

Introduction to aging and degradation

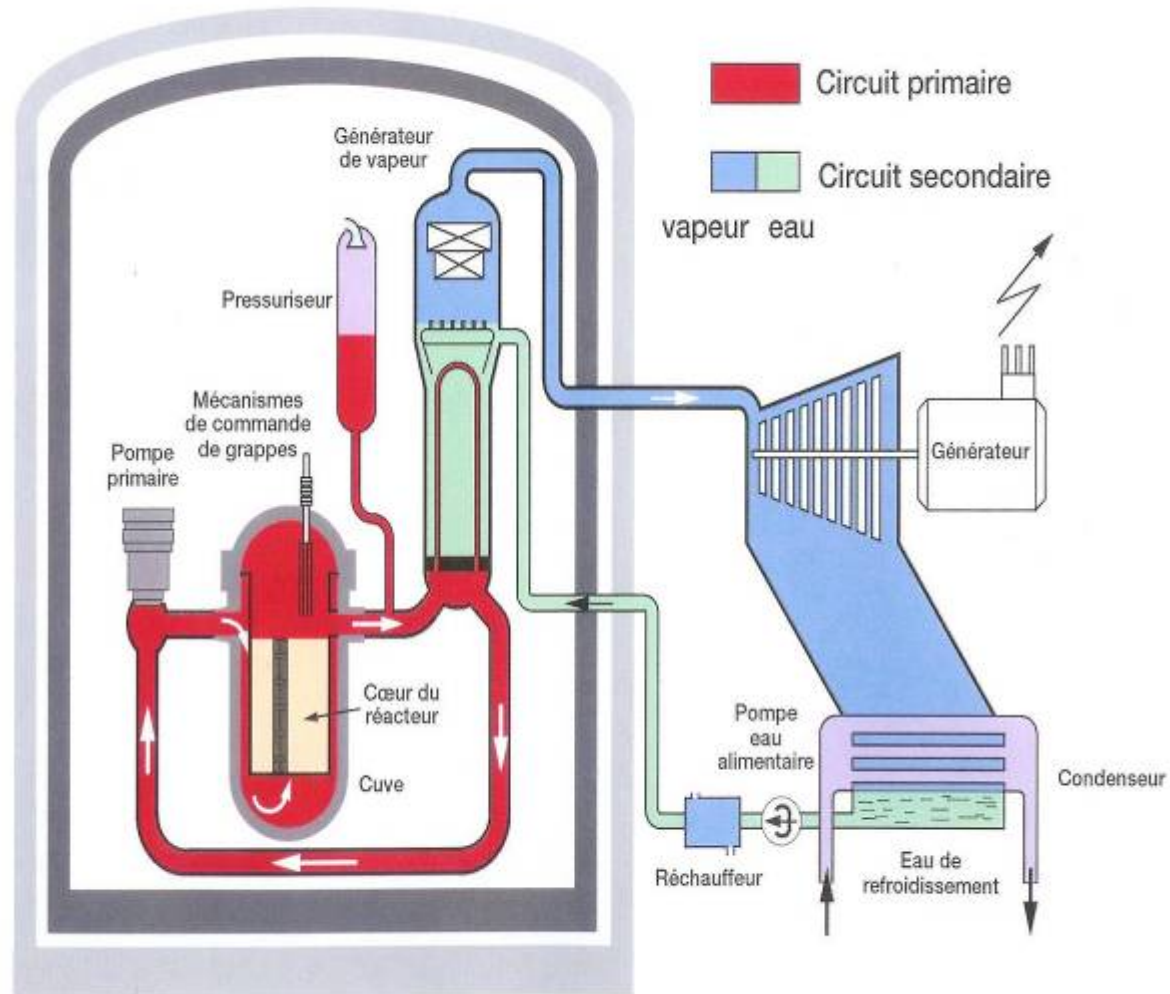
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December 9, 2008

