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NRC/DOE workshop on research and development issues

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Bethesda, Maryland

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Southern Nuclear

Chairman, Primary Systems Corrosion Research Steering Committee

Background

- In 2002 Industry Executives formed a Task Group to assess materials issues and the industry's efforts to deal with them
- As a result NEI 03-08, "Guideline for the Management of Materials Issues" was approved by NSIAC
- Establishes two Standing Committees
  - Executive Oversight – 'MEOG'
    - Overall coordination/broad policy guidance
      - NSIAC members, Executive Leads of Issue Programs
  - Technical Advisory – 'MTAG'
    - Support MEOG and IPs, develop 'strategic' plan
      - Technical leads of the IPs
- Establishes Policy
  - Defines roles, responsibilities, and expectations
- Develop Proactive tools and approaches to manage materials aging

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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

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Revision 1 DM Results Table (example)

TABLE 3-1
PWR REACTOR PRESSURE VESSEL (2007 MATERIALS DEGRADATION MATRIX)

MATERIAL	DEGRADATION MODE												
	SCC		Corrosion & Wear				Fatigue		Reduction in Toughness		Irradiation Effects		
	IG/TG	IA	Wstg.	Pitting	Wear	FAC	HC	LC-Env.	Th.	Env.	Emb.	VS	SR
C&LAS	N	N	N	N	N	N	Y p1-1	Y p1-2	? p1-3	? p1-4	Y p1-5	N	N
C&LAS: Welds	N	N	N	N	N	N	Y p1-1	Y p1-2	? p1-3	? p1-4	Y p1-5	N	N
SS: Wrought / Forged / HAZ	Y p1-6	N	N	N	N	N	Y p1-1	Y	N	? p1-4	N	N	N
SS: Welds & Clad	Y p1-6	N	N	N	Y p1-7	N	Y p1-1	Y	Y p1-8	? p1-4	Y p1-9	N	N
CASS	? p1-10	N/A p1-11	N	N	N	N	Y p1-1	Y	Y p1-12	Y p1-4	N/A p1-11	N	N
Ni-Alloy: Wrought	Y p1-13	N p1-14	N	N	Y p1-15	N	Y p1-1	Y	N	? p1-4	N p1-14	N	N
Ni-Alloy: Welds & Clad	Y p1-13	N p1-14	N	N	N	N	Y p1-1	Y	Y-600 p1-16 Y-690 p1-16	Y p1-4	N p1-14	N	N

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Revision 1 Materials Degradation Matrix Results

- Compared with the 2004 MDM, the numbers of blue and yellow cells have both decreased and the number of green cells has increased
- Additional orange cells are apparent in the Revision 1 MDM related to:
  - SCC of irradiated materials and nickel alloys in PWRs
  - Environmental fatigue
  - Reduction in toughness
- An emerging issue of concern is reduction in fracture resistance of structural materials in environment
- All of the important degradation mechanisms identified in the **NRC PMDA** are reflected in the revised MDM

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Revision 1 Materials Degradation Matrix Strategic Issues

- Environmental Effects on Fracture Resistance
- Environmental Effects on Fatigue Life
- SCC of Ni-Base Alloys
- SCC of Stainless Steels
- Effect of Fluence on SCC Susceptibility and SCC Crack Growth Rates

