Overview of NRC Research into Proactive Management of Materials Degradation (PMMD)

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

C.E. Carpenter, Group Lead for Aging Management Issues
Office of Nuclear Regulatory Research

NRC/JNES Bilateral Information Exchange Meeting
Tokyo, Japan

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

Outline

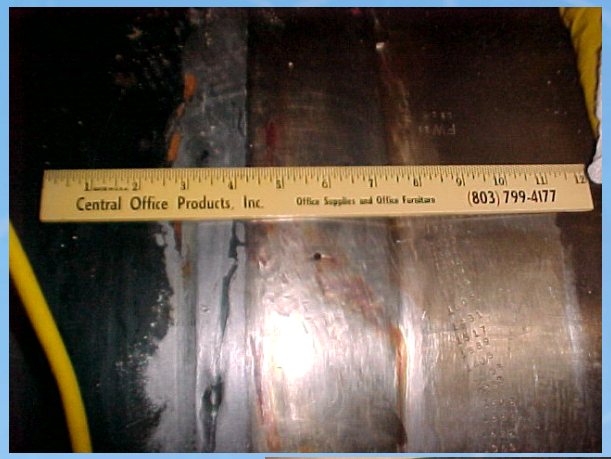
- History of PMMD
- Nuclear Industry - Past Experience
- Proactive Management of Materials Degradation (PMMD)
- Identification of Components with Highest Susceptibility to Degradation
- PMMD Information Tool
- Proactive Approach to Assessment & Management of Materials Degradation
- International Outreach
- Conclusions

History of Proactive Management of Materials Degradation (PMMD)

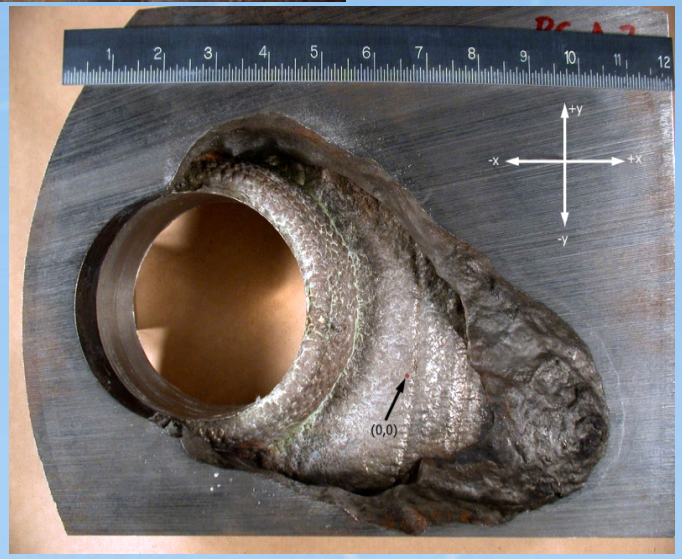
- Following the vessel head degradation at Davis-Besse, there was an increased emphasis on being more proactive at managing degradation in order to preclude future "surprises"
- The Commission indicated that the industry and NRC should be more proactive in their approach to assessing and managing materials degradation
- Results would provide the technical basis for assessing the need to change current inspection and monitoring requirements (e.g., 50.55a)
- Risk information would be used to prioritize/justify any needed changes

PMMD Impetus

- Develop Information
  - Materials Behavior
  - Mitigation or Repair
  - Inspection or Monitoring
- Proactively Address Potential Future Degradation
  - Avoid Failures
  - Maintain Integrity and Safety
- Increase Cooperation
  - Prioritize PMMD Research with Industry
  - Pursue Additional International Partners
- Evaluate Existing Requirements
  - Integrity of Susceptible Components
  - Inspection and Monitoring Requirements



Avoid surprises like V.C. Summer and Davis-Besse



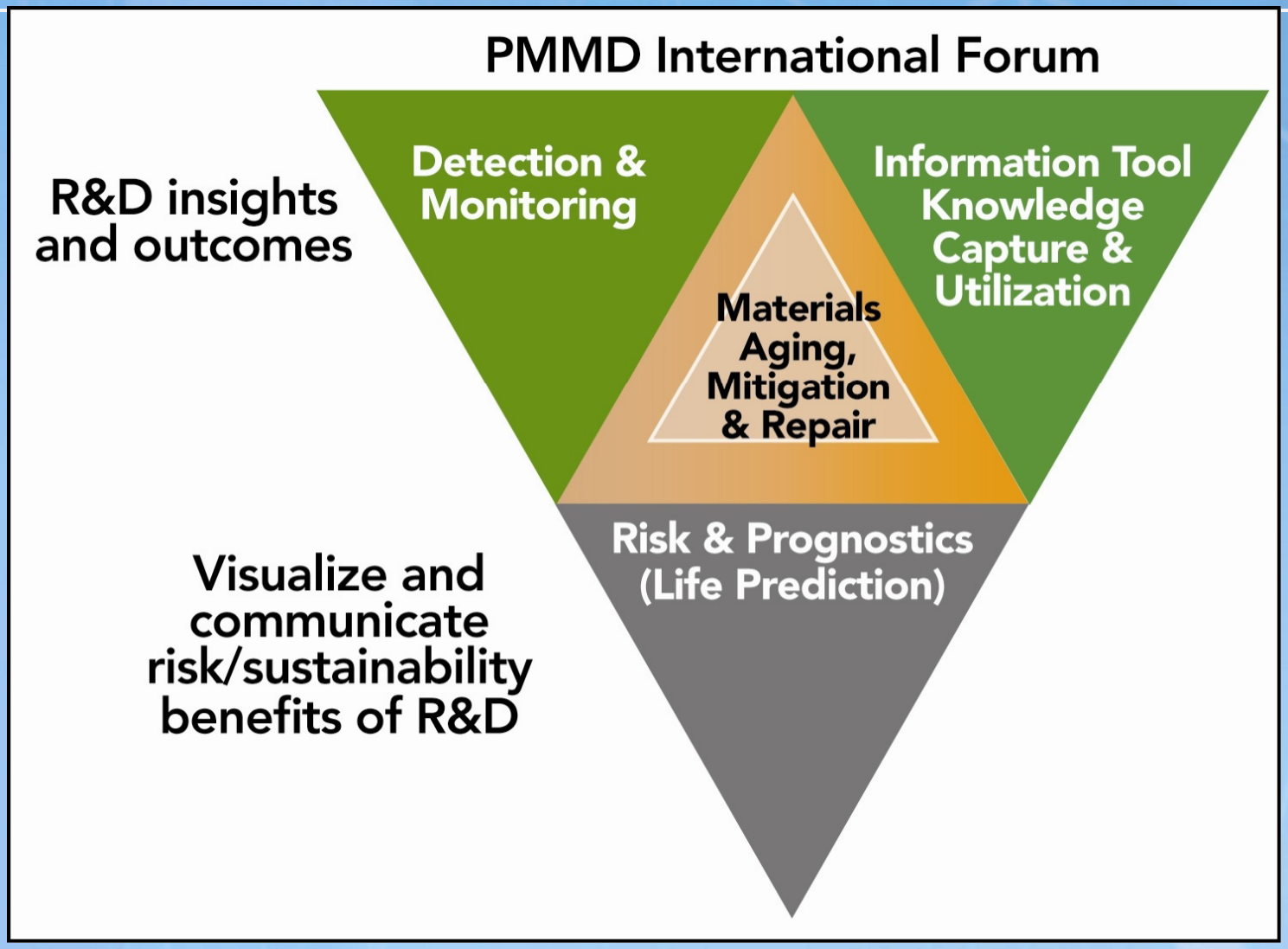
Nuclear Industry - Past Experience

- Two types of component failures
  - Active components – e.g. valve not operating
  - Passive components – service degradation
- **Active components** managed through maintenance program
- **Passive components** managed through periodic inspection – the limitations are:
  - Inaccessible locations
  - Materials that challenge NDE – cast stainless steel
  - Surface conditions – tapers, as welded crowns, etc
  - Fast growing degradation