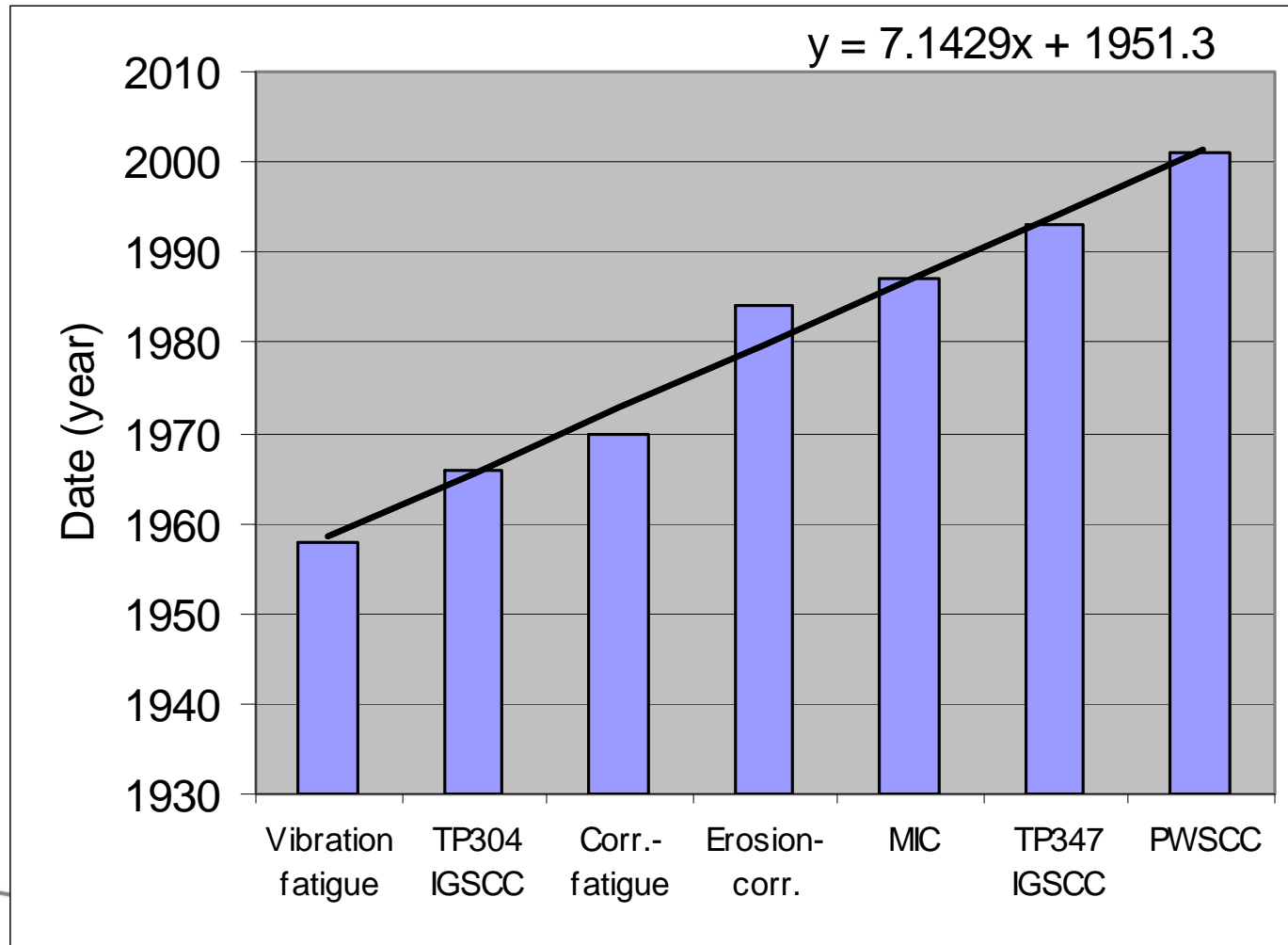
OUTLINE

- ▶ Degradation
- ▶ Materials & water chemistry
- ▶ Aging Issues
- ▶ Possible PWR R&D issues (open corrosion topics)
- ▶ PMMD

