CSAT 2019

Pacific Northwest NATIONAL LABORATORY

Potential Cold Spray Applications for Mitigation and Repair in Nuclear Power Plants

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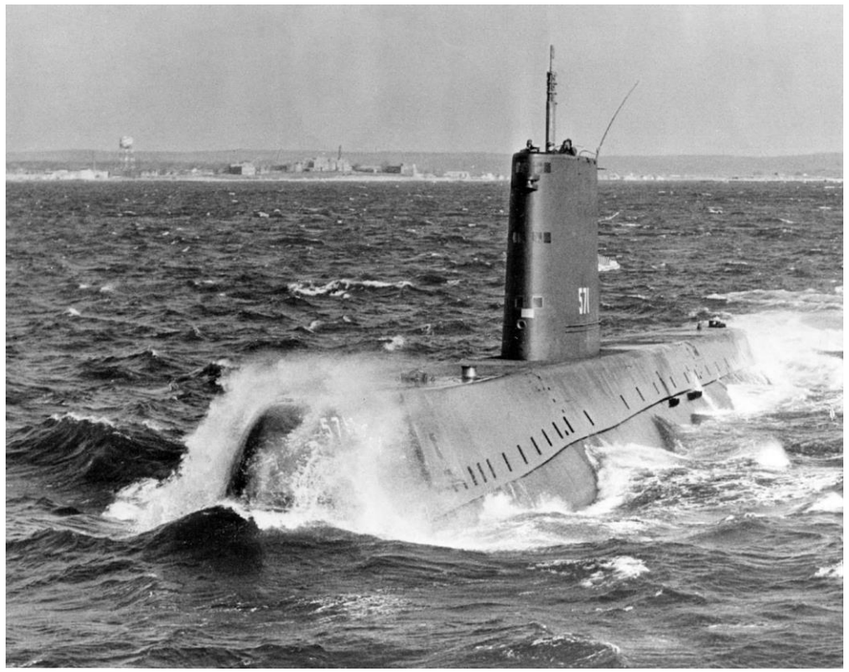
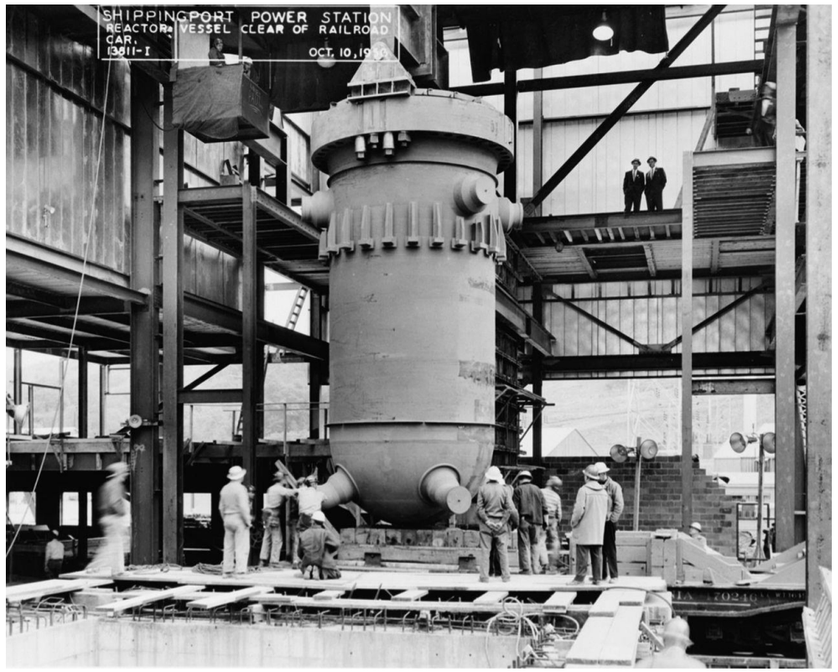
The Advent of Nuclear Power

