Materials Issues Related to Reactor Design, Operation & Safety

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Objective

- **To Develop an Understanding of Materials Issues and Their Implications for Design, Operation & Safety**

Outline

Lecture #1: Materials Selection

Lecture #2: Radiation Damage/Effects & Implications for Design

Lecture #3: Environmental Degradation & Implications for Design

Lecture #4: Applications to PWR Design (Steam Generator Design, Penetrations)

Lecture #5: Applications to GFR Design

Materials Selection Considerations

- Applicability
- Suitability
- Fabricability
- Availability
- Economics
- Compromise

Assessment of Applicability

1. Mechanical Environment
    - Stress (Load) History
    - Strain History
    - Normal, Transient, Accident
2. Chemical (Electrochemical) Environment
    - Normal, Faulted
3. Thermal Environment

4. Nuclear Environment

5. Mechanical-Chemical-Thermal-Nuclear

General Material Failure Modes

1. Overload

2. Creep Rupture

3. Fatigue

4. Brittle Fracture

5. Wastage

6. Environmentally Enhanced

7. Radiation Effects Related

Environmentally Enhanced Failure Modes

1. Stress Corrosion Cracking
2. Hydrogen Embrittlement
3. Corrosion Fatigue
4. Intergranular Attack
5. Erosion-Corrosion
6. Creep-Fatigue Interaction

Key Point

- **Big Difference Between General & Localized Corrosion**
  - General Corrosion
    - » Predictable
    - » Slow (Normally)
  - Localized Corrosion
    - » “Unpredictable
    - » Potentially Very Rapid
    - » Can be Multi-Phenomena (Pitting leading to Crack Initiation)
  - Significant Design Implications
    - » Example-PWR Steam Generators

Radiation Effects Related

- Radiation Embrittlement
- Radiation Enhanced Creep
- Swelling
- Radiation Induced Growth
- Fuel/Clad Interaction

Mechanical Environment

1. Load-Time History (Operational)
    - Static
    - Cyclic (Fatigue)
    - Elastic vs. Plastic
2. Fabrication Related Loads
    - Welding
    - Machining
3. Environment Related Loads
    - Thermal (Static, Cyclic)
    - Nuclear (Distortion due to swelling)
4. Time Dependent vs. Time Independent
    - Creep
    - Creep-Fatigue

