ELECTRIC POWER RESEARCH INSTITUTE

MDM and IMT Update for 2010

Robin Dyle - EPRI

Industry NRC Technical Exchange Meeting

May 25-26, 2010

Integrated Materials Issues Strategic Plan

- Provides Systematic Approach to Managing Materials Issues
  - Identify vulnerabilities
  - Assess condition (inspect & evaluate)
  - Mitigate degradation initiation and propagation mechanism
  - Repair or replace as required
- Approach Used:
  - Degradation Matrix and Issue Management Tables
    - Degradation Matrix and Issues Management Tables to be maintained as living documents

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MDM Background

- A comprehensive listing of likely degradation mechanisms for LWR primary system components
- Assesses the extent to which applicable degradation mechanisms are understood.
- The state of industry knowledge worldwide associated with mitigation of applicable degradation mechanisms.
- MDM results are used as direct inputs into BWR IMTs and PWR IMTs. MDM is based on an expert elicitation process.
- The initial version of MDM was developed in 2004. The 1st MDM revision was published in 2008.

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Benefits

- ✓ Key materials initiative document and a foundation for issue management tables (IMTs).
- ✓ Most effective way to identify the current and future materials degradation issues, and degradation mechanisms for applicable materials
- ✓ Establish technical basis to determine R&D direction and allocate resource in the most efficient way.
- ✓ Proactive management on emerging degradation issues, for extended operation life beyond 60 years.
- ✓ A collection of information obtained from materials experts, laboratory R&D, and operating experience.

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Example: MDM Rev-1 Results for PWR Internals

Table 3-2
PWR Reactor Vessel Internals Component Level Results

MATERIAL	DEGRADATION MODE												
	SCC		Corrosion & Wear				Fatigue		Reduction in Frac. Resistance		Irradiation Effects		
	IG/TG	IA	Wstg.	Pitting	Wear	FAC	HC	LC-Env.	Th.	Env.	Emb.	VS	SR
C&LAS p2-1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
C&LAS: Welds p2-1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SS: Wrought / Forged / HAZ	Y p2-2	Y p2-3	N	N	Y p2-5	N	Y p2-7	Y p2-8	N	? p2-10	Y p2-11	Y p2-12	Y p2-13
SS: Welds & Clad	Y p2-2	Y p2-4	N	N	Y p2-6	N	Y p2-7	Y p2-8	Y p2-9	? p2-10	Y p2-11	Y p2-12	Y p2-13
CASS	Y p2-14	Y p2-15	N	N	Y p2-6	N	Y p2-7	Y p2-8	Y p2-16	? p2-10	Y p2-17	N/A p2-18	N/A p2-18
Ni-Alloy: Wrought	Y p2-19	N/A	N	N	Y p2-20	N	Y p2-7	Y p2-8	N	Y p2-10	N/A p2-21	N/A p2-21	N/A p2-21
Ni-Alloy: Welds & Clad p2-1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

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Example: MDM Rev-1 Results for BWR Internals

Table 4-2
BWR Reactor Vessel Internals Component Level Results

MATERIAL	DEGRADATION MODE												
	SCC		Corrosion & Wear				Fatigue		Reduction in Frac. Resistance		Irradiation Effects		
	IG/TG	IA	Wstg.	Pitting	Wear	FAC	HC	LC-Env.	Th.	Env.	Emb.	VS	SR
C&LAS b2-1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
C&LAS: Welds b2-1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SS: Wrought / Forged / HAZ	Y b2-2	Y b2-3	N	N	Y b2-4	N	Y b2-5	Y b2-6	N	? b2-8	Y b2-3	N	Y b2-9
SS: Welds & Clad	Y b2-2	Y b2-3	N	N	Y b2-4	N	Y b2-5	Y b2-6	Y b2-7	? b2-8	Y b2-3	N	Y b2-9
CASS	Y b2-19	Y b2-10	N	N	N	N	N/A	N/A	Y b2-11	? b2-8	Y b2-12	N/A	N/A
Ni-Alloy: Wrought	Y b2-13	Y b2-14	N	N	N	N	Y b2-15	Y b2-6	N	Y b2-8	Y b2-14	N	Y b2-16
Ni-Alloy: Welds & Clad	Y b2-17	N/A	N	N	N	N	Y b2-18	Y b2-6	N	Y b2-8	Y b2-14	N/A	Y b2-9

