Extended Proactive Materials Degradation Analysis

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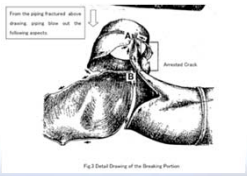
Light Water Reactor Sustainability R&D Program

Materials issues are a key concern for the existing nuclear reactor fleet

- Materials research is already a key need for the existing nuclear reactor fleet
- Materials degradation has led to increased maintenance, increased downtime, and increased risk.
- Materials issues must be resolved for:
  - Reactor Pressure Vessels and Primary Piping
  - Core Internals
  - Secondary System
  - Weldments
  - Concrete
  - Cabling
  - Buried Piping



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Extension of service life may cause new challenges for materials service

- Increased lifetime leads to increased exposures
  - Time at temperature
  - Stress
  - Coolant
  - Neutrons
- Extending reactor life to beyond 60 years will likely increase susceptibility and severity of known forms of degradation
- New mechanisms of materials degradation are possible and synergistic effects between degradation modes may raise new concerns.
- The motivation of several Department of Energy, Nuclear Regulatory Commission and Electric Power Research Institute projects is to provide improved understanding of degradation under extended service and provide alternative mitigation strategies.

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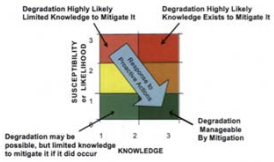
In addition to other tasks, research must also identify other or new topics before they become life-limiting

- "Knowing the unknowns" is a difficult problem that must be addressed.
- This is a particularly difficult issue for such a complex and varied material/environment system.
- An organized PMDA approach is being employed.
- Together with the USNRC, the LWRS program is working to expand the initial PMDA activity (*NUREG 6923)* to encompass broader systems and longer lifetimes
  - Core internals and primary piping
  - Pressure Vessel
  - Concrete
  - Cabling



Proactive **M**aterials **D**egradation **A**ssessment Matrix

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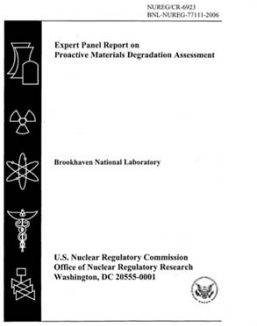
The US NRC and LWRS are co-funding the EPMDA

- Both sides are contributing funding
- *NUREG 6923* is being expanded beyond initial scope
  - *Longer lifetimes*
  - *Additional systems*
- Similar PIRT process and expert panels are being employed.
- Product is complementary to EPRI's MDM


NUREG/CR-6923
BNL-NUREG-77111-2006

Expert Panel Report on
Proactive Materials Degradation Assessment

Brookhaven National Laboratory

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555-0001

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A world-class group of panelists has been assembled

Core Internals and Piping		RPV	Concrete	Cables
J. Busby (ORNL)	S. Bruemmer (PNNL)	R. Nanstad (ORNL)	D. Naus (ORNL)	R. Bernstein (SNL)
A. Hull (NRC)	G. Carpenter (NRC)	T. Rosseel (ORNL)	H. Graves (NRC)	S. Ray (NRC)
R. Dyle (EPRI)	K. Arioka (INSS)	M. Kirk (NRC)	J. Wall (EPRI)	G. Toman (EPRI)
P. Andresen (GE)	R. Staehle (Consult)	B. Server (Consult)	J. Rashid (Anatech)	K. Simmons (PNNL)
K. Gott (SSI)	G. Was (UM)	B. Odette (UCSB)	Y. Le Pape (EdF)	K. Gillen (Consult)
P. Ford (Consult)	M. Wright (AECL)	N. Soneda (CRIEPI)	V. Sauma (UC)	B. Kinnick (Consult)
		B. Burgos (Westinghouse)		S. Burnay (UK)

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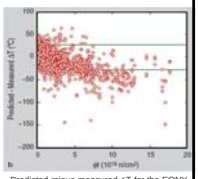
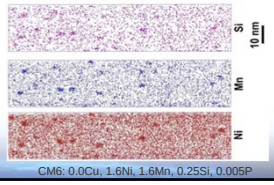
The RPV panel has carefully reviewed a wide range of issues

- Environmental effects on fracture resistance
- Thermal embrittlement of RPV steels
- Long-term integrity of dissimilar metal welds
- Neutron embrittlement
  - rate effects
  - high fluence
  - high nickel content
  - Attenuation
  - master curve fracture toughness
  - thermal annealing
  - embrittlement beyond the beltline
  - material variability.