USS Nautilis (SSN 571): 1954



Shipping port Atomic Power Station: 1957



Images credit to Wikipedia on respective subjects

60+ Years of Operating Experience

- Nuclear Power Plants were initially licensed for 40 years
  - License Renewal Extends Operations to 60 Years
  - Many expect an additional extension to 80 years will be needed
  - License renewal requires addressing known degradation mechanisms

- Spent Fuel Dry Storage Canisters were initially Licensed for 20 Years
  - Expectation for long term federal depository at Yucca Mt. never occurred
  - License renewals in process for indefinite period of operation
  - Potential degradation mechanisms must be addressed for renewal

- AGING MANAGEMENT PROGRAMS
  - Particularly after first 40 year license period

Governing Regulations

- ASME Boiler and Pressure Vessel Code
  - Section III: Construction and Replacements
  - Section XI: Inspection, Repair and Mitigation
    - Repair is partial or complete flaw removal
    - Mitigation and flaw arresting and prevention

- Code of Federal Regulations
  - Part 50 for Operating Power Reactors
  - Part 72 for Spent Fuel Storage Canisters

- Additional Nuclear Regulatory Guidelines (NUREGs)

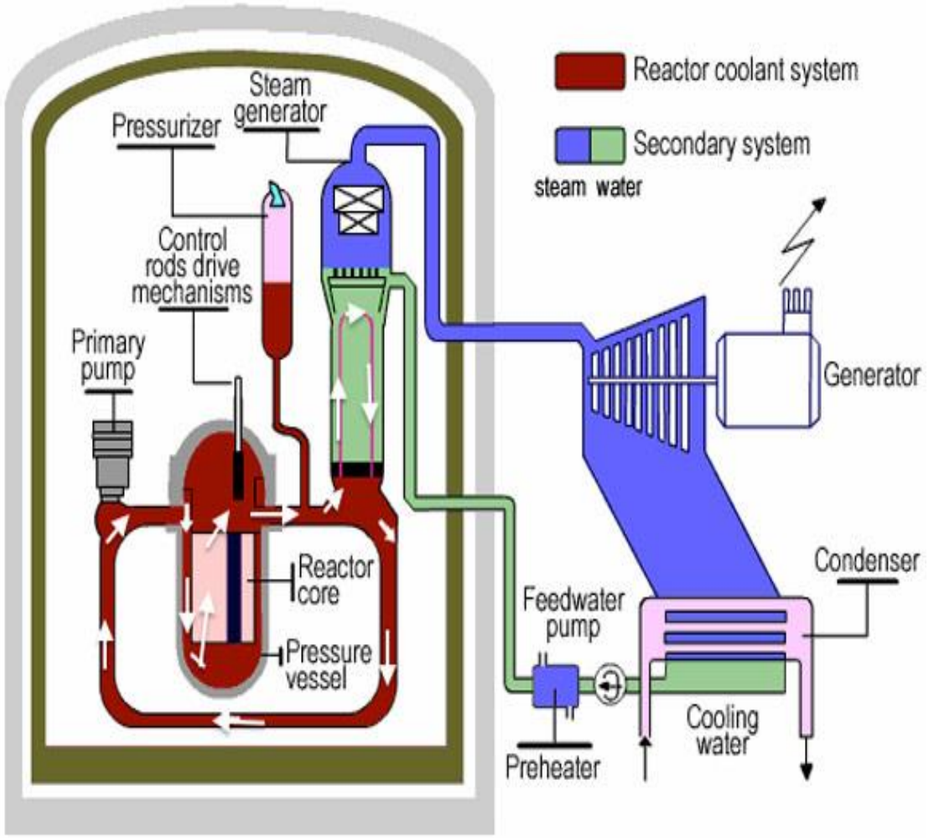
- Utility submits a Relief Request for alternate approach with Technical Justification

