



ELECTRIC POWER RESEARCH INSTITUTE

Peening for Mitigation of PWSCC in Alloy 600

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NRC/Industry Tech Meeting
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Outline

- Objectives
- Introduction and Background
- Processes
- Applications
  - LWRs in Japan
  - Potential US Application Locations
- Industry R&D Program Status
- Industry Implementation and Perspective
- Inspection Credit and Regulatory Acceptance

Objectives for this Meeting

- Facilitate dialogue between NRC and Industry on implementation of advanced PWSCC mitigation techniques
- Review status of Industry R&D Program
- Review plans for technical transfer of peening basis for mitigation of PWSCC
- Present Industry perspective of potential implementation project drivers
- Review potential approaches for the Industry to receive inspection credit for pro-actively addressing PWSCC through the application of peening processes

Process Overview

- Surface stress mitigation is effective for mitigating PWSCC in Alloy 600/82/182 by imparting compressive residual stresses
  - Widely implemented in Japan in PWRs and BWRs
  - EPRI's testing shows mitigation of crack initiation
  - Relaxation of the compressive stresses during operational cycles is not significant and does not affect the efficacy
- Application of surface stress mitigation techniques (peening) are also widely implemented outside the Nuclear Industry
  - Aerospace, power generation and defense industries in safety critical components for fatigue, SCC and shaping
- Peening enables the extension of the operational life of Alloy 600 components through initiation elimination or delay

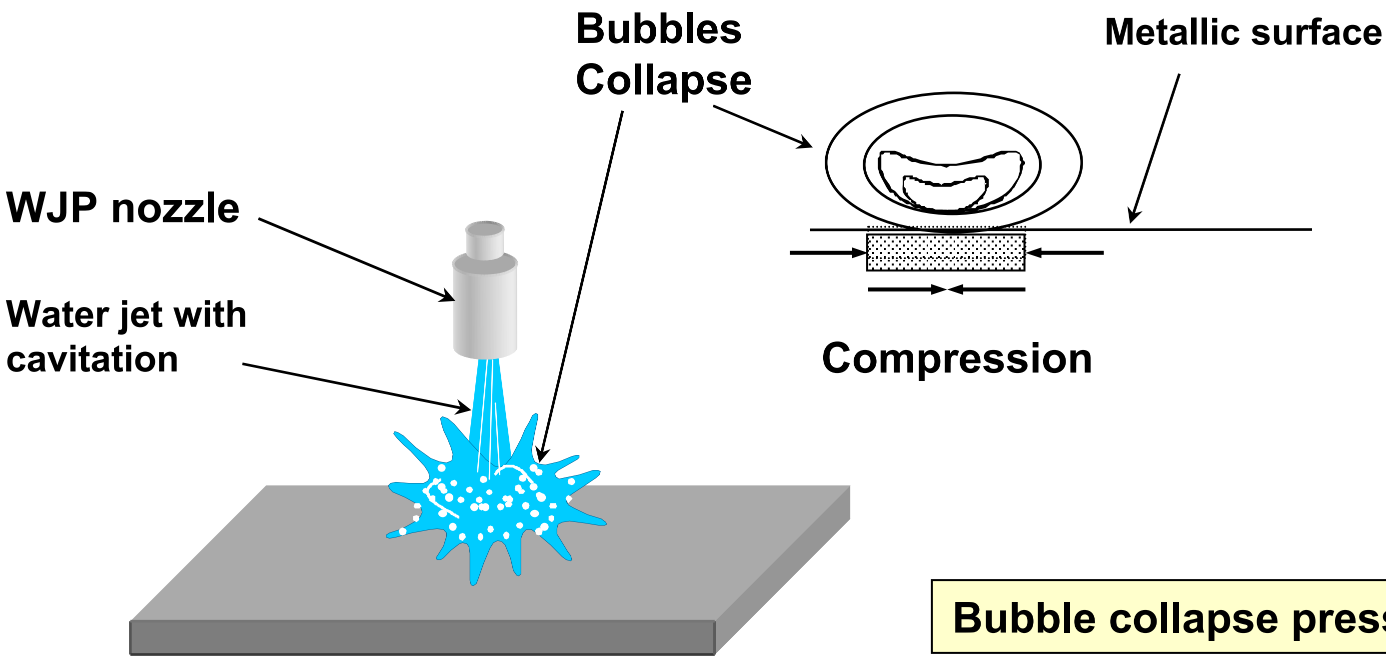
Peening Processes

- Peening methods considered by MRP Program
  - Water Jet Peening
  - Fiber Laser Peening
  - Laser Shock Peening
- Peening methods require:
  - Process controls
  - Demonstrated effectiveness for application geometry

