US NRC Program for Proactive Management of Materials Degradation

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UNITED STATES NUCLEAR REGULATORY COMMISSION

Protecting People and the Environment

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Presentation at

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Outline

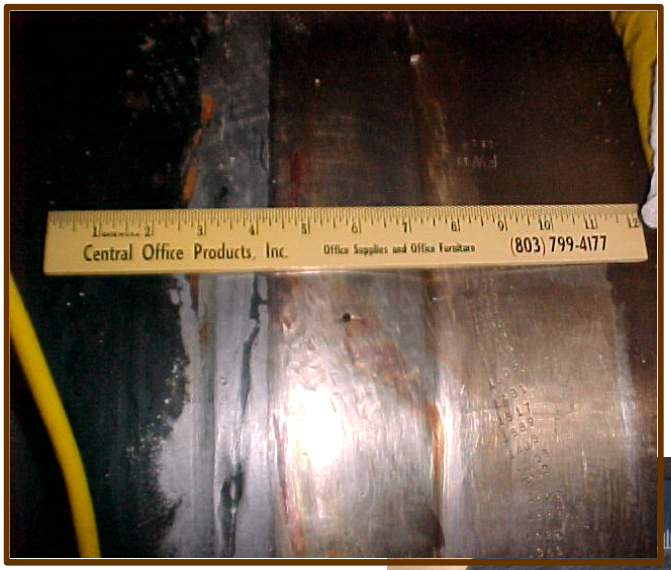
- Potential US Nuclear expansion and life extension
- Proactive Management of Materials Degradation
- PMMD – Information tool – an introduction
- Conclusions/Path Forward

NPP Aging & Life Extension

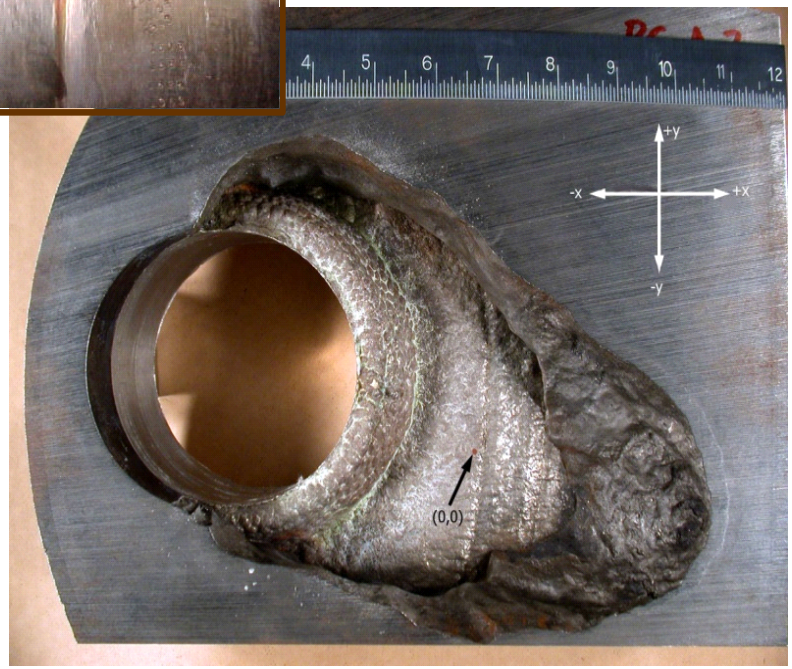
- Nuclear power plant life extension – developing since ~ 1972
  - (US supporting 40-60 years)
- NRC & DOE-NE --- “Life beyond 60” (for LWRs)
  - EPRI, INPO, NEI etc – looking at “40-60” needs.
  - NRC-DOE Workshop Feb 2008 -- Roadmap development
  - DOE-NE new program --- LWR Sustainability Program
  - NRC – Proactive Management of Materials Degradation

Impetus for Proactive Management of Materials Degradation

- 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 collaborations
- Evaluate existing requirements
  - Integrity of susceptible components
  - Inspection and monitoring regulations

