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NRC Research PMDM Meeting
Charleston, SC; May 11, 2006

Status of U.S. Industry Initiative on Anticipating and Managing Materials Degradation in Light Water Reactors

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Introduction

- In May 2003, the U.S. Chief Nuclear Officers unanimously approved the “Industry Initiative on Management of Materials Issues” and the associated “Guideline for the Management of Materials Issues”, NEI 03-08.

- One of the requirements of NEI 03-08, which became effective January 2, 2004, is the preparation and annual updating of a strategic plan that identifies the U.S. nuclear industry’s high priority materials degradation issues.

- Rev. 0 of the “Integrated Materials Issues Strategic Plan”, which was issued in March 2004, identifies PWSCC of Alloy 600/82/182 as the “single biggest challenge facing the PWR industry”.

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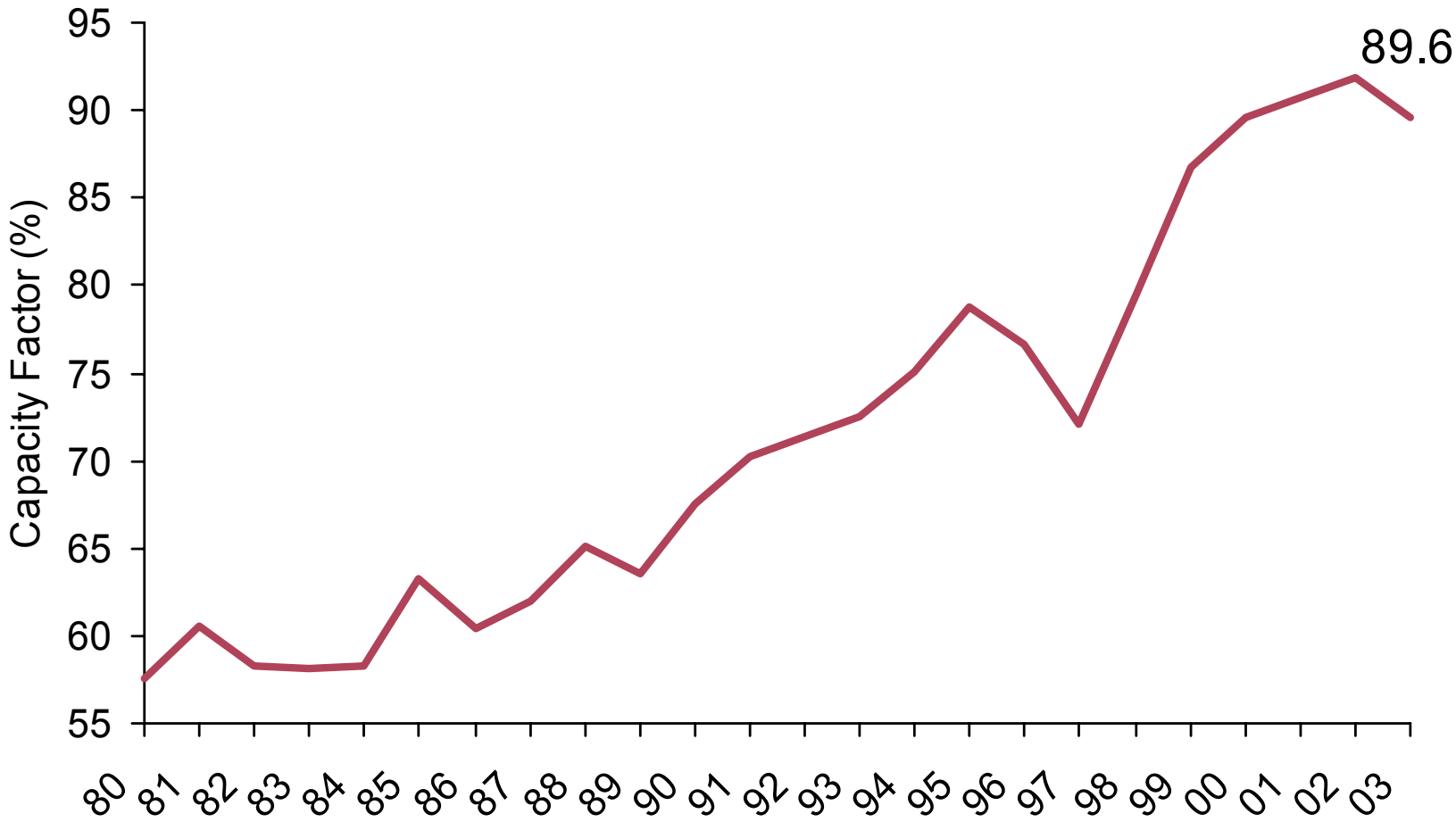
U.S. Nuclear Industry Is Achieving Record Levels of Performance