Technical Justification Requirements

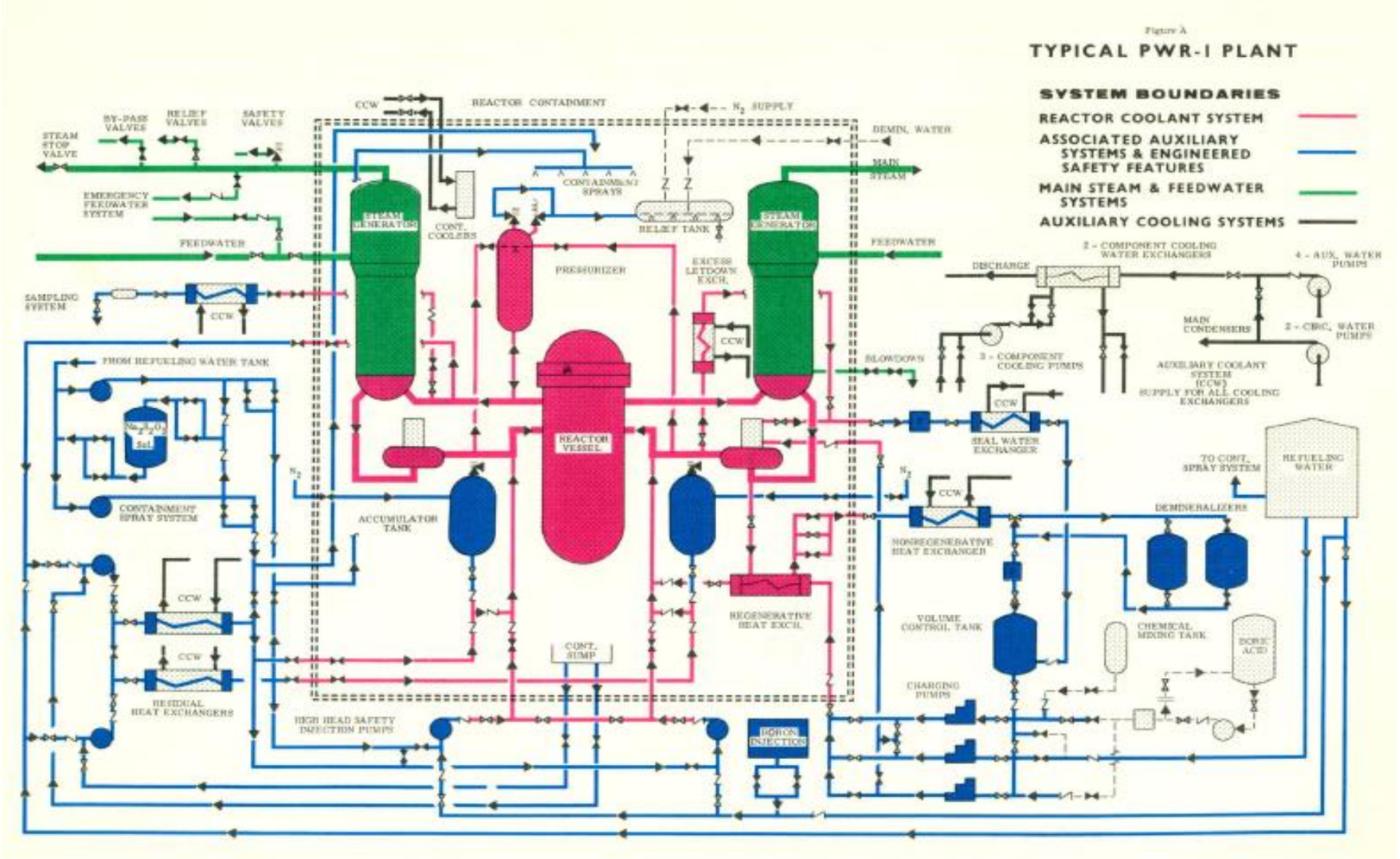
- DO NO HARM
  - Assess any potential unintended consequences
  - What happens to over spray
  - Cleaning process
- PREVENT/ARREST DEGRADATION PROCESS
  - Extensive laboratory study required
- MAINTAINS INSPECTABILITY
  - Both the coating integrity and substrate condition must be inspectable
  - Trust, but Verify

Nuclear Power Primer

- Reactor Vessel
  - 500+ tons
  - 6”-10” thick
  - 200” diameter
- Steam Generators (2 or 4)
  - 300-800 tons
  - 200,000+ sq. ft. heat transfer surface
- Pumps (4)
  - @ 6 Mw
  - @ 90,000 gal/min
- Steel and Concrete Containment



