Materials Aging Management Programs at Nuclear Power Plants in the United States

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IAEA 2nd International Symposium on Nuclear Power Plant Life Mgmt.
15-18 October, 2007
Shanghai, China

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Overview

Primary system materials degradation is a high priority concern for all operating plants

Need to understand:

- **When will materials degrade or fail?**
- **What components will be involved?**
- **How will plant operations be affected in the near and long term?**

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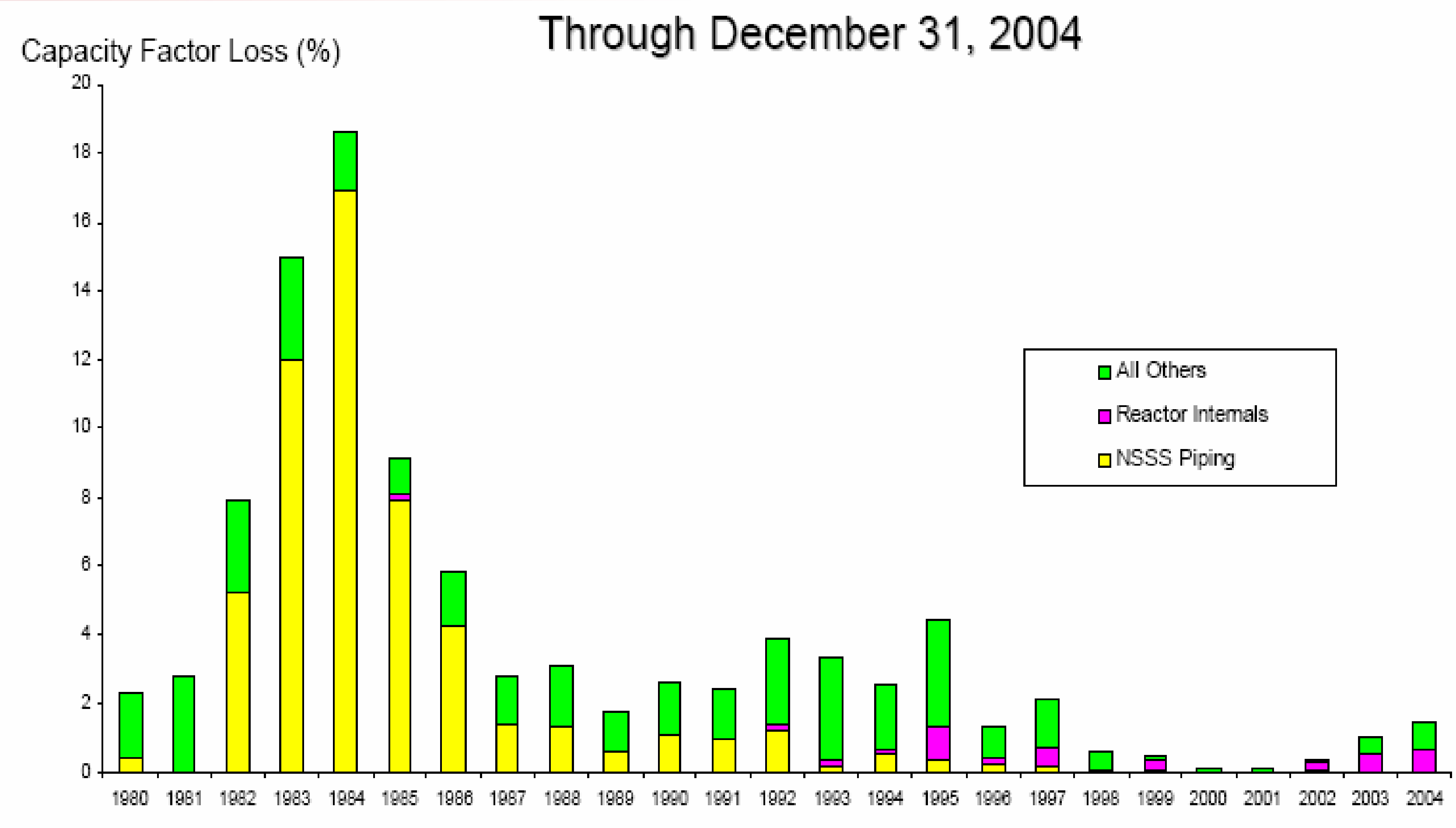
Capacity Factor Losses due to Corrosion in BWRs



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Annual Costs of Corrosion in Nuclear Power Plants in the U.S.

