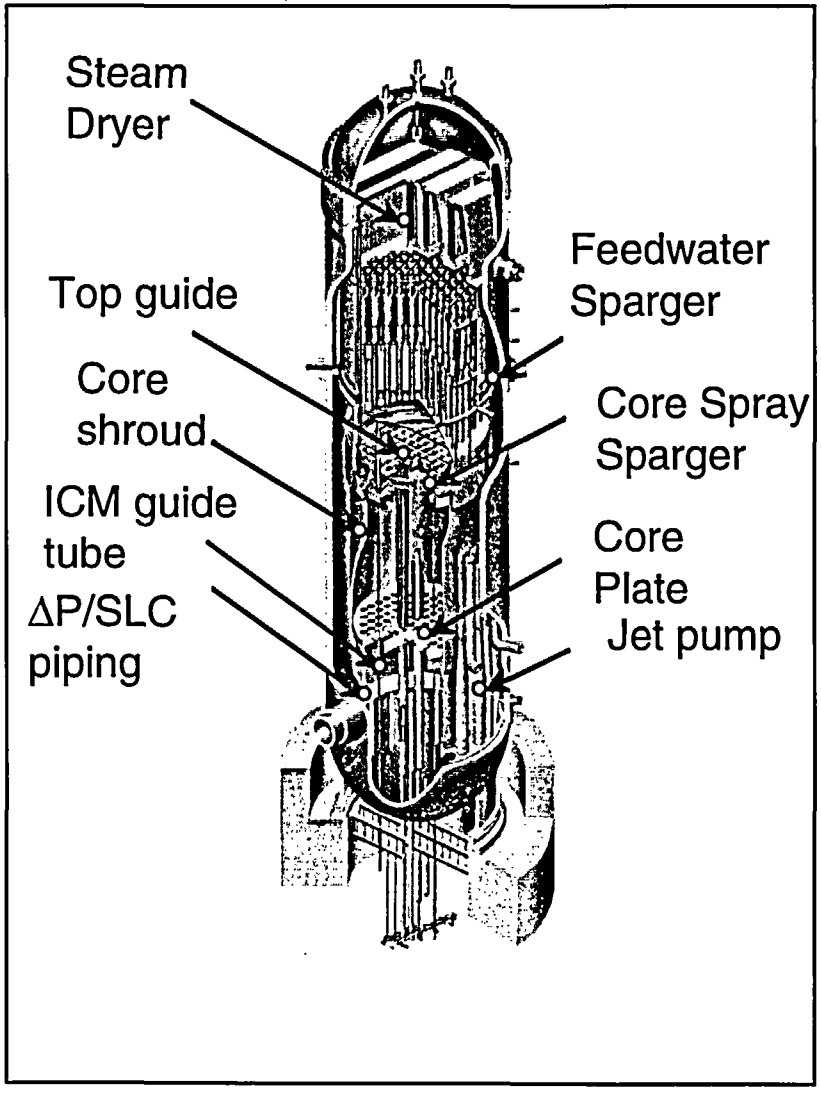


IGSCC of 316NG Stainless Steel Piping in Japan

George Inch

Constellation Generation

EPRI

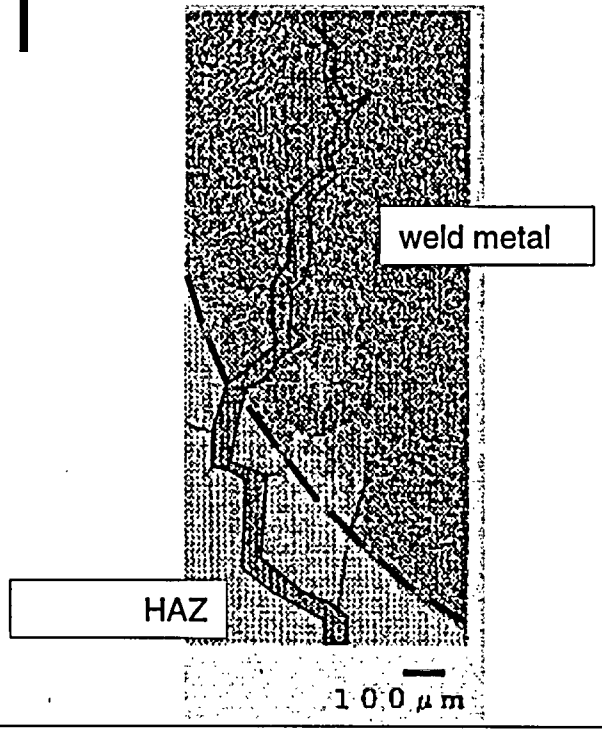
Background

- SCC of low carbon stainless steels (type 316L, 316NG, 304L) has been reported in many Japanese BWRs
  - 2001: SCC of a 316L core shroud
  - 2002: SCC of 316L/304L core shrouds and 316NG recirculation pipes
- Sources of Information
  - February 2003: GE informed BWRVIP of cracking
  - June 2003: BWRVIP / INPO / CRIEPI Technical Exchange Visit
    - TEPCO reviewed root cause investigation of SCC
  - July 2003: IAEA Meeting
    - Presentation by Hitachi on SCC in Japanese BWRs