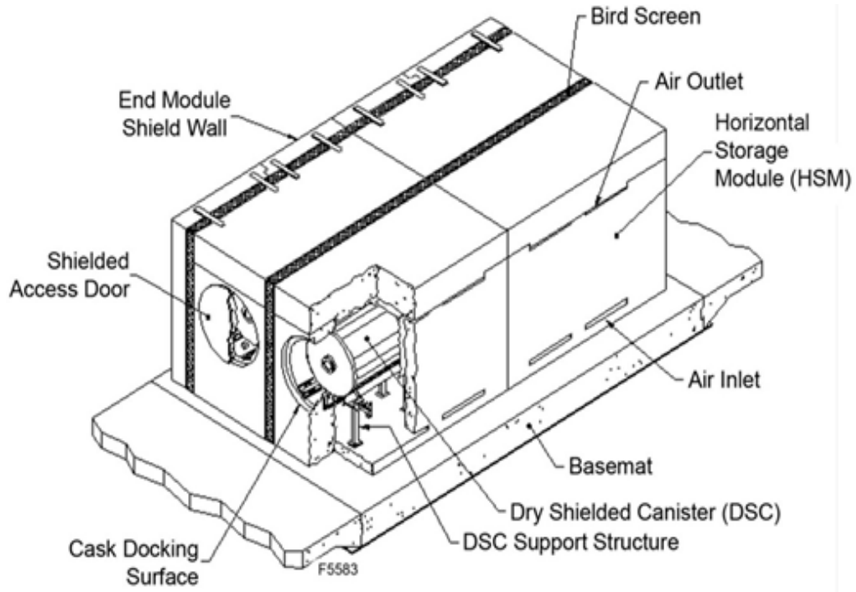
More Detailed System Diagram



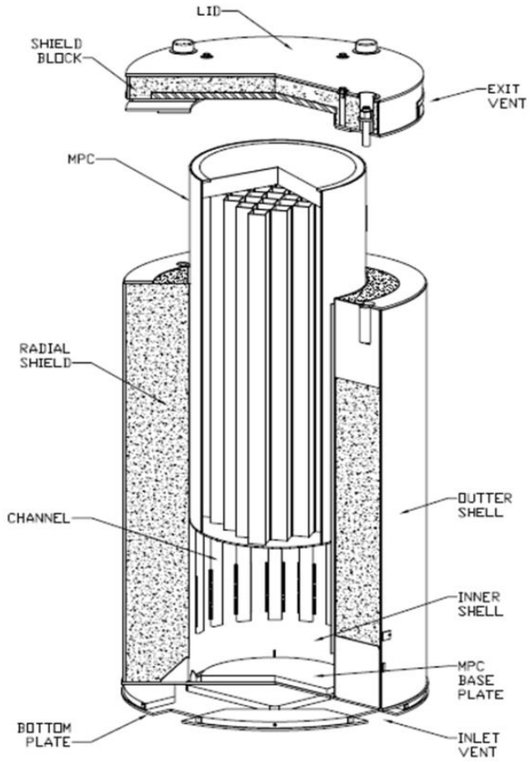
ASME Boiler and Pressure Vessel Code, Section XI, 1971 Edition