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Example IMT – PWR

Table A-1
Issue Management Table: PWR Reactor Pressure Vessel

Component & ID No.	Material	Degradation Mechanism[1]	Conseq. of Failure	Mitigation[2]	Repair / Replace	I & E Guidance	Gaps
1.1 Upper Shell Assembly							
1.1-1 Upper Shell Flange (Vessel Flange)	C&LAS/ SS Clad *(SA-336 or A/SA-508, Cl 2 or 3)*	SCC: IG, IA, TG, LTCP, PW C&W: Wstg, Wear Fat: LC/Th, Env RiT: Th, Emb, Fl	A, B, E, F, G	Water Chemistry TR-105714, *Primary Water Chemistry*	ASME Sect. XI IWA-4000	Boric Acid Corrosion Control EPRI: 1000975, *BAC Handbook* Vendor: WCAP-15988-NP, *BAC Prog.* NRC: GL 88-05 LC / Env. Fatigue Management EPRI: MRP-148, *Fatigue Mgmnt.* MRP-149, *Lic. Basis Mon.* MRP-47, *Fatigue Env. Effects* NRC: GALL X.M1, *Fatigue Mon.* NUREGs 6260 & 6583 ASME Code Sect. XI IWB-2500-1: *B-A (Vol)–R.G.1.150* *B-P (VT-2)*	DM-01 DM-02 AS-02 AS-27

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Example Gap Description – PWR

Table 3-2
Degradation Mechanism Understanding Gaps

R&D Gap Description	Applicable Components
DM-01 - Environmentally Assisted Cracking: LAS Develop an improved understanding regarding the potential for environmentally assisted cracking of clad LAS materials (IGSCC, TGSCC, PWSCC) in the primary water environment. Some of the concern is related to cracking of LAS materials exposed to the CANDU reactor heavy water environment, but to date there have been no documented instances of environmentally assisted cracking of any domestic PWR. Currently, there is wide scatter in the laboratory data for stress corrosion crack propagation in low alloy steels, likely due to differences in the experiment assumptions and structure. Basis: MDM: e002, e003 EPRI: TR-103160 (BWR Environment), NP-7473-L, TR-102796, TR-102692	RESULTS DATA: Priority: LOW Resp. Program: To be determined per NEI 03-08 Summary Level Applicability: RPV Pressurizer SG Shell ASME Class 1 Ppg., Vlvs., Fittings

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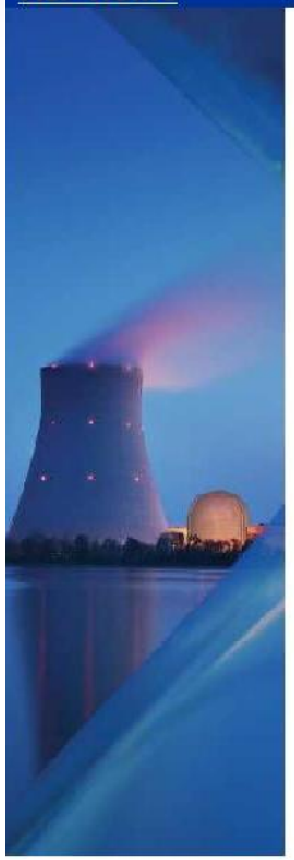

EPRI Materials Information Portal

ENTER

The EPRI Materials Information Portal (MIP) is an online collection of EPRI materials initiative related information and presently includes the EPRI Materials Degradation Matrix (MDM), Issue Management Tables (IMTs), and the Materials Handbook. The EPRI MIP is an EPRI materials tool provided to the authorized EPRI members only. However, the public can view the following key components in MIP:

- Materials Degradation Matrix (MDM)
- PWR Issue Management Tables (PWRIMT)
- BWR Issue Management Tables (BWRIMT)

For additional information, please contact Tiangan Lian at (650) 855-2405.