Proactive Management of Materials Degradation (PMMD)

- Goal is to proactively address potential future degradation in operating plants to avoid failures and to maintain integrity, operability and safety
- NRC has developed a Road Map for PMMD
  - Identification of technical and regulatory gaps and research needs
  - Developing an **Information Tool – PMMD.PNL.GOV**
    - NUREG/CR-6923 PMDA
    - Other reports such as GALL
    - LWR component failure databases
    - Operating history

Elements in PMMD Program



Moving Forward: Major Thrust Areas

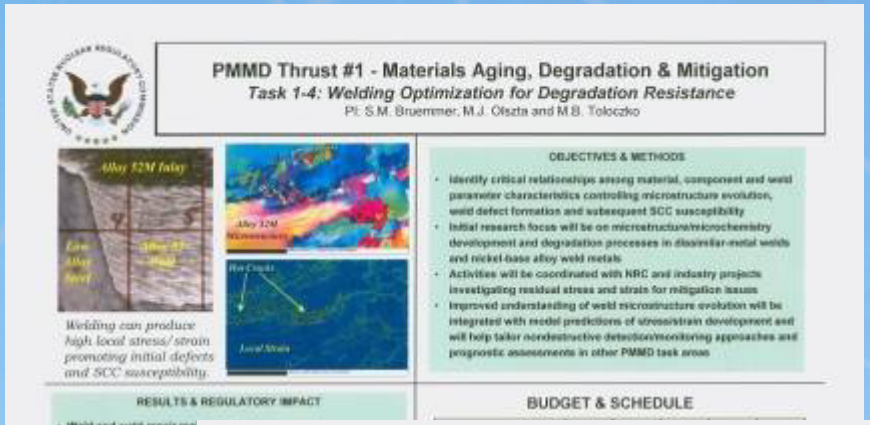
#1: Materials Aging, Degradation and Mitigation

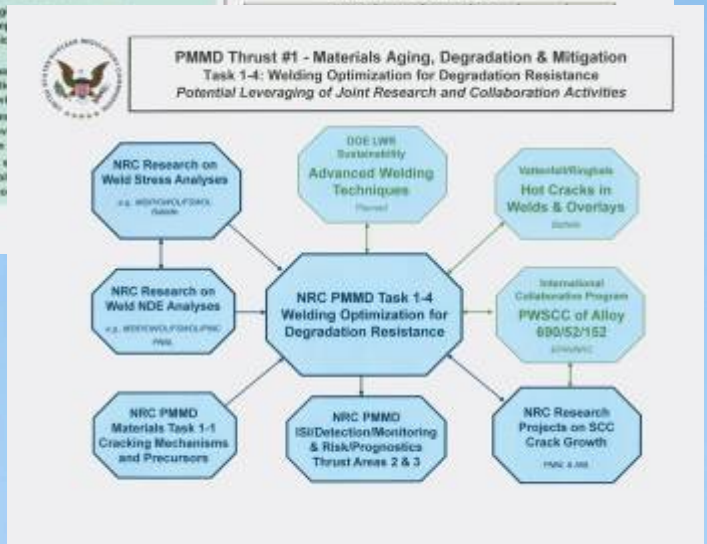
#2: Detection and Monitoring

#3: Risk and Prognostics

#4: Information tool, web site and knowledge capture

Also discussed: concrete, cables, and international engagement



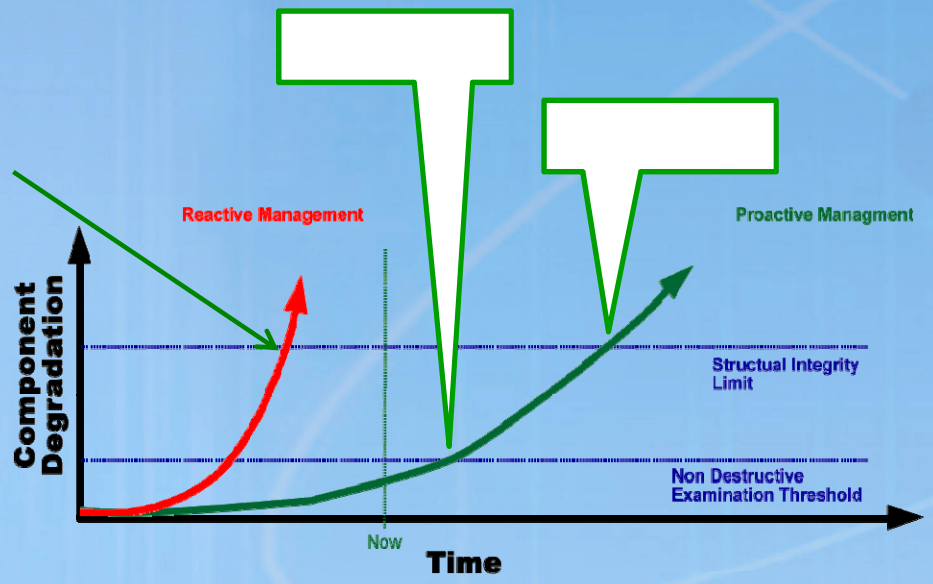


PMMD Products

- REACTOR COMPONENTS - Identify possible future degradation
  - NUREG/CR-6923 - "Expert Panel Report on Proactive Materials Degradation Assessment," 3895 pp. (Feb.'07)
  - PMMD Information Tool development
- ISI PROGRAMS - Assess for component degradation
  - PNNL-TLR "Assessment of Current Inservice Inspection and Leak Monitoring Practices for Detecting Materials Degradation in LWRs"
- RISK SIGNIFICANCE - Assess for component failure
  - Passive Component Conditional Core Damage Probability (Mar.'05)
  - Proactive Management of Materials Degradation: A Risk Evaluation Demonstration
- FAILURE PROBABILITY - Estimate for susceptible components
  - NUREG/CR-6936 "Probabilities of Failure and Uncertainty Estimate Information for Passive Components – A Literature Review" (May '07)
  - PNNL-16625 Technical Letter Report (TLR) "Probabilistic Fracture Mechanics Evaluation of Selected Passive Components" (ML071620303, May '07)