Water Jet Peening (WJP)

Process

- *High velocity jet results in pressure below vapor pressure in water*
- *Vapor bubbles form in water*
- *Bubbles collapse at surface generating high pressures*
- *Compressive stresses in the surface layer of material result*



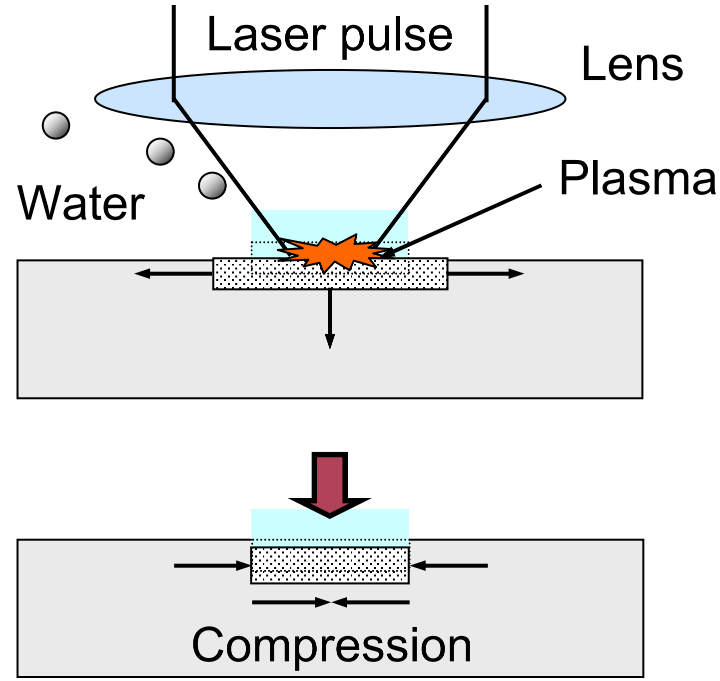
Bubble collapse pressure ~ 150 ksi

Schematic

Laser Peening (FLP or LSP)

Process

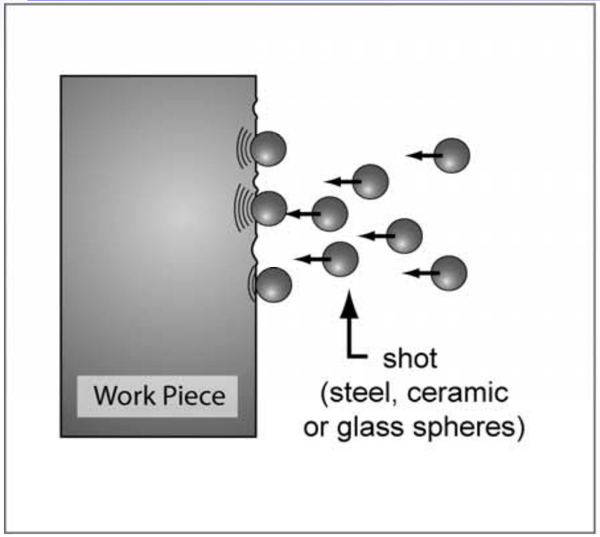
- *Focused high-energy laser pulse irradiates metal surface in water*
- *High-pressure plasma forms on the metal surface*
- *Shock wave forms, impinges on metal surface, and creates permanent local strains*
- *Compressive residual stress is produced by constraint of surrounding material*