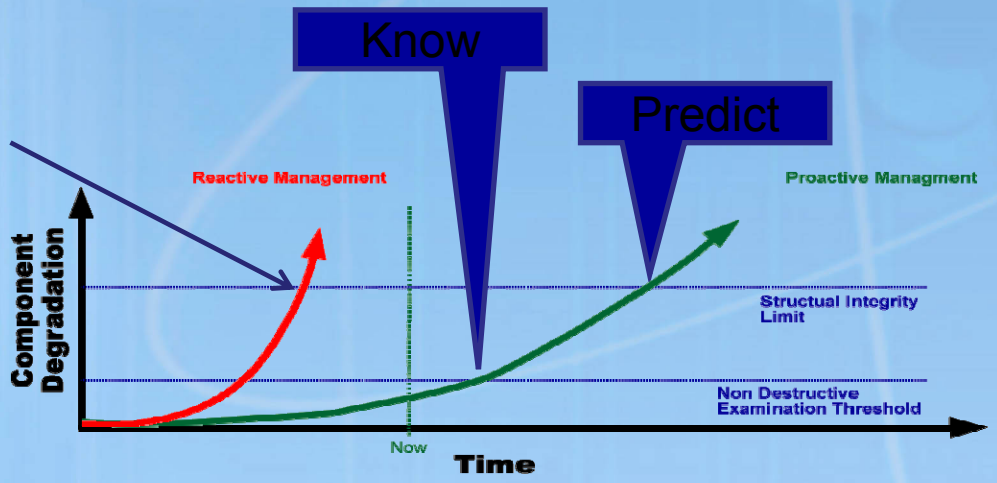


Avoid Surprises e.g. V.C. Summer And Davis Besse



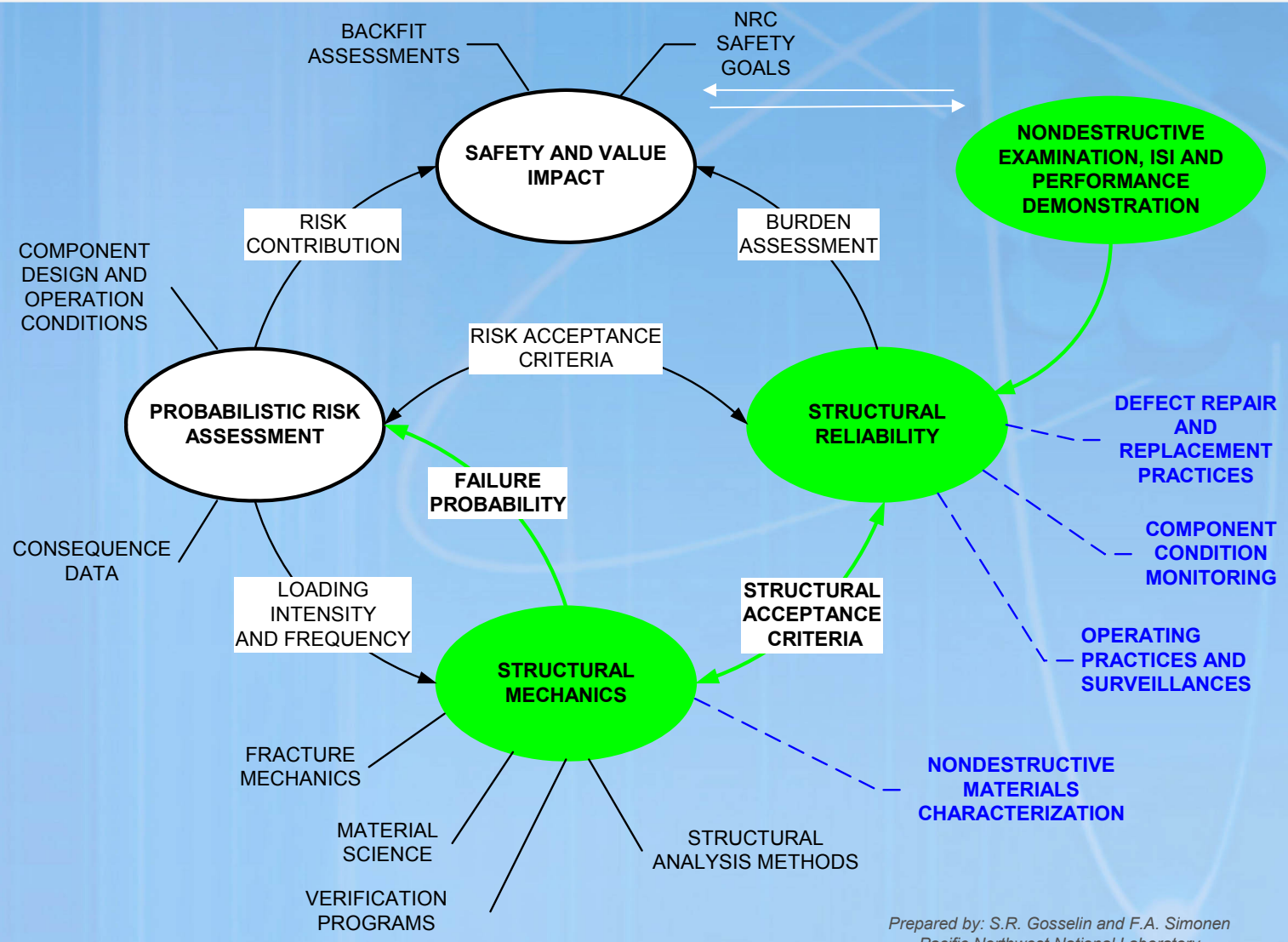
Proactive Approach to Materials Degradation: Products