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

PMMD

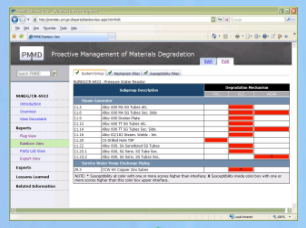


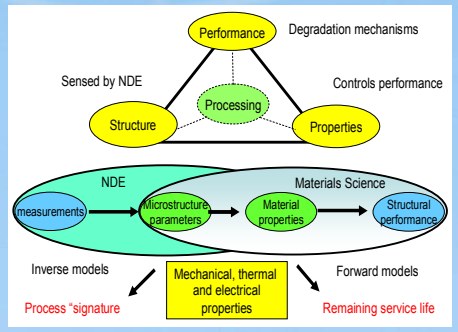
Numerous Large Reports

Distilled and Integrated via Information Tool

Help Identify Research Program Priorities

Degradation Time Line Knowledge Improved

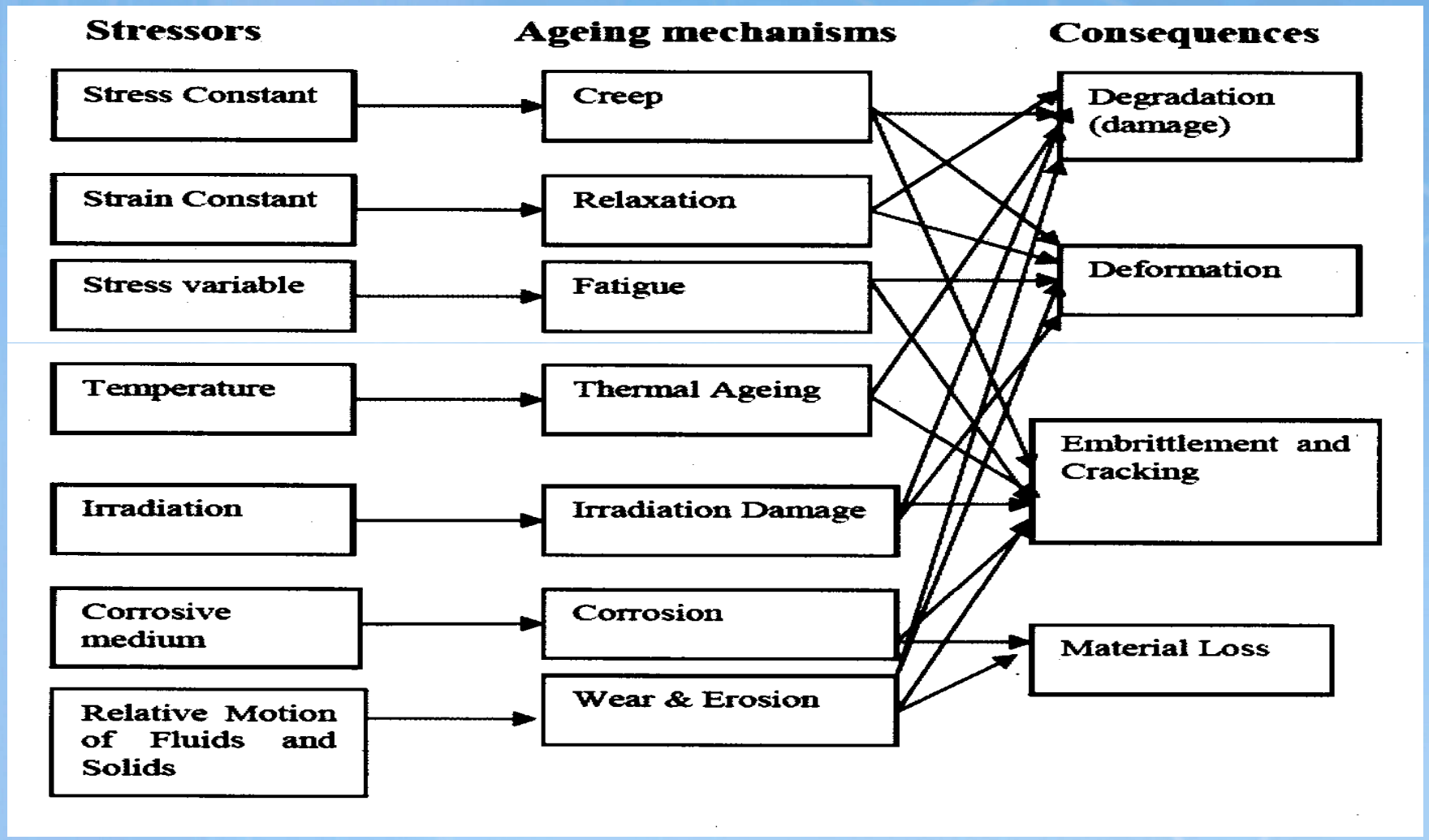




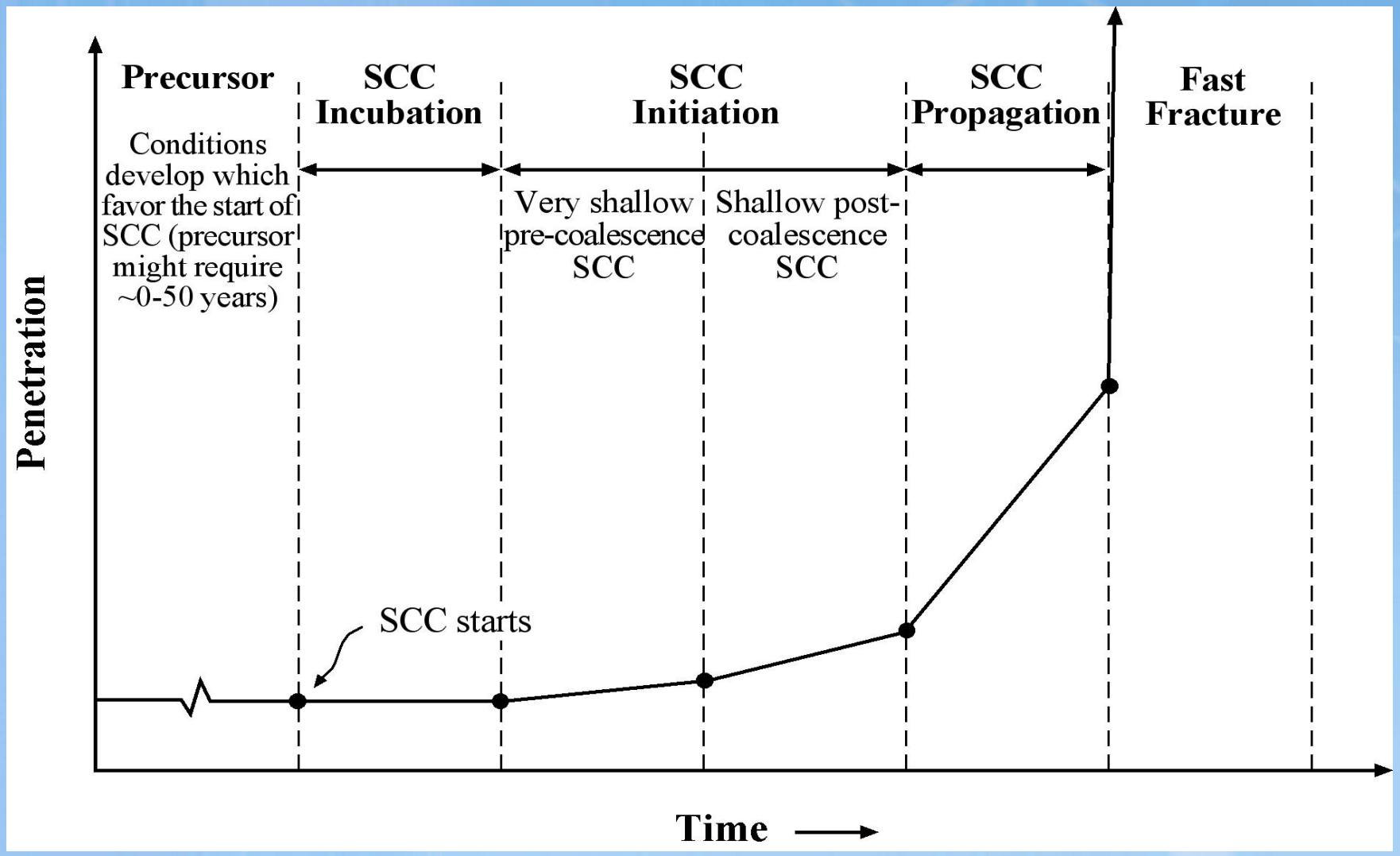
KNOW <u>SOONER</u>

PREDICT <u>ACCURATELY</u>

Aging Factors, Mechanisms & Possible Consequences



Six Stages of Stress Corrosion Cracking vs. Time

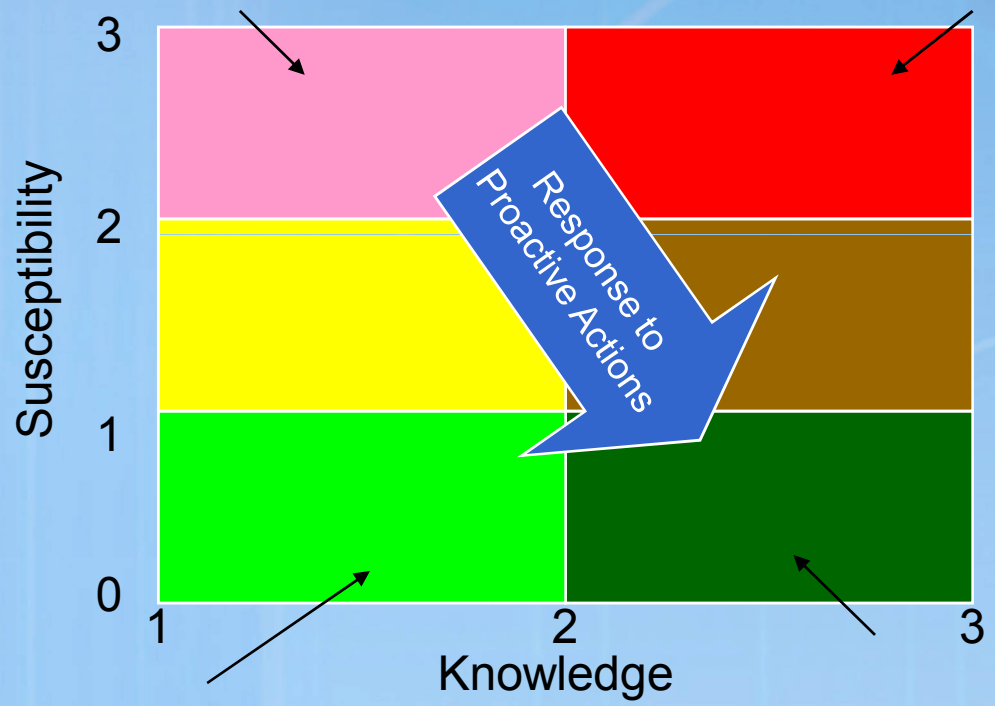


'The Science Approach to Degradation' from NUREG/CR-6923

PMDA Susceptibility-Knowledge-Confidence (SKC) Scores

Degradation highly likely, limited knowledge to mitigate it

Degradation highly likely, knowledge exists to mitigate it

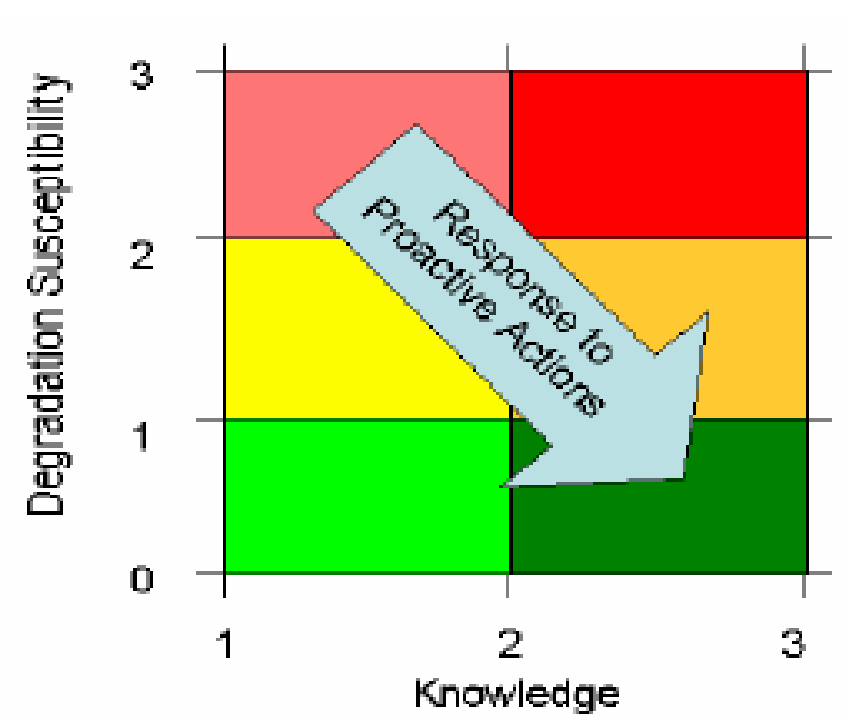


Degradation may be possible, but limited knowledge to mitigate if it did occur

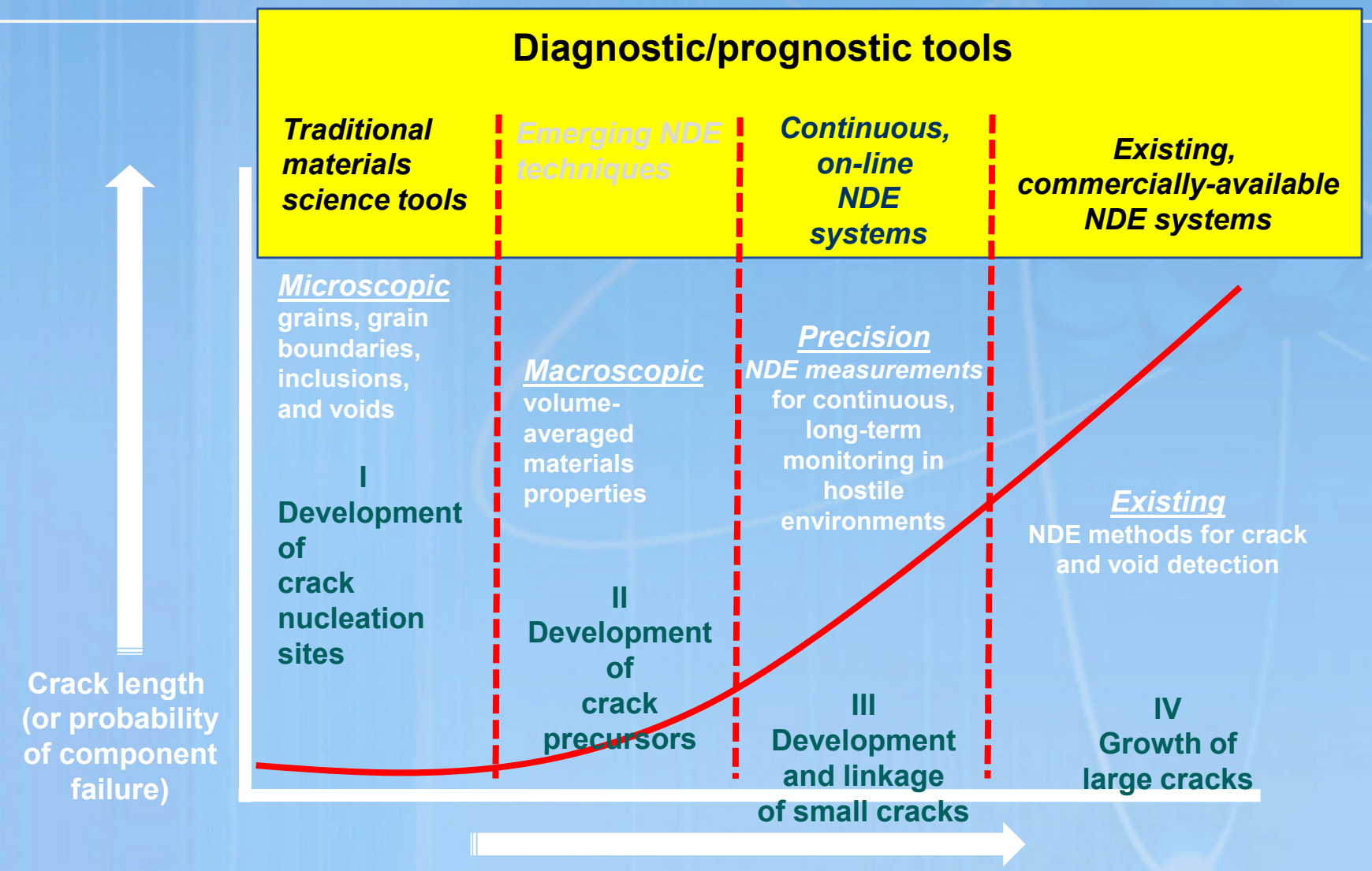
