

Evaluation of Structural Limits

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Introduction

- General Considerations for Design Limits
 - Classes of material limits
 - Hard limits vs. soft limits
 - Specific operating limits depend on both materials selected and design.
 - How far can limits be pushed and still provide acceptable lifetime?
(Design by test)
- ITER Structural Design Criteria (ISDC)
 - Approach
 - Areas addressed
 - Flow chart for satisfying design criteria
- Examples of Design Limits for First Wall
 - Austenitic stainless steel
 - Vanadium alloy

Classes of Material Limits

- Design Stress Limits
 - Maximum allowable stresses
 - Ratcheting
- Material Damage Limits
 - Thermal creep
 - Fatigue/crack growth
 - Corrosion/impurity diffusion
- Safety Limits
 - Transport of activation products
 - Margin against failure during accidents
 - Fracture toughness
 - Ductility
 - Uniform elongation
 - Total elongation
 - Reduction in area
 - D/T inventory

Classes of Material Limits (Contd.)

- Dimension Limits (No Material Damage-Design Limited)
 - Radiation creep
 - Radiation swelling
- Plasma Limits
 - Vapor pressure
 - D/T Recycling

ITER Structural Design Criteria

- Based on European code - RCC-MR
 - Similar to ASME B&PV Code
 - Adds radiation effects rules
 - Will be modified over time
- Code is Primarily Aimed at FW/B/S Components
 - In-vessel components treated as Quality Class 1 (*highest level*)
 - It is recognized that in-vessel components are classified as experimental
 - Class 1 chosen because of cost and importance of components plus the difficulty of repair
 - Not much practical difference between Class 1 and Class 2 components

ITER Structural Design Criteria (Contd.)

- Utilitizes Different Criteria Levels

Criteria (class)	Level Objective	Damage Limit
A	Negligible damage	Normal
A	Negligible damage	Upset
C	May be significant local distortion. May need to inspect.	Emergency
D	May be large general distortion and investment loss. No loss or safety function.	Faulted

ITER Structural Design Criteria (Contd.)

- Emphasis Placed on Fatigue as Dominant Failure Mode
 - Less important for advanced blankets
- Reduced Ductility with Irradiation Affects Primarily Limits on Secondary and Peak Stresses
 - Primary stress limits not expected to be reduced by irradiation

ITER Structural Design Criteria (Contd.)

- Damage and Failure Modes
 - M-type damage
 - Steady or increasing loads
 - Considers plastic instability and thermal creep
 - C-type damage
 - Cyclic loading
 - Racheting progressive deformation
 - Fatigue-creep/fatigue
 - Buckling
 - Compressive or shear loading conditions
 - Corrosion and Erosion
 - Corrosion thickness allowance

Criteria Levels

- Level A Protects Against:
 - Immediate plastic collapse
 - Immediate plastic instability
 - Immediate flow localization
 - Fast fracture
 - Local fracture due to exhaustion of ductility
 - Ratcheting
 - Fatigue
 - Thermal creep
 - Buckling
- Level C Protects Against
 - Same damages as level A but with lower safety margins
 - Local permanent deformation and small levels of overall deformation could occur, while the component is limited, with reasonable confidence against the damage, of immediate fracture.

Criteria Levels (contd.)

- Level D Criteria Protects Against:
 - Same M-type damage (excluding ratcheting and fatigue) as level C but with lower safety margins.
 - Gross overall deformations could occur but with some protection against immediate fracture

Stress Types

- Primary Stress
 - Primary membrane - P_m
 - Primary bending - P_B
 - Does not diminish after small scale deformation
- Non-Primary
 - Peak stress - F
 - Secondary stress - Q
 - Additional local membrane stress - L
 - All thermal stresses and swelling stresses are generally classified as secondary stresses
 - Peak stresses are generally localized and include non-linear portion of through thickness stress, stress due to major discontinuities, skin stresses caused by thermal shocks