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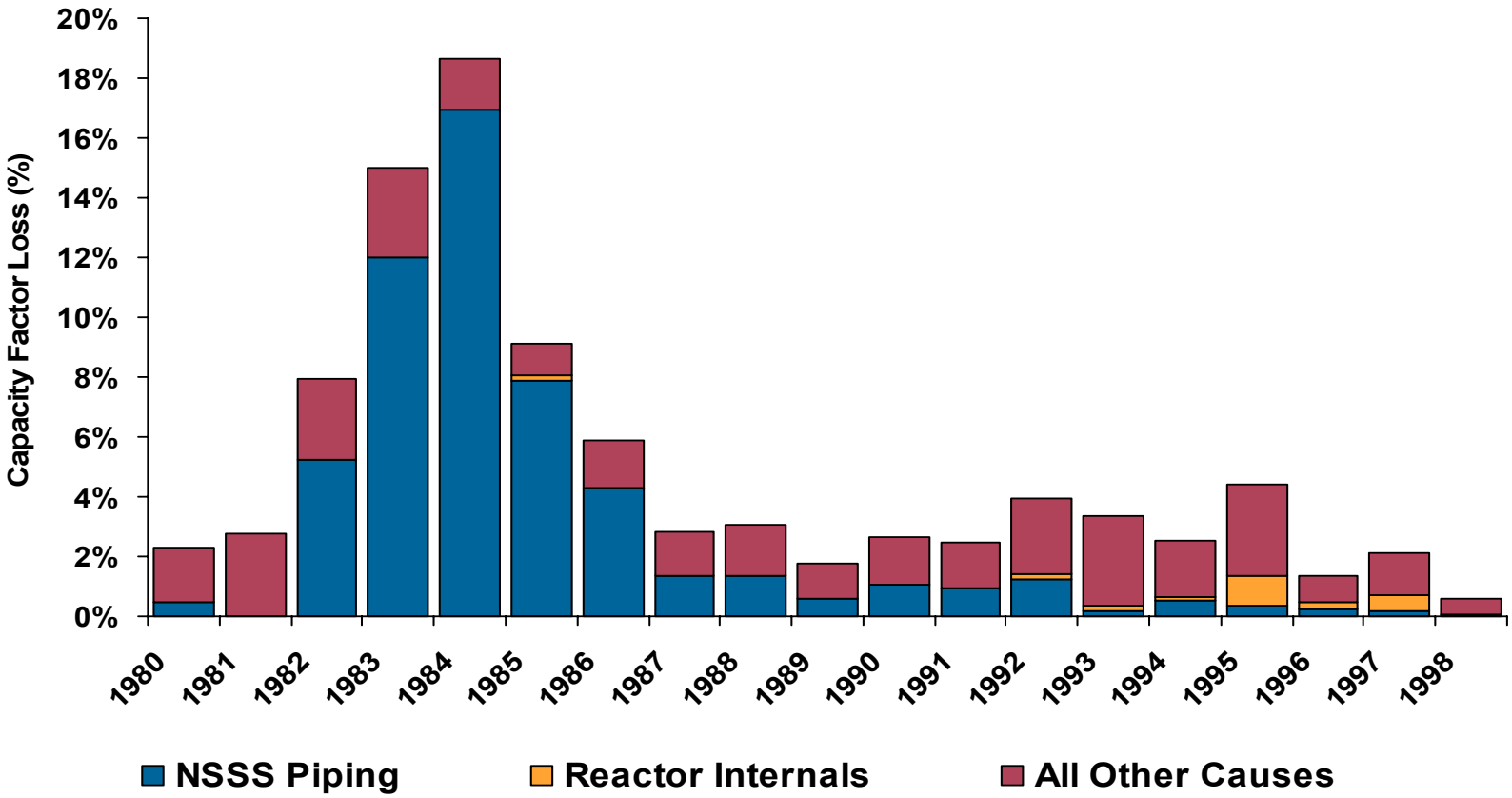
Corrosion-Related Capacity Factor Losses in BWRs