Spent Fuel Dry Storage Canister Designs

Horizontal, Stainless Steel/Concrete



Vertical, Stainless Steel/Concrete



R. Meyer et al. PNNL 22495, 2013

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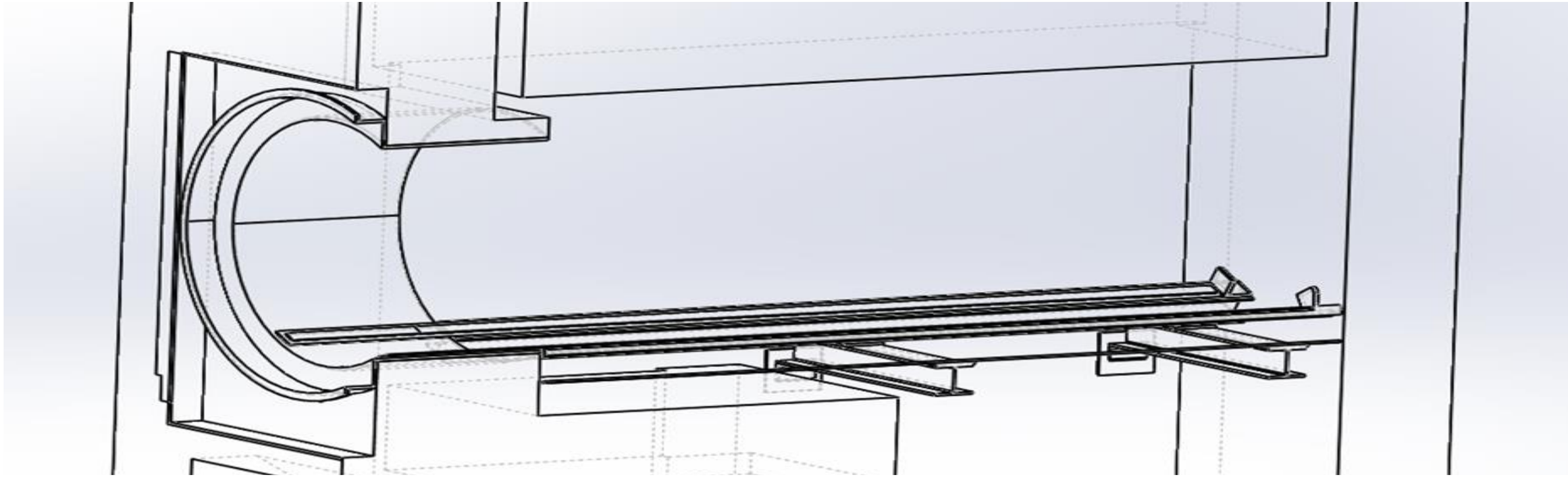
Horizontal Canister



Rests on steel rails for support

R. Meyer et al. PNNL 22495, 2013

Operating Experience: Degradation Types and Cold Spray Mitigation: Potential N/A

- Cracking
  - Primary Water Stress Corrosion Cracking (PWSCC)
    - Attacks high Ni alloys (inconel base metal and welds))
    - No contaminants needed, just stress and temperature
  - Intergrannular Stress Corrosion Cracking (IGSCC)
    - Attacks stainless steels (weld heat affected zone)
    - Stress, temperature and oxygen required

Operating Experience: Degradation Types

- Cracking
  - Chloride Stress Corrosion Cracking (Cl-SCC)
    - Attacks stainless steels
    - Cl comes from sea mists, construction material and human sweat
    - Crevices concentrate Cl contamination
  - Caustic Cracking
    - Associated with Shielded Metal Arc Welds (SMAW)
    - KSiC Flux (slag) entrapped and later exposed to high temperature water
    - Stainless steel and inconel susceptible

Operating Experience: Degradation Types

- Cracking
  - Hot tears
    - More prevalent in Gas Tungsten Arc Welds (GTAW)
    - High Cr steels more susceptible (Alloy 690 inconel)
    - Create stress risers for later SCC
  - Thermal and Mechanical Fatigue
    - Primary design basis for ASME Code
    - Not suitable for cold spray mitigation

Operating Experience: Degradation Types

- Chloride pitting
  - Affects stainless steels
  - Relatively high Cl concentrations
  - Absence of high stresses

- Flow Assisted Corrosion (FAC)
  - Affects carbon steel
  - Two phase turbulent flow
  - Similar to cavitation