Degradation manageable by mitigation

Identification of Components with Highest Susceptibility to Degradation

- Materials degradation is highly likely, with limited knowledge for mitigation (pink zone)
  - 21 scenarios for PWRs
  - 1 scenario for BWRs
- Materials degradation is highly likely, but knowledge exists for mitigation (red zone)
  - 24 scenarios for PWRs
  - 62 scenarios for BWRs



U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment



Traditional Materials Surface Science Tools

Method	Physical property	Spatial/volumetric resolution
SEM	microstructure	
ESCA/XPS	chemical species	
SIMS	""	Individual grains, grain boundaries, voids, inclusions
AS	""	
EDS	""	
AFM	""	

SEM - Scanning electron microscopy, ESCA - Electron spectroscopy for chemical analysis/x-ray photoelectron spectroscopy, SIMS - secondary ion mass spectroscopy, AFM - atomic force microscopy, EDS - energy dispersive xray spectroscopy, AS- Auger spectroscopy

Bond et al (2009) ANS NPIC HMIT

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

Emerging NDE Techniques Based on Physical Measurements

Method	Physical property	Sampling volume
Acoustic microscopy	microstructure	1-1000 mm^3
B-H curve analysis[a]	magnetic domain distribution, voids	
Electrical conductivity	radiation/mechanical damage	
Thermal conductivity	radiation/mechanical damage	
Ultrasonic velocity, attenuation, absorption[b]	acousto-elastic properties	
Small-angle neutron scattering	voids, scattering centers	
X-ray diffraction	crystal size distribution	
Positron annihilation	electron density	
Frictional heating	surface and internal cracks/voids	

a - Includes coercive force, residual induction, B-H harmonic analysis, magnetic/acoustic Barkhausen emission, b-Excitation using piezo transducer, magnetic field, laser pulse, etc.

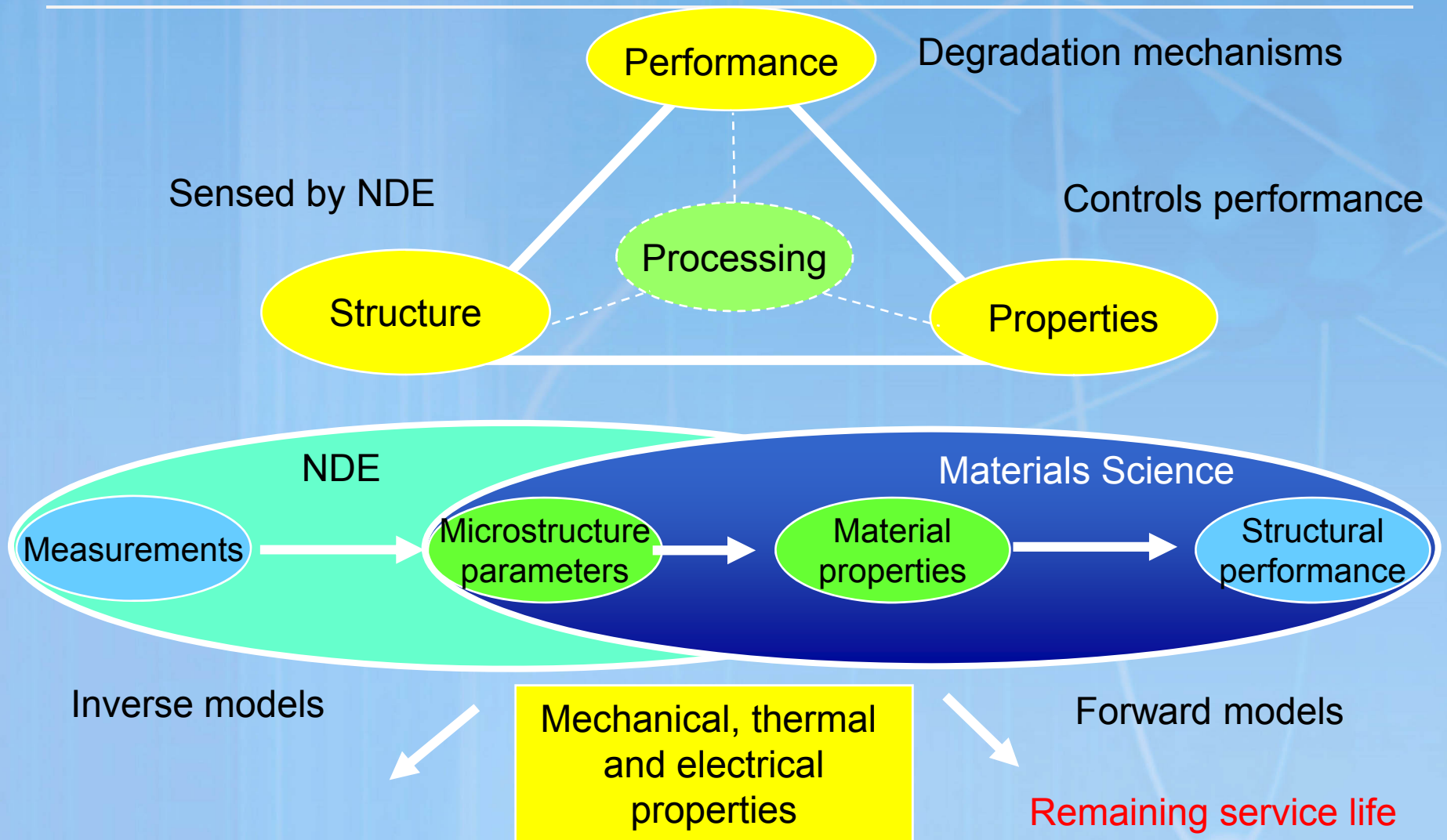
U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