- Corrosion-related causes of partial LWR outages - $5M/year
- Corrosion-related causes of zero power LWR outages - $665M/year
- Contribution of corrosion to LWR operation and maintenance (O&M) - $2B/year

Materials Degradation Examples

- Materials that have cracked in LWRs
  - Internals components:
    - BWR Jet Pump Beams
    - BWR Steam Dryers
    - PWR Split Pins
  - Pressure boundary components:
    - BWR recirculation piping
    - CRDM head penetrations
    - Reactor vessel BMI penetrations
    - Primary system full penetration butt welds
    - Pressurizer heater sleeves

RCS Butt Weld Degradation in Dissimilar Metal (Alloy 600 Type) Welds

- Instances of detected butt weld cracking
  - Virgil C Summer (through wall leak)
  - Three Mile Island
  - Palisades
  - Susquehanna
  - Callaway
  - DC Cook
  - Wolf Creek

What Happened?

CRDM Penetrations Leaking

RCS Hot Leg Leaks

BMI Penetrations

Surprises Every Outage Season!!!

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These events are costly and impact plant safety and performance

Industry must get ahead of these issues by identifying potential problems *before they occur*

Materials Degradation Matrix- First Level

Carbon / Low-Alloy Steel C&LAS.doc C&LAS welds.doc	Stainless Steel Wrought SS.doc SS Welds & Clad.doc	Cast SS CASS.doc	Nickel-based Alloys Wrought Ni-base.doc Ni-base Welds & Clad.doc
PWR Reactor Pressure Vessel	PWR Reactor Pressure Vessel		PWR Reactor Pressure Vessel
PWR Pressurizer	PWR Pressurizer		PWR Pressurizer
PWR SG Shell	PWR SG Shell		PWR SG Shell
	PWR Reactor Internals	PWR Reactor Internals	PWR Reactor Internals
PWR Piping	PWR Piping	PWR Piping	PWR Piping
PWR SG Tubes & Internals	PWR SG Tubes & Internals		PWR SG Tubes & Internals
BWR Pressure Vessel	BWR Pressure Vessel		
	BWR Reactor Internals	BWR Reactor Internals	BWR Reactor Internals
BWR Piping	BWR Piping	BWR Piping	BWR Piping

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Materials Degradation Matrix in Terms of Degradation Mechanisms

SCC (EAC) SCC.doc	Corrosion Corr & Wear.doc	Wear Corr & Wear.doc	Fatigue Fatigue.doc	Reduction in Toughness RiT.doc	
				Thermal Aging	*Irradiation*
PWR Reactor Pressure Vessel	PWR Reactor Pressure Vessel		PWR Reactor Pressure Vessel	PWR Reactor Pressure Vessel	PWR Reactor Pressure Vessel
PWR Pressurizer	PWR Pressurizer		PWR Pressurizer	PWR Pressurizer	
PWR SG Shell	PWR SG Shell		PWR SG Shell	PWR SG Shell	
PWR Reactor Internals		PWR Reactor Internals	PWR Reactor Internals	PWR Reactor Internals	PWR Reactor Internals
PWR Piping	PWR Piping		PWR Piping	PWR Piping	
PWR SG Tubes & Internals	PWR SG Tubes & Internals	PWR SG Tubes & Internals	PWR SG Tubes & Internals	PWR SG Tubes & Internals	
BWR Pressure Vessel	BWR Pressure Vessel	BWR Pressure Vessel	BWR Pressure Vessel	BWR Pressure Vessel	BWR Pressure Vessel
BWR Reactor Internals			BWR Reactor Internals	BWR Reactor Internals	BWR Reactor Internals
BWR Piping	BWR Piping	BWR Piping	BWR Piping	BWR Piping	

