PWR issues for LWR life extension

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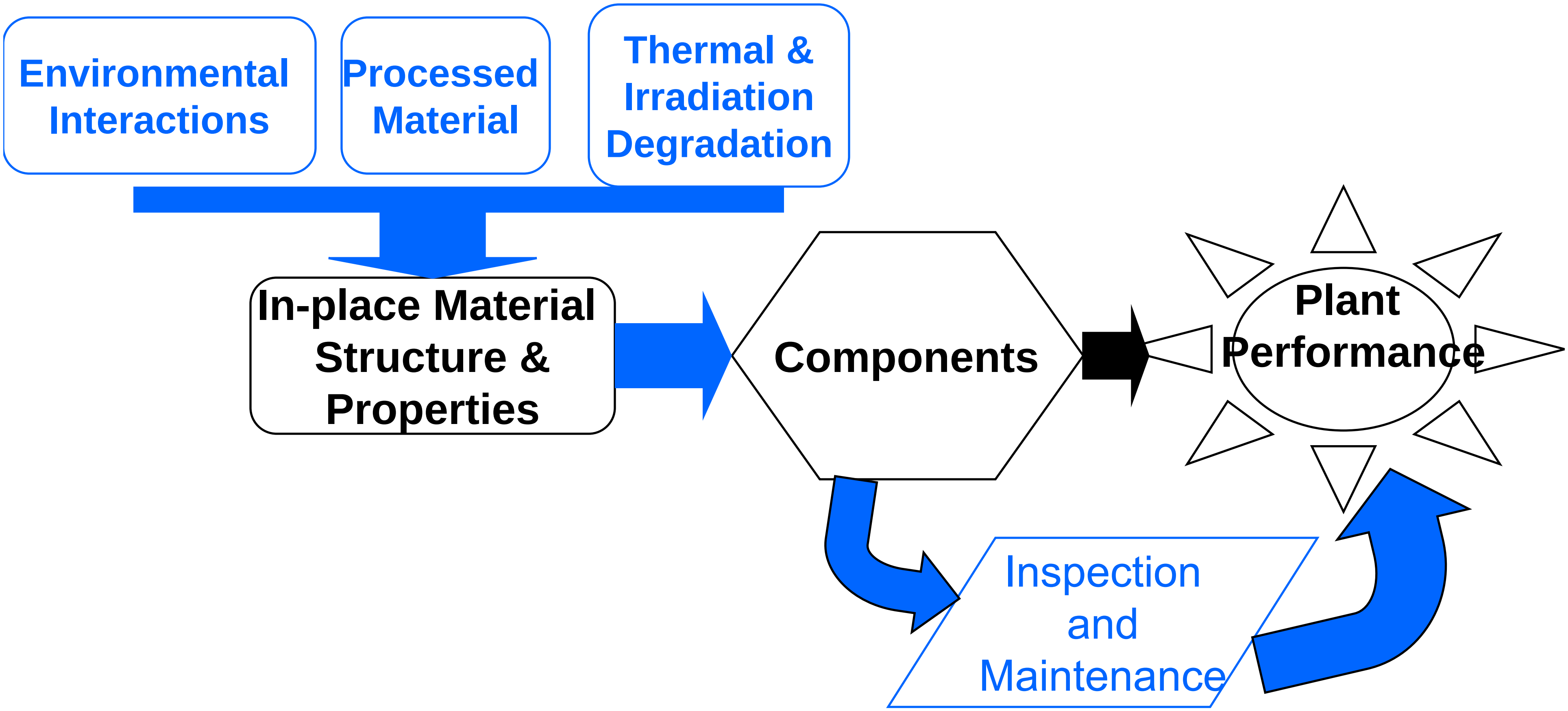
“Life After 60” Workshop
Panel 3 : Materials”

