FIRE
Structural Design Criteria

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Purpose of FIRE Design Criteria

- Criteria to be utilized when conventional industrial design codes and standards do not apply
  - Operating conditions
  - Materials

The FIRE Design Criteria has evolved from:

- BPX Magnet Structural Design Criteria
- TPX Structural and Cryogenic Design Criteria
- ITER Structural Design Criteria for Coils and In-Vessel Components
- ASME B & PV

National Criteria Meetings

- Design criteria evolved, in large part, due to two meetings of professionals
  - MIT - 9/90
  - NIST, Boulder - 8/92
- Participants included fusion community, aerospace, university, industry, and NIST
- Criteria issues resolved by consensus

The FIRE Criteria:

- Uses the basic framework of the BPX and TPX structural criteria
- Incorporates features from the ITER criteria (especially for non-metallic criteria)
- Provides detailed references and notations throughout the document

Definition of Tresca Stress

Tresca stress is defined as twice the maximum shear stress and is equal to the largest algebraic difference between any two of the three principal stresses. This is equivalent to stress intensity as referred to in the ASME Boiler and Pressure Vessel (B & PV) Code.

Designate the design Tresca stress as Sm

Monotonic Metallic Stress Limits

- For steel structures, Sm = lesser of 2/3 yield at temperature or 1/2 ultimate at temperature (1/3 ultimate for welds)
- For metals other than steel including conductors and welds, Sm $\leq$ 2/3 yield at temperature while demonstrating adequate ductility

Metallic Stress Allowable Limits

- For general primary membrane ≤ Sm
- For primary membrane + bending ≤ 1.5 Sm (i.e., yield)
- For complex unresolvable behavior, perform detailed analysis to determine limit load and apply safety factor of 2

Basic Non-Metallic Stress Limits

- Compressive stress $\leq$ 2/3 ultimate stress at temperature
- Shear allowable Ss = [2/3 τ_o] + [C_2 x Sc(n)] where τ_o = intrinsic shear strength of material, C_2 = material constant relating dependence of
  shear to compressive strength,
  Sc(n) = applied normal compressive stress

Basic Non-Metallic Stress Limits (cont.)

- Radiation limits - Peak dose and peak fast neutron fluence
- Allowable coefficient of friction guidelines specified in the absence of actual data
- When slippage due to shear is anticipated, must demonstrate 5X design life in representative tests

FIRE & Fatigue

- FIRE is designed for approximately 3000 full power and 30,000 two-thirds power pulses
- A fatigue strength evaluation is required for those components with undetectable flaws that are either cycled over 10,000 times or exposed to cyclic peak stresses exceeding yield

FIRE & Fatigue (cont.)

- When a fatigue evaluation is required, the ASME B & PV approach is followed based on the peak difference in principal stresses
- On an S-n curve, allowable stress amplitude limited to the lesser of:
  - 1/2 the fatigue stress for the design life
  - the stress at 20X design life

FIRE & Fatigue (cont.)

- Cumulative Usage Factor must be < 1.0
  - The cumulative effect of the various stress cycles is evaluated and combined via a linear damage relationship and based on the design S-n curve
  - For FIRE, the 3000 full power pulses are expected to account for nearly all of the fatigue in the device

FIRE Fracture Requirements

- Using LEFM, determine the maximum permissible initial flaw size for a given geometry.
- Maximum initial flaw size governed by:
  - 2X growth life for component testing
  - 4X growth life for material testing
- The calculated initial flaw should not be smaller than 2X the flaw that can be resolved by non-destructive testing

FIRE Fracture Requirements (cont.)

- ASTM Standards shall be adhered to in the determination of fracture and crack growth constants, including:
  - ASTM E399 or E813 (for plane strain fracture toughness)
  - ASTM E647 (crack growth constants)

FIRE Design Approach

- Operational experience has shown that failures are most likely to occur at points of discontinuity (joints, electrical lead terminations, coolant connections) which are often deferred until late in the design process. FIRE requires that these design details be addressed and reviewed at a level consistent with the overall design.

Future Criteria Work

- Cryogenic Design Criteria
- High Heat Flux and High Temperature Component Design Criteria
- Vacuum Viewports and Viewing Windows Design Criteria
- Appendices containing commentary on sections listed above
- Reference for material properties