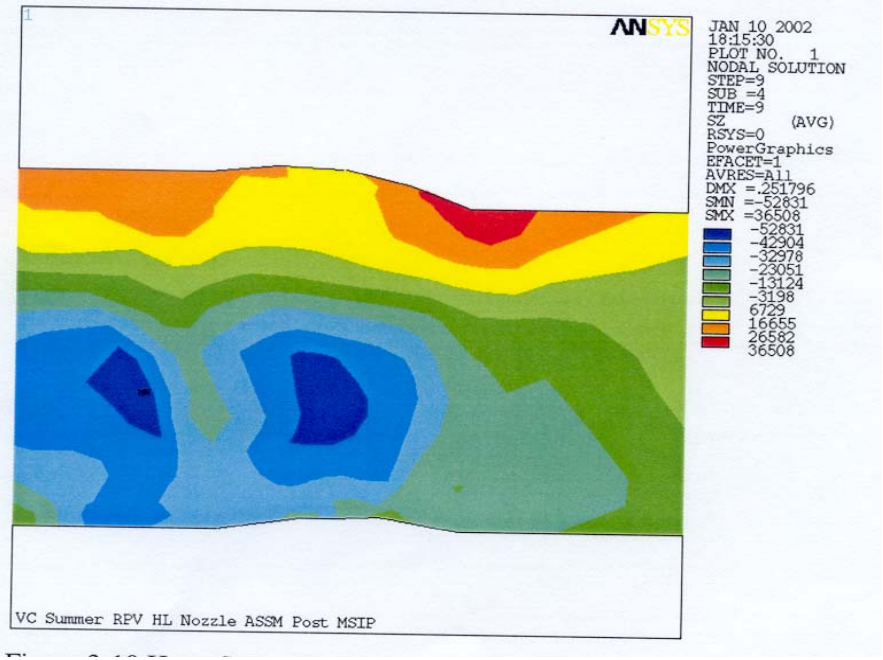
V. C. SUMMER HOT LEG NOZZLE POST-MSIP® STRESSES





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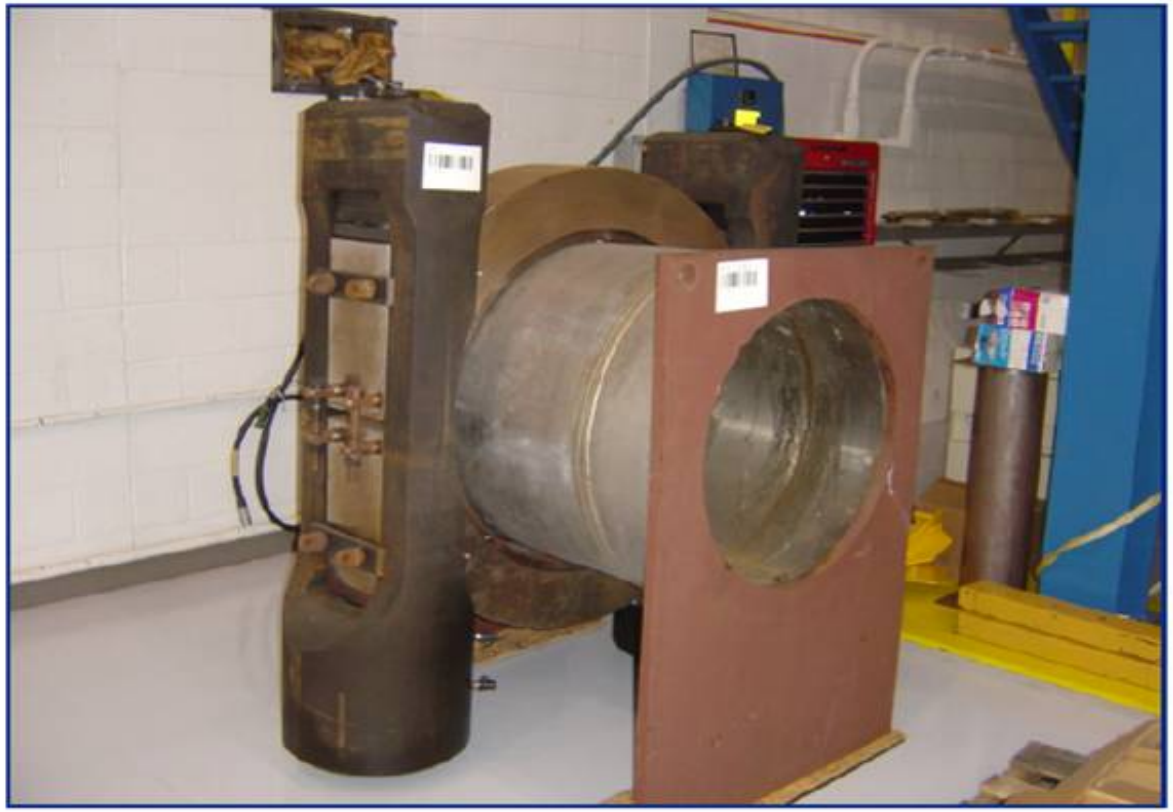
RPV MOCKUP