Continuous, On-line NDE Diagnostic/Prognostic Systems

Method	Physical property	Minimum Detectable Flaw Size
Ultrasonic flaw detection	crack detection and characterization, internal stress/strain, dimensional changes, changes in bulk material properties	Same limits as off-line laboratory systems
Acoustic emission	crack formation and growth	
Eddy current	surface cracks	
Acoustic microscopy	surface/volume cracks	
Remote visual microscopic inspection	surface topography	

SEM - scanning electron microscopy, ESCA - electron spectroscopy for chemical analysis, SIMS - secondary ion mass spectroscopy, AS- Auger spectroscopy

Advanced Monitoring + Materials Science



PMMD Information Tool: Background

- NUREG/CR 6923 ("Expert Panel Report on Proactive Materials Degradation Assessment," 3895 pages) -- published March 2007
  - identifies reactor components that could experience future degradation (susceptibility, confidence, knowledge rankings)
- Several databases available at NRC on components' degradation
  - PINC (Program for Inspection of Nickel-Alloy Components) Atlas database
  - GALL (Generic Aging Lessons Learned) – NUREG-1801
  - SCAP (Stress Corrosion Cracking) database
  - OPDE (OECD Piping Failure Data Exchange) database
- EPRI Materials Reliability Program (MRP) issue management tables (IMTs) in PWR MRP-205 and BWR VIP-167 reports
- There is a significant need to develop an integrated, comprehensive living database tool that incorporates information from these databases to access all available information on a particular component's susceptibility to known potential materials' degradations

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

New PMMD Program and Information Tool Website

PMMD Proactive Management of Materials Degradation

Search PMMD

PMMD Program

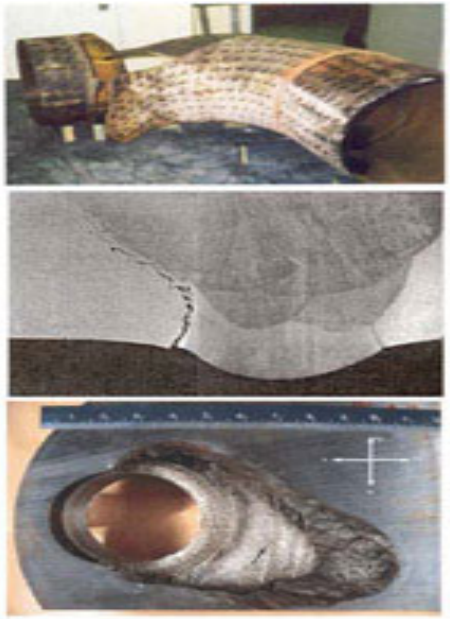
- Rationale
- Thrusts
- PMMD Project
- International Forum
- Technical Issues
- Technical Reports
- Technical Meetings
- Contact Us
- Links
- Home

PMMD Information Tool

- Users Guide (1.4Mb)
- Users Guide (Power Point 4Mb)
- NUREG/CR-6923
- Flag View
- Rainbow View
- Parts List View
- Expert View

Welcome to the U.S. Nuclear Regulatory Commission Program on Proactive Management of Materials Degradation (PMMD) for LWRs. The NRC has initiated a new program to promote the understanding and use of PMMD methods and technology in extending the life of LWRs. The program will build national and international collaboration on regulatory research issues. The goal of PMMD activities over the next five years is to place NRC in a position where it has the technical basis to answer some key aging-related degradation questions, including:

- Can licensees safely extend the operating life of existing NPPs to 60-80 years and potentially longer?
- What are the key technical and regulatory issues that require attention to enable license extension?
- What information is needed to position NRC to adequately process and respond to applications for a second (and subsequent) license extension?
- What are the remaining open technical and regulatory issues?



Last Updated: March, 2009
Pacific Northwest National Laboratory
Operated by Battelle for the US Department of Energy
Security & Privacy | Contact Us

Pacific Northwest | U.S.NRC

PMMD Flag View - Windows Internet Explorer

http://pmmddev.pnl.gov/Reports/FlagView.aspx

File Edit View Favorites Tools Help

PMMD Flag View

PMMD Proactive Management of Materials Degradation

BWR PWR

Search PMMD go

NUREG/CR-6923
- Introduction
- Overview
- View Document

Reports
- Flag View
- Rainbow View
- Parts List View
- Expert View

Experts

Lessons Learned

Related Information

System/Group | Mechanism Filter | Susceptibility Filter

NUREG/CR-6923 : Boiling Water Reactor

1 Reactor Coolant System : Reactor Pressure Vessel Closure Head

		Susceptibility					Confidence				Knowledge			
		Average	0	1	2	3	Average	1	2	3	Average	1	2	3
Subgroup 1.1	• Pressure Vessel Head Flanges and Nozzles • SA 508 Cl.2 Forging • Reactor Coolant Steam, 547°F, 1020 psia													
	FAT	1.000	0	8	0	0	3.000	0	0	8	3.000	0	0	8
	FAT-HWC	1.125	0	7	1	0	2.875	0	1	7	2.750	0	2	6
	FR	1.000	0	8	0	0	2.750	0	2	6	2.375	0	5	3
	SCC	1.375	0	5	3	0	3.000	0	0	8	2.875	0	1	7
	SCC-HWC	1.125	0	7	1	0	2.875	0	1	7	2.750	0	2	6
Subgroup 1.2	• Pressure Vessel Plate • SA-533 Gr.B Rolled Plate • Reactor Coolant Steam, 547°F, 1020 psia													
	FAT	0.500	4	4	0	0	3.000	0	0	8	3.000	0	0	8
*	FAT-HWC	0.750	3	4	1	0	2.875	0	1	7	2.750	0	2	6
	FR	1.125	0	7	1	0	2.500	0	4	4	2.250	0	6	2
	SCC	1.125	0	7	1	0	3.000	0	0	8	2.875	0	1	7
	SCC-HWC	1.125	0	7	1	0	2.875	0	1	7	2.750	0	2	6
Subgroup 1.3	• RPV Cladding • 309 SS 7/32" thick .08%C max. • Reactor Coolant Steam, 547°F, 1020 psia													
	DEBOND	0.875	1	7	0	0	2.750	0	2	6	2.875	0	1	7
	FAT	1.000	0	8	0	0	2.875	0	1	7	3.000	0	0	8
	FAT-HWC	1.125	0	7	1	0	2.750	0	2	6	2.875	0	1	7
	FR	1.000	0	8	0	0	2.750	0	2	6	2.000	0	8	0
	SCC	1.250	0	6	2	0	3.000	0	0	8	2.875	0	1	7
	SCC-HWC	1.250	0	6	2	0	2.875	0	1	7	2.750	0	2	6
Subgroup 1.4	• Closure Studs, Nuts and Washers													