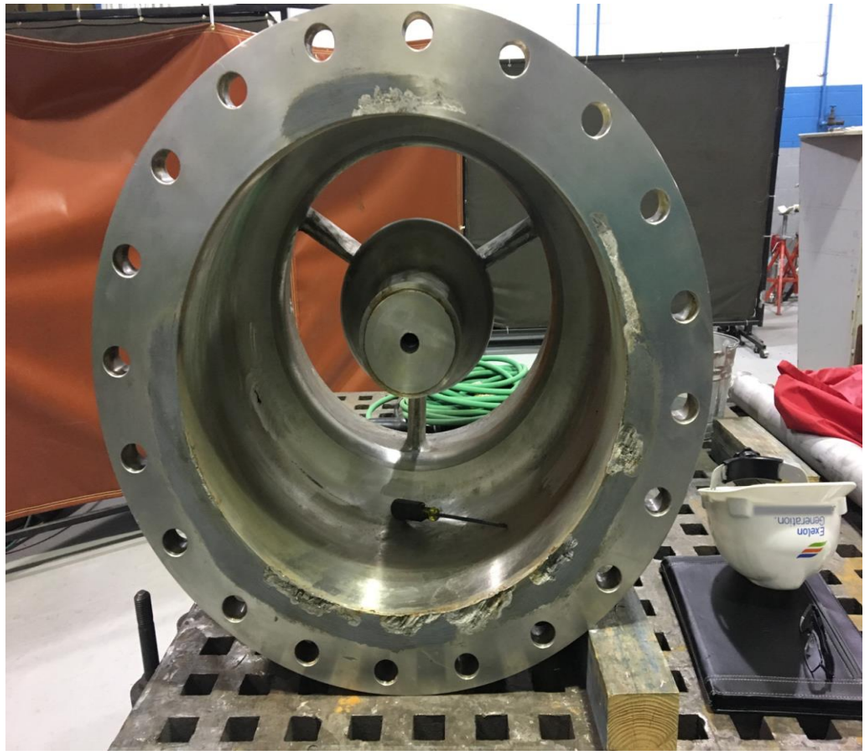
Chloride Induce SCC of SS304 Piping

- Cracking occurred under pipe hanger (crevice environment)
- Inland location (no sea mist)
- 25 year incubation period before through wall cracking observed
- Cold Spray NI coating would arrest/prevent this failure
- Sealing crevice entry with cold spray fillet would also work

Chloride Pitting

- Stainless Steel Valve Flange Face
- Concentration of Cl in the absence of large stresses resulted in pitting
- Some pits also had cracking at their base
- Cold Spray Ni would prevent/arrest this degradation

