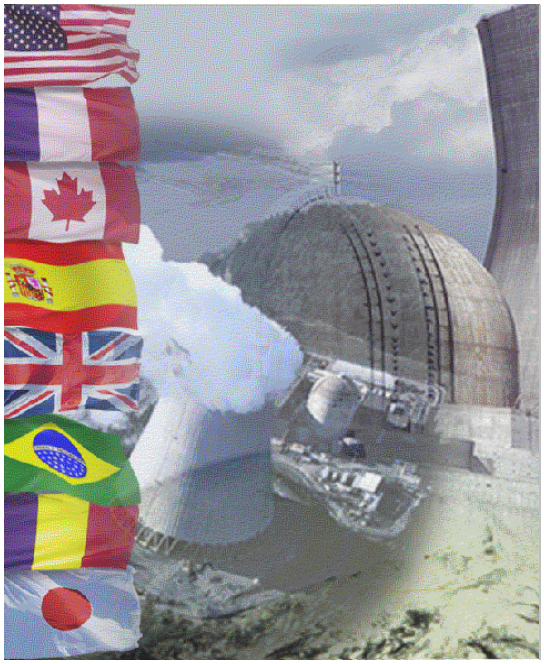

Defining Materials Degradation Issues and Approaches for Resolution

Robin Jones, EPRI
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January 17, 2005

EPRI

Overview

- 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 is the preparation and annual updating of a strategic plan that identifies the U.S. nuclear industry’s high priority materials degradation issues.

- To aid in development of the strategic plan, an expert elicitation process has been used to develop a Materials Degradation Matrix information that then feeds an assessment process using Issue Management Tables to identify gaps and develop plans for resolution from a strategic perspective.

- The Degradation Matrix and the Issue Management Tables will be updated to reflect knowledge gained and problems identified, and will be used to adjust the strategic plan in the future..

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Materials Initiative

- Approved by NSIAC in May 2003

- Initiative
  - Each licensee will endorse, support and meet the intent of NEI 03-08
  - The Initiative provides for:
    - Consistent management processes
    - **Prioritization of materials issues**
    - **Proactive, integrated and coordinated approaches**
  - Assure the safe, reliable and efficient operation of U.S. nuclear power plants in the management of materials issues

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Materials Initiative

- Policy Statement
  - Through the activities described in the following sections, 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***.

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Materials Initiative Issue Programs (IPs)

- Programs/Areas Governed by Materials Initiative
  - BWRVIP
  - MRP
  - SGMP
  - FRP
  - Non-Destructive Examination Program and Performance Demonstration Initiative (NDE, PDI)
  - Chemistry and Corrosion Research Programs
  - NSSS Owners Groups Programs for Materials Management

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How Much Are These IPs Spending on Resolving Materials Issues?

	2004 Budget ($K)	2005 Budget ($K)
BWRVIP	7000	9000
MRP	9000	9000
SGMP	6700	6700
FRP	7600	7600
NDE Center	7000	7000
Water Chemistry	2000	2000
Corrosion Research	1000	1000
WOG	3300	3200
BWOG	2100	2000
Total	**45700**	**47500**

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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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IMT Table format

•*Section 1 — Issue Management Table for XXXXXX*

Component	Material	Degradation Mechanism	Consequences of Failure	Mitigation	Repair / Replace	I & E Guidance	Gaps, Priority & Basis	Responsible Program(s)

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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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Materials Degradation Matrix: Goals

- 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
- Proactively identify potential challenges to avoid surprises

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Materials Degradation Matrix: Participants in first expert meeting (May 12/13, 2004 in Palo Alto)

- US LWR materials experts and senior industry advisors
  - Peter Andresen (GE GRC), Warren Bamford (W), Steve Bruemmer (PNL), Omesh Chopra (ANL), Peter Ford (ACRS), Steve Fyfitch (F-ANP), Tony Giannuzzi (SI), Jeff Gorman (DEI), John Hall (W), Sam Ranganath (XGEN)
  - Mike Robinson (Duke Power), Les Spain (Dominion), Robin Dyle (Southern Company)

- International material experts and senior industry advisors
  - Ian Armson (Rolls Royce, UK), Noel Peat (FCC, UK)
    Peter Scott (F-ANP, France)
  - Francois Cattant (EDF, France) – *advance input in writing*

- EPRI staff (full or part-time participation)
  - Bob Carter, John Hickling, Robin Jones, Al McIlree, Raj Pathania, Stan Rosinski, H. T. Tang, Chuck Welty

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Materials Degradation Matrix

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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Materials Degradation Matrix

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					
														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)	C&LAS																		
	C&LAS Welds																		
	Wrought SS																		
	SS Welds & Clad																		
	Wrought Ni Alloys																		
	Ni-base Welds & Clad																		