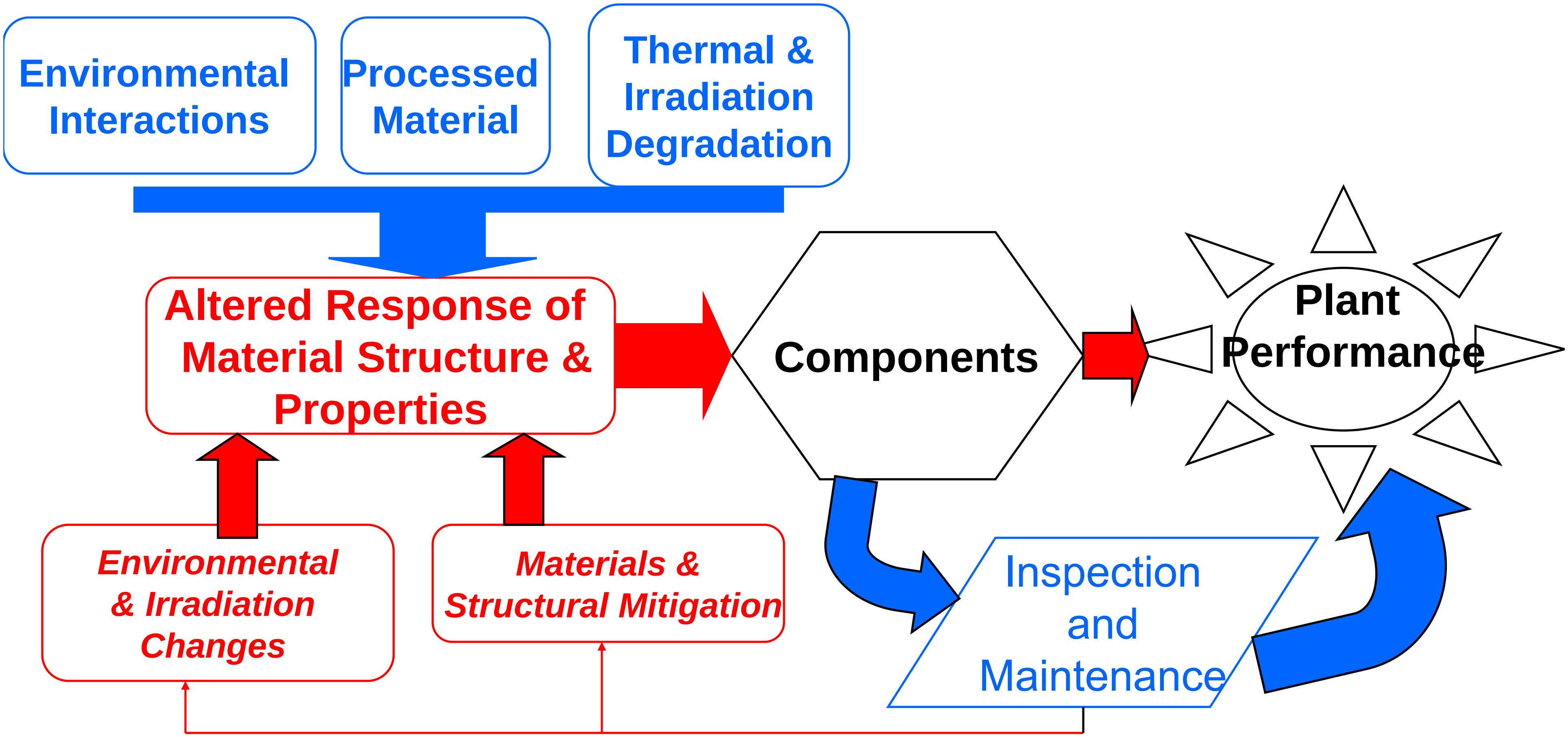
February 20th 2008
Bethesda Md.