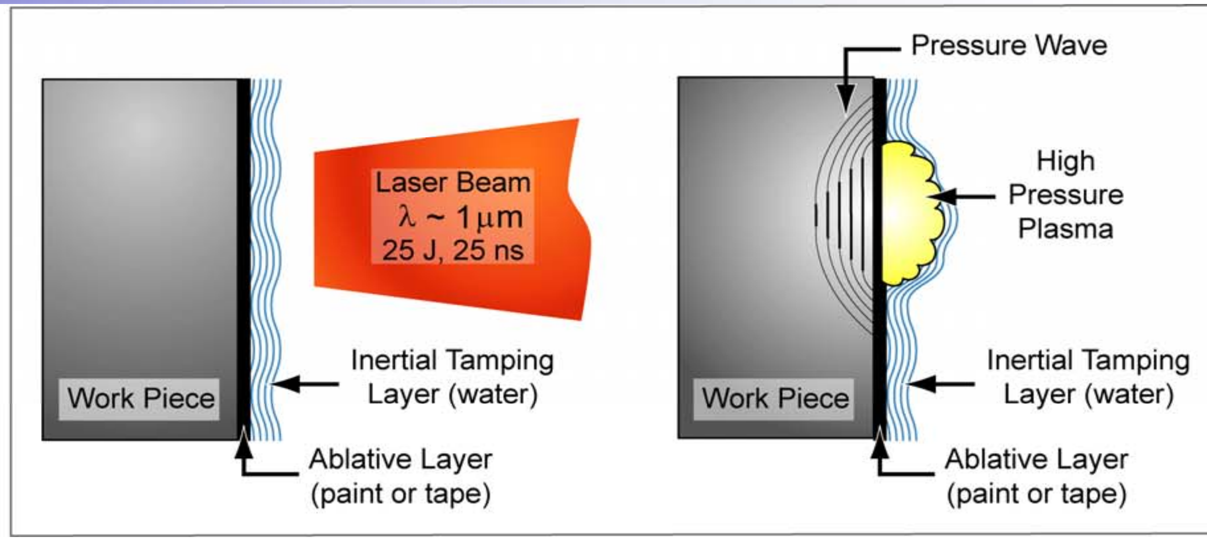


Schematic

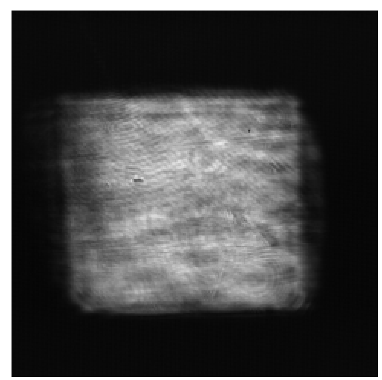
- Plasma pressure ~ 725 ksi
- Alloy 600 Yield Strength ~ 35-42 ksi

Laser Shock Peening (air)