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Materials Degradation Matrix

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					
														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)	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

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					
														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)	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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Sample BWR IMT (draft)

Section 3 — Issue Management Table for BWR ASME Class 1 Piping and Components

Component	Material	Degradation Mechanism	Consequences of Failure	Mitigation	Repair / Replace	I & E Guidance	Gaps, Priority & Basis	Responsible Program(s)
3.1 Reactor Coolant Recirculation								
3.1.1 Recirculation Loop Piping and Fittings & Branch Piping and Fittings *(RHR Suction and Discharge, RWCU)* *(Piping ≥ NPS 4)*	SS (Typ. 304, 304L, 316, 316L, 316NG, 347, 347NG)	IGSCC *(NUREG-0313)* Fatigue *(e105)* Env. Fatigue *(NUREG-6260, e007)*	Loss of Pressure Retaining Boundary	Chemistry Control: BWRVIP-130 HWC: BWRVIP-62	ASME Section XI: IWA-4000 Weld Overlay, IHSI, MSIP (BWRVIP-61)	Fatigue Monitoring ASME Section XI IWB-2500-1: Cat. B-J - Surf & UT Cat. B-P - VT-2 BWRVIP-75: *(Inspection Schedule Relief)*	Resolve environmentally assisted fatigue concerns *(e007)*	BWRVIP Assessment Committee (supported by MRP Fatigue ITG)
3.1.2 Flow Nozzle	SS (Typ. 304, 304L, 316, 316L, 316NG, 347, 347NG)	IGSCC *(NUREG-0313)*	Loss of Pressure Retaining Boundary	Chemistry Control: BWRVIP-130 HWC: BWRVIP-62	ASME Section XI: IWA-4000	ASME Section XI IWB-2500-1: Cat. B-P - VT-2	None	N/A
	CASS (Typ. CF3, CF3M, CF8, CF8M)	IGSCC *(NUREG-0313 R2, > 0.035% C or < 7.5 FN)* Thermal Emb. *(R-52)*	Loss of Pressure Retaining Boundary	Chemistry Control: BWRVIP-130 HWC: BWRVIP-62	ASME Section XI: IWA-4000	ASME Section XI IWB-2500-1: Cat. B-P - VT-2	CASS piping embrittlement - assessment or examination *(GALL XI.M12)*	BWRVIP Assessment Committee

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Sample BWR IMT (draft), cont.

Section 3 — Issue Management Table for BWR ASME Class 1 Piping and Components

Component	Material	Degradation Mechanism	Consequences of Failure	Mitigation	Repair / Replace	I & E Guidance	Gaps, Priority & Basis	Responsible Program(s)
3.1 Reactor Coolant Recirculation								
3.1.3 Small Bore Piping and Fittings *(Piping < NPS 4)* *(Includes Vents, Drains, Instrument Lines)*	SS (Typ. 304, 304L, 316, 316L, 316NG, 347, 347NG)	IGSCC *(GALL-R03)* HC Fatigue *(GALL-R55)*	Loss of Pressure Retaining Boundary	Chemistry Control: BWRVIP-130 HWC: BWRVIP-62	ASME Section XI: IWA-4000	ASME Section XI IWB-2500-1: Cat. B-J - Surf Cat. B-P - VT-2 MRP-24: UT (Interim Fatigue Guidelines)	Resolve HC Fatigue & IGSCC issues for BWR small bore piping. *(GALL XI.M32)*	BWRVIP Assessment Committee (supported by MRP Fatigue ITG)
3.1.4 Reactor Vessel Drain Line *(Piping < NPS 4)*	C&LAS (Carbon Steel)	FAC *(Brunswick LRA)* Pitting *(e127)* HC Fatigue *(GALL-R55)*	Loss of Pressure Retaining Boundary	Chemistry Control: BWRVIP-130	ASME Section XI: IWA-4000	EPRI NSAC 202L: FAC Modeling ASME Section XI IWB-2500-1: Cat. B-J - Surf Cat. B-P - VT-2 MRP-24: UT (Interim Fatigue Guidelines)	Resolve HC Fatigue & IGSCC issues for BWR small bore piping. *(GALL XI.M32)* Assess adequacy of FAC modeling for RPV Drain Line.	BWRVIP Assessment Committee (supported by MRP Fatigue ITG) BWRVIP Assessment Committee
3.1.5 Recirculation Pump Casing	CASS (Typ. CF3, CF3M, CF8, CF8M)	IGSCC *(NUREG-0313 R2, > 0.035% C or < 7.5 FN)* Thermal Emb. *(R-52)*	Loss of Pressure Retaining Boundary	Chemistry Control: BWRVIP-130 HWC: BWRVIP-62	ASME Section XI: IWA-4000	ASME Section XI IWB-2500-1: Cat. B-L-1 - Vol. & VT-3 Cat. B-P - VT-2 Code Case N-481: (Relief from Vol. Exam. of Casing Welds)	None	N/A

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Sample BWR IMT (draft), cont.