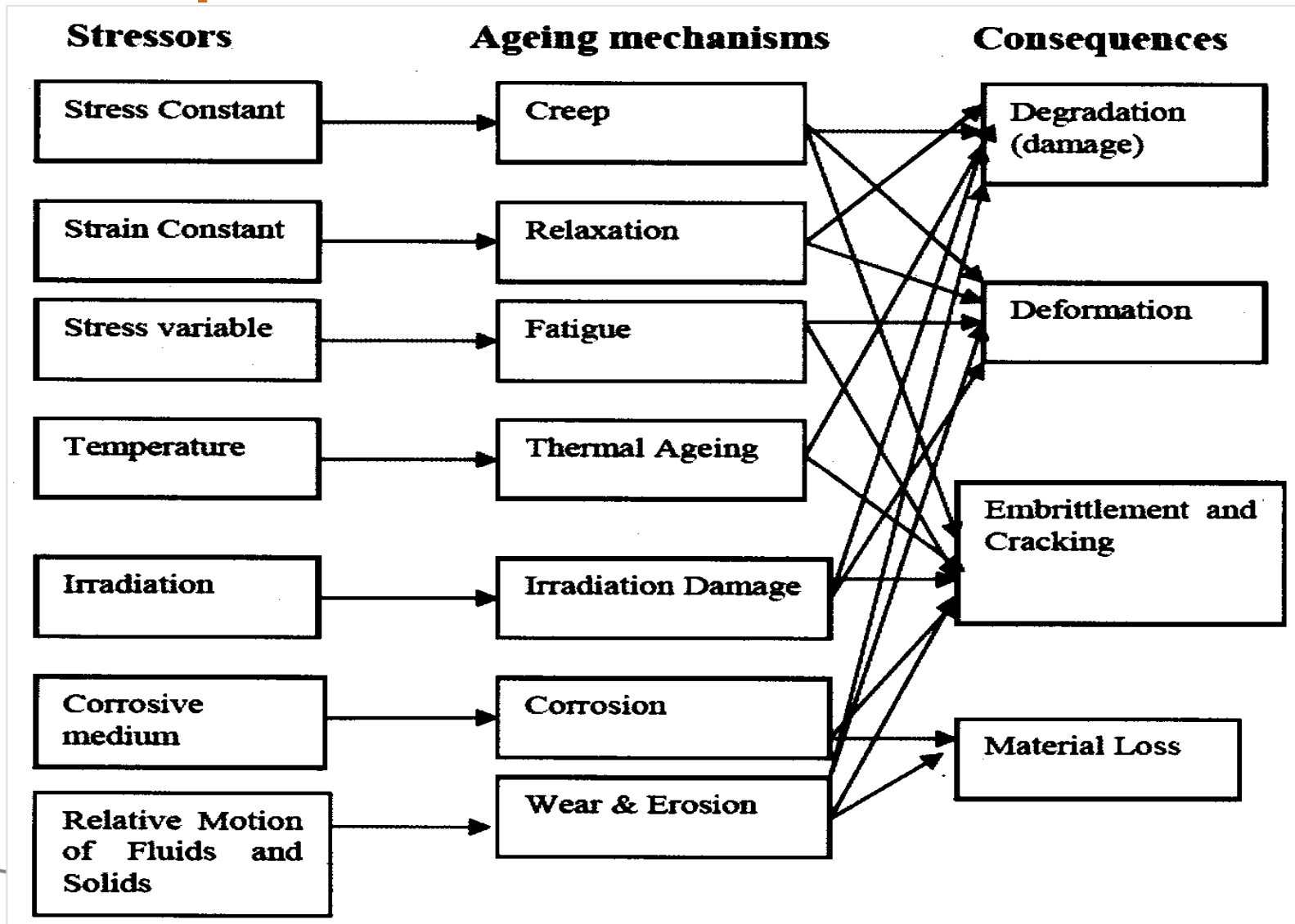
Schematic for a PWR



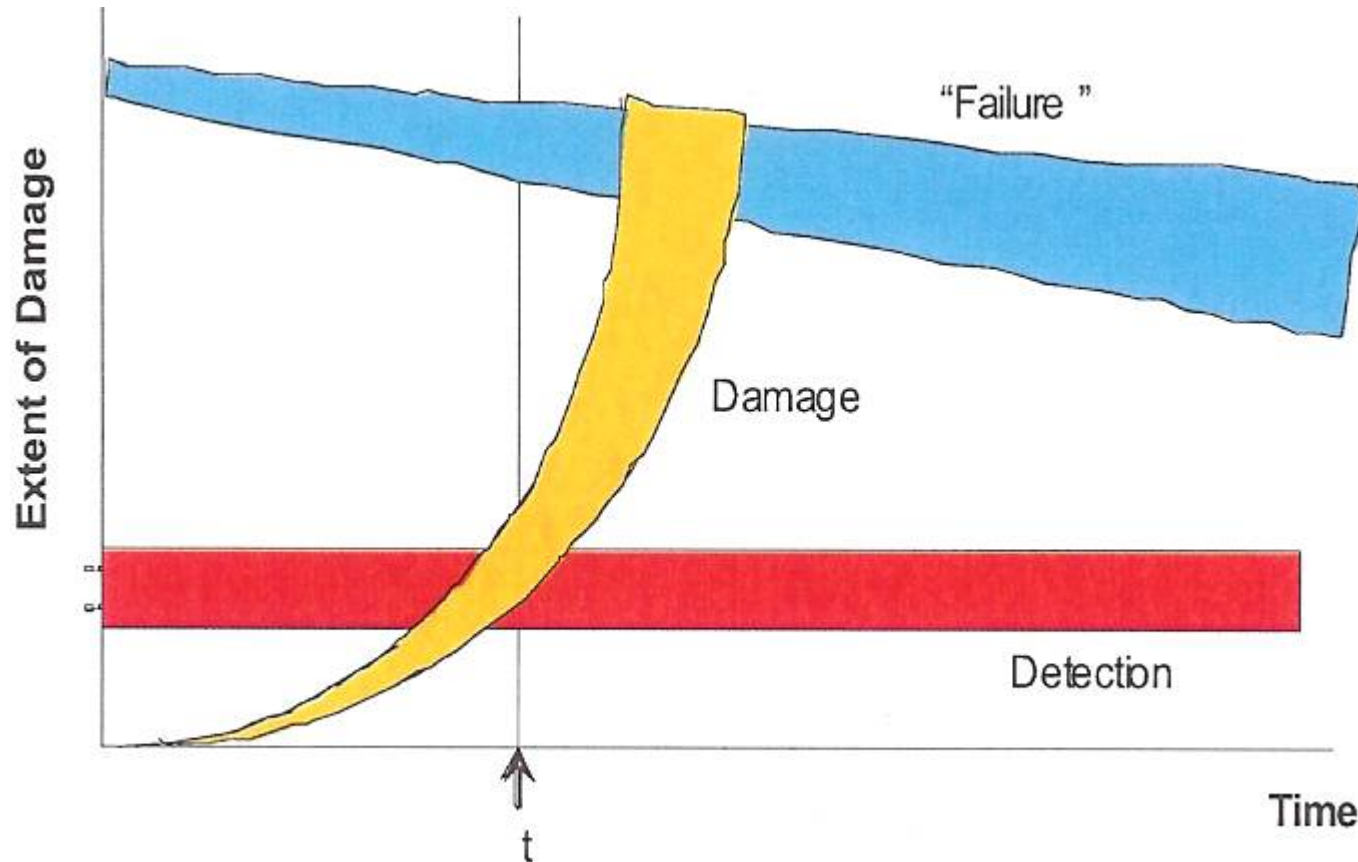
Degradation Processes Found in U.S. Nuclear Power Plants (Wilkowski 2002)