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PWSCC Experience Outside of SG

1980s

- Leak - pressurizer instrument nozzle
- Leak - pressurizer heater sleeve
- Leak - two steam generator drain nozzles
- Leaks - 20 pressurizer heater sleeves
- Fail - steam generator tube plug
- Leaks - pressurizer instrument nozzles (non-US)

1990s

- Leak - control rod drive mechanism nozzle (non-US)
- Leak – replaced pressurizer instrument nozzle (original nozzle involved)
- Cracks - two hot leg piping instrument nozzles
- DE of Leaking CRDM nozzle - indications near the top of the J-groove weld (included OD circ crack and cracks in weld)
- Leak - circ crack pressurizer relief valve nozzle safe end.
- 7 mm deep crack - CRDM nozzle

2000s

- Shallow ID cracks - hot leg nozzle butt welds (non-US).
- Leak - reactor vessel hot leg nozzle pipe butt weld
- Leaks - CRDM nozzle and five thermocouple nozzles
- Through-wall circ crack - in CRDM nozzle above the J-groove weld
- Leaks - two CRDM nozzles - significant boric acid wastage of the reactor vessel top- head surface.
- Several CRDM nozzle leaks – after full inspection, most of the welds had cracks with many requiring repair.
- Leaks - Two bottom mounted instrument (BMI) nozzles
- Circ through-wall cracks five pressurizer heater sleeves
- Cracks – CRDM Nozzle weld
- Leaks and Cracks – pressurizer relief nozzle and safety nozzles
- Crack – surge line butt weld
- Cracks – hot leg drain line butt weld and cold leg drain line butt weld

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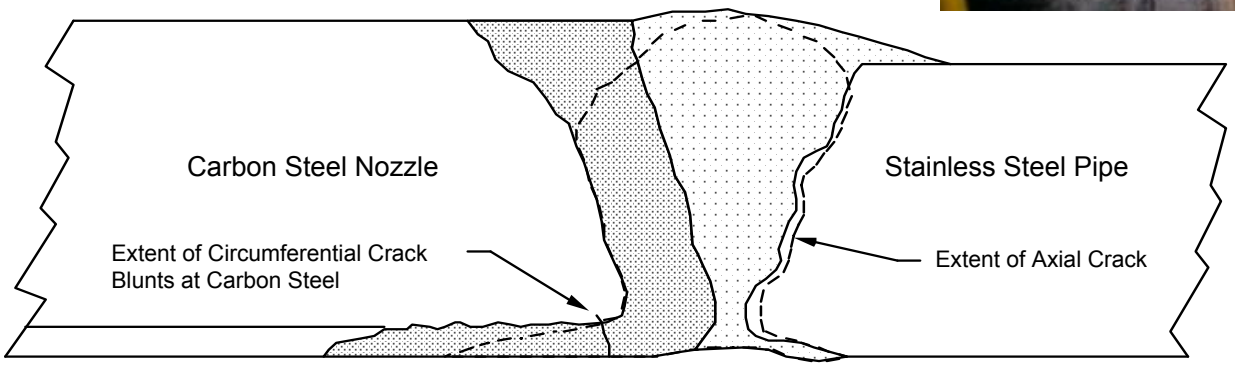
V. C. Summer