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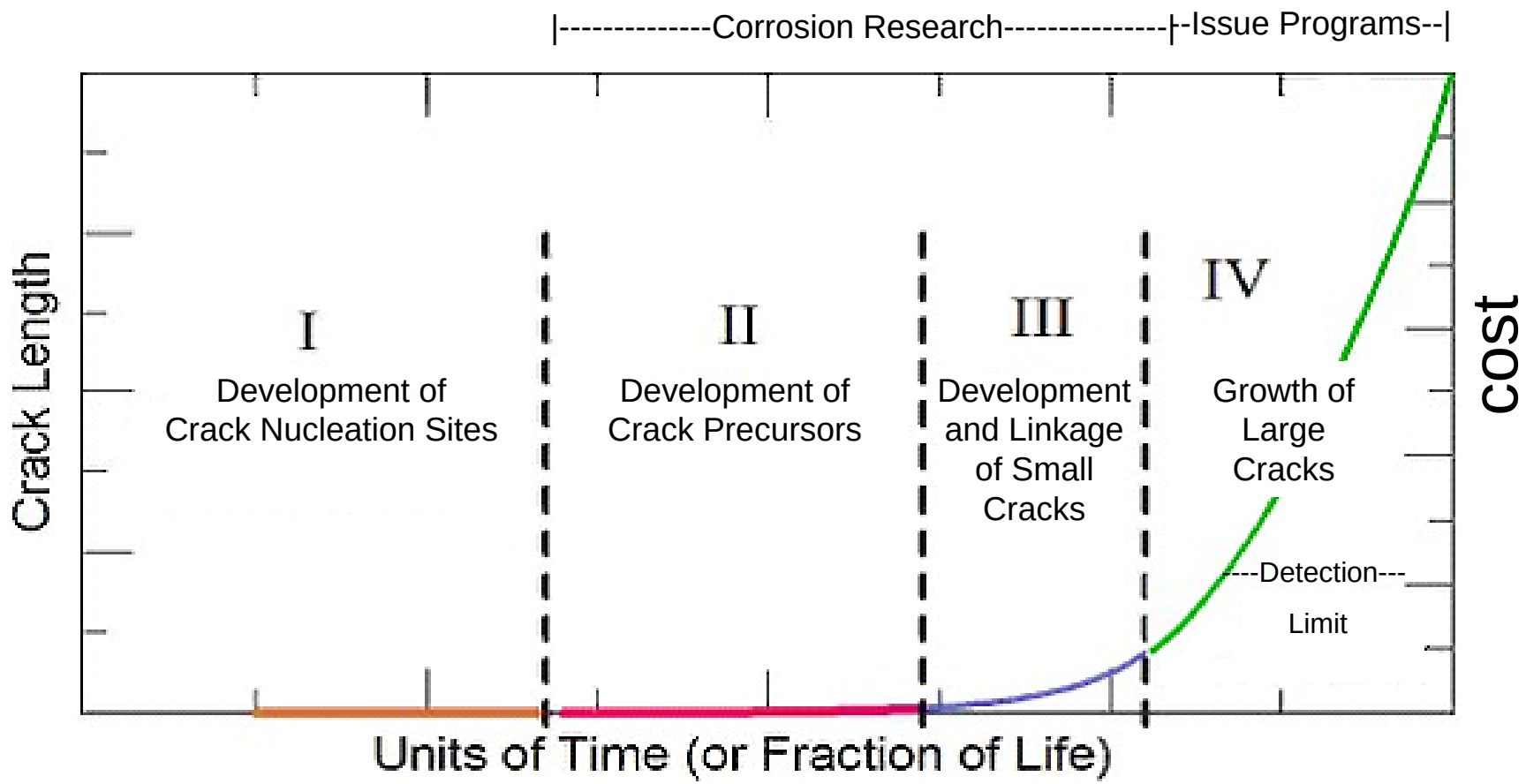
Progression of Environmental Cracking Damage