Aging factors, mechanisms and possible consequences

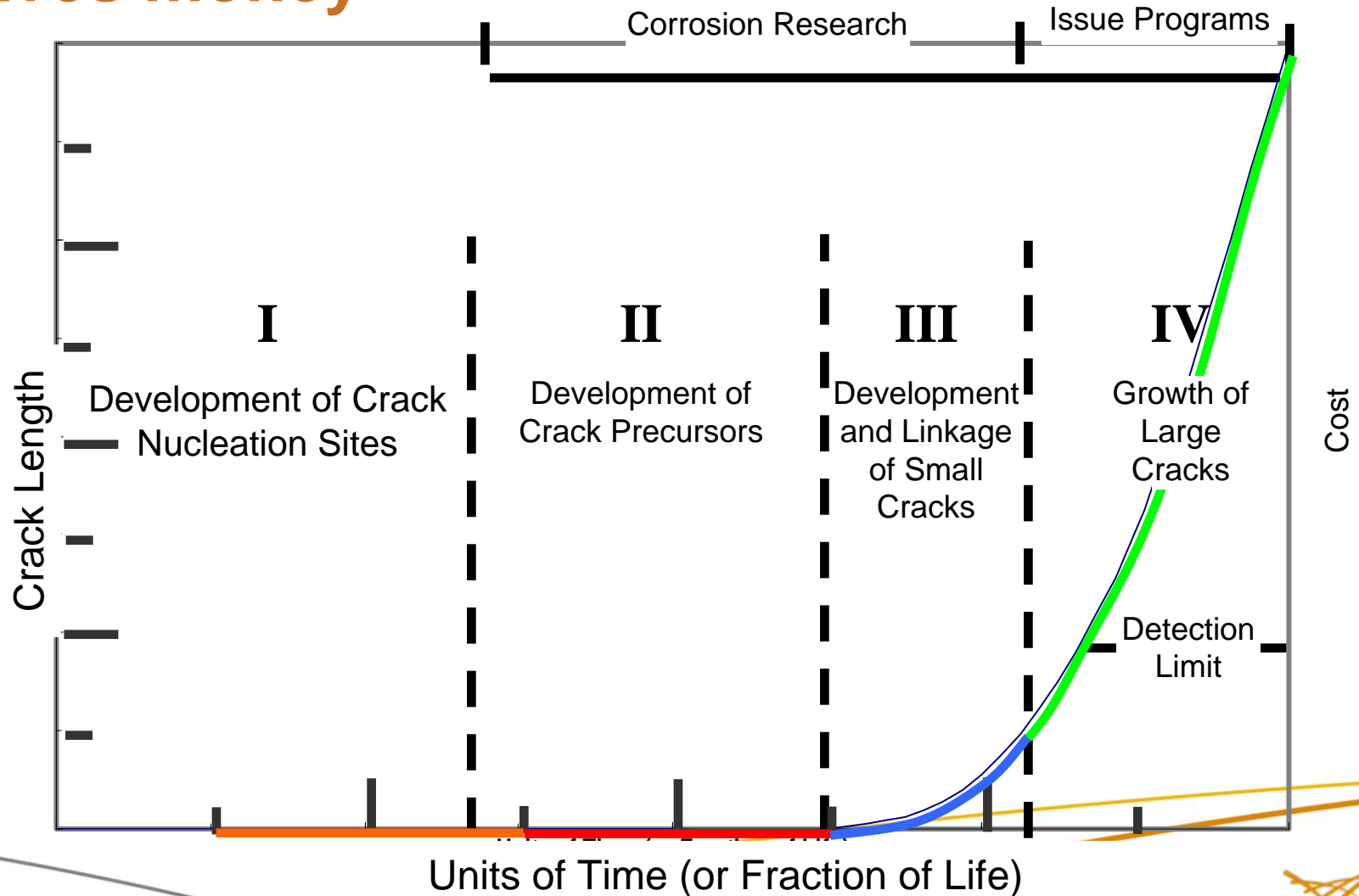


Damage as a function of time – relationship to detection and failure



After NUREG/CR 6923

Phases in degradation - early intervention saves money



Degradation comes in many forms

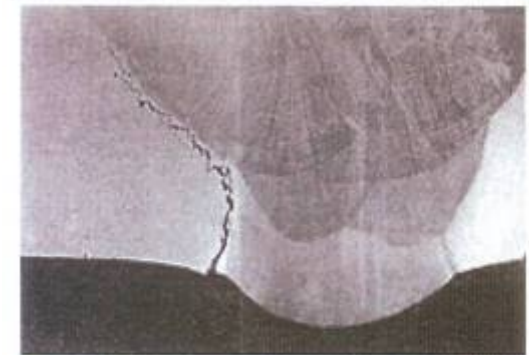


Materials and water chemistry

- Austenitic stainless steels
- High strength stainless steels
- Nickel-base alloys
- Carbon and low alloy steels
- Copper and titanium alloys
- PWR primary water:
 - H_2 , LiOH, H_3BO_3 , $O_2 < 10$ ppb, sometimes 5-10 ppb Zn^{++}
 - 284 – 345°C
 - pH=6.8 – 7.4 at 300°C
- PWR secondary water:
 - NH_3 , N_2H_4 , ETA, morpholine, $O_2 < 3$ ppb
 - 270 – 293°C in the SGs (excluding superheated crevices)
 - pH=9.2 – 10.0 at 25°C
- BWR water:
 - NWC $O_2 \sim 100$ -400 ppb
 - HWC NobleChem™, $H_2 \sim 0.02$ - 0.1ppb
 - 274 – 288°C
 - pH~5.65 at 300°C

Aging Issues

- Primary circuit materials corrosion
- Secondary circuit materials corrosion
- Balance of plant corrosion
- External surface corrosion
- Thermal aging
- Irradiation effects on core internals
- Irradiation embrittlement of RPV steels
- Fatigue and corrosion fatigue