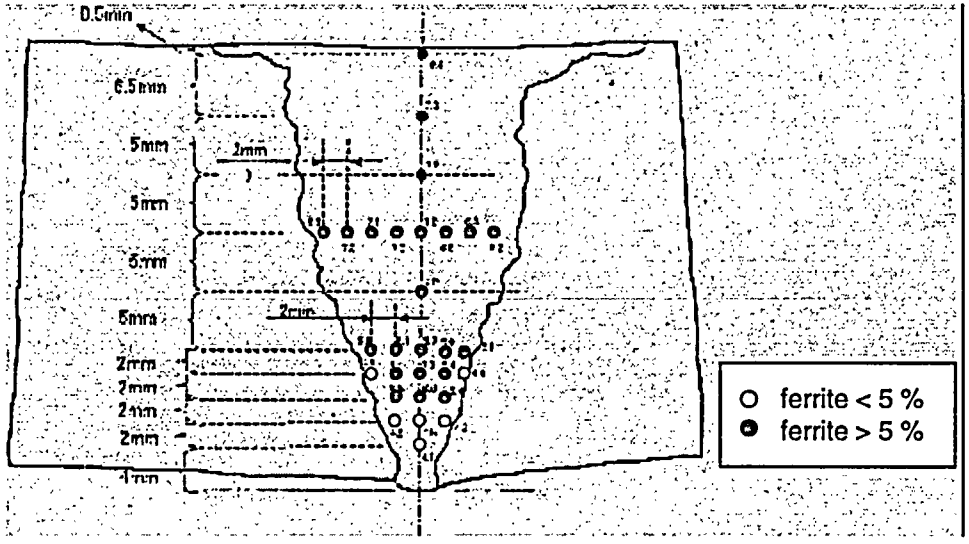
Characteristics of Cracking

- Transgranular cracking initiated at surface hardening layer and propagated intergranularly
- Circumferential cracks close to the fusion line
- Some cracks propagated into the 316L weld metal

Characteristics of Cracking



cracking into weld metal



ferrite distribution

- Cracking propagated into weld metal containing ferrite less than 5%

Suspected Causes for Crack Initiation in Japanese BWRs 316NG

- Excessive cold work during fabrication is the primary root cause based on the Japanese evaluations
  - Japanese testing shows vickers micro-hardness over 300 Hv at a depth up to 0.1mm from pipe inside surface
    - Threshold for concern above 270 - 300 Hv
  - Lack of cold work reduction controls on counter-boring
  - No surface polishing of counter-bore
- GE evaluation postulates chemical composition as a suspected contributor to pipe cracking
  - Ultra low sulfur content
    - Requires higher heat input to weld which can cause hot cracking in base material
  - Higher nickel (JIS spec) and nitrogen promoting low or negative ferrite potential

US Recirculation Piping Replacements

- Reduction of cold work recognized as important for 316NG pipe replacements
  - Special machining procedures to reduce cold work (typical)
  - Polishing of counter bores (some plants)
  - Polishing of entire pipe ID (some plants)
- Stress mitigation was recognized as important
  - IHSI or MSIP (some cases)
  - Heat sink welding (some cases)
- Positive ferrite potential
  - Typically 3-5 % in piping material
  - Higher ferrite forming potential in U.S. 316NG reduces the propensity for hot cracking
  - Weld metal typically 308L with 8 ferrite number minimum

Japanese Inspection Experience

- Japanese UT was capable of detecting the indications
- Crack orientation different than typical IGSCC HAZ cracking profiles
- Japanese have used a shear wave crack tip echo method. This method demonstrated to have a substantial difference between actual and measured crack depth
  - Reason has been attributed to direction of crack propagation into the weld metal
- Japanese working to improve sizing capabilities for UT of weld metal

Assessment of 316NG Piping in the US

- The operating time of US 316NG piping equivalent to the Japanese
- A significant number of Type 316NG welds have been inspected
  - Current inspection procedures used in the US are very effective in detecting IGSCC
  - Inspection methods and frequency at least equivalent to the inspections that have identified the condition in Japan
  - Confidence in these procedures has increased with the implementation of GL88-01 inspection program and PDI
- Many plants have operated with effective HWC for many years adding margin against IGSCC initiation
- Stress mitigation considerations
  - Many welds stress relieved using IHSI or MSIP
  - Some welds stress relieved using heat sink welding
  - Cold work mitigation measures were typical
    - GE specifications after 1985 ensured cold work minimized

Conclusions

- Inspection experience in US demonstrates exceptional performance of 316NG pipe replacements
- No changes to inspection programs recommended at this time
- Follow-on activities
  - Continue to monitor Japanese developments and evaluate applicability to US fleet