Proactive Materials Management Has a Big Payoff

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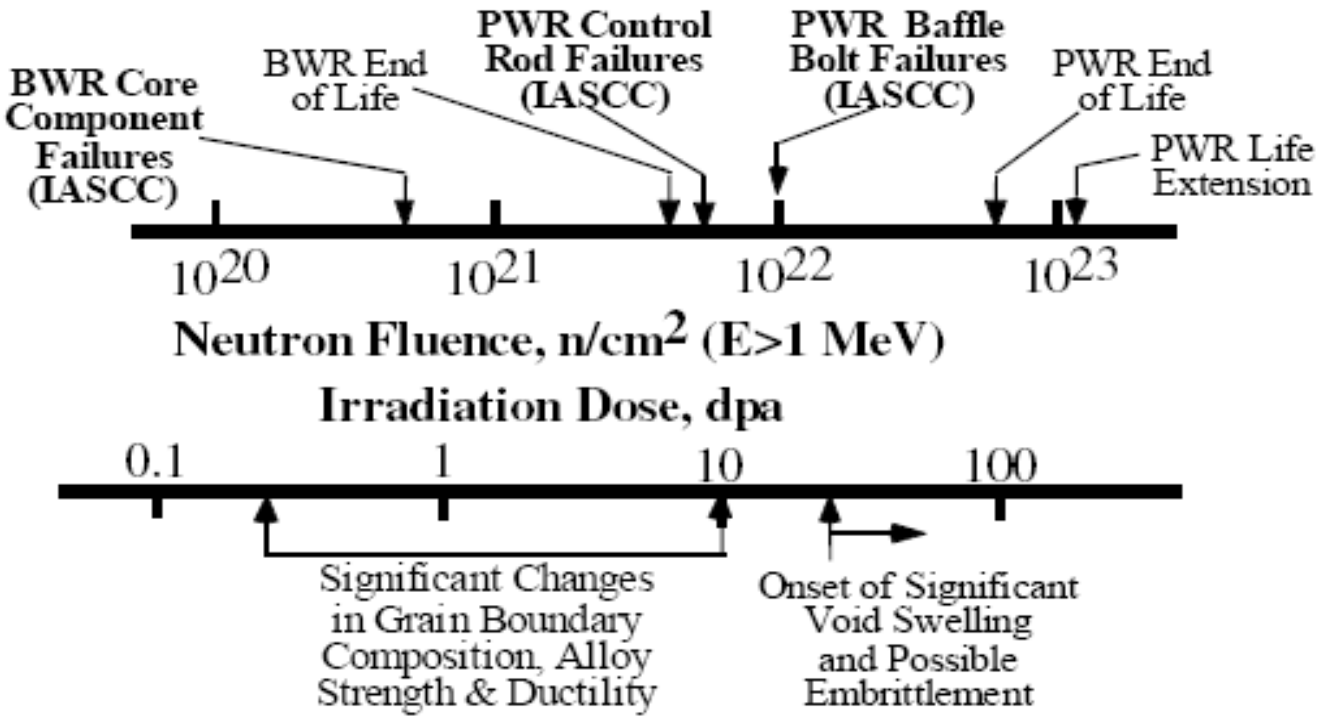
Characteristics of IASCC in Austenitic Stainless Steels



Note : ~15 dpa • 10^{22} n/cm^2 E • 1 MeV (for PWR and BWR neutron spectra)
~7 dpa • 10^{22} n/cm^2 E • 0.1 MeV (for PWR and BWR neutron spectra)

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Current Activities

Current Primary Systems Corrosion Research Activities

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Primary Systems Corrosion Research Projects: Scope

- Cooperative IASCC Research (CIR) Program-Extension
  - International collaborative research program managed by EPRI and co-sponsored by organizations from U.S., Europe and Japan
  - Members include utilities, regulators, vendors and research organizations
- Scope
  - Develop a mechanistic understanding of key parameters (material, fluence, flux, temperature, chemistry and stress) that control IASCC initiation and growth
  - Formulate predictive models for IASCC based on a mechanistic understanding
  - Identify suitable countermeasures for IASCC
- Status
  - An interim review of the CIR Program (1015493) and CIR II CD (10151760) issued in 2007
  - Crack growth tests on BOR 60 irradiated materials are in progress at Studsvik and NRI Rez
  - Final deliverables will be completed in 2009

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Primary Systems Corrosion Research Projects: Scope (contd.)

- International Program on Prediction and Evaluation of EAC in LWR Structural Materials at Tohoku University, Japan
  - Program co-sponsored by EPRI, Japanese government, utilities, vendors and several international organizations
  - Allows significant leveraging of EPRI resources
  - Sponsors have agreed on a follow-on program to improve the fundamental understanding of crack initiation and propagation processes
- Scope
  - Develop data and predictive models to improve the mechanistic understanding of SCC of stainless steels and Ni alloys in BWR and PWR environments
- Status
  - A final report on Phase III of program (1014977) issued in 2007

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Primary Systems Corrosion Research Projects: Scope (contd.)