. Predicted minus measured ΔT for the EONY model applied to high-flux test reactor data, showing increasing nonconservatism with increasing fluence. The two solid lines are ±2σ



CM6: 0.0Cu, 1.6Ni, 1.6Mn, 0.25Si, 0.005P

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Piping and core internal issues have been considered similar to previous PMDA and EPRI's MDM

- Previous efforts provide an opportunity to focus on extended service.

Reactor Type	PWR
Material	C&LAS Welds
System	Reactor Coolant
Form/Function	Welds
Subgroups	11.3

Degradation Mode	Sub-Mode	NU-REG Susceptibility	NU-REG Confidence	NU-REG Knowledge	Code	MDM 2008	MDM 2010	LTO/IMP
Stress Corrosion Cracking	IG/TG	1.13	2.63	2.80	O	B	B	LTO
	IASCC	*	*	*				
	OD	*	*	*				
	ID	*	*	*				
Corrosion	BAC	3.75	3.63	3.25	O	*	*	*
	CREV	*	*	*		*	*	*
	EC	*	*	*				
	FAC	0.88	3.00	2.50	O			
	FAGL	*	*	*				
	GALV					*	*	*
	GC/WASTE							
	MIC					*	*	*
	PIT	1.00	2.63	2.25	O			
Wear								
Fatigue	HC					Y		
	LC-Env	1.00	3.00	3.00	G	Y		LTO
Reduction Fracture Resistance	Thermal					B	B	LTO
	Environmental					B	B	LTO
Irradiation	EMB	*	*	*		Y	Y	LTO
	VS							
	IC/SR							
Creep						*	*	*
De-bonding						*	*	*

*Degradation mode not considered

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Cable aging panelists evaluated a wide range of materials under different conditions

- A general opinion was that most materials are in environments less severe than the design environment (however these need to be quantified).
- Thermal aging is expected to be the dominant aging mechanism
- Industry and regulator will need to conduct additional research to confirm the expected lifetimes of safety-related cables

Summary of types of insulation in US fleet

	Insulation Material	Entries	% Total
1	XLPE	439	36%
2	EPR	434	36%
3	Silicone Rubber	63	5%
4	Kerite	61	5%
5	Polyethylene	52	4%
6	ETFE	39	3%
7	Flame Retardant	36	3%
8	CSPE	28	2%
9	Butyl Rubber	20	2%
10	Mineral	12	1%
11	PVC	12	1%
12	Polyimide	8	1%
13	Polypropylene	3	0%
14	XLN (Crosslinked Neoprene)	3	0%
15	Neoprene	2	0%
16	Industrite	2	0%
17	Styrene	1	0%
		1215	

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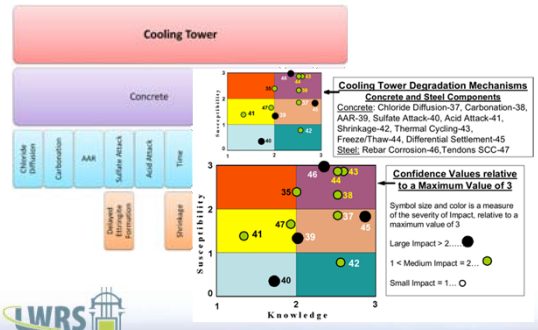
Concrete degradation is complex and varied

Degradation modes considered for cooling towers



The PMDA documents are currently under review and revision

- Panel documents have been internally reviewed by the panelists
- The US NRC has reviewed each document for content and technical details
- Revisions are currently underway for each document
- Additional reviews by industry and US NRC are anticipated in coming months
- Final documents are expected to be released by late spring 2012.

Successful conclusion of the Expanded PMDA will be beneficial to all stakeholders

- May help “know” some of the current “unknowns”
- Involves input from a wide range of perspectives
- This systematic analysis will provide a firm foundation for task prioritization and research needs for regulators, industry, and researchers
- Additional efforts on visualization of results may provide a concise presentation of risks and needs to other sponsors

Acronyms

- PIRT: Phenomena Identification Ranking Table
- LWRS: Light Water Reactor Sustainability
- MDM: Materials Degradation Matrix
- PMDA: Proactive Materials Degradation Analysis

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