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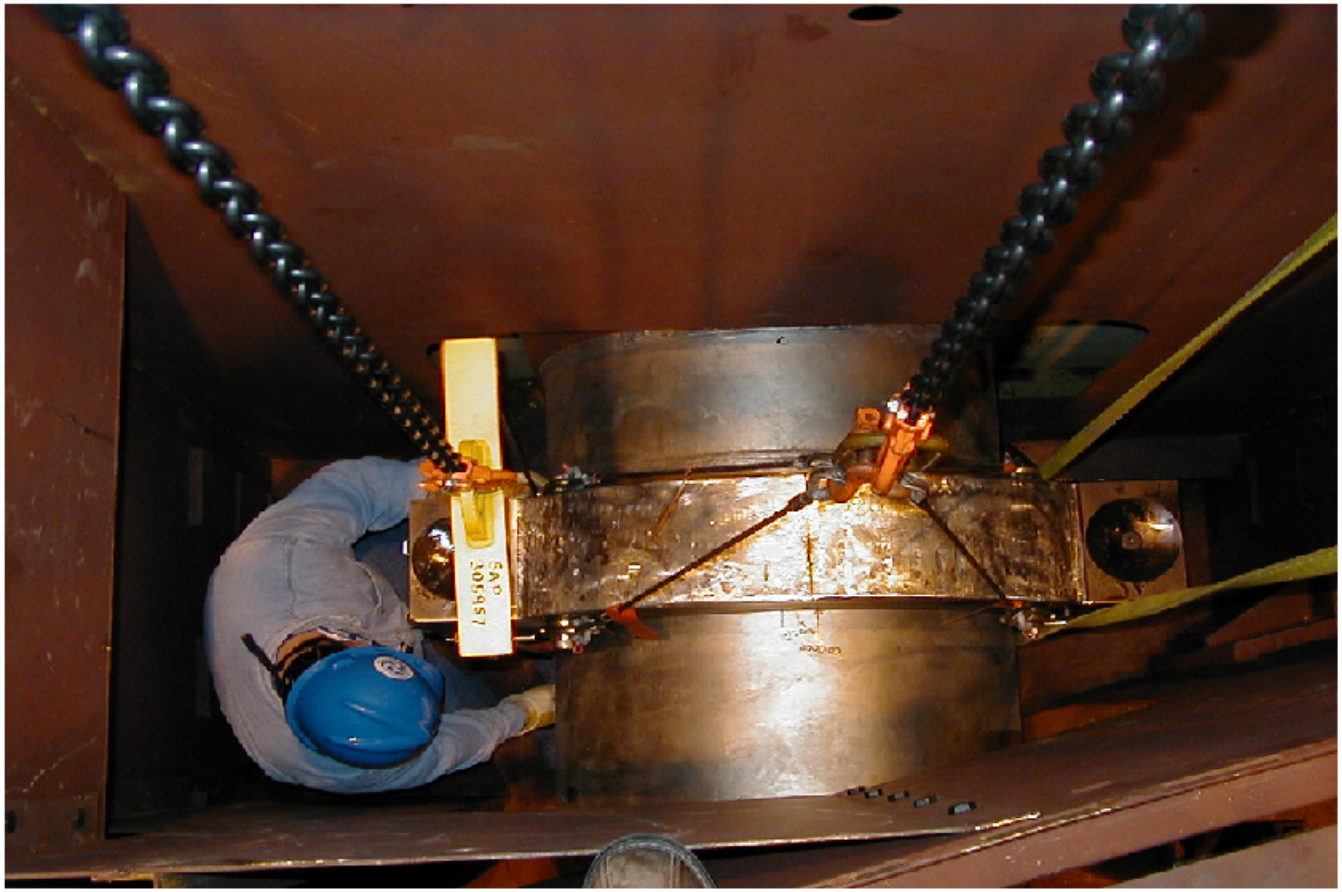
Rigging/Handling for V. C. Summer