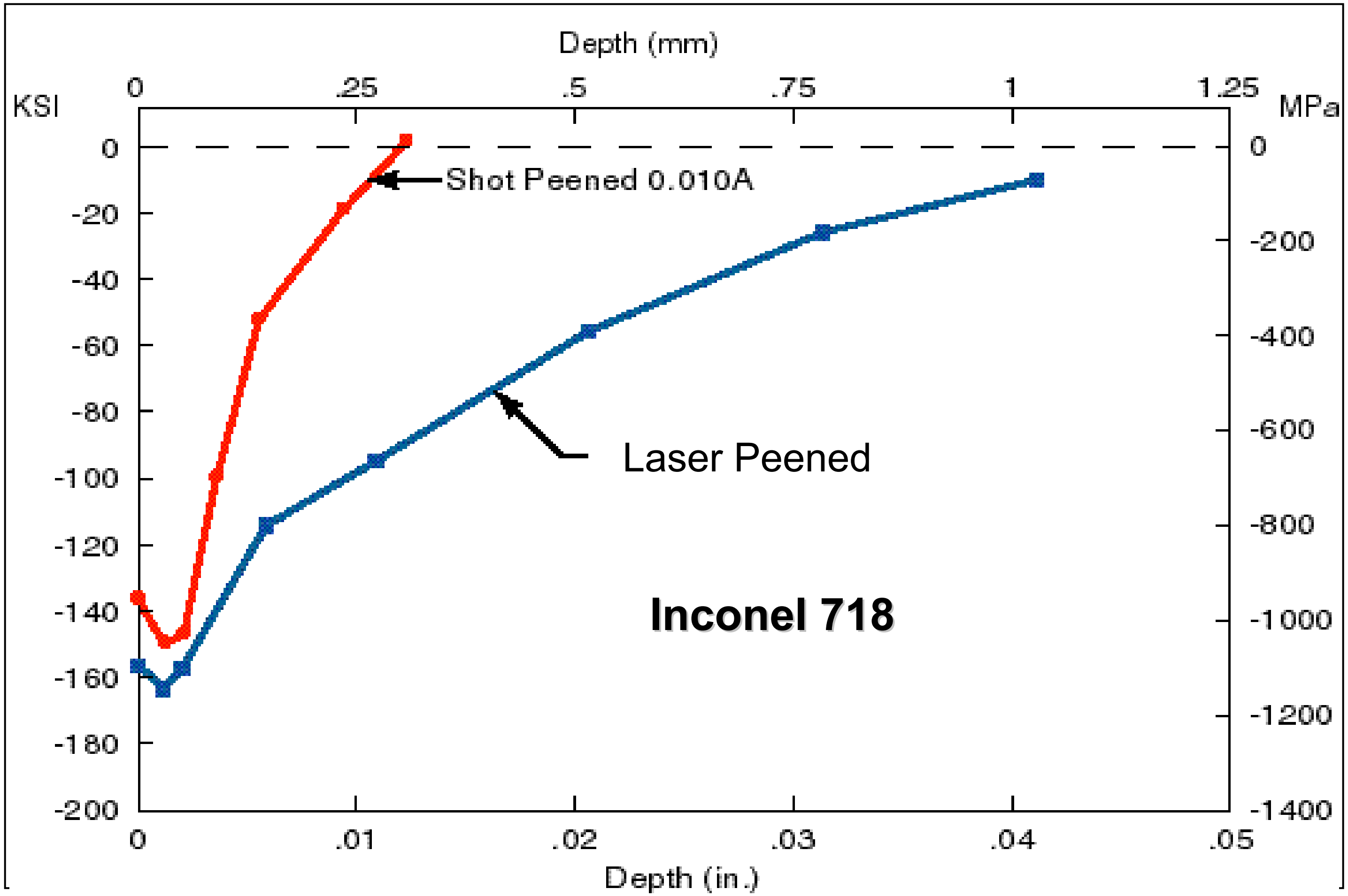


- **An extension of conventional peening**
- **Laser peening provides**
  - **Highly compressive surface residual stress**
  - **Deep layer of compressive residual stress**
  - **Smooth surface**
  - **Excellent process control**