Original Plant Design Approach : Materials Response to Service Controls Component and Plant Performance



Life Extension Plant Design Approach :

Component and Plant Performance Are Controlled by Materials Mitigation and Service Cycle Changes



Materials for Pressure Boundary –
Pressure Vessel Steels

- Status
  - Low Alloy Steel Selections – A508, A533
  - Existing Steels with in-place Chemistries
  - Welded Construction
  - Established Welding Practices
  - Established Database on Pressure Vessel Embrittlement
- Challenges
  - Follow Embrittlement Correlations to 80 years
  - Changes to Embrittlement Correlations Equations
  - Development of Minimally Conservative Extension of Embrittlement Correlations to Support Realistic and Operationally Viable Pressurized Thermal Shock Rules.
  - Transition from Charpy Toughness Measurements to Proper Fracture Toughness Testing
  - Resolution of chemical, flux and temperature effects in datasets

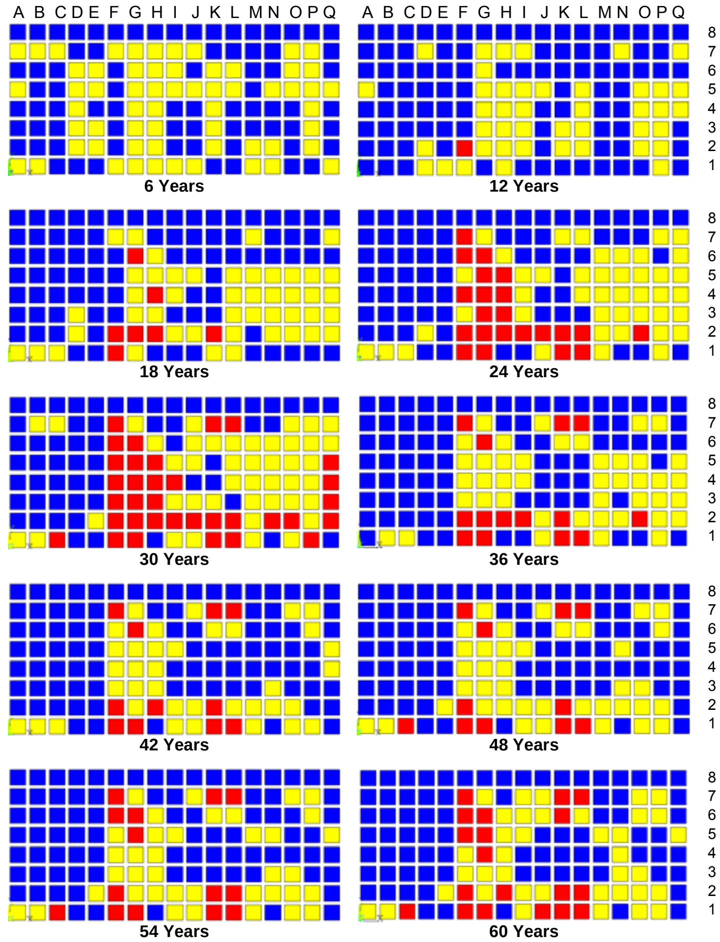
Materials for Pressure Boundary – Ni Alloys for Vessel Penetrations And Dissimilar Metal Welds

- Status
  - Alloy 690 has supplanted Alloy 600
  - Alloy 690 shows superior service capabilities to alloy 600 – Heat treatments for 690 based on optimization of Heat Treatment for Alloy 600
  - Behavior of Alloy 690 Weld Metals (Filler Metal 52/152) Follows Improvements of Wrought Alloys
  - Properties of Deposited Filler Metal 52 Shown to be Sensitive to Processing and Interactions with substrates
- Challenges
  - Optimization of weld alloy and procedures for Alloy 690 Welding (Performance of Filler Metal 52)
  - Determination of Effect of Filler Metal Dilution on SCC of Deposited Filler Metal 52 – limit of acceptable level of Cr in deposits ?
  - Assurance of Long Term Alloy 690 properties – SCC Crack Initiation Lives
  - Quantitative Determination of Crack Propagation Rates for Alloy 690 and Weld Metals (e.g. for LBB analyses)
  - Understanding Chemical Effects (H_2, Zn mitigation treatments …)