- **Fall 2000, Discovered Crack**
  - A Hot Leg Nozzle to Pipe Weld (Alloys 182 and 82)



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Oconee 1

- November 2000, Discovered Leaking Alloy 600 Penetration

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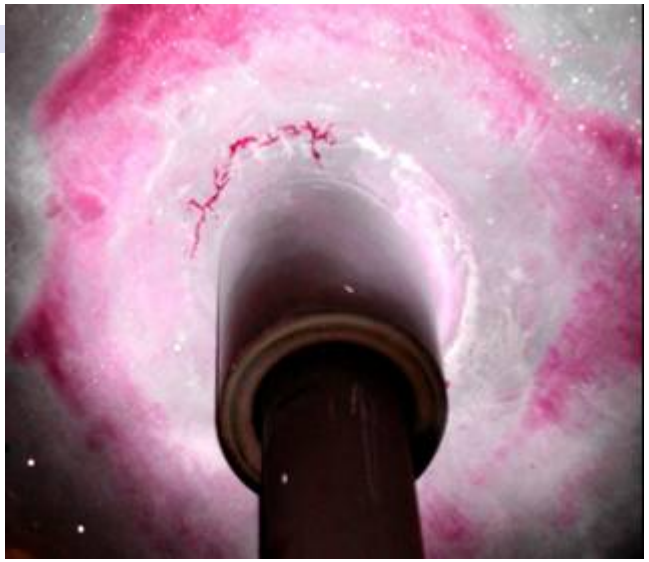
RPVH Penetrations, Davis-Besse, Replacement Head, BMI's



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Statements from a 2004 Nuclear Energy Institute (NEI) presentation to U.S. utility management

Issue

Primary system materials will degrade at your plant

The problem can be characterized as:

- What is going to crack next?
- Where will it occur?
- When?
- Can you live with it throughout station life?

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Statements from a 2004 Nuclear Energy Institute (NEI) presentation to U.S. utility management

Background

- Working groups formed in response to NEI Executive Committee recommendations – Aug 02
  - Overall goal – be more forward-looking and integrated
  - Charter
    - Assess materials issue programs to identify strengths and weaknesses
    - Report findings and recommendations to NSIAC
  - Scope
    - PWR primary and SG secondary, BWR RPV and primary pressure boundary components, materials issues related to nuclear fuels, and related NDE and chemistry/corrosion control programs

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Statements from a 2004 Nuclear Energy Institute (NEI) presentation to U.S. utility management

Materials Initiative

- Policy Statement
  - "… the industry will ensure that its management of materials degradation and aging is ***forward-looking and coordinated*** to the maximum extent practical. Additionally, the industry will ***continue*** to rapidly identify, react and ***effectively respond to emerging issues***. The associated work will be managed to emphasize safety and operational risk significance as the first priority, appropriately balancing long term aging management and cost as additional considerations. To that end, as issues are identified and as work is planned, the groups involved in funding, managing and providing program oversight will ensure that the ***safety and operational risk significance of each issue is fully established prior to final disposition***."

Strategic plan took effect on 2nd January 2004

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Statements from a 2004 Nuclear Energy Institute (NEI) presentation to U.S. utility management

Strategic Plan

- High-level industry 'roadmap' that identifies the highest priority materials challenges and the work that is necessary to meet those challenges
  - This year uses Issue Program existing work plans
  - Includes initial "Degradation Matrix" and the "Issue Management Table"
  - Focus on RCS components and materials
  - Will be issued to the industry by March 31st
- Issue Management Table will become the basis for the Strategic Plan in the future
- Issue Program work plans will adopt strategic plan approach in future

"Issue Programs" include EPRI (BWRVIP, MRP, SGMP, FRP, CR, Chemistry, NDE) and Plant Owners Group Subcommittees