Phenomena that enhance general corrosion

- Flow assisted corrosion (FAC) due high flow rates – does not concern stainless alloys
- Erosion-corrosion due to abrasive particles in the fluid (also steam cutting)
- Cavitation provoked by implosion of steam bubbles
- Galvanic corrosion due to electrical contact between different metallic materials that leads to accelerated degradation of the less noble material and cathodic protection (of variable effectiveness) of the other –not usually significant in deoxygenated and especially hydrogenated environments or water with very low conductivity
- Boric acid corrosion due to concentration of PWR primary water leaks
- Microbial Corrosion

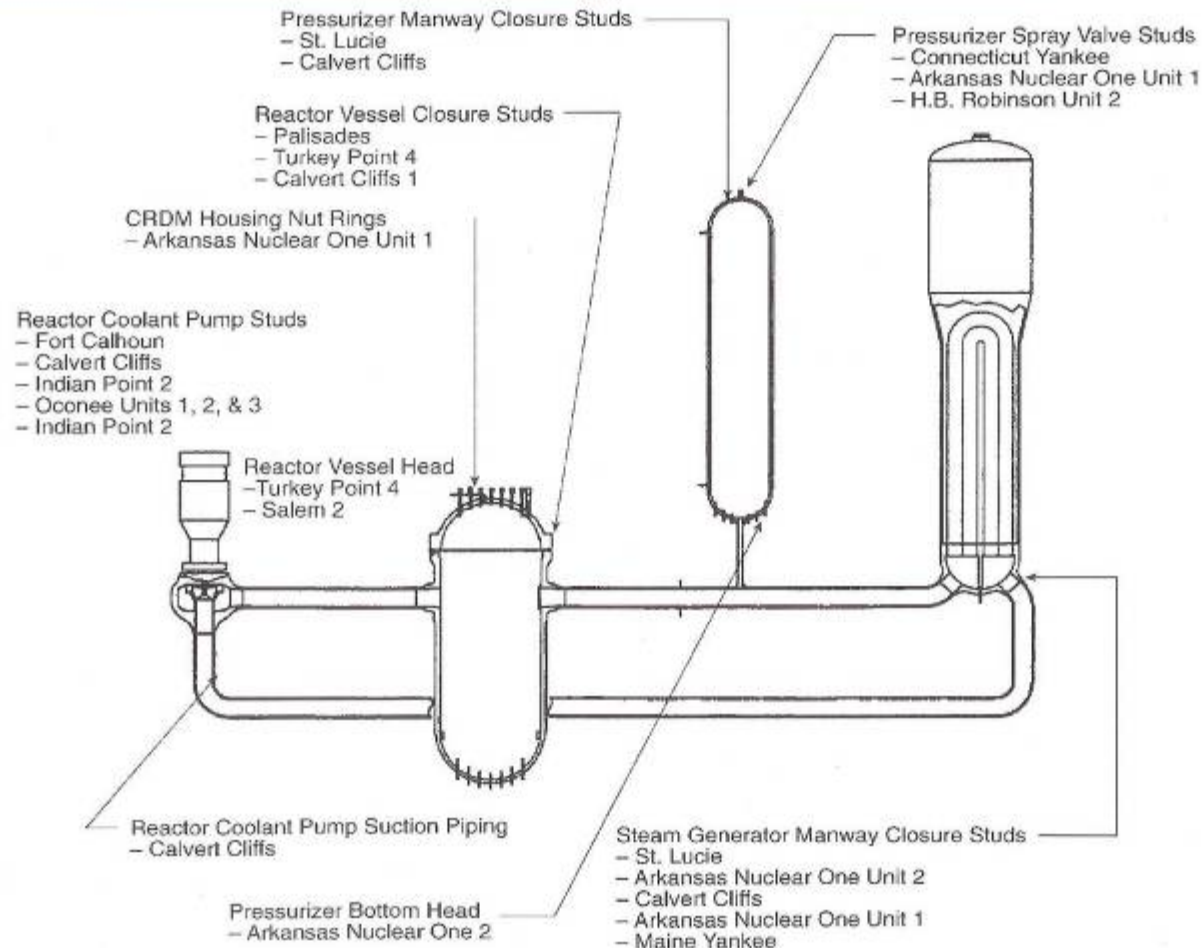
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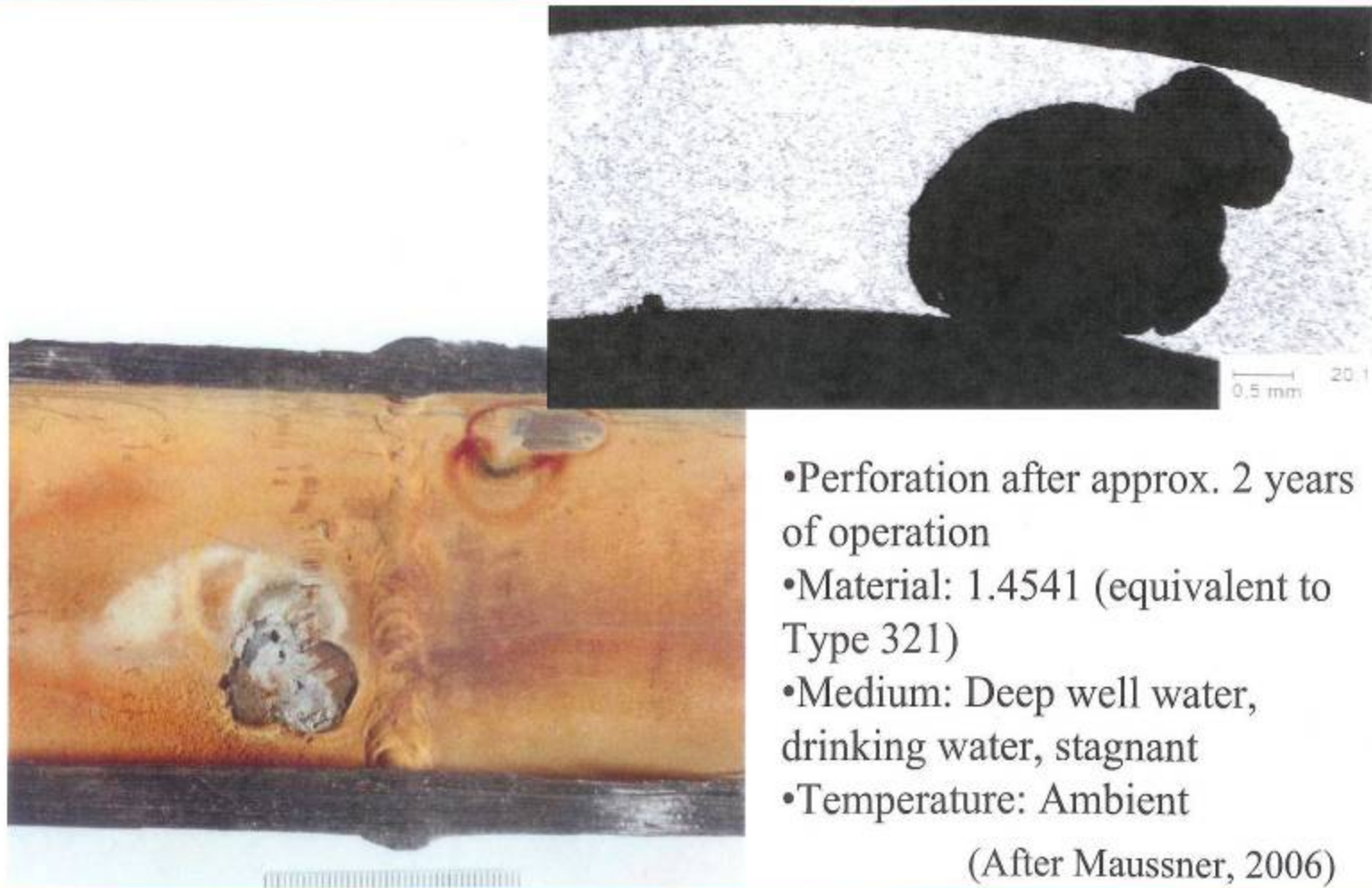
Aging effects on selected steel alloys