- Expert panel report on proactive materials degradation assessment
- Proceedings from international meetings
- Literature review on passive components probabilities of failure
- Evaluation of probabilistic fracture mechanics
- Assessment of inservice inspection & leak monitoring



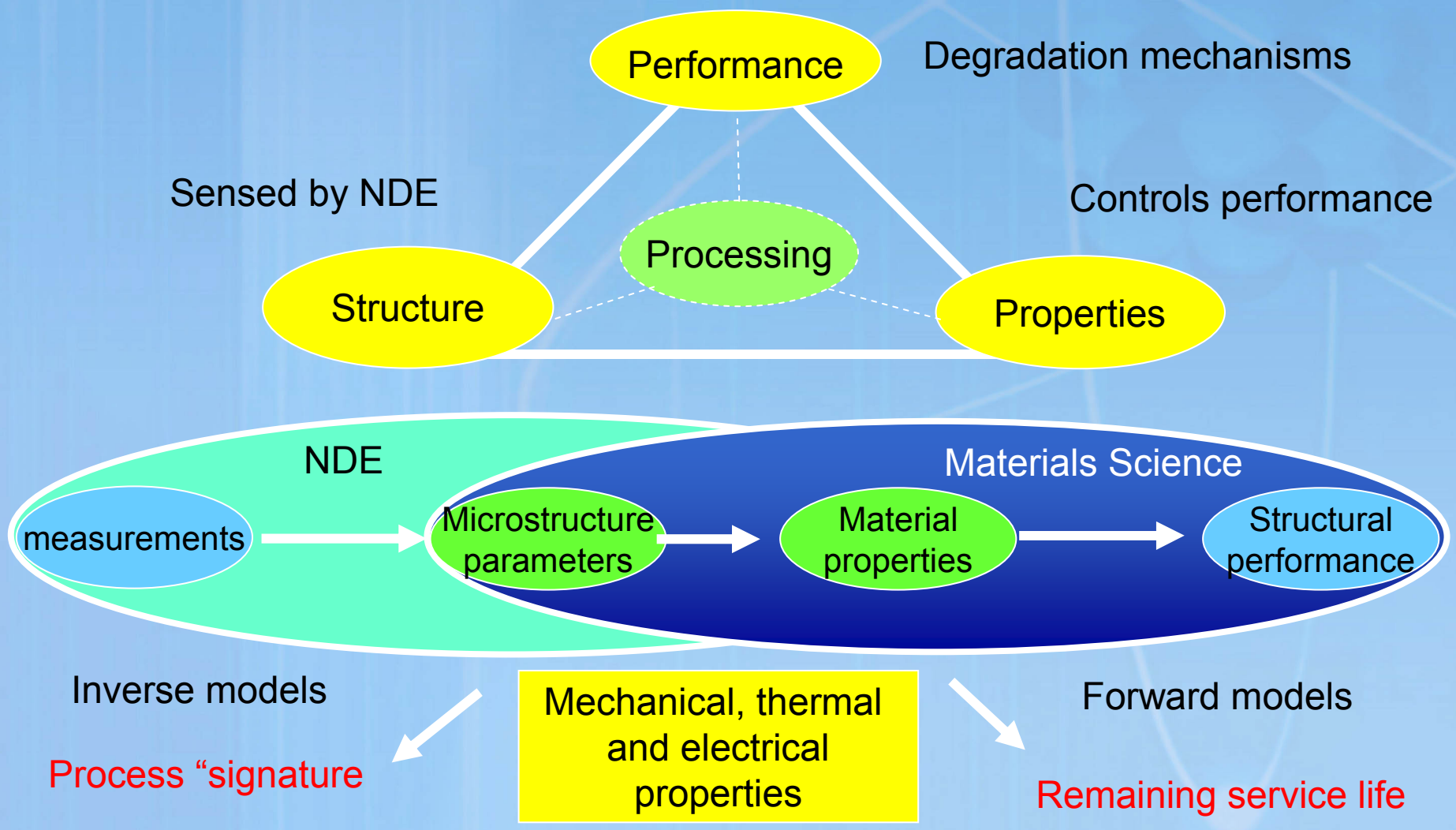
Move from reactive regime to proactive regime

Integrated Structural & Materials Reliability Program



Prepared by: S.R. Gosselin and F.A. Simonen
Pacific Northwest National Laboratory