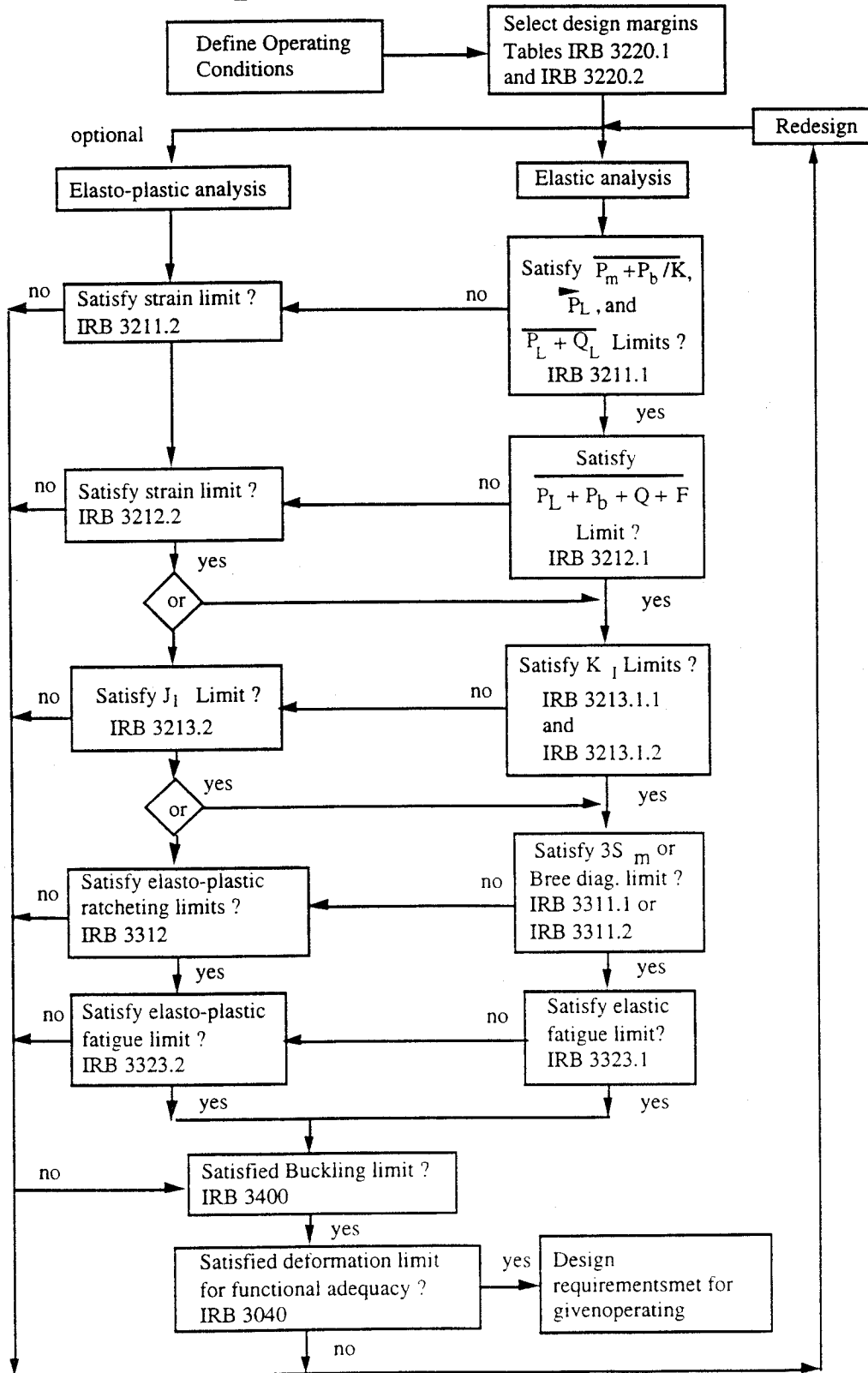
Stress Types (contd.)

- Detailed Descriptions for Calculating Stress Types and Equivalent Strains are Included
- The stresses are Then Compared with Allowable Stress Intensities
- Different Criteria Levels use Different Coefficients for Allowable Stress Intensities ^(margins)