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Statements from a 2004 Nuclear Energy Institute (NEI) presentation to U.S. utility management

- Key issues
  - Nickel based alloy SCC
  - NDE technology
  - High fluence issues in BWRs and PWRs
  - SG tubing
  - Nuclear fuel integrity
  - Water chemistry
  - Effect of power uprate on materials reliability

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Statements from a 2004 Nuclear Energy Institute (NEI) presentation to U.S. utility management

Materials Metrics

- Performance metrics for industry
  - Unexpected materials related NRC generic correspondence
  - New materials degradation morphologies
  - Lost capacity or unplanned/extended outages due to materials issues
  - INPO materials program related AFIs
  - Corrective action program effectiveness
  - Proactive, safety focused materials management culture

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Statements from a 2004 Nuclear Energy Institute (NEI) presentation to U.S. utility management

- Performance metrics for IPs
  - Number of materials issues closed
  - Utilization of materials related products
  - Timely delivery of materials products
  - Completed internal reviews
  - IP budget performance
  - Industry participation in materials IPs

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Materials Degradation Matrix (MDM) - created 2004 at EPRI with expert participation

- Identify materials used for major passive components/systems within Materials Initiative Scope
- Obtain inputs from experts, laboratory R&D, industry OE
  - Identify potential degradation mechanisms
  - Determine material applicability
  - Define areas of uncertainty
- Identify and characterize issues that pose potential threats
  - Adequately addressed, programs managing issues
  - Work in progress that will develop tools to manage issues
  - No program to address, insufficient work in progress to address vulnerability

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Materials Degradation Matrix (MDM)

Level 1

PWR						BWR		
PWR Reactor Pressure Vessel	PWR Pressurizer	PWR SG Shell	PWR Reactor Internals	PWR Piping	PWR SG Tubes & Internals	BWR Pressure Vessel	BWR Reactor Internals	BWR Piping

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Level 2

PWR Component	Material	SCC SCC					Corrosion/Wear C & W				Fatigue Fat.			Reduction in Toughness RiT					
														Aging	*Irradiation*				
	[1]*Subdivision→*	IG	IA	TG	LTCP	PW	Wstg	Pit	Wear	FAC	HC	LC/Th	Env	Th	Emb	VS	SR	Th_n	Fl
PWR Pressurizer (Including Shell, Surge and Spray Nozzles, Heater Sleeves and Sheaths, Instrument Penetrations)	Co																		
	Co W																		
	Wr																		
	SS W C																		
	Wr Ni																		
	Ni W C																		

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PWR Pressurizer (Including Shell, Surge and Spray Nozzles, Heater Sleeves and Sheaths, Instrument Penetrations)	C&LAS	? e002	N	? e002	N	? e003	Y e004	N	N	Y e005	N	Y e006	Y e007	Y e008	N/A	N/A	N/A	N/A	N/A
	C&LAS Welds	? e002	N	? e002	N	? e003	Y e004	N	N	Y e005	N	Y e006	Y e007	Y e008	N/A	N/A	N/A	N/A	N/A
	Wrought SS	? e012	N	? e012	? e013	? e012	N	N	N	N	N	Y e014	Y e015	N	N/A	N/A	N/A	N/A	N/A
	SS Welds & Clad	Y e016	? e017	Y e018	? e013	? e019	N	N	? e020	N	N	? e014	Y e015	Y e022	N/A	N/A	N/A	N/A	N/A
	Wrought Ni Alloys	N	N	N	? e023	Y e023	N	N	N	N	Y e014	Y e014	Y e015	N	N/A	N/A	N/A	N/A	N/A
	Ni-base Welds & Clad	N	? e024	N	Y e023	Y e025	N	N	N	N	N	Y e014	Y e015	N	N/A	N/A	N/A	N/A	N/A

Level 3

e030	Corrosion-assisted fatigue is a known phenomenon on secondary side (e.g., in the vicinity of girth welds in steam generator shells and in the region of feedwater nozzles) and is not like environmental fatigue described in other areas of this DM. Environmental fatigue research relevant to this specific phenomenon is not ongoing within MRP Fatigue ITG, and is a potential gap.