Laser near field image

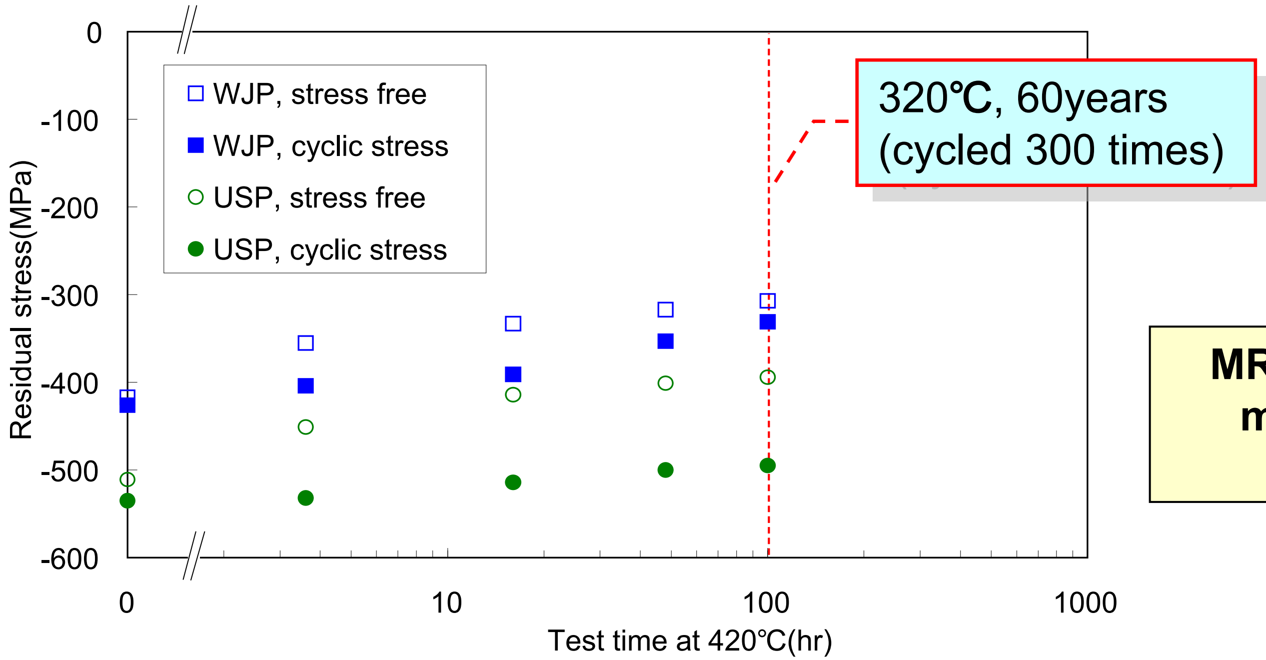

Laser peened aluminum

Advanced Peening Techniques Provide Deeper Residual Compressive Stress



R&D Status (continued)
Stress Relaxation – Affect of temperature and cyclic stress

Vendor Supplied Data



MRP testing shows that most relaxation occurs during early cycles

"60 years" is the evaluation time in 593K(320℃) which calculated the result of examination temperature 693K(420℃) in Larson-Miller parameter
[T×(Log t +20) = const.   T : temp (K)   t : time]

Reliability of WJP Effect – Vendor Evaluation

Evaluation points		Verification results
Relaxation of compressive stress	Under high temperature environment	Effectiveness of WJP is kept more than 30 years under the operating temperature.
	Under cyclic stress	Compressive stress remains after 2000 loading cycles
	Under high temperature and cyclic stress simultaneously	Stress improvement effectiveness of WJP is estimated to be about 60 years at T-hot condition
Affect to the existing crack with WJP application		• Crack size is not propagated due to WJP operation • Even to the crack area, compressive stress can be achieved • For the shallow crack less than 1mm depth, crack growth can be mitigated

MRP R&D Status

- Technical Basis Document for PWSCC Mitigation by Surface Treatments (MRP-267) - Product ID – 1020481 (January 2010)
  - Cavitation/Water Jet Peening and Fiber Laser Peening
    - Surface Stress Mitigation Technologies
    - Vendor laboratory testing and data
    - MRP laboratory testing and data
    - Factor of Improvements
    - Definition of effective application
    - Plant application and experience
- Experimental Program on the Effects of Surface Condition and Mitigation of Primary Water Stress Corrosion Cracking of Alloy 182 Welds (MRP-265) - Product ID – 1019084 (December 2009)

2011 MRP R&D Status

- Address technical questions raised by the end of the year
  - Pre-existing Crack Testing Feasibility Technical Report (in draft)
  - Compressive Stress Relaxation and Shakedown
    - FEA Model development
    - Testing and analyses
  - Thin layers of compressive stress and transition profiles in thick PWR components
    - Modeling, analyses and knowledge/data gaps
    - Testing and analyses, as needed
- Investigate initiation (1000 and 2000 hours in primary water) benefits from techniques and incorporate into the next revision of the Technical Basis Document Report (MRP-267)
- Initiated ASME Code Committee interactions to incorporate into Code Cases