APPLICABLE AGING EFFECTS	CARBON STEEL	LOW-ALLOY STEEL	GALVANIZED STEEL	STAINLESS STEEL
Loss of Material				
General Corrosion	Y	Y	N-protected atmosphere/weather Y-exposed atmosphere/weather	N
Galvanic Corrosion	N	N	N	N
Crevice Corrosion	N	N	N	N
Pitting Corrosion	N	N	N	N
Erosion and Erosion Corrosion	NA	NA	NA	NA
Microbiologically Induced Corrosion	N	N	N	N
Wear	N	N	N	N
Cracking				
Hydrogen Damage	N	N	N	N
Stress Corrosion	N	N	N	N
Fatigue	N	N	N	N
Mechanical Distortion				
Creep	N	N	N	N
Fatigue	N	N	N	N
Change in Material Properties				
Elevated temperatures	N	N	N	N
Irradiation Embrittlement	N*	N*	N*	N*
Intermetallic Embrittlement	NA	NA	N-provided temperature < 400 °F	NA
Key: Y- aging mechanism is applicable . N- aging mechanism is not applicable NA- Not Applicable to this chapter *- Outside Primary Shield Wall.				

Locations in US PWR Primary Systems where Boric Acid Corrosion has been Observed



Example of MIC in a FFW-line *



- Perforation after approx. 2 years of operation
- Material: 1.4541 (equivalent to Type 321)
- Medium: Deep well water, drinking water, stagnant
- Temperature: Ambient

(After Maussner, 2006)

*FFW – firefighting water

PWR – possible R&D Topics (Compiled by Peter Scott – 2008)

PWR Generic R&D Topics (1)

- General corrosion, localized corrosion and corrosion product release
 - Oxide composition, structure, ion transport properties, modelling oxidation and cation release from first principles, changes of metal substrate composition below the oxide film
 - Flow assisted corrosion, reliability of current predictive models
 - Fouling, modelling of flow effects
 - Boric acid corrosion, leak modelling
 - Compendium of good practice for protecting tertiary cooling systems from internal and external corrosion, microbiological corrosion
 - Steel corrosion in contact with concrete, crevice effects
-

PWR – possible R&D Topics (Compiled by Peter Scott – 2008)

PWR Generic R&D Topics (2)

Stress corrosion cracking:

- Initiation of SCC in austenitic alloys, stochastic features, heat to heat variability
- Crack growth mechanisms, narrow crack tips, load/unload & ripple loading, dK/da effects, crack coalescence
- Weld metals, hot cracks, HAZs and dilution zones, residual stresses and their measurement, strain localization
- Water chemistry, pH_2 , Zn, water chemistry transients, particularly oxygen
- Effects of long exposure periods (definition of initial condition and precursors), plant upgrades
- Effects of cold work and deformation path, CW and compositional banding
- Pb SCC and scaling of Alloy 690, reduced S SCC of Alloy 690
- External surface SCC due to surface chloride contamination, effect of modern SS compositions, influence of choice of thermal insulation
- Creep, hydrogen effects, strain aging and impurity effects on SICC of LAS & C steels

More topics....