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Materials Degradation Matrix (MDM)

Level 1

PWR						BWR		
PWR Reactor Pressure Vessel	PWR Pressurizer	PWR SG Shell	PWR Reactor Internals	PWR Piping	PWR SG Tubes & Internals	BWR Pressure Vessel	BWR Reactor Internals	BWR Piping

Level 2

PWR Component	Material	SCC SCC					Corrosion/Wear C & W				Fatigue Fat.			Reduction in Toughness RiT					
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PWR Pressurizer (Including Shell, Surge and Spray Nozzles, Heater Sleeves and Sheaths, Instrument Penetrations)	C&LAS	? e002	N	? e002	N	? e003	Y e004	N	N	Y e005	N	Y e006	Y e007	Y e008	N/A	N/A	N/A	N/A	N/A
	C&LAS Welds	? e002	N	? e002	N	? e003	Y e004	N	N	Y e005	N	Y e006	Y e007	Y e008	N/A	N/A	N/A	N/A	N/A
	Wrought SS	? e012	N	? e012	? e013	? e012	N	N	N	N	N	Y e014	Y e015	N	N/A	N/A	N/A	N/A	N/A
	SS Welds & Clad	Y e016	? e017	Y e018	? e013	? e019	N	N	? e020	N	N	? e014	Y e015	Y e022	N/A	N/A	N/A	N/A	N/A
	Wrought Ni Alloys	N	N	N	? e023	Y e023	N	N	N	N	Y e014	Y e014	Y e015	N	N/A	N/A	N/A	N/A	N/A
	Ni-base Welds & Clad	N	? e024	N	Y e023	Y e025	N	N	N	N	N	Y e014	Y e015	N	N/A	N/A	N/A	N/A	N/A

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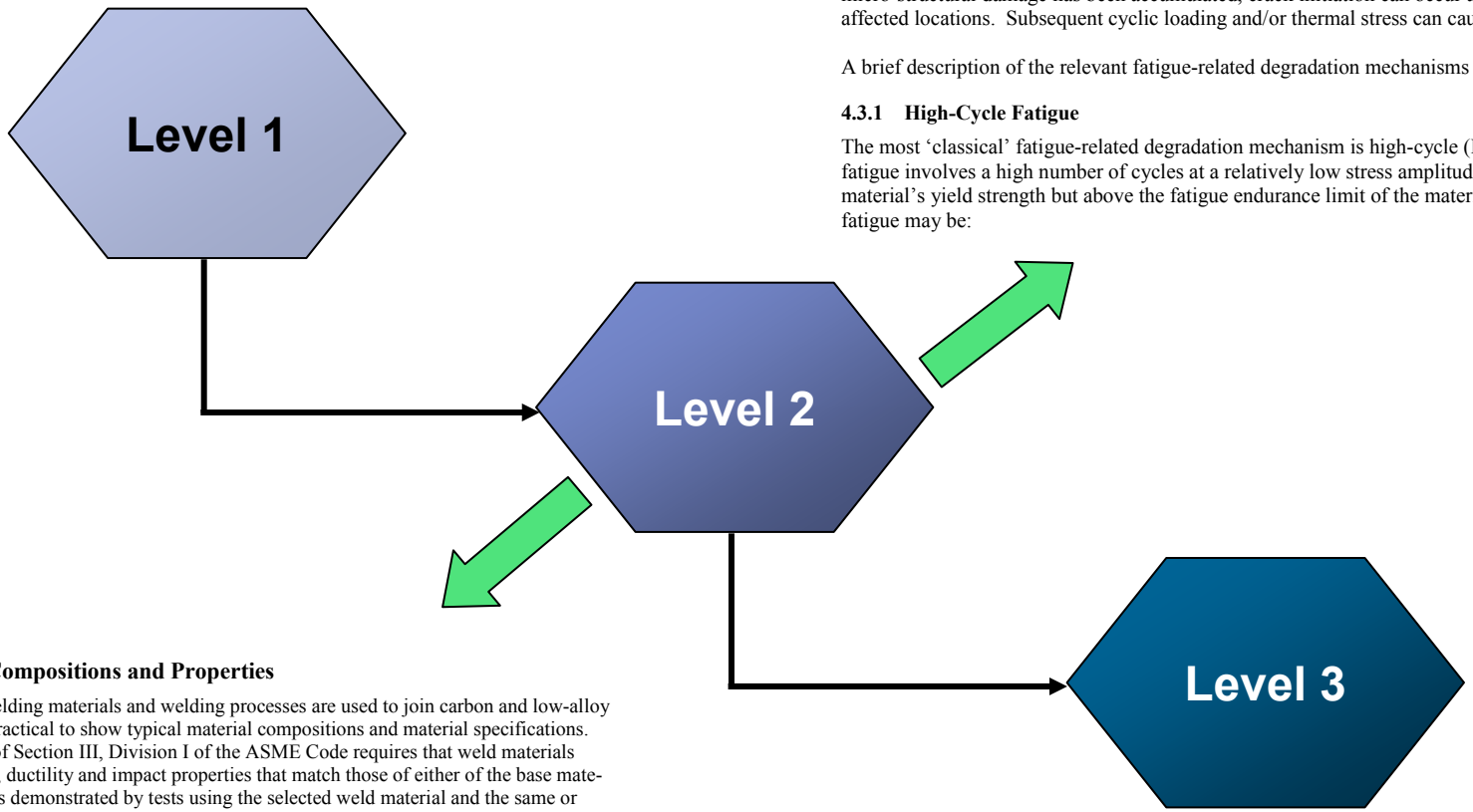
Materials Degradation Matrix (MDM)