Materials Degradation Matrix – Second Level

PWR Component	Material	SCC SCC.doc					Corrosion/Wear Corr & Wear.doc				Fatigue Fatigue.doc			Reduction in Toughness RiT.doc					
														Aging	*Irradiation*				
	³Subdivision→	IG	IA	TG	LTCP	PW	Watg	Pit	Wear	FAC	HC	Th	Env	Th	Emb	VS	SR	Th	Fl
PWR Reactor Pressure Vessel	C&LAS.doc	? n2	?	Y n198	N	N n43	Y n3	Y	N	Y n4	N	Y	Y n184	Y n5	Y n6	N	N	N	Y n7
	C&LAS welds.doc	? n2	?	Y n198	N	N n43	Y n3	Y	N	Y n4	N	Y	Y n184	Y n5	Y n6	N	N	N	Y n7
	Wrought SS.doc	? n196	N/A	? n196	? n48	? n196	N	N	N	N	N	Y	Y n11	N	N	N	N	N	N
	SS Welds & Clad.doc	Y n8	? n47	N n9	? n48	?	N	N	? n37	N	N	? n185	Y	Y n178	Y n178	N	N	N	N
	Wrought Ni-base.doc	N	N	N	?	Y/m n10	N	N	N	N	Y	Y	Y n11	N	N	N	N	N	N
	Ni-base Welds & Clad.doc	N	? n12	N	Y n10	Y n13	N	N	N	N	N	Y	Y n11	N	N	N	N	N	N
PWR Pressurizer (Including Shell, Surge and Spray Nozzles, Heater Sleeves and Sheaths, Instrument Penetrations)	C&LAS.doc	? n2	?	Y n198	N	N n43	Y n3	Y	N	Y n4	N	Y	Y n184	Y n5	N/A	N/A	N/A	N/A	N/A
	C&LAS welds.doc	? n2	?	Y n198	N	N n43	Y n3	Y	N	Y n4	N	Y	Y n184	Y n5	N/A	N/A	N/A	N/A	N/A
	Wrought SS.doc	? n196	N/A	? n196	? n48	? n196	N	N	N	N	N	Y	Y n11	N	N/A	N/A	N/A	N/A	N/A
	SS Welds & Clad.doc	Y n8	? n47	N n9	? n48	?	N	N	? n37	N	N	?	Y	Y n178	N/A	N/A	N/A	N/A	N/A
	Wrought Ni-base.doc	N	N	N	?	Y/m n10	N	N	N	N	Y	Y	Y n11	N	N/A	N/A	N/A	N/A	N/A
	Ni-base Welds & Clad.doc	N	? n12	N	Y n10	Y n13	N	N	N	N	N	Y	Y n11	N	N/A	N/A	N/A	N/A	N/A

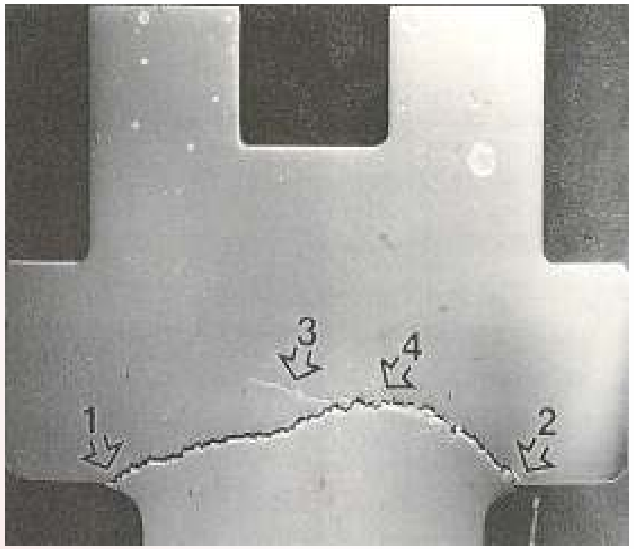
³ IG = intergranular; IA = irradiation assisted; TG = transgranular; LTCP = low temperature crack propagation; PW = primary water; Watg = wastage; FAC = flow accelerated corrosion; HC = high cycle; Th = thermal; Env = environmental; Emb = embrittlement (from fluence); VS = void swelling SR = stress relaxation; Fl = flux effect