Chemical Environment

1. Electrochemical Compatibility
2. Bulk vs. Local
3. Normal vs. Faulted
4. Nominal vs. Actual

Thermal Environment

1. Steady State
2. Startup/Shutdown
3. Transient
4. Accident

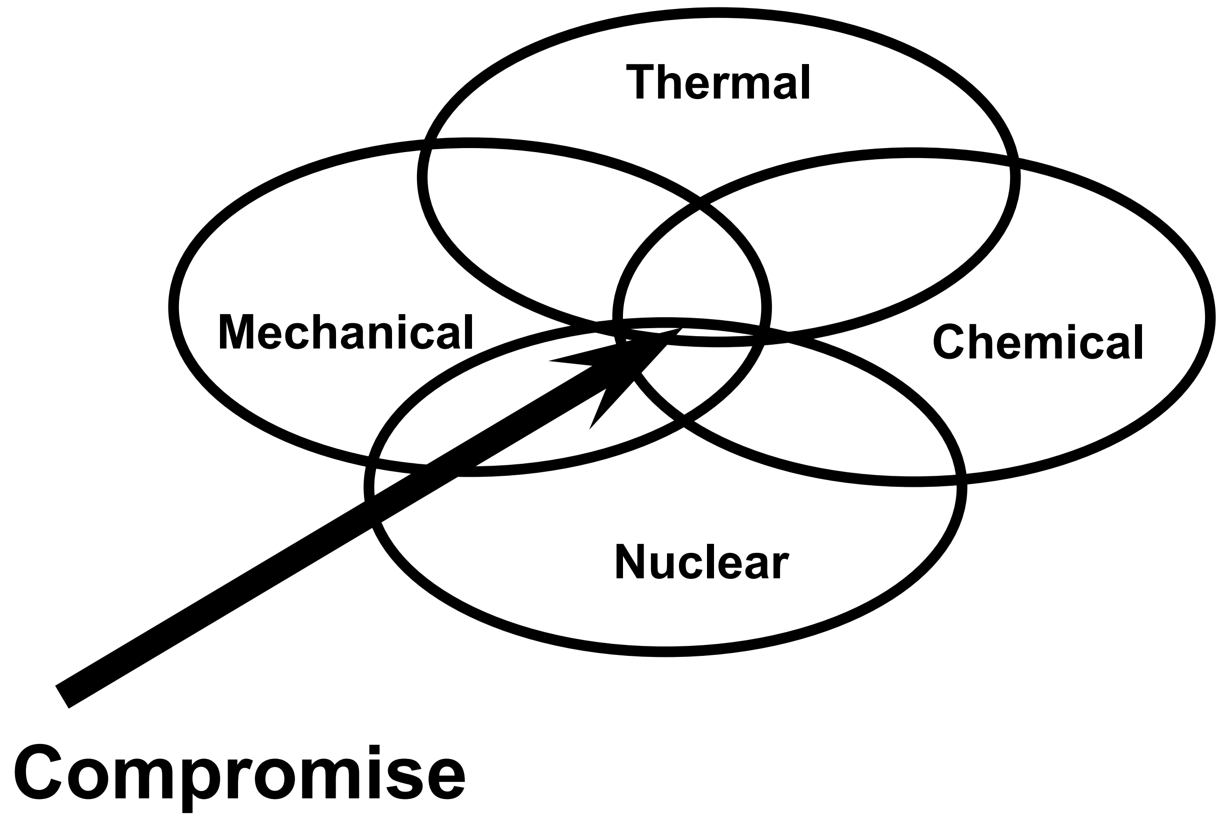
Nuclear Environment

1. Effects on Mechanical Properties
   - Ductility
   - Toughness
   - Strength
2. Dynamic Effects
   - Radiation Induced Segregation (RIS)
   - Growth
   - Fission Gas Release & Fuel Swelling
3. Effects on Chemical Environment
   - Fuel Rod Chemistry
   - Coolant Chemistry
4. Effects on Corrosion Products
   - Activation Products

Mechanical/Chemical/Thermal/ Nuclear Environment Interactions

- Stress Corrosion Cracking
- Corrosion Fatigue
- Hydrogen Embrittlement
- Creep-Fatigue Interaction
- Pellet Clad Mechanical Interaction (PCMI)
- Fretting
- Corrosion Product Transport
- Flow Assisted Corrosion
- Radiation Induced Segregation

Interactions



Assessment of Suitability

1. Is the material qualified for use in the environment?

2. Is there an existing data base?

Is The Material In The ASME Code

3. If not, what information will be required?

4. Can the information be obtained in time?

Assessment of Fabricability

1. Thermomechanical Processing

2. Can the component be fabricated from the material?

3. Quality Control

4. Quality Assurance

Thermomechanical Processing

1. Can the desired mechanical properties be obtained?
2. Mechanical properties variability? How much can be allowed?
3. Can the desired properties be obtained?
4. Can the desired properties be maintained?

Component Fabrication

1. Fabrication techniques
    - Welding
        - Effects on Chemistry
        - Effects on Mechanical Properties
        - Effects on Chemical/Electrochem. Props.
        - Effects on Mechanical Environment
            - Residual Stress•
    - Machining
        - Stress Concentrators
2. Assembly
    - Crevices
    - Couples

Assessment of Availability

1. Is the Material Available?

2. Is the Source Reliable?

3. Is there Enough of it?

4. At What Cost?

Assessment of Economics

1. How Much Does it Cost Now?

2. How Much Could it Cost?

Compromise

The Great Tragedy of Engineering:

The slaying of a great hypothesis by an ugly fact

Corollary

Don’t Do Stupid Things- a.k.a. Davis Besse

Material Degradation Prevention Options

1. Design:

Proper Materials Selection at the Initial Design Phase
Material "Friendly" Design

2. Remediation

Alteration of Chemical Environment
Alteration of Mechanical Environment
Alteration of Operating Conditions

3. Replacement

Materials Selection

1. Select The Right Material in the First Place

2. Change the Material Properties

3. Replace the Material

Alteration of Environment

1. Changing System Conditions
   - Lower Temperature
   - Change Chemistry

Material “Friendly” Design

1. Avoid Stress/ Stress Concentrations
2. Avoid Galvanic Couples
3. Avoid Sharp Bends of Velocity Changes in Piping Systems
4. Design Tanks for Complete Draining
5. To Weld or Not to Weld?
6. Design to Exclude Air
7. Avoid Heterogeneity
8. Design for Replacement