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V.C. Summer
PWR Reactor Vessel Nozzle Summary

- The MSIP® application on two RV Hot-Leg Safe-end Nozzles to piping welds at V.C. Summer was successfully accomplished on schedule (24 HRS.)
- 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)
  - Eddy current testing (ECT) was used as a complementary inspection technique

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LEAK-BEFORE-BREAK

Dulal Bhowmick
Fellow Engineer
Westinghouse Electric Company

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Leak-Before-Break Evaluation

- Flaw Selection
- Leak Rate Predictions
- Flaw Stability Evaluation
- Fatigue Crack Growth Evaluation

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Leak Rate Calculation

- Calculate crack opening area due to normal operating loads
- Calculate leak rate using two-phase flow formulation. Account for crack surface roughness
- Show that the calculated leak rate is detectable

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Flaw Stability Evaluation

- Perform stability evaluation using faulted loads
- Limit Load Approach
  - $M_{APP} < M_{LIM}$
- J-Integral Approach
  - $J_{APP} < J_{Ic}$
  - $T_{APP} < T_{MAT}$ IF $J_{APP} \geq J_{IC}$
  - $J_{APP} \leq J_{MAX}$

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Fatigue Crack Growth Evaluation

- Allowable flaw depth for ASME Section XI Standards is approximately 10% of wall thickness 0.1T
- Assume 0.1T as the initial flaw depth
- Calculate final flaw depth a_f by FCG
- Show that a_f will not grow through the pipe wall
- FCG evaluation provides assurance that any undetected flaw will not grow through the wall

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Recommended LBB Margins Per SRP 3.6.3

- Margin of 10 on Leak Rate
- Margin of 2 on Flaw Size
- Margin of $\sqrt{2}$ on Loads
- Margin of 1 on loads is permitted if absolute load summation is used

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Typical LBB Conclusions

- No mechanism is known that can cause the large size of flaw assumed in the evaluation
- The flaws will remain stable
- Large leak rates assumed in the evaluation will be detected
- LBB evaluation demonstrates that double ended guillotine breaks are not possible

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Effects of MSIP in LBB

- LBB is not considered applicable to systems if operating experience indicates susceptibility to failure from the effects of corrosion, water hammer or low and high cycle fatigue
- V. C. Summer primary loop piping cracking incident at the Alloy 82/182 weld was due to PWSCC
- Alloy 82/182 weld exists at the primary loop piping Reactor Vessel inlet and outlet nozzles to safe-end for the majority of the Westinghouse designed plants

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Effects of MSIP in LBB (cont'd)

- PWSCC is considered to be an active degradation mechanism in Alloy 600/82/182 materials in PWR reactor plants (SRP 3.6.3 in NUREG-0800 Revision 1-March 2007)
- The best mitigation approach for PWSCC is to apply Mechanical Stress Improvement Process (MSIP®)
- The MSIP® process applies a narrow permanent radial deformation adjacent to the Alloy 82/182 weld that causes redistribution of the "as-welded" residual stresses in the weld resulting in a zone of compressive residual stress at the inner region of the weld joints

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Effects of MSIP in LBB (cont'd)

- Compressive residual stress at the inner region of the weld joints prevents future crack initiation or growth of existing undetected cracks
- No crack initiation or crack growth means no through-wall flaw and prevents leak
- MSIP® was initially used for BWRs, starting in 1986
- The application of MSIP® has been extended to Pressurized Water Reactors (PWRs) in the U.S., where it was first used to mitigate primary water stress corrosion cracking (PWSCC) in reactor vessel hot-leg nozzle welds at V. C. Summer

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Conclusions

- MSIP® application process mitigates PWSCC
- MSIP® prevents crack initiation/growth and leak
- MSIP® has a significant benefit in reducing the potential for a through-wall flaw and also the probability of pipe rupture
- Preserves LBB status of the PWSCC susceptible welds
- Net impact of MSIP® is to improve LBB defense

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