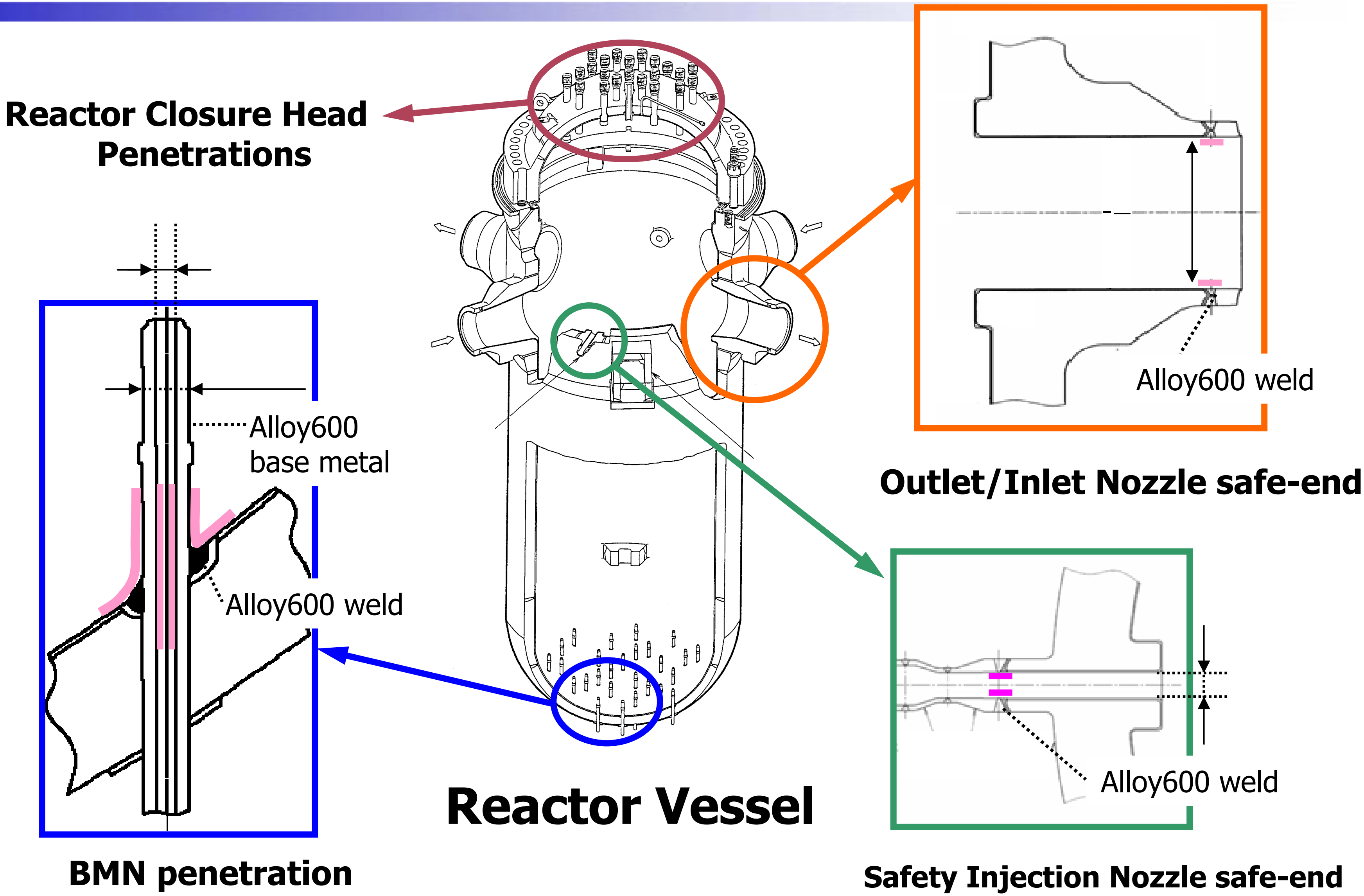
Addressing remaining technical questions with resolution planned for the end of 2011 with no outstanding issues

Implementation in the US PWRs

What's required for the successful implementation?

- Solid technical basis ✓
- Qualified and verifiable process control ✓
- Asset preservation drivers must be positive ✓
- Timeliness (before crack initiation is best) ✓
- Utility desiring Implementation ✓
- Inspection Credit ?