Materials For Reactor Internals
Austenitic Stainless Steels

- Status
  - Degradation of Forged Austenitic Stainless Steels in Irradiation Field is Well Established
  - Quantification of Such Degradation is in Progress – (Data Scatter)
  - Potential Onset of Marked Swelling after 60 years ?
  - Automated Evaluation Programs Have Been Demonstrated
  - CASS Remains a Challenge – Potential Synergy of Thermal and Irradiation Embrittlement Could Call for Excessive Conservativism
- Challenges
  - Understanding very long term behaviors – PWSCC, Fracture Toughness, Swelling (High Fluence, End of Life)
  - Better Quantification of Properties and Failure Lives – Understand Test Method Dependence of Data → Resolve Scatter in Data
  - Improvement of Automated Analyses (Reliability, Acceptance, Flexibility)
  - Resolution of Thermal vs Irradiation Embrittlement Effects in CASS
  - Key Understanding of In-Reactor vs In Lab/Hot Cell Behavior

Materials For Reactor Internals
Automated Evaluation of IASCC Susceptibility



Global IASCC Susceptibility

- **Blue : No Concern**
- **Yellow : Minimal Concern**
- **Red > Increase Concern**

Constitutive Modeling of Materials Degradation Can Provide Rapid Screening of Large Systems and Precise Analysis of Highly Localized Systems but…

The Output is Only as Good as the Inputs and the Evaluation Criteria !

Materials for Pressure Boundary – Stainless Steel Penetrations for Pressurizers

- Status
  - Stainless Steels have Performed Well over 20 Years
  - Some Recent Failures in France and US – Mainly in Replacements

- Challenges
  - Resolution of Recent Effects

Materials for Steam Generator Internals
Nickel Base Alloys

- Status
  - Alloy 690 and its Weld Metals are now well established in Corrosion resistant application.
  - Heat Treatment of Alloy 690 based on optimized practices for Alloy 600
  - Alloy 690 Filler Metals (52, 152) have been developed
- Challenges
  - Variations in Alloy 690 SCC database for crack propagation – Need to understand the effects of processing etc.
  - Complete characterization of Weld alloy Chemistry-Processing-Property Relationships.
  - Structure and long time behavior of weldments and cladding
  - Fully quantify benefits over Alloy 600
  - Understanding Chemical Effects (H_2, Zn mitigation treatments …)

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Materials For Fuel

- Status
  - UO_2-Zirconium Alloy Clad fuel systems are well established
  - Improvements to cladding include improved alloys

    Zirc → Zirlo → Beyond
  - Development of Alloys is Ongoing
  - Testing is Very Time Consuming – Long Lead Time to Implementation

- Challenges
  - Pellet-clad interactions
  - High Burn-up fuel system for more economic operation
  - Surface Interactions of Fuel Clad Rod with Reactor Environment and Surrounding structure
  - Fuel-Coolant Interaction (Crud) Mitigation

Materials Issues For Existing Plants

Ferritic Low Alloy steels	Irradiation Embrittlement →PTS Rules, Resistance of Head Penetrations to SCC, Fatigue of Piping
Ni Base Alloys	SCC of Head Penetration Welds, SCC of Dissimilar Metal Welds in RV and Pressurizer Nozzles, SCC in SG Tubing, Protection of SG Tube Sheets,
Stainless Steels	Internals Hardening and Embrittlement, SCC of baffle Bolts, SCC of Welded Internals, Mitigation of Piping Welds, Thermal and Irradiation Embrittlement of CASS
Zr Alloys	Fuel Rod Leakage, Integrity of Welds, New Materials with Reduced Oxidation/Hydriding CRUD Formation Mitigation