Cl Pitting from Sea Water

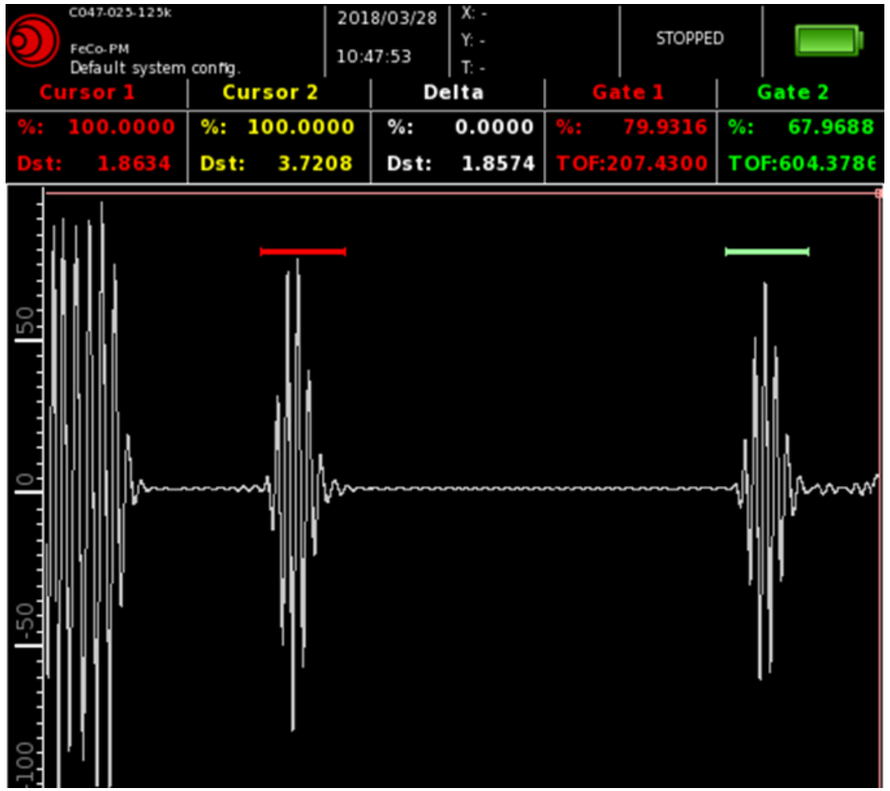


Dual Purpose Ni Coating

Ni Coating Provides SCC Protection and Monitoring

- Ni Cold Spray has been demonstrated for SCC mitigation
  - CSAT 2012 Westinghouse
- Ni is magnetostricitve and can be used to produce an electromagnetic acoustic transducer
- Provides on-line monitoring capability for pre-existing cracks

Ni Cold Spray as a Base for Magnetostrictive EMAT-UT



Flow Assisted Corrosion

FAC Process

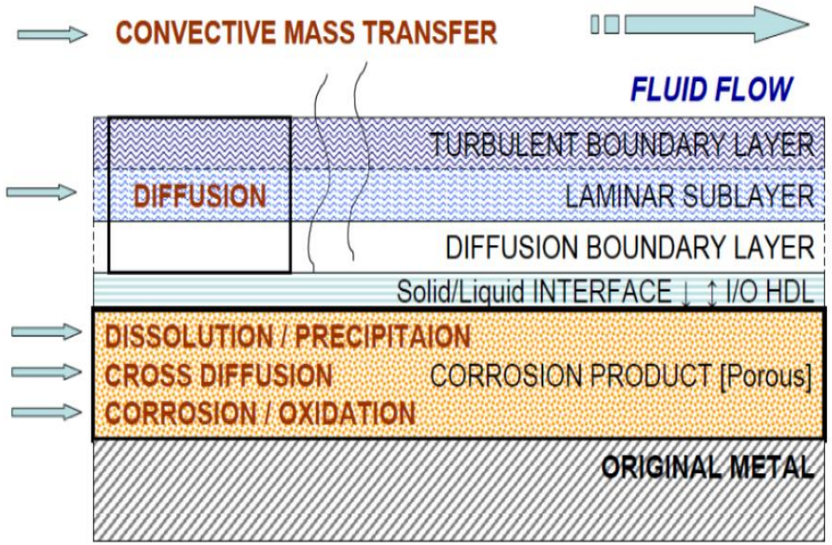


Figure 1. Schematic summary of key processes underlying the FAC phenomenon (Ref. 136, ©NACE).

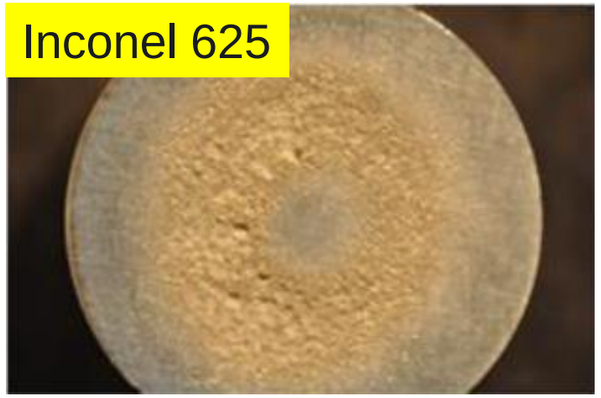
Y. S. Garud, Issues and Advances in Flow Assisted Corrosion, ANS Conference, 2009, Paper #203160