3.2 Material Compositions and Properties

A large variety of welding materials and welding processes are used to join carbon and low-alloy steels, and it is not practical to show typical material compositions and material specifications. Section NB-2431.1 of Section III, Division I of the ASME Code requires that weld materials have tensile strength, ductility and impact properties that match those of either of the base materials being welded, as demonstrated by tests using the selected weld material and the same or similar base materials. Section NB-2432.2 of Section III, Division I of the ASME Code requires that the chemical composition of the welding material be in accordance with an appropriate ASME Code welding specification (in Section II.C of the Code), but leaves the choice of the specific material up to the manufacturer.

The most common weld processes used to join carbon steel and LAS parts include submerged arc welding, shielded metal arc welding (SMAW), and gas tungsten arc welding (GTAW). Post-weld heat treatment is generally required per ASME Code rules after welding of the carbon and low-alloy steels used for reactor coolant system service.

4.3 Fatigue Degradation Mechanisms and Mitigation Options

Fatigue is the structural deterioration that can occur as the result of repeated stress/strain cycles caused by fluctuating loads or temperatures. After repeated cyclic loading, if sufficient localized micro-structural damage has been accumulated, crack initiation can occur at the most highly affected locations. Subsequent cyclic loading and/or thermal stress can cause crack growth.

A brief description of the relevant fatigue-related degradation mechanisms is provided below.

4.3.1 High-Cycle Fatigue

The most 'classical' fatigue-related degradation mechanism is high-cycle (HC) fatigue. HC fatigue involves a high number of cycles at a relatively low stress amplitude (typically below the material's yield strength but above the fatigue endurance limit of the material). High cycle fatigue may be:

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Materials Degradation Matrix (MDM): How is the final product being used?