S_m and Safety Factors for Elastic Analysis Rules for M-type Damage

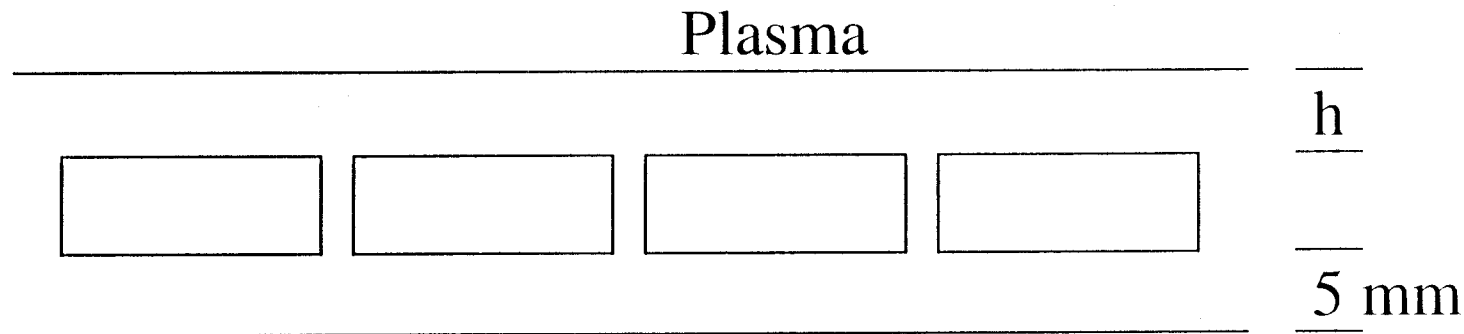
Damage	Level A	Level C	Level D
Immediate plastic collapse and instability (IRB 3211.1)	$S_m(\theta_m, \phi t)$	$\min \begin{cases} 1.2S_m(\theta_m, \phi t) \\ S_{y,\min}(\theta_m, \phi t) \end{cases}$	$\min \begin{cases} 2.4S_m(\theta_m, \phi t) \\ 0.7S_{u,\min}(\theta_m, \phi t) \end{cases}$
Immediate plastic strain localization (IRB 3212.1)	$\beta_1=0.33$	$\beta_1=0.40$	$\beta_1=0.67$
Immediate local fracture due to exhaustion of ductility (IRB 3213.1)	$\beta_2=0.67$	$\beta_2=0.80$	$\beta_2=0.90$
<u>Fast fracture</u>			
Global (IRB 3214.1.1)	$\gamma_1 = 0.33$	$\gamma_1 = 0.40$	$\gamma_1 = 0.67$
Local (IRB 3214.1.2)	$\gamma_2 = 0.67$	$\gamma_2 = 0.80$	$\gamma_2 = 0.90$