Section 2 — Issue Management Table for BWR Reactor Vessel Internals

Component	Material	Degradation Mechanism	Consequences of Failure	Mitigation	Repair / Replace	I & E Guidance	Gaps, Priority & Basis	Responsible Program(s)
2.1 Control Rod Guide Tube Assembly								
2.1.1 Control Rod Guide Tube Assembly *(Body, Sleeve, Base, Alignment Lugs)*	SS *(304, 316L)*	IGSCC *(BWRVIP-47)*	Loss of support and / or orientation	Chemistry Control: BWRVIP-130 HWC: BWRVIP-62	BWRVIP-55: Repair Design Criteria	BWRVIP-47: EVT-1 & VT-3 *(alignment lug to tube sleeve weld)*	None	N/A
	CASS *(CF3 / CF8)* *Base Only*	Thermal Emb. *(GALL R-103)* Irradiation Emb. *(GALL R-103)*	Loss of support and / or orientation	None	BWRVIP-55: Repair Design Criteria	BWRVIP-47: No Inspection Required	CASS Internals embrittlement - assessment or examination *(GALL XI.M13)*	BWRVIP Assessment Committee
2.1.2 CRGT / OFS Alignment Pin	SS *(304 typ.)*	IGSCC *(BWRVIP-47)*	Loss of Flow Distribution	Chemistry Control: BWRVIP-130 HWC: BWRVIP-62	BWRVIP-55: Repair Design Criteria	BWRVIP-47: VT-3	None	N/A
2.2 SLC / Core Plate DP Piping Assembly								
2.2.1 SLC / Core Plate ΔP Piping, Fittings, Tee, Support Brackets inside Vessel	SS *(304 typ)*	IGSCC *(BWRVIP-27A)*	No Safety Consequences	Chemistry Control: BWRVIP-130 HWC: BWRVIP-62	BWRVIP-53: (Abandon in Place, Removal, Repair)	BWRVIP-27A: No Inspection Required	None	N/A

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Sample BWR IMT (draft), cont.

Section 2 — Issue Management Table for BWR Reactor Vessel Internals

Component	Material	Degradation Mechanism	Consequences of Failure	Mitigation	Repair / Replace	I & E Guidance	Gaps, Priority & Basis	Responsible Program(s)
2.3 Core Plate								
2.3.1 Core Plate Welded Assy (Plate, Rim, Stiffener Beams, Stabilizer Beams, Aligner Pins, Peripheral Fuel Support)	SS *(304, 304L)*	IGSCC *(BWRVIP-25)* IASCC / Irradiation Emb. *(e045)*	No Safety Consequences	Chemistry Control: BWRVIP-130 HWC: BWRVIP-62	BWRVIP-50: Repair Design Criteria	BWRVIP-25: No Inspection Required	Assess effectiveness of HWC and NMCA at high fluence locations Assess impact of high fluence on crack growth and fracture toughness	BWRVIP Mitigation Committee BWRVIP Assessment Committee
2.3.2 Rim Hold-down Bolts	SS *(304, XM-19)* *(XM-19 is specified as an alternative material for BWR/6)*	IGSCC *(BWRVIP-25)* IASCC / Irradiation Emb. *(e045)* Stress Relaxation *(e115)*	Loss of support and / or orientation	Chemistry Control: BWRVIP-130 HWC: BWRVIP-62	BWRVIP-50: Repair Design Criteria *(Install Wedge Restraints. If wedges are present, lateral support is assured & inspection is not required)*	BWRVIP-25: EVT-1 UT	Assess effectiveness of HWC and NMCA at high fluence locations Assess impact of high fluence on crack growth and fracture toughness Develop UT inspection techniques	BWRVIP Mitigation Committee BWRVIP Assessment Committee BWRVIP Inspection Committee

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Integrated Materials Issues Strategic Plan

- ***Current Strategic Issues Identified*** by DM/IMT Process
  - Nickel Based Alloy Stress Corrosion Cracking (SCC)
  - NDE Technology
  - High Fluence in BWRs and PWRs
  - Steam Generator Tubing
  - Fuel Integrity
  - Water Chemistry
- Detailed in 'Industry Materials Management Annual Work Plan'
  - Managed as a Supplement to the 'Strategic Plan'
  - DM/IMT are living documents an will be updated at least annually

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