- Starting point for the “bottom-up” approach being developed in the BWR and PWR Issue Management Tables (see next slide)
- Key input to updating the annual Materials Workplan within the Strategic Initiative
- Aid to planning and prioritizing new research (e.g. within the EPRI Corrosion Research and Chemistry programs)
- Provided to the NRC to demonstrate more proactive approach now being adopted by the industry and to compare with the component-level PDMA/PIRT analysis they are undertaking
- Used as a “teaching aid” in industry workshops
- Has been incorporated into a “Materials Management Toolkit” developed by NEI for use at individual utility/plant level

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Materials Initiative – Issue Management Table (IMT) Process

- Identify component and component function
- Identify material(s) of construction
- Identify degradation mechanism(s)
  - May be a different mechanism for different location/material of a component
  - Likelihood or predominance of a mechanism should be considered and ranked (e.g. IGSCC may overwhelm fatigue)
- Identify locations that can fail
- Identify consequences of failure, including system responses to help prioritize location/component importance
- Identify inspection capabilities and history – what can be done and is it effective to deal with the degradation of concern

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IMT Process (cont.)

- Identify evaluation capabilities – what is known about environmental effects on crack growth and initiation etc.
- Identify mitigation options/technologies. This would include things such as chemical (e.g. zinc, NMCA), mechanical (e.g. MSIP), or system operation changes (e.g. BWR feedwater flow controller)
- Identify repair or replacement options, capabilities and limitations
- Based on the information above, identify knowledge gaps/needs
- Prioritize the work to resolve gaps and identify who will do what pieces of the work to eliminate the gap

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Example IMT for BWRs

Equipment	Material	Failure Mechanism	Consequences of Failure	Mitigation	Repair / Replace	I & E Guidance	Gaps	Priority & Basis	Responsible Program(s)
BWR Recirculation piping	SS (lc and hc), Inconel welds	SCC, fatigue	Leakage, forced outage	Yes, chemical and stress improvement	Yes, replace pipe or weld overlay	Yes, BWRVIP-75		Low – solution available	BWRVIP, WCC
BWR Vessel	Cs/las, ss clad, welds	IGSCC, IASCC, TGSCC, FIV, Th & Env Fatigue, Emb, Th aging, Fluence	LOCA – loss of asset	Yes – HWC, NMCA	Yes – nozzle repair	Yes – covers embrittlement and weld degradation		Low – solution available	BWRVIP
BWR Internals	Ss, cass, cs, welds, Inc	IASCC, IGSCC, FIV, Wear, EF, Emb, Fluence – R&D needed	Core configuration	Yes – some, work needed	Yes – shroud and top-guide, costly – work needed	Yes (interim) – 13 BWRVIP I&E Guidelines – work needed		High – existing and potential unresolve d issues	BWRVIP, WCC, FRP, Corrosion Research

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Industry Materials Initiative - MDM and IMT Status / Future Work

- MDM Rev. 0 is complete and was distributed (via NEI) to the NRC and to industry in November 2004
- IMTs nearly complete – will be finalized Summer 2006
- Materials Degradation Matrix and Issue Management Tables to be maintained as living documents (first revision of MDM will be carried out 2006/2007)
- Materials Information Management Portal (MIP) being created to
  - Establish a unified access tool to key information on materials behavior in nuclear systems for users at all levels
  - Enable materials experts to comment on and suggest modifications to content in a simple and intuitive manner
  - Capture progress of ongoing industry efforts to tackle LWR materials degradation in a proactive manner

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Future prospects for taking a more proactive approach to LWR materials degradation in U.S.

- U.S. industry and NRC efforts to date have proceeded independently, although some experts were common to both MDM and PIRT projects
- The industry materials initiative has received solid support at the highest utility management levels and has already resulted in increased funding for proactive research
- EPRI continues to broaden and coordinate activities so as to achieve maximum benefit from the momentum generated
- EPRI also has a long tradition of cooperation with NRC Research via a Memorandum of Understanding and this continues to function well
- However, the U.S. industry is not supportive of the current PMDM approach (see NEI letter of 02/28/06 to Dr. Paperiello)
- Prefers instead to continue to identify and collaborate on opportunities for research on materials degradation with the NRC under the existing arrangements

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