- In-situ characterization of surface films on Ni-base alloys in LWR environments
- Scope
  - Use in-situ laser Raman and electrochemical techniques to characterize composition of surface films formed on Ni alloys under PWR conditions and their role in SCC
  - Evaluate the effect of chemical additives (e.g., zinc) on surface films
- Status
  - Interim report to be issued in Q1 2008

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Primary Systems Corrosion Research Projects: Scope (contd.)

- Ex-situ surface film studies of SCC initiation on SS and Ni-base alloys
- Scope
  - Study incipient crack formation with state-of-the art analytical techniques
  - Status
  - Report to be issued in 2008

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Primary Systems Corrosion Research Projects: Scope (contd.)

- Damage Processes Prior to Crack Initiation in Ni-Base Alloys
- Scope
  - Study role of intergranular oxidation of Ni-base alloys (A600 and A690) in crack initiation under PWR conditions
  - Evaluate effects of temperature, corrosion potential, cold work and stress on kinetics of intergranular penetration and GB embrittlement
  - Focus on crack precursors (Stage II) of EAC degradation
- Status
  - Agreement signed with Areva
  - Work to begin in Jan 2008 on a 2-year project

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Primary Systems Corrosion Research Projects: Scope (contd.)

- Mechanistically Based Predictive Model for Environmentally Assisted Cracking of Ni-Base Alloys in PWRs
- Scope
  - A theoretical model of SCC propagation based on work at FRRI, Japan and KAPL will be modified and validated by EPRI for application to SCC of Ni-base alloys and weld metals in PWR environments
  - Explore extending the model to irradiated materials
- Status
  - A report on application of model to Alloy 600 is being reviewed by EPRI and will be issued in 2008

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Primary Systems Corrosion Research Projects: Scope (contd.)

- Initiation of EAC and Short Crack Growth
  - Follow-on work recommended by MEOG Gap project report 1011788 prepared by Areva and GE
- Scope
  - Conduct follow-on experimental and modeling work based on recommendations of EPRI Report 1011788 on Status Review of Initiation of EAC and Short Crack Growth
  - Focus on Stage III of EAC degradation
  - Status
  - An interim report to be issued in 2008

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Primary Systems Corrosion Research Projects: Scope (contd.)

- Understanding of Interaction between Localized Deformation in Materials and Environmentally Assisted Cracking (EAC)
  - Follow-on work recommended by MEOG Gap project report 1011789 prepared by EDF
- Scope
  - Conduct follow-on experimental and modeling work on Interaction between Localized Deformation in Materials and Environmentally Assisted Cracking
  - Investigate role of localized deformation in IASCC of stainless steels on proton irradiated stainless steels
- Status
  - Interim report to be issued in 2008

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Primary Systems Corrosion Research Projects: Scope (contd.)

- Assessment of Fracture Resistance Issues in LWR Environments at Low Temperature
  - Address gaps in current knowledge of LTCP susceptibility of LWR materials identified in the MDM
- Scope
  - Fracture resistance of Alloy 182 in BWR-HWC environment at low temperature
  - Fracture resistance of cast austenitic SS in PWR environment at low temperature
- Status
  - Interim report to be issued in 2008

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Corrosion Research: 2008 Planned Deliverables

- Materials Degradation Matrix – Revision 1
- Characterization of Surface Oxide Films in PWR Environments – Interim Report
- Experimental Results of Interaction between Localized Deformation and EAC – Interim Report
- Experimental Results of EAC Initiation and Short Crack Growth – Interim Report
- Damage Processes Prior to Crack Initiation in Ni-Base Alloys – Interim Report

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Future IASCC Research

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Future IASCC Research: Background

- The CIR Program irradiated commercial and solute addition alloys (tensile and round compact tension specimens) in the BOR 60 fast reactor to study the effect of specific solutes on IASCC
- Some of these alloys will be tested in the CIR II Extension program but resources were not available to test all irradiated alloys
- The remaining solute addition and commercial alloys are available to CIR sponsors for future IASCC research
- NRC RES and EPRI have discussed a joint program (at University of Michigan) to:
  - *determine the roles of key solute additions and microstructures on both crack initiation and crack growth*
  - *develop a more complete understanding of IASCC by building on the CIR work*
- Results of this work will be shared with CIR sponsors who funded the irradiations