Materials Degradation Matrix – Second Level

PWR	Material	SCC SCC.doc					Corrosion/Wear Corr & Wear.doc				Fatigue Fatigue.doc			Reduction in Toughness RiT.doc					
														Aging	*Irradiation*				
	←Subdivision→				LTCP	PW	Wstg	Pit	Wear	FAC	HC	Th	Env	Th	Emb	VS	SR	Th$_n$	Fl
PWR SG Shell (Including Feedwater and Main Steam Nozzles)	C&LAS.doc	? n14	?	Y n198	N	N n43	Y n3	Y n187	N	Y n4	N	Y	Y n184	Y n5	N/A	N/A	N/A	N/A	N/A
	C&LAS welds.doc	? n14	?	Y n198	N	N n43	Y n3	Y n187	N	Y n4	N	Y	Y n184	Y n5	N/A	N/A	N/A	N/A	N/A
	Wrought SS.doc	? n196	N/A	? n196	? n48	? n196	N	N	N	N	N	Y	Y n11	N	N/A	N/A	N/A	N/A	N/A
	SS Welds & Clad.doc	Y n8	? n47	N n9	? n48	?	N	N	? n37	N	N	?	Y	Y n178	N/A	N/A	N/A	N/A	N/A
	Wrought Ni-base.doc	N	N	N	?	Y/m n10	N	N	N	N	Y	Y	Y n11	N	N/A	N/A	N/A	N/A	N/A
	Ni-base Welds & Clad.doc	N	? n12	N	Y n10	Y n13	N	N	N	N	N	Y	Y n11	N	N/A	N/A	N/A	N/A	N/A
PWR Reactor Internals n62 n71 n24	Wrought SS.doc	N	Y n64	N	? n48	Y n197	N	N	Y	N	Y n65	N	Y n53	N	Y n181	Y	Y	Y n23	? n67
	CASS.doc	N	Y n40	N	? n48	Y n40	N	N	Y	N	Y	N	Y	Y n68	Y n68	N n38	N n38	N n38	? n67
	SS Welds & Clad.doc	N	Y n40	N	? n48	Y n40	N	N	N	N	N	N	N	Y n178	Y n1	Y	Y	Y	? n66
	Wrought Ni-base.doc	N	?	N	Y n58	Y n72	N	N	? n37	N	N	N	N	N	Y	? n35	? n75	N	? n35

What PWR Internals Issues do we Have Now?

- Flow induced vibration fatigue
  - Early incidence of thermal shield vibration
  - Most early issues have already played out
- SCC of bolting and pins
  - A286 and X750 susceptibility
  - "Split pins"
- Wear
  - Flux thimble tubes
- IASCC of bolting



What Issues Might we Have in the Future?

- Stress Corrosion Cracking (SCC)
- Wear
- Fatigue
- Thermal Aging Embrittlement (TE)
- Irradiation Assisted SCC (IASCC)*
- Irradiation Embrittlement (IE)*
- Irradiation-induced Stress Relaxation (IR)* and Creep (IC)*
- Void Swelling (VS)*

* Neutron fluence driven

How will the industry manage these issues?

- Operating Experience
- Continuing research
- Monitoring observable operating parameters
- Integrated inspection programs
- Fleet Inspections
- Evaluate experience and data, and revise guidance
- Repair/Replacement activities

Industry Efforts Underway

- The Materials Initiative (NEI 03-08) began in 2003
  - Industry-wide commitment by the Chief Nuclear Officers
  - Coordination of materials issues through EPRI MRP, BWRVIP and Owners Groups (Issue Programs)
  - Industry guidance is published in Inspection & Evaluation (I&E) Guidelines documents
  - Materials Initiative protocols establish the expectations for the management of materials degradation concerns

Summary of Materials Degradation Management Programs (MDMP)

- **MDMP implemented at all U.S. plants, including:**
  - ♦ **A high-level (overarching) program identifying roles and responsibilities and key utility actions**
  - ♦ **Coordination of many subprograms under this high-level program**
  - ♦ **Defined program goals and attributes**
    - – Clearly stated objectives
    - – Subprogram identification
    - – Gap analysis – schedules – self-assessments
  - ♦ **Implementation of all defined "Mandatory" and "Needed" NEI 03-08 Program actions**