Potential US PWR Locations for Application



Peening Utility Drivers

Why consider peening at this time:

- Maximize the remaining service life of the component or asset
- **Pro-active** rather than reactive to SCC degradation
- Mitigation of SCC initiation on the wetted surface
- The sooner it is applied the more likely it is to be effective
- Existing Code recognition by JSME as an effective mitigation strategy in Japan with no identified failure issues
- Potential for inspection relief similar to other stress improvement processes
- Through control of the degradation process the impact on outage schedules, radiation exposure and costs are minimized

Implementation of Peening in Japan

PWR plants:

- 16 out of 23 PWR units have applied WJP or FLP to:
  - BMI nozzles/J-groove welds
  - Inlet/outlet nozzles
  - Safety Injection nozzles
- Remaining 7 PWR units have plans to apply peening within 2 to 3 years
- Peening has been applied to the new Alloy 690 penetrations

BWR plants:

- 20 BWR units have applied WJP or FLP to:
  - Shrouds
  - Bottom head penetrations (i.e. CRD stub tubes)
- Planning to peen the remaining BWR plants
- Applying to new ABWR units during the fabrication and construction phases

Peening Implementation

Implementation by the US Nuclear Industry:

- Pro-actively addressing degradation through the Asset Management process
- Sound basis supported by EPRI and Vendor research
- Capable process control and substantial vendor application experience
- Utilize the 50.59 Process to proceed immediately

Utility/Industry Perspective

Historical

- For over 20 years we have been studying and talking about mitigation
- Utilities waiting on vendors to develop, vendors waiting on utilities to fund, and utilities waiting on inspection credit
- The Japanese experience provides additional confidences.
  - Adopted into JSME in 2004 and JANTI Guidelines in 2006
  - Began Implementation in BWR piping applications in 1976 and core shrouds in 1994
- In the U. S. 124 CRDM nozzles have been mitigated with the AREVA ½ Nozzle repair which are peened
  - Although only 27 remain in service due to head replacement there has been NO identified crack initiation following mitigation
  - 2 have been in service since 2004

Utility/Industry Perspective

Peening might be the only or preferred option

- Not Feasible / Practical Locations
  - Some Westinghouse plants due obstruction and limited space in sandbox, MSIP or Weld Overlay is not practical
    - ID welding under development but high risk
- Difficult/High Risk Locations
  - B&W Core Flood location
- Option to prolong service life of the RV Head rather than replace
  - Cost effective and minimizes exposure to personnel
  - Shorter outage duration for mitigation than replacement
  - No Containment opening required
  - Eliminates the need for future repair contingency following mitigation

Utility/Industry Perspective

Protect Plant Assets and Reduce operating costs

- Avoid component replacement
- Avoid unnecessary costly repairs
- Eliminate repair dose
- Eliminates the need for contingencies
- Optimize inspection timing for Hot and Cold Legs DM welds to coincide with 10 year ISI frequency to minimize the number of core barrel movements
- Plants are considering peening now with the desire to get inspection relief in the future
  - At a recent Industry meeting, the utilities present voted unanimously to request funding for development of a technical basis for inspection relief

Utility/Industry Perspective

Inspection Relaxation Goals following Peening Mitigation

- Have inspection frequency for Hot and Cold Legs DM welds match the 10 year ISI Interval exam frequency
  - Minimizes core barrel removal
- Reduced Head Exams after first or second volumetric inspections
- Reduced BMN exams for plants using UT as an alternative to bare metal visual

Technical document/report needed to provide bases and final recommendation through either a regulatory or an ASME Code approach

Inspection Credit Options

- Relief Request - 10CFR50.55a Technical Alternative
  - Can be sought on an individual plant basis
  - Can be sought on a Fleet basis through a Topical Report
- ASME Codification of inspection credit through changes in inspection frequencies associated with Alloy 600 Code Cases
  - N-722 – BMN - BMV (UT alternative)
  - N-729 – Head Penetrations
  - N-770 – DM welds

Conclusions

- Robust technologies
  - Implemented routinely in LWRs in Japan
  - Implemented in routinely Safety Critical Applications in Power, Defense, Aerospace, Automotive and Medical Industries
  - CRDM repair mitigation used in the U. S. in numerous PWRs
    - Abrasive Water Jet Peening part of ½ nozzle repairs

- Proactive mitigation desired

- Utilities are making near-term decisions on implementation for asset protection

- Warrants inspection credit and currently Code actions have been initiated

- Seek further NRC engagement

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