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MDM Revision 1 Strategic Issues

- Environmental Effects on Fracture Resistance
- *Environmental Effects on Fatigue Life*
- SCC of Ni-Base Alloys
- SCC of Stainless Steels
- Effect of Fluence on SCC Susceptibility and SCC Crack Growth Rates

NRC PMDA reached the same conclusions

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2010 Materials Degradation Matrix (MDM) Status

- 2010 MDM panel meeting held in Feb at EPRI's Palo Alto offices
- Focus Included:
  - Long-Term Operations - "LTO"
    Defined as operation through a 2nd 20-year license renewal term (80-years)
  - Recent research program results
- Major LTO issues identified include:
  - Increased EOL Neutron Fluence
    (*RPV integrity, high fluence effects on austenitic stainless steels, expanded regions of neutron effects*)
  - Increased Fatigue Cycles (*with focus on environmental effects*)
  - Late-Life SCC Initiation and Stress Improvement Technique Stability
  - Steam Generator Fouling / Corrosion / Long-Term Management
- Major "Non-LTO" issues include:
  - Effect of environment on fracture properties
  - SCC initiation factors (*cold work, welding effects, PWR system oxygen ingress*)
- Assessment of implementation concerns in the IMTs is currently in progress

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2010 MDM Results Presentation [PROPOSED APPROACH]

- Final presentation look still being discussed
- R&D Results (cell background color)
  - Consideration of LTO generic would result in many Orange cell results
  - Would obscure progress toward near-term R&D objectives
  - Background colors continue to represent progress toward closure of near-term objectives
- Cell Tags Added
  - LTO tags used to indicate where one or more LTO related issues apply – and future work remains needed to resolve the LTO concern(s)
  - Implementation (IMP) tags added to identify areas where no strategic materials degradation issue exists, but there are some remaining issues from an implementation / application viewpoint

MATERIAL	IG/TG	IA
SS: Wrought / Forged	Y LTO b2-2	Y LTO b2-3
SS: Welds & Clad	Y LTO b2-2	Y LTO b2-3

Fatigue	
HC	LC-Env.
Y IMP b1-7	Y LTO b1-8
Y IMP b1-7	Y LTO b1-8

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Long-Term Operations Issues

- Neutron Fluence Effects
- Fatigue Usage and Environmental Effects
- Late Life SCC Vulnerability
- Long-Term Stress Stability
- Long-Term Steam Generator Asset Management

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Neutron Fluence Effects (1 of 3)

- Reactor Vessel Integrity
  - Late blooming “brittle” phases associated with Ni, Mn, and Si
  - “Expanded Beltline”
    (*upper shell plates, nozzle forgings, associated welds*)
  - Surveillance program implementation
    (*fleet-wide optimization of surveillance capsule materials and re-constitution of some materials*)
  - Accumulated effects of radiation hardening, thermal aging, and SCC (*potential for crack extension into vessel from clad or welded attachment cracking*)
  - U.S. NRC position on 80-year embrittlement monitoring is uncertain
    (*GALL Report addresses NRC expectations for 60-year operation only*)

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Neutron Fluence Effects (2 of 3)

- High Fluence Effects on Austenitic Stainless Steels
  - High fluence data (> 10^{23} n/cm^2)
  - Void swelling model uncertainties (*shifts in lower bound onset temperatures and peak swelling locations based on additional neutron fluence. Complex issue involving competing phenomena*)
  - Void swelling effects on lower bound fracture toughness values
  - Effect of increased irradiation enhanced stress relaxation on bolted connections requiring preload

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Neutron Fluence Effects (3 of 3)

- Expanded Region of Neutron Fluence Effects
  - Additional stainless steel component locations will exceed fluence thresholds for IASCC and irradiation embrittlement (*May affect FMECA screening results and MRP-227 inspection requirements*)
  - Irradiated materials data for welds (*Particularly important for designs using welded shrouds*)
  - Appearance of fluence effects for additional materials (*e.g. X-750 CRGT Support Pins - 80-year values could approach 3 dpa*)

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Fatigue Usage (1 of 2)

- Low-cycle fatigue and associated environmental factors primarily a license renewal implementation issue for 60-year operations.
- Additional accumulated fatigue cycles increase concerns for 80-year operation
- It is likely that CUF values < 1.0 cannot be demonstrated for 80-year operations using current calculation methods (*even when stress-based fatigue monitoring and advanced algorithms are employed*)
- Current approach inadequate
  - Based on laboratory testing of samples with simple geometries
  - Application of environmental factors based on bounding strain rate and chemistry conditions
  - Additional testing and development of improved calculation algorithms are needed