Done Local intranet 100%

PMMD Rainbow View - Windows Internet Explorer

http://pmmddev.pnl.gov/Reports/RainbowView.aspx?rid=PWR

File Edit View Favorites Tools Help

PMMD Rainbow View

PMMD Proactive Management of Materials Degradation

BWR PWR

Search PMMD go

NUREG/CR-6923

- Introduction
- Overview
- View Document

Reports

- Flag View
- Rainbow View
- Parts List View
- Expert View

Experts

Lessons Learned

Related Information

System/Group | Mechanism Filter | Susceptibility Filter

NUREG/CR-6923 : Pressure Water Reactor

Subgroup Description		Degradation Mechanism									
		BAC	CREV	DEBOND	FAC	FAT	FR	MIC	PIT	SCC	WEAR
Steam Generator											
11.1	SS External Surface										
11.2	Shell/Plates, Forgings				*				*	*	
11.3	LAS Nozzles/Welds	*			*				*		
11.4	308/309 SS Chaneel Head Clad			*			*				
11.5	Alloy 600 MA SG Tubes etc.										
11.6	Alloy 600 MA SG Tubes Sec. Side										
11.7	308/309 Dissimilar Welds - Int.										
11.8	Forged 316 SS Nozzles										
11.9	Alloy 600 Divider Plate										
11.10	SA-553 Gr. A Manways										
11.11	Alloy 52/82 Channel Head Clad										
11.12	Alloy 600 TT SG Tubes etc.										
11.13	Alloy 690 TT SG Tubes etc.										
11.14	Alloy 600 TT SG Tubes Sec. Side										
11.15	Alloy 690 TT SG Tubes Sec. Side										
11.16	Alloy 82/182 Dissim. Welds - Int.										
11.17	Type 308/309 Dissim. Welds - Ext.										
11.18	Alloy 82/182 Dissim. Welds - Ext.										
11.19	Alloy 690 Divider Plate										
11.20	CS Drilled Hole TSP		X								
11.21	SS Line Contact/Drilled Hole TSP		*								
11.22	Alloy 600, SA Sensitized SG Tubes										
11.23.1	Alloy 600, SA Sens. SG Tube Sec.										
11.23.2	Alloy 600, SA Sens. SG Tubes Sec.										*
Service Water Pump Discharge Piping											
29.1	CS Comp/Weld/HAZ Ext.										
29.2	CS Comp/Weld/HAZ (Pond)							*	*		
29.3	CCW HX Copper Zinc tubes				X					*	
29.4	CS CCW HX Shell and Tubesheets							*	*		
29.5	CCW HX SS tubes										
29.6	CCW HX Copper Nickel tubes										

NOTE: * Susceptibility at color with one or more scores higher than interface; **X** Susceptibility inside color box with one or more scores higher than this color box upper interface.

Local intranet 100%

PMMD Expert View - Windows Internet Explorer

http://pmmddev.pnl.gov/Reports/ExpertView.aspx

File Edit View Favorites Tools Help

PMMD Expert View

PMMD Proactive Management of Materials Degradation

BWR PWR

Search PMMD go

System/Group Mechanism Filter Susceptibility Filter

NUREG/CR-6923
- Introduction
- Overview
- View Document

Reports
- Flag View
- Rainbow View
- Parts List View
- Expert View

Experts

Lessons Learned

Related Information

NUREG/CR-6923 : Pressure Water Reactor

Subgroup1.1

- All stainless steel components
- External surfaces when at <150°C
- Containment air
- Normally dry when at low temp

PITTING CORROSION

Expert	Susceptibility	Confidence	Knowledge	Rationale	Factors Controlling Occurrence
1	Low	High	High	Cl in insulation or from ocean aerosols.	Concern only if wet. Silicate buffer / inhibitor
2	Low	High	Medium	2 scoring for knowledge in PIT and SCC associated with lack of knowledge of Cl and sensitivity of damage to this value	Pitting of internally wetted components possible at contaminant concentration regions during layup. Not a problem if good practice used. Unknown effects of secondary anions
3	Low	High	High	Well known phenomenon. Unlikely with good practice.	Can occur under the same circumstances as SCC, but contaminants not limited to Cl, not only low temperature phenomenon.
4	Low	High	High	Most likely for outdoor piping/tanks in seaside plants. Potential sources of Cl indoors are insulation and aerosols.	Concern only if wet. Tolerance level for Cl depends on buffer availability from insulation.
5	Low	High	High	Well known phenomenon. Cl from insulation and aerosols, the latter increasing with time	Concern only if wet. Tolerance level for Cl depends on buffer availability from insulation
6	Low	High	High	Well known phenomenon. Cl from insulation and aerosols, the latter increasing with time	Concern only if wet. Insulation material is critical
7	Low	High	High	Pitting of SS also occurs with impurities and wetness but these are not normal. Pitting is particularly important since it can lead to initiating corrosion fatigue as well as SCC while the pitting itself is not likely to perforate.	Exposure to wetness and impurities.
8	Low	High	High	Unlikely if surfaces uncontaminated or remain dry (possibly wet only under off-power conditions). Most likely for outside components. Tolerance level depends on alkali buffer from insulation.	

STRESS CORROSION CRACKING

Local intranet 100%

Proactive Approach to Assessment & Management of Materials Degradation

- Phase I: Identify materials and locations in LWRs where future degradation may occur in specific systems, determine risk significance
- Phase II: Participate in international cooperative research program addressing components of most concern
  - Review knowledge gaps and industry priorities identified in the EPRI BWR and PWR Issue Management Tables
    - Work with industry to establish joint priorities for PMDM research.
      - Financially advantageous to both NRC and industry
      - Avoid unnecessary duplication
  - Cooperatively undertake the proactive R&D needed, starting with the highest priority projects, address topics such as:
    - Materials and degradation mechanisms,
    - Mitigation, repair and replacement,
    - Nondestructive examination and continuous monitoring.
  - Pursue additional related R&D collaborations with international organizations including regulatory bodies.