Advanced Monitoring + Materials Science



DOE-NRC Workshop – February 2008

- U.S. Nuclear Power Plant Life Extension Research and Development.
  - gain a better understanding from stakeholders and the scientific community on needed research to support continued operation of current commercial light water reactor (LWR) beyond a 60-year lifetime.
- Specific breakout sessions included:
  - Industry Discussion on Historical License Renewal Efforts
  - Industry Perspective on Future Industry Needs for Continued Operation Beyond 60 Years
  - Long-Term Reliability of Systems, Structures, and Components
  - Management of Age-Related Materials Degradation Issues
  - Determination of New Technologies, Tools, and Applications for Diagnostics and Monitoring
- This three-day R&D workshop was held February 19-21, 2008 at the Hyatt Regency, Bethesda, Maryland. For more information visit the following website: www.energetics.com/NRCDOEFeb08.

Accomplishments from NRC Work on Proactive Approach to Assessment & Management of Materials Degradation

1. REACTOR COMPONENTS - Identify possible future degradation
   - NUREG/CR-6923 - "Expert Panel Report on Proactive Materials Degradation Assessment," 3895 pp. (published February 07)

2. ISI PROGRAMS - Assess regarding component degradation
   - NUREG "Assessment of Current Inservice Inspection and Leak Monitoring Practices for Detecting Materials Degradation in LWRs" (under revision)

3. RISK SIGNIFICANCE - Assess for component failure
   - Passive Component Conditional Core Damage Probability, Interim Report, March 2005 (John Ridgely –NRC PM)

4. FAILURE PROBABILITY - Estimate for susceptible components.
   - NUREG/CR-6936 "Probabilities of Failure and Uncertainty Estimate Information for Passive Components – A Literature Review (published May 2007, Shah Malik-NRC PM)
   - PNNL-16625 Technical Letter Report "Probabilistic Fracture Mechanics Evaluation of Selected Passive Components -- Technical Letter Report" (published May 2007, Shah Malik – NRC PM)

5. COLLABORATION - develop integrated research materials reliability research per SRM M041108AB and SRM M060206A
   - Proc. 3rd Planning Meeting for International Cooperative Group and Research Program for Proactive Materials Degradation (ML070540111 and CD, Feb'07)

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

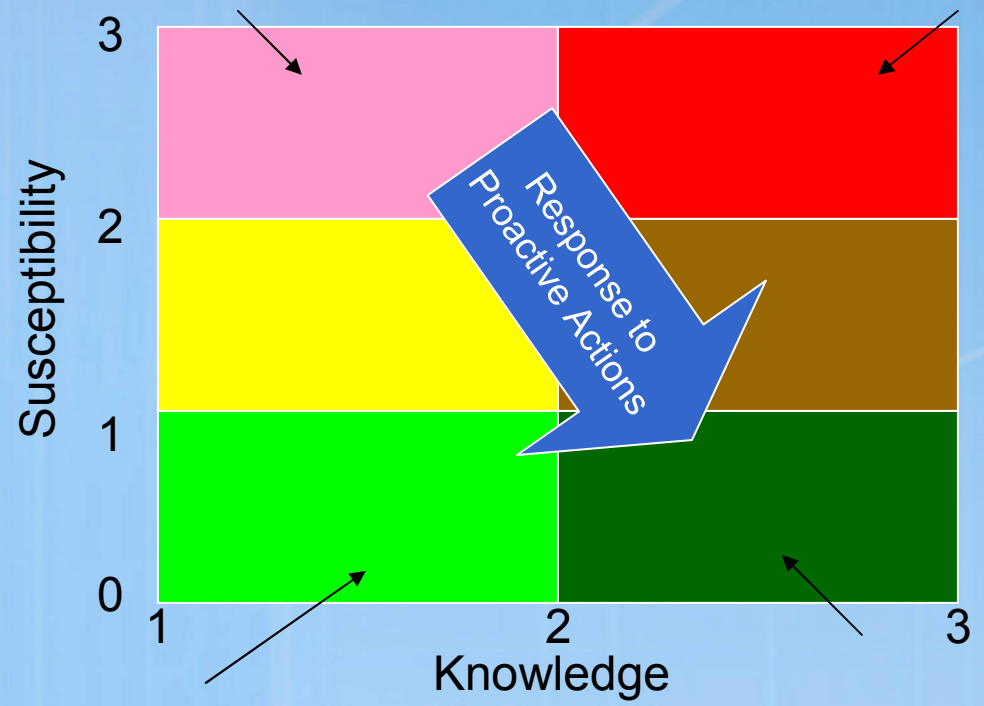
LWR Issue Management Tables

- Bottom-up Approach" based on Materials Degradation Matrix (MDM)
  - Complementary to "Top-Down Approach" used in component-level PMDA/PIRT analysis
  - MDM and IMTs to be maintained as living documents
- IMT focus on degradation of long-lived passive components
- Post-PMDA planning meetings addressed R&D on topics such as:
  - Materials and degradation mechanisms,
  - Mitigation, repair and replacement,
  - Nondestructive examination and continuous monitoring
- Common high priority R&D "gaps" identified from both PMDA and IMT evaluations
  - Inspection & evaluation (I&E) guidelines of reactor internals
  - Environmental fatigue of pressure boundary components
  - PWSCC management: Ni alloy reactor internals