Analysis Flow Chart for Satisfying Low Temperature Design Rules



First Wall Examples

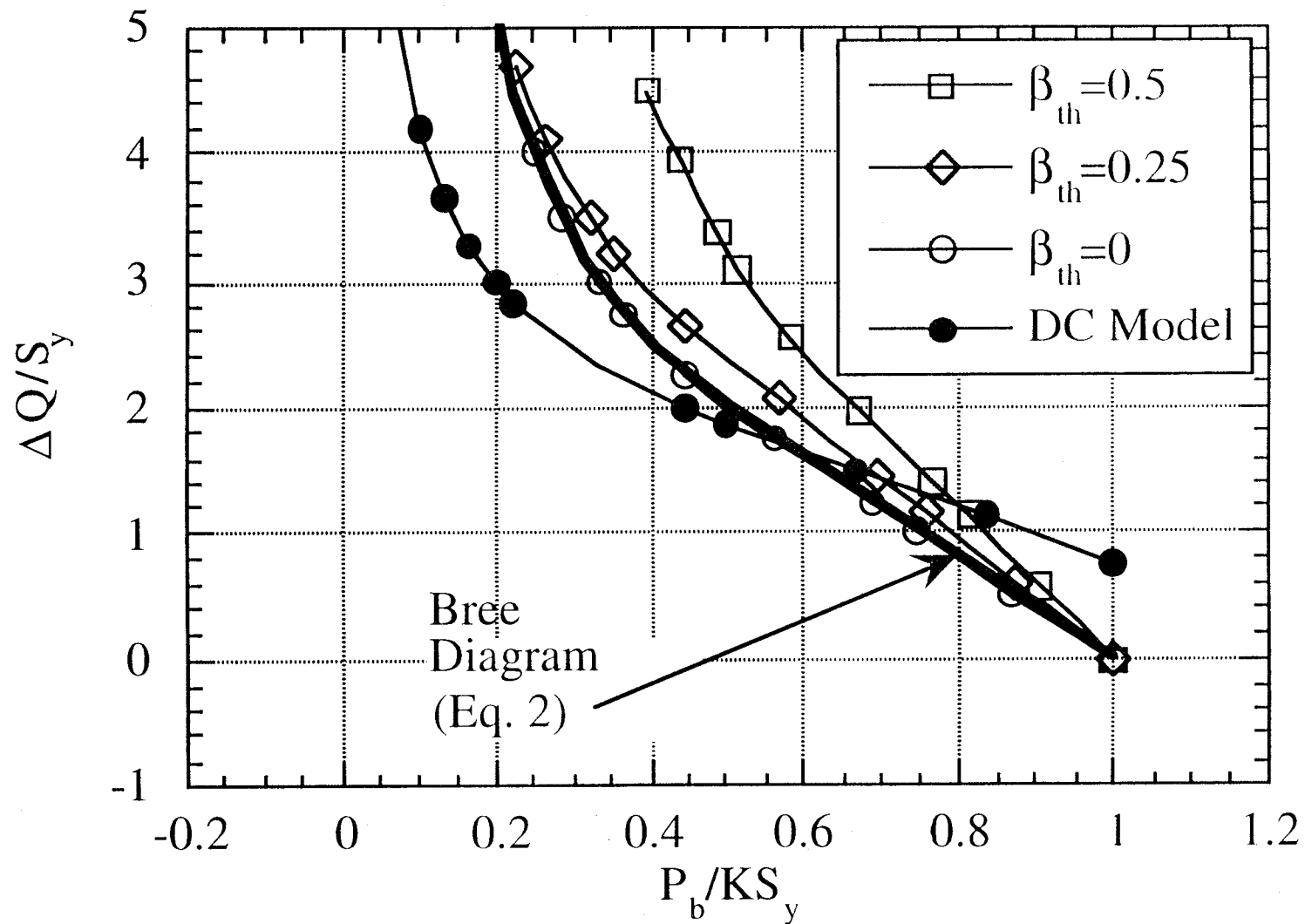
- Design



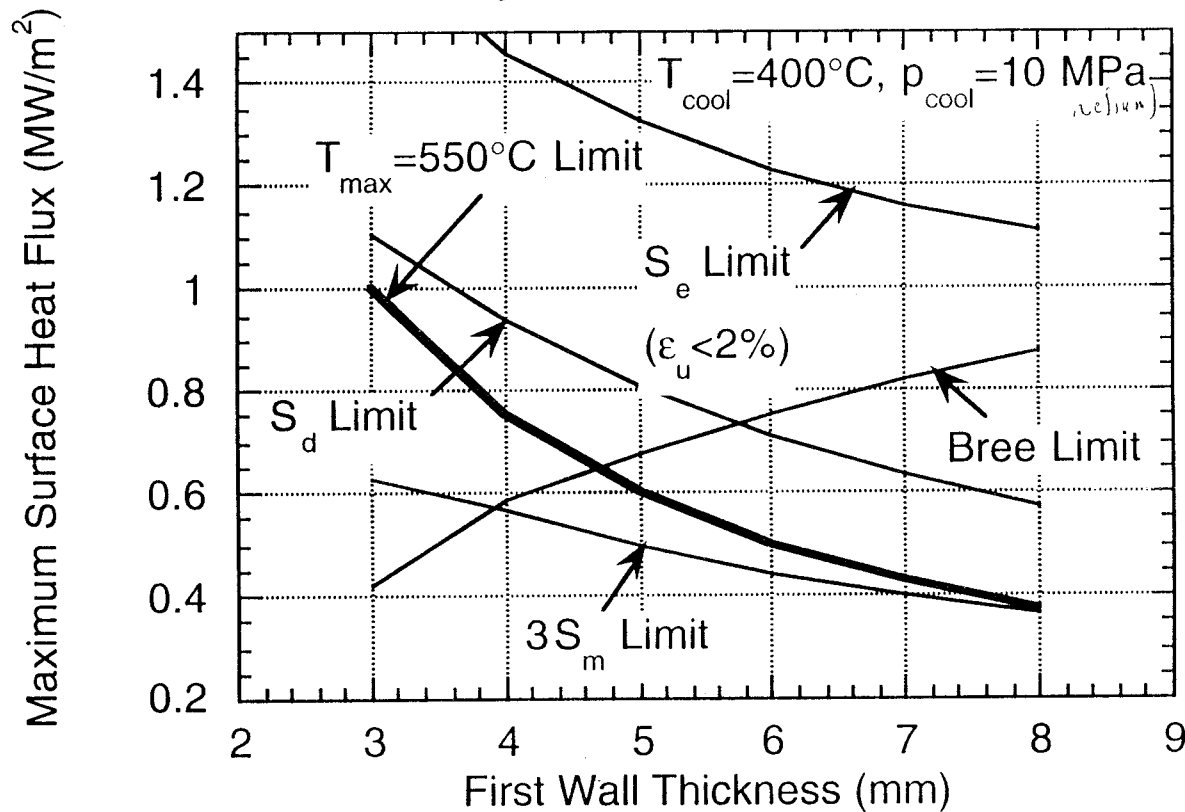
- Assumptions

- First wall allowed to expand but not bend
- No nuclear heating
- No ΔT between coolant and structure
- Fatigue/crack growth not included
- Thermal creep not included
- Saturation of radiation effects on tensile properties assumed