PWR Generic R&D Topics (3)

Effects of irradiation on stainless steel core support structures:

- IASCC initiation criteria as a function of dose, stress, time and dynamic loading
- Neutron spectrum effects, high neutron doses, late blooming phases, transmutation gas products/bubbles
- Swelling & irradiation creep, non-destructive detection of degradation

More topics....

PWR Generic R&D Topics (4)

Fracture resistance

- Effects of environment including LTCP
- Irradiation embrittlement, high fluence, large forgings, predictive models
- Thermal embrittlement of LAS at pressurizer temperatures, predictive models
- Thermal embrittlement of CASS and weld metals and possible degradation of SCC resistance, non destructive detection of embrittlement
- Hot cracking, causes, discriminating hot cracks from SCC
- Properties of weld dilution and heat affected zones, residual stresses and their measurement, strain localisation
- Strain aging of LAS and carbon steels



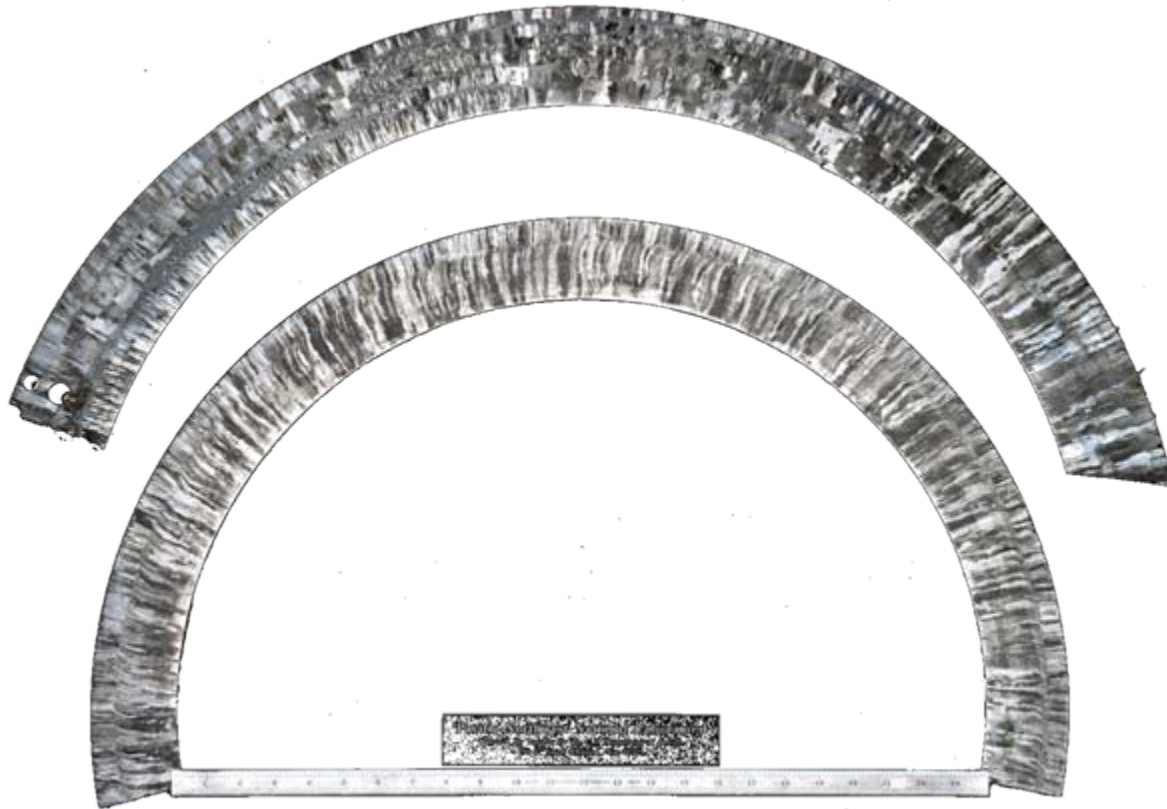
PWR Generic R&D Topics (5)

