Interfacing Materials Development & Design: A “No-Choice” Pathway

Shahram Sharafat (UCLA) and Robert Odette (UCSB)

with input from
R. Kurtz, R. Stoller, M. Nastasi, M. Mauel, A. Rowcliffe, S. Zinkle

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Fusion Materials-Structural Challenges

- Large & complex interconnected structures

- **Unprecedented loading conditions:**
  - Severe time varying **thermal**, **mechanical**, **nuclear**, and **electromagnetic** loads along with associated gradients

- **Dynamic Materials Aging:**
  - Phase transformations; grain boundary segregation; grain growth; dissolution of strengthening phases; re-crystallization …

- **Time-dependent Radiation Damage Accumulation:**
  - Fatigue, creep, irradiation creep, perhaps swelling, fracture issues (both low and high temperatures) …

- **Synergy and adverse interactions between processes:**
  - e.g., creep and creep-fatigue crack growth …
Fusion Materials-Structural Challenges

- Additionally, issues of fabrication, qualification, and in service inspection.

- Designer needs to realistically model the structure through a life cycle including start-up/shut-down and abnormal transients.

  Real Challenge is coupling of materials performance limits with the “incredible” combined structural level demands.

  - **Lack of any fusion simulation facility**

Even for an LWR (a pressure cooker connected to a few pipes) lifecycle modeling is a challenge.
Materials-Structural Challenges

Giant Machine that *never stops moving*

on all Multiscale Levels

Development of

*Radiation Resistant Materials*

alone can no longer address the larger challenge of

*Material Systems and Multifunctional Structures*
Materials and Design Process
Assuming ALL necessary material property databases EXIST

Challenges (cont.)

Application Driven Material Design

Design Process Flow

Conceptual Design

Preliminary Design

Detailed Engineering Design

System Performance Design

Structure-Property Driven System Design

- Functional Design Requirements
- Physical Structure Identification
- Design Concepts of Both Structure and Material
- All Materials identified?
- Existing Materials?

- Preliminary Design
- Design Rules Design Codes
- Criteria for Manufacturing
- Design for Manufacturing
- Component Testing
- Design for Operation

Product
Challenges (cont.)

Application Driven Material Design

Structure-Property Driven System Design

- Functional Design Requirements
- Physical Structure Identification
- Design Concepts of Both Structure and Material
  - All Materials Identified?
    - Yes: Preliminary Design
    - No: Existing Materials?
      - Yes: Design Rules Design Codes
        - Criteria for Manufacturing
          - Design for Manufacturing
            - Component Testing
              - Design for Operation
              - Product
      - No: Return to previous step

If necessary materials and/or databases Do NOT exits
Challenges (cont.)

Application Driven Material Design

Structure-Property Driven System Design

Design Process Flow

Conceptual Design

Preliminary Design

Detailed Engineering Design

System Performance Design
Stage – I: Identify Candidate Materials

Stage - II: Develop Materials based on Functional Criteria

Stage - III: Improve Materials based on Design Codes & Manufacturing Rules

Stage - IV: Component Testing → Improve Materials based on Regulatory, Operation, Safety Rules
Fusion Materials Devl. Status

Current Fusion Power Reactor Materials Development Stage

Identified Candidate Materials & Developed Some Functionality

Non-existing Materials Databases and Design & Operating Knowledge
The “Non-existing Databases” implies that a large scale Fusion Nuclear Science Energy “Laboratory” such as FDF/VNS/CTF are necessary.

→ DEMO can not be designed reliably without these databases.

Redefine DEMO to demonstrate production of Energy, Tritium, Hydrogen etc. and not Electrical Power Generation.
Required Material Property Databases

Requirements → DESIGN → Fabrication → Component Testing

- Design Rules
- Fabrication Rules
- Safety & Regulatory
- Material Databases
  - Functional Level
    - Radiation-Resistance
    - Tritium Breeding
    - Corrosion Resistance
    - Thermo-Physical Props.
  - Structural Level
    - Mechanical Props.: Fatigue, cracking, ...
    - Deformation: Creep, Ratcheting, ...
    - Fabrication
  - System Level
    - Interactions: Mass transfer...
    - Qualification
    - Reliability
    - Safety

Fusion is Missing Extensive Data on ALL Three Levels
Fusion structures are faced with unprecedented demands.

Fusion is missing material information on all Levels: Functional, Structural, and System.

Fusion Power Reactor Materials Development is currently at Stage-I:

Established some required functionalities of candidate materials.