PMMD- International Outreach

- NRC looking at developing a multi-year international activity
  - IAEA engagement (e.g. 3 year Research Agreement – PNNL/NRC – workshop May 2008)
  - Japanese and European engagement being investigated
  - PMMD – A review of principles and programs – NUREG/CR in Draft (January 2008)
  - PMMD – PNNL activity being developed
- PHM International Conf. on Prognostics & Health Management 2008 http://www.phmconf.org/OCS/index.php/phm
  - *Proactive Management of Materials Degradation,*

    Leonard Bond, Tom Taylor, Steven Doctor, Amy Hull, Shah Malik

Process to Develop Plan for Cooperation on PMMD Research

- Coordination between prospective national & international partners
- Focus only on safety-significant items that correspond to high susceptibility, low knowledge, of relevance to operating and new reactors
  - Compare priorities established by EPRI IMTs, LWRSP, and NUREG/CR-6923
  - Draw <u>as appropriate</u> upon draft overview program plan (OPP) w/62 work plans (WP) (Appendix B of PNNL-17779)
    - Materials degradation (46 WPs)
    - Mitigation strategies (7 WPs)
    - NDE techniques (5 WPs)

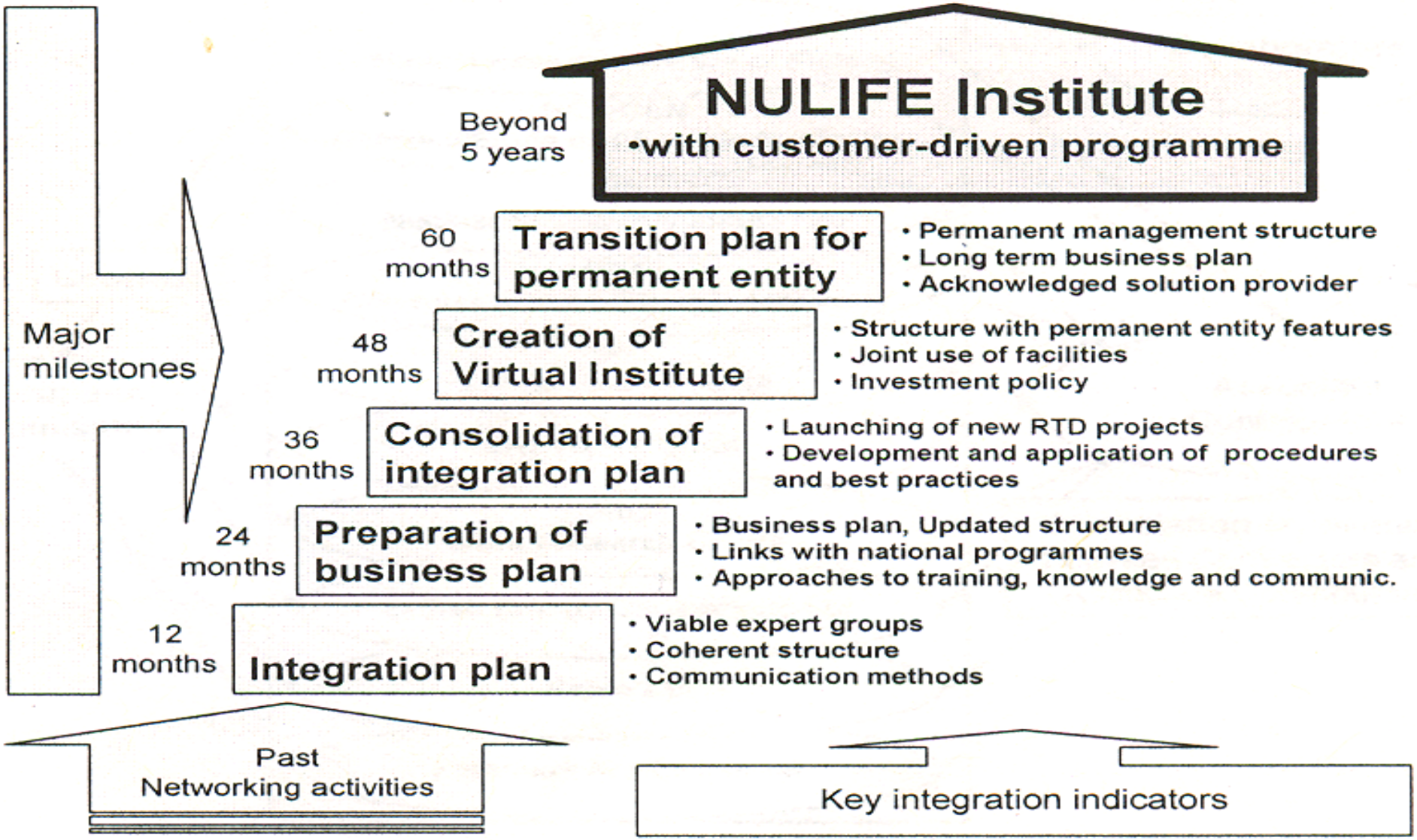
Parallels in Asia

- 2nd International Symposium on the Ageing Management and Maintenance of Nuclear Power Plants - http://nisaplm.jp/H20_0ISaG/
- Coordinating meetings in July, September, and October 2008
  - Tohoku University PMMD Steering Committee
  - PRIMA-NET sponsored International PMMD Workshop
  - FY08 PMMD Experts Meeting

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

Parallels in Europe

(from PNNL-17779)



U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

Results & Path Forward

- NUREG/CR-6923 published 2/07
- NUREG/CR-6936 published 5/07
- Preliminary Analysis of PMDA and IMTs – May-Oct'07
- Presentation to EPRI on 10/24/07
- Follow-on Meeting with Industry – FY09
- Presentations to international regulators & potential participants – FY07-08
- NUREG in preparation for analysis of ISI – FY08
- Develop methodology & user's guide to create PMDA Tool – FY08
- PMMD: Review of Principles & Programs (PNNL-17779) published 9/08
  - includes Appendix B with proposed 62-WP overview program plan
- Develop & revise 5-year research plan – FY08-09
- Engage Potential Partners – FY09
- Begin Research – FY08
- Participate in international LWRSP/PMMD cooperative research group – FY09

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

Conclusions

- Proactive Management of Materials Degradation (PMMD) for nuclear power plant (NPP) systems has the potential to move degradation assessment and its management from a reactive mode to a proactive one through understanding, monitoring and managing materials degradation/aging processes and plant operational practices to optimize life-cycle economics while maintaining the highest levels of safety.
- PMMD will enable extended operation for existing legacy NPP's and moves monitoring and assessment from periodic inspections to use of various forms of on-line monitoring and predictive remaining-life methodologies.
- NRC is investigating how to best developing an international program in the area of Proactive Management of Materials Degradation (PMMD).
- The PMMD Information Tool, and original NUREG/CR-6923, form a core element in the program.
  - Other sources of information will include, as appropriate and publicly available:
    - OPDE Piping Database
    - Operating experience
    - NUREGs, GALL, other NRC sources
    - SCAP & PINC International activities

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

Acronyms

- ADAMS — Agency-Wide Document Access and Management System
- DOE — Department of Energy (U.S.)
- EPRI — Electric Power Research Institute
- IAEA — International Atomic Energy Agency
- I&E — Inspection and Evaluation
- IMT — Issues Management Table
- INPO — Institute of Nuclear Power Operations
- ISI — Inservice Inspection
- LWR — Light Water Reactor
- LWRSP — Light Water Reactor Sustainability Program
- MDM — Materials Degradation Matrix
- NEI — Nuclear Energy Institute
- NPP — Nuclear Power Plant
- NRC — Nuclear Regulatory Commission (U.S.)
- NUREG/CR — Nuclear Regulatory/ contractor report
- PIRT — Phenomena Identification and Ranking Table
- PMDA — Proactive Material Degradation Assessment
- PMMD — Proactive Management of Materials Degradation
- PNNL — Pacific Northwest National Laboratory
- PWSCC — Primary water stress corrosion cracking
- RCS — Reactor coolant system
- SCC — Stress corrosion cracking
- SRM — Staff Requirement Memorandum
- TLR — Technical Letter Report
- WP — Work Plan (detail presented in overview program plan, App. B – PNNL-17779)