PMDA Susceptibility-Knowledge-Confidence (SKC) Scores

Degradation highly likely, limited knowledge to mitigate it

Degradation highly likely, knowledge exists to mitigate it

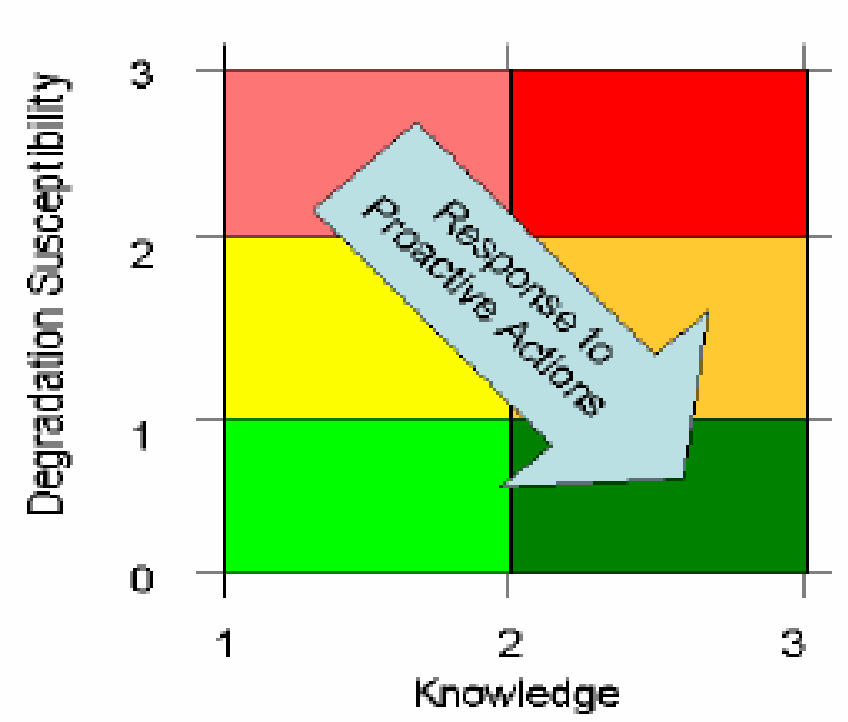


Degradation may be possible, but limited knowledge to mitigate if it did occur

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



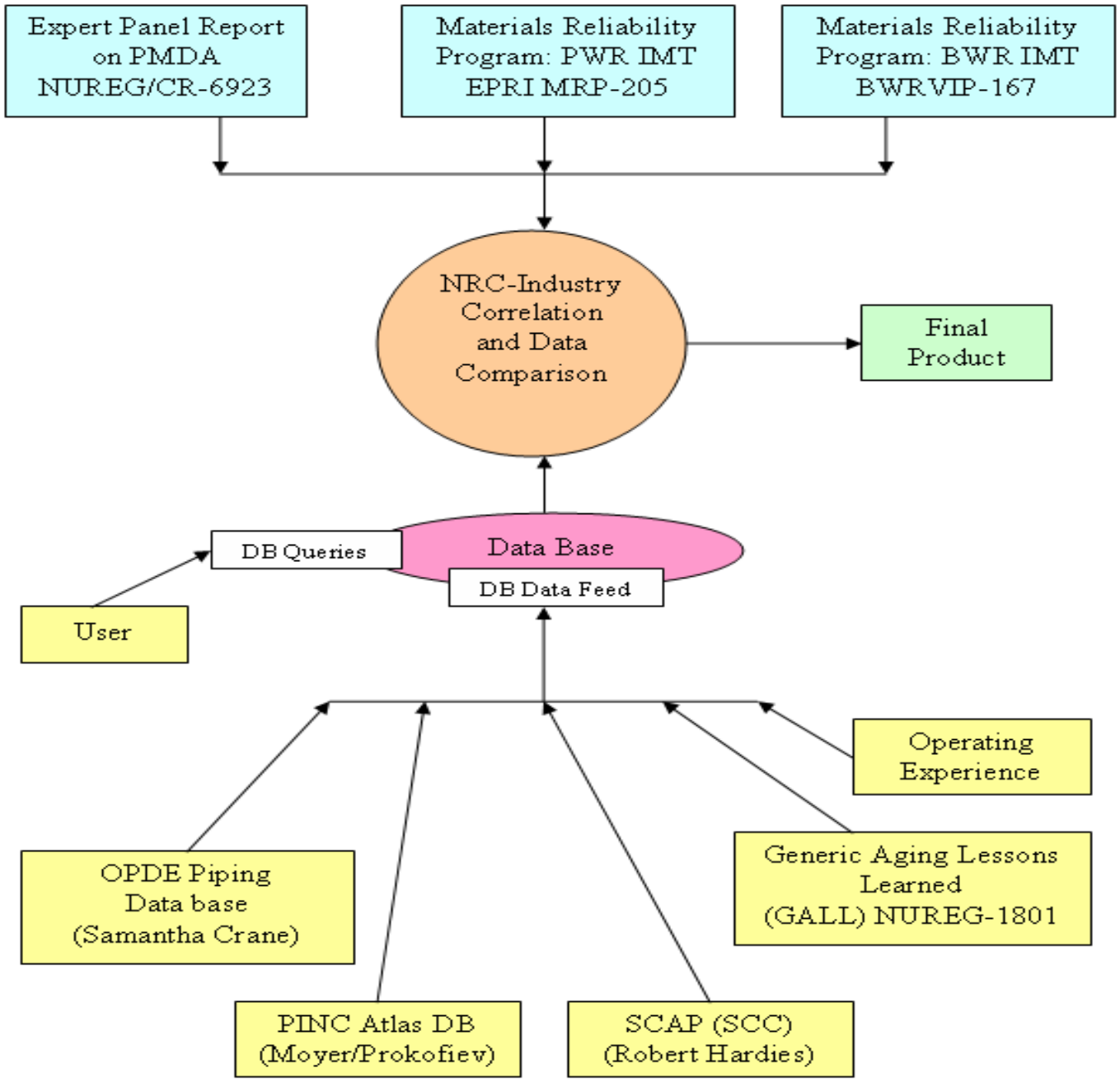
Work on Internals Testing Supported by Analyses of PMDA Results – high degradation susceptibility with limited knowledge for mitigation

System	Subgroup (Structure and/or Component)	Location on Structure and/or Component	Material	Environment	Aging Mechanism	LWR Type	Susceptibility
RCS	12.11 (reactor vessel internals)	Cold-worked austenitic reactor vessel internals	Type 316 austenitic SS	PWR primary water, >0.5 dpa (high fluence); 556°F to 620°F, 2250 psia	Irradiation creep (IC)	PWR	Pink
RCS	12.11 (reactor vessel internals)	Cold-worked austenitic reactor vessel internals	Type 316 austenitic SS	PWR primary water, >0.5 dpa (high fluence); 556°F to 620°F, 2250 psia	SCC	PWR	Pink
RCS	12.11 (reactor vessel internals)	Cold-worked austenitic reactor vessel internals	Type 316 austenitic SS	PWR primary water, >0.5 dpa (high fluence); 556°F to 620°F, 2250 psia	Swelling	PWR	Pink