Actual Elbow Failure

Press release, Kansai Electric, 2010

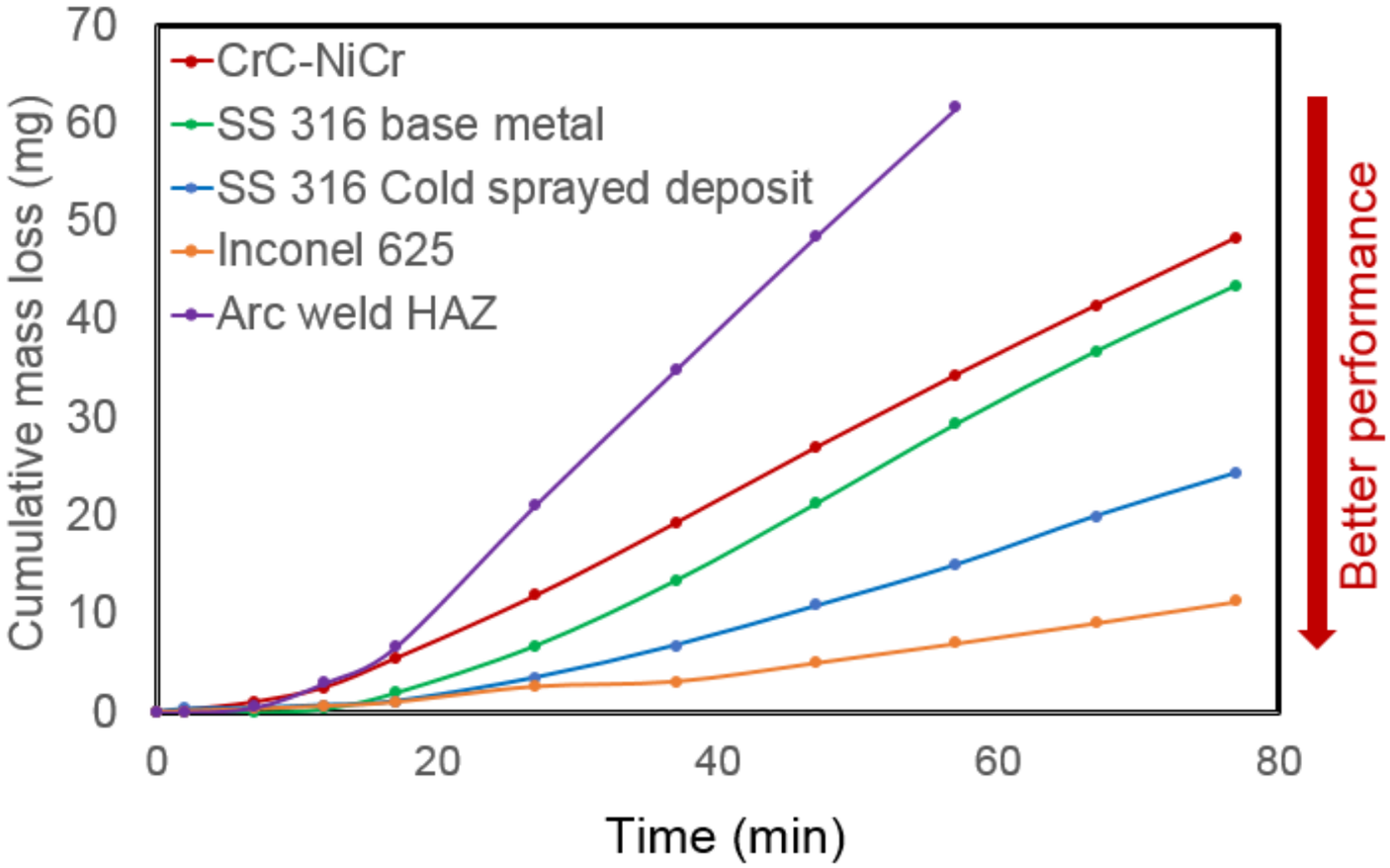
Cavitation Erosion Metal Loss Samples

- ASTM 134-1 Cavitation Results
- CW from top left: CrC-NiCr, wrought SS 316 Base Metal , SS 316, Inc 625



PNNL internal experimental results

ASTM 134-1 Cavitation Results



PNNL internal experimental results

Flow Assisted Corrosion

- Cold Spray Coating on inconnel 625 or SS 316 would prevent FAC
  - Eliminates magnetite dissolution
  - Survives turbulent flow
  - During elbow fabrication would be best approach
  - Arc Weld repairs actually would accelerate failures

Nuclear Applications for Cold Spray

QUESTIONS ??