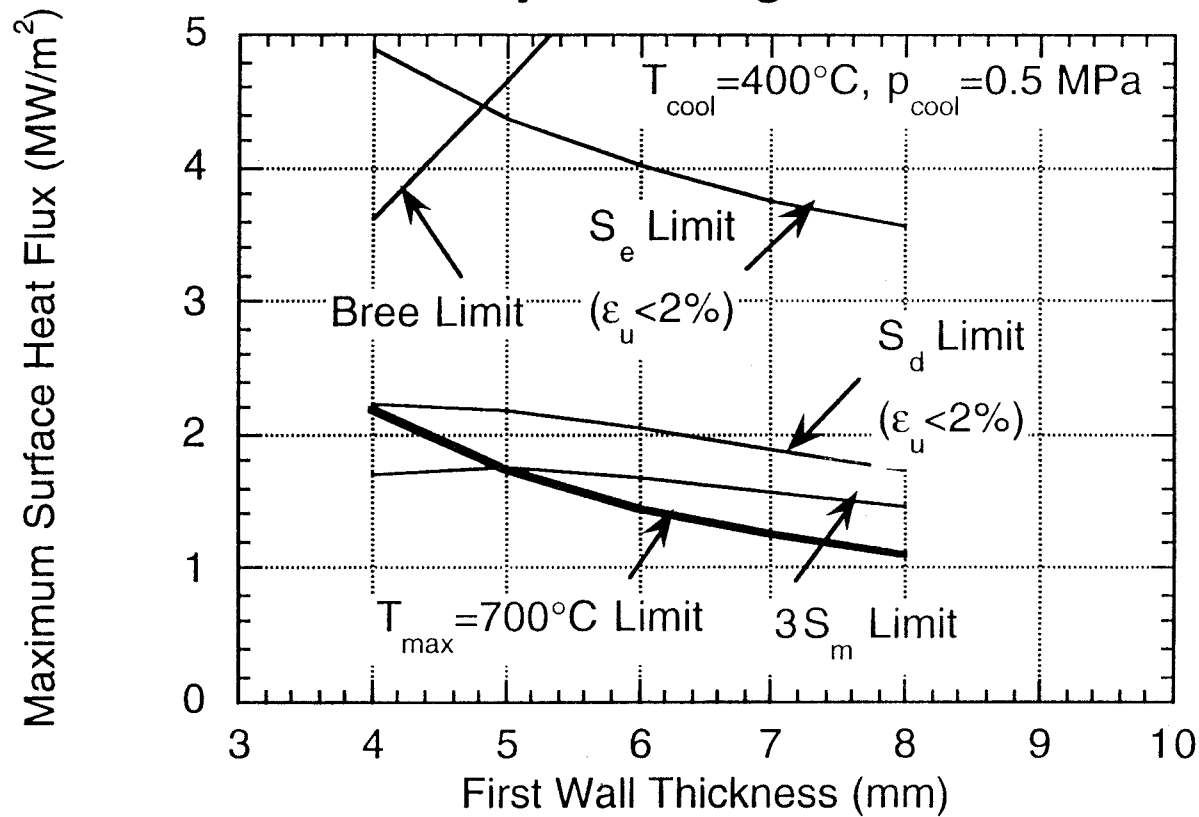
Comparison of the ASME Code Bree Diagram with Those Calculated for Structures Primarily Loaded in Bending



Stainless Steel First Wall, 5 mm Thick Back Wall 10 mm Wide by 20 mm High Coolant Channel



V-4Cr-4Ti First Wall, 5 mm Thick Back Wall 10 cm Wide by 5 cm High Coolant Channel



Conclusions

- The ISDC Is the First Comprehensive Document to Address Fusion Structural Limits
- Application of the ISDC to the First Wall Indicates That There May Be More Capability to Accommodate Heat Loads Than Originally Thought.
 - $3 S_m$ is not the absolute limit
- Additional Work is Necessary
 - To include all relevant limits
 - To add additional materials
 - To augment rules for advanced systems
 - To apply criteria to specific designs

The Full ISDC Can Be Made Available to Anyone Who
Would Like a Copy