Process to Develop Plan for Cooperation on PMMD Research

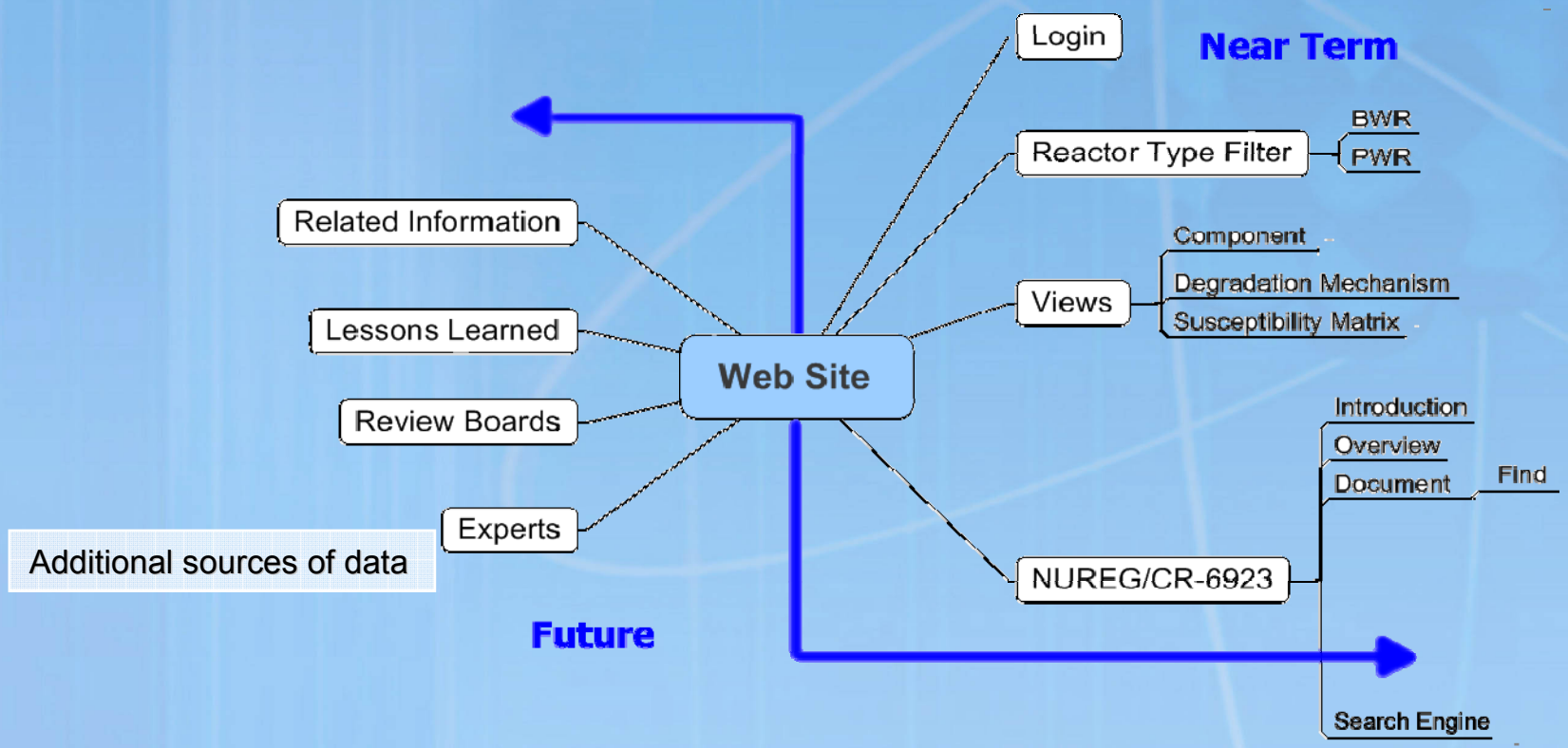
- Focus only on safety-significant items that correspond to high susceptibility, low knowledge, of relevance to operating and new reactors
  - Draw <u>as appropriate</u> upon draft overview program plan (OPP) w/ 62 work plans
    - ❑ Materials degradation (46)
    - ❑ Mitigation strategies (7)
    - ❑ NDE techniques (5)

Topic #	NUREG/CR-6923 Issue	OPP Chapter	OPP Section	PMDM Work Plan ID	OPP Title (NRC PMDM)	PWR IMT counterpart (from MRP-2005, Oct. 2006)	EPRI '07 Portfolio	MRP Project & Task Descroptions for 2007-2008 (Nov.06)
9	high susceptibility to SCC and wear for Alloy 600 MA SG tubes secondary side including crevices, PWR secondary water,544-620F, 1000psia (subgroups 11.6 and 11.14)	component	steam generators	5.1.1.10	SCC and mitigation for Alloy 600TT and 690TT in lead and sulfur contaminated solutions	MT-04 - ODSCC: Ni-Alloy SG Tubing ---- Investigate potential impact of impurities, most notably Pb on the SCC initiation and propagation in Ni Base Alloy Steam Generator Tubes (rated at medium priority) Resolution of this gap will involve development of	P41.01.02.02.01 Steam Generator Management Program (SGMP) Advanced Water Chemistry; P41.01.02.02.04 SGMP Materials and Thermal/Hydraulics -- Secondary-side steam generator tubing degradation continues in both recirculation and once-through steam generato	Although MT-04 was not referenced, a number of projects were generically related to Alloy 600.



Preconceptual "Living" PMMD Tool for Materials Degradation Management

Functional View of PMMD Website



Loaded locally on PNNL computer until any possible security issues are resolved

PMMD Flag View - Windows Internet Explorer

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

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PMMD Flag View

PMMD Proactive Management of Materials Degradation

BWR PWR

Search PMMD go

System/Group | Mechanism Filter | Susceptibility Filter

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- Rainbow View
- Parts List View
- Expert View

Experts

Lessons Learned

Related Information

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

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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.