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Objectives of Proposed Program on Identifying Mechanisms & Mitigation Strategies for IASCC of Austenitic Steels in LWR Core Components

- Full assessment of **solute addition** alloys and in particular, the roles of all 9 solute additions on *crack initiation* and the roles of C, Mo, Ti, Nb, Cr+Ni and P on *crack growth rate*.
- Determination of the roles of **commercial alloy microstructure** on *crack initiation* and *crack growth rate*.
- **Linkage** between irradiated *microstructure* and *crack initiation/crack growth* for solute addition and commercial alloys as well as effects of CW and dose.
- Relation between **cracking susceptibility** as measured by *CERT tests* and *CGR tests* on neutron irradiated alloys.
- Determination of the predictive capability of crack initiation due to **proton irradiation** as compared to **neutron irradiation**.
- Role of **localized deformation** in the IASCC susceptibility in neutron irradiated materials.

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Significance of the Proposed Program

The proposed work will determine:

- The roles of key solute additions and starting microstructures on both crack initiation and crack growth
- The degree to which crack initiation and crack growth respond in the same way to alloy composition and microstructure
- Whether proton irradiation is a robust predictor of neutron irradiation effects for both crack initiation and crack growth
- The importance of localized deformation and stacking fault energy in IASCC
- What mitigation measures should be adopted to minimize IASCC in current LWR stainless steel components
- This work will build on the CIR program and help to significantly advance our knowledge and understanding of the IASCC process, and provide a large contribution to the IASCC database for further study and analysis

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Other IASCC Research Areas

- Effect of specimen size and K on crack growth in irradiated specimens
  - Most CGR tests have been done on small CT specimens (0.3 to 0.4 T)
  - There are no ASTM standards re K validity limits for irradiated materials
    - ASTM E399 standard may not be appropriate
  - It is necessary to test thicker specimens from retired components to determine K validity limits and to demonstrate that CGRs are independent of specimen size

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Environmental Effect on Fracture Properties

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Background – EPRI MDM / NRC PMDA on Fracture Resistance Issues

***Generic concerns emphasized by both panels*:**

1. Degradation of fracture resistance of certain Ni-base alloys at low temperature (**L**ow **T**emperature **C**rack **P**ropagation)
   - Considered a form of hydrogen embrittlement
   - Observed in laboratory tests (Bettis & MRP studies)
2. PSCR is addressing potential for LTCP phenomenon in other materials and environments where no data is available
   - LTCP of Alloy 182 in BWR-HWC
   - LTCP of Cast SS in PWR water
3. Concerns remain (for irradiated and non-irradiated materials) about the validity of fracture toughness values measured in air compared to values in the operating environment at temperature

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Irradiated Wrought and CASS in BWR Env.
(From O. Chopra: Interim Conclusions)

- Results from ANL tests in water show the same general trend in irradiation effects on embrittlement (J_{IC}), but values are lower than those from air tests
- Controlled companion tests in air on the same materials are needed to determine the effect of water environment on fracture toughness

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Proposed 2009 Project: Effect of Environment on Fracture Resistance in LWR Materials

- Objective
  - Conduct a scoping study to evaluate the effect of BWR and PWR environments on fracture resistance of:
    - Task A: Irradiated stainless steels
    - Task B: Non-irradiated Alloy 182 weld metal
  - Assess need for additional work based on test results
- Value
  - Degradation of fracture toughness by environment is an important issue for structural integrity evaluations
  - This study will address an important knowledge gap in the MDM
  - This work is cross-cutting and of interest to PSCR, BWRVIP and MRP

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Conclusions

- Industry's focus on Materials Aging and Degradation has provided strategic direction
- Efforts underway address the high priority items from the strategic plan
- Current research underway is focused primarily on nearer term (5-10 years)
- Research looking at longer-term issues is limited and will produce valuable insights into early stages of degradation and identify methods of mitigation. Additional research will be required develop and implement the mitigation technologies

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