Thermal fatigue crack initiation and propagation in austenitic stainless steels

- Surface condition, environmental effects, transient waveform effects

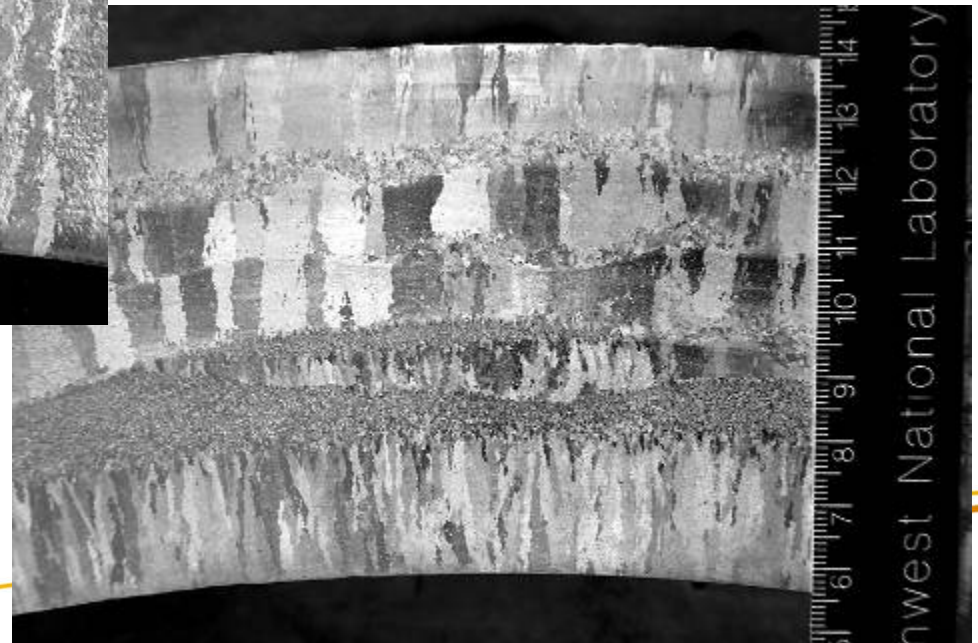
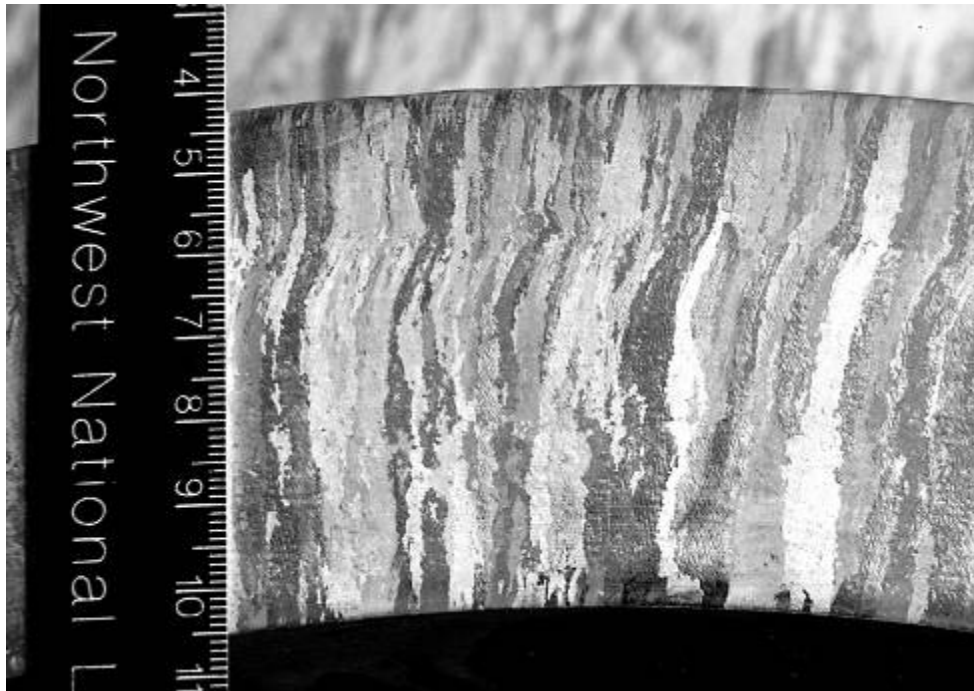
Vibration fatigue – small amplitude very high cycle fatigue

Performance Demonstration Vintage Cast Stainless Steel



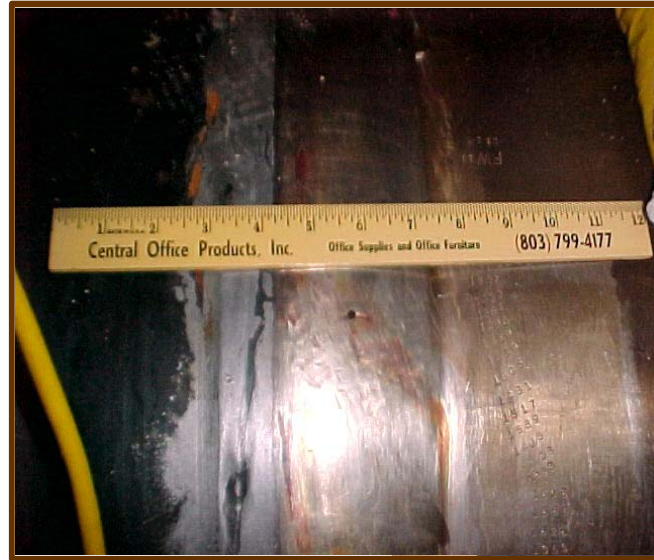
- ▶ All supplements in ASME B&PC Code **Appendix VIII** are implemented except for **Supplement 9** on **centrifugally cast austenitic stainless steel piping welds**

Performance Demonstration Vintage Cast Stainless Steel



Impetus for Proactive Management of Materials Degradation

- Develop information
 - Materials behavior
 - Mitigation or repair
 - Inspection or monitoring
- Proactively address potential future degradation
 - Avoid failures
 - Maintain integrity and safety
- Increase cooperation
 - Prioritize PMMD research with industry
 - Pursue additional international collaborations
- Evaluate existing requirements
 - Integrity of susceptible components
 - Inspection and monitoring regulations



Avoid Surprises e.g. V.C. Summer And Davis Besse



Acknowledgement

- ▶ Parts of the work presented in this talk were supported through the US Nuclear Regulatory Commissions – Proactive Management of Materials Degradation (PMMD) program