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PMMD Expert View - Windows Internet Explorer

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

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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

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Results & Path Forward

- NUREG/CR-6923 published 2/07
- NUREG/CR-6936 published 5/07
- Preliminary Analysis of PMDA and IMTs May-Oct'07
- Presentations to international regulators -- AERB, ASN, HSK, RIC – FY 07-08
- NUREG in preparation for analysis of ISI (FY08)
- Companion Guide to NUREG/CR-6923 (FY08)
- Develop methodology & user's guide to create PMDA Tool (FY08)
- Revise original Draft Research Plan "Experiential Approach to Proactive Management of LWR Materials Degradation"
- Internal coordination with NRC stakeholders
- Presentation to EPRI on 10/24/07
- Follow-on Meeting with Industry - FY08
- Engage Potential Partners - FY08
- Begin Research - FY08
- Review, Revise, & Release 60-topic International Program Plan – FY08
- Participate in international PMMD cooperative research group – FY09

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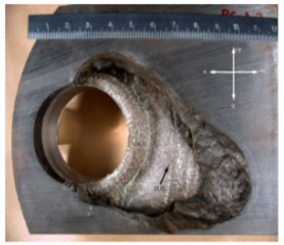
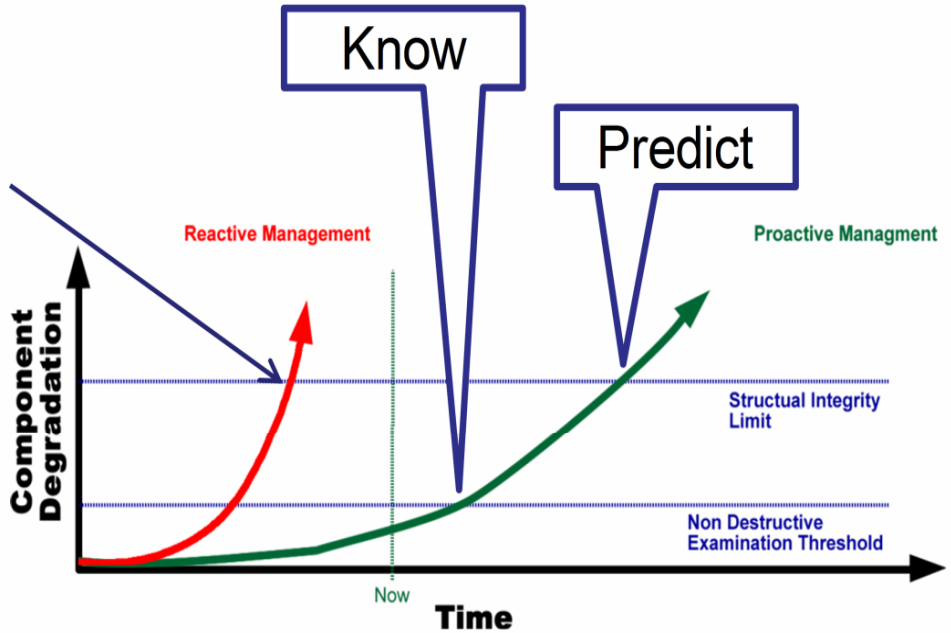
Solution: PMMD





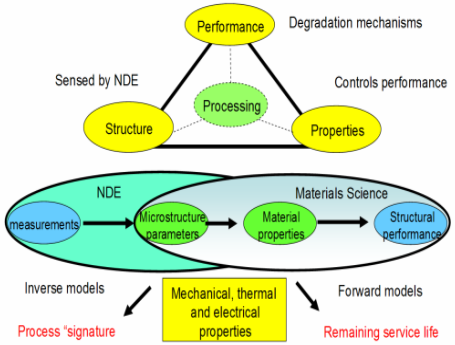
Numerous Large Reports

Distilled and Integrated via Information Tool

Help Identify Research Program Priorities

Degradation Time Line Knowledge Improved

KNOW <u>SOONER</u>



PREDICT <u>ACCURATELY</u>

Better Regulation

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Acronyms

- ADAMS — Agency-Wide Document Access and Management System
- EPRI — Electric Power Research Institute
- IAEA — International Atomic Energy Agency
- I&E — Inspection and Evaluation
- IMT — Issue Management Table
- LWR — Light Water Reactor
- MDM — Materials Degradation Matrix
- NPP — Nuclear Power Plant
- NRC — Nuclear Regulatory Agency
- PIRT — Phenomena Identification and Ranking Table
- PMDA — Proactive Material Degradation Assessment
- PMMD — Proactive Management of Materials Degradation
- PNNL — Pacific Northwest National Laboratory
- RIC — Regulatory Information Conference
- RIS — Regulatory Information Summary
- SKC — Susceptibility Knowledge-Confidence
- SRM — Staff Requirement Memorandum