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Fatigue Usage (2 of 2)

- Fatigue environmental effects not comprehensively studied for reactor internals
  - Limited fatigue data for irradiated materials and fastener materials
  - Fatigue loading of reactor internals less likely to include low strain rates, but this area has not been comprehensively reviewed
  - New plant design is leading in this area
    - R.G. 1.207 requires consideration of environmental effects for all primary system components
    - Currently being applied only to new plant designs
- NRC expectations for 80-year implementation are uncertain
  - GALL Report requires 60-year license renewals to address fatigue environmental effects for only a select number of locations (as identified in NUREG-6260)
  - No guidance provided to address 80-year operation.

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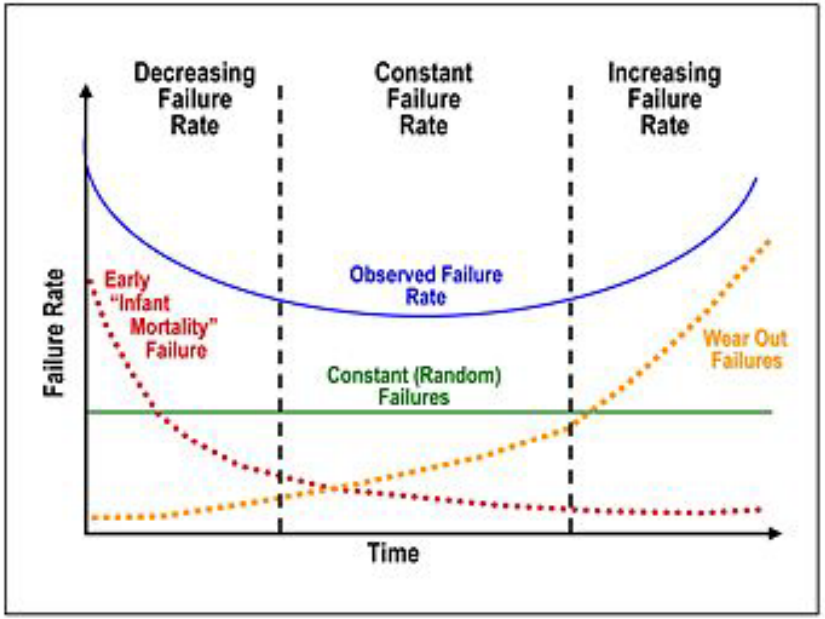
SCC at Long Exposure Times

- Cold worked layers considered important in SCC initiation for both BWRs and PWRs.
- Oxide formation / penetration in cold worked layers known to affect SCC in BWRs
- Longer times for grain boundary oxide formation / transitions could render less severely cold-worked material susceptible to SCC.
- Long term vulnerabilities could also occur in strained HAZ material.



"Bathtub" curve:

- Early life failures associated with aggravating conditions not anticipated by design
- Late life aging may be metallurgical in origin and/or due to slow accumulation of environmental condition

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Long Term Stress Stability

- Current stress improvement mitigation approaches include both bulk and surface stress improvement processes
  - Bulk processes include MSIP, IHSI, and optimized weld overlay
  - Surface processes currently focused on peening
- LTO concerns primarily focused on surface techniques
  - Thermal / stress cycles associated with LTO may result in shakedown of the thin compressive stress layer
- Candidate technologies developed without the context of 80-year operations

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Long-Term Steam Generator Management

- Improved tube materials potentially shift limiting factors for service life.
  - Early generation steam generator service lives controlled by tube cracking concerns (e.g. mill annealed Alloy 600 tubing)
  - Replacement SGs may need to operate for up to 60 years AND Alloy 690 tubing may perform well enough to support LTO.
- SG shell and internals are known to be susceptible to FAC (*Especially in regions of higher velocity/turbulence and/or two phase flow*)
- Chemical Cleaning is needed to ensure SG flow patterns are maintained
  - Fouling and flow blockage occurs preferentially on outer diameter tubes and eventually results in flow-induced tube damage.
- Additional chemical cleanings needed to remove fouling and to address LTO.
- This combination of effects represents an LTO concern.

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