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Reactor Coolant System MDMP Must Include:

- PWR reactor vessel integrity management program
- BWR vessel and internals management program
- Alloy 600 management program
- Boric acid corrosion control program
- PWR steam generator management program

Reactor Coolant System MDMP May Include:

- In-service Inspection (ISI) program
- Nondestructive examination program
- Chemistry control program
- Fatigue management program (thermal and environmental fatigue)
- PWR internals aging management program
- Reactor fuel performance program
- Flow accelerated corrosion control program
- Others (e.g., buried piping program)

Key NEI 03-08 Actions in 2007

Alloy 600 Weld Examination Actions

- By December 31, 2007, all Alloy 82/182 butt welds associated with the pressurizer and exposed to pressurizer-like temperatures will be volumetrically inspected in accordance with the MRP-139 guideline. This also applies to surge line nozzle welds near the pressurizer.

Thermal Fatigue Evaluation Actions

- Perform a screening evaluation for thermal fatigue of normally stagnant non-isolable RCS branch lines in accordance with MRP-146 and MRP-132.

Future NEI 03-08 Actions

PWR Internals Aging Management Actions

- Many plants have committed to inspect internals as part of a license renewal program
- PWR internals Inspection & Evaluation (I&E) guidelines to be completed in 2008
  - Upper core barrel bolts inspections will begin ASAP in all B&W designed reactors
  - Inspections of PWR internals to begin as early as 2009-2010 (Ginna and H. B. Robinson)

Future NEI 03-08 Actions (cont.)

Alloy 600 Weld Examination Actions

- By December 31, 2008, Alloy 82/182 butt welds in pipes greater than 4” and less than 14” diameter and exposed to hot leg temperatures will be volumetrically inspected per MRP-139 guidance.
- By December 31, 2009, Alloy 82/182 butt welds in pipes greater than 14” diameter and exposed to hot leg temperatures will be volumetrically inspected per MRP-139 guidance.
- By December 31, 2010, Alloy 82/182 butt welds in pipes greater than 14” diameter and exposed to cold leg temperatures will be volumetrically inspected per MRP-139 guidance.

Expectations of Industry

- Continued high level oversight of materials issues
- Industry guidance from Issue Programs (IPs) to define implementation expectations and actions
- Improved communications on new materials issues and related interface with the NRC
- Industry to be more proactive on materials issues
- Improved integration/coordination among Issue Program Groups
- EPRI to provide lead technical support on these materials aging issues

Expectations for Utilities

- Implement the Materials Initiative actions
- Adopt a proactive approach to materials issues
- Implement a RCS MDMP by August 2006 (done)
- Adopt all implementing guidelines documents
- Support ongoing materials Issue Programs with financial and personnel resources
- INPO to monitor compliance in future audits

Summary of MDMP Programs

- All U.S. utilities have implemented a NEI 03-08 Materials Degradation Management Program
- Subprograms are being developed to include all “Mandatory” and “Needed” actions identified under this program, and may also include “Good Practice” recommendations
- More actions will be taken as the need arises
- These programs have been initiated without the need for additional Code or regulatory requirements

Coming Trends in Nuclear Power Plant Aging Management

- More preventive maintenance and predictive maintenance solutions being implemented
- Expanded use of on-line monitoring techniques
- Inspection/repairs/replacement of accelerated degradation in replacement steam generators
- Inspection/repairs/replacement of BWR core shroud tie rod repairs
- Inspection of CASS piping and components using improved NDE techniques

Coming Trends in Nuclear Power Plant Aging Management (cont.)

- Inspection of buried piping using improved NDE techniques (e.g., long-range guided wave)
- Improved reliability of valves, pumps and rotating equipment using vibration monitoring
- Decisions for plant repairs and replacements based on 60 – 80 years of planned operation
- More advanced welding and weld repair techniques being used for mitigation purposes
- Application of lessons learned from the past for new plant design and construction