Evaluation of Structural Limits

S. Majumdar
R. Mattas

Argonne National Laboratory

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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
  - Racheting
- 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
  - Racheting
  - 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 racheting 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

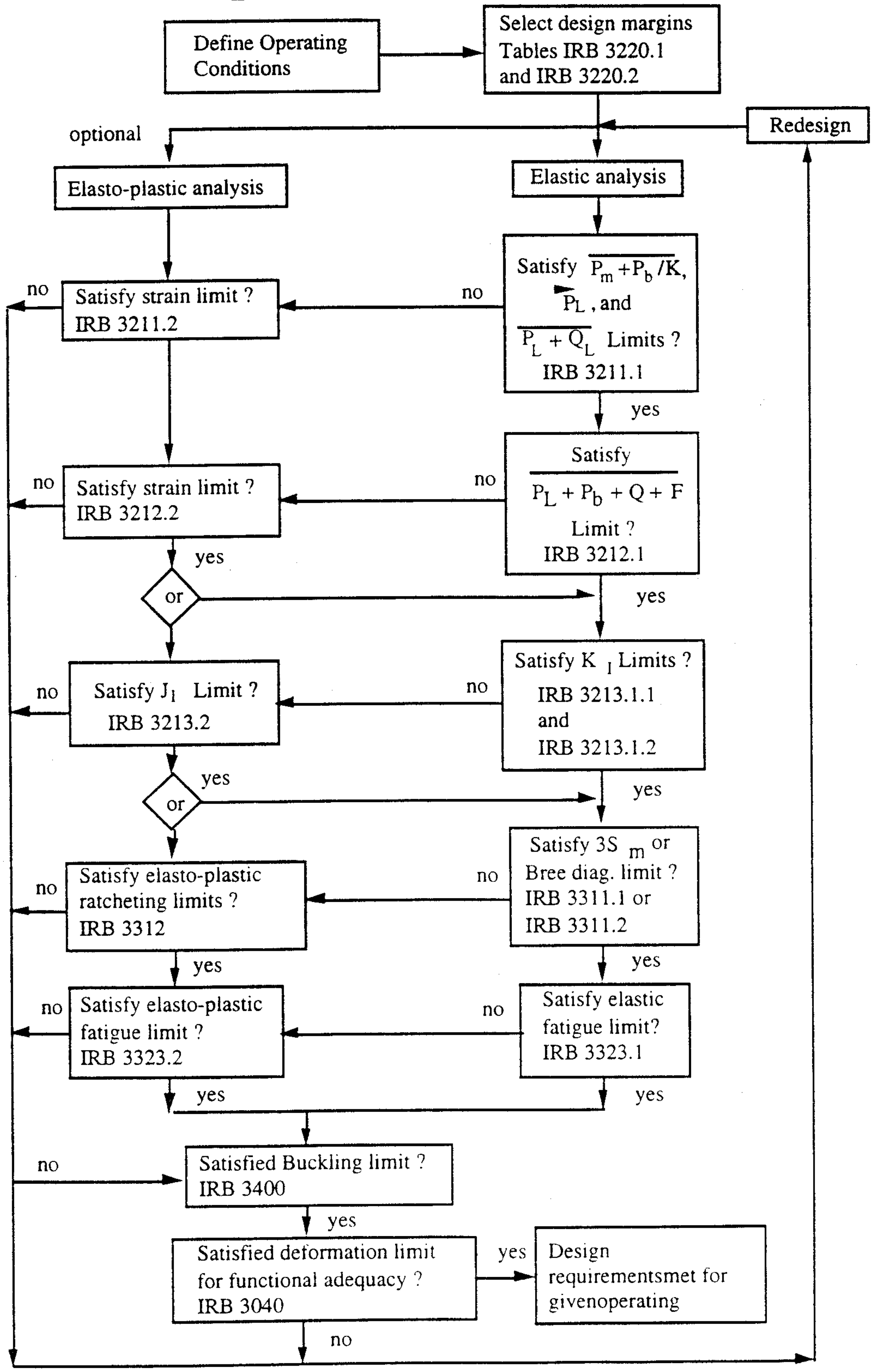
- The stresses are Then Compared with Allowable Stress Intensities

- Different Criteria Levels use Different Coefficients (margins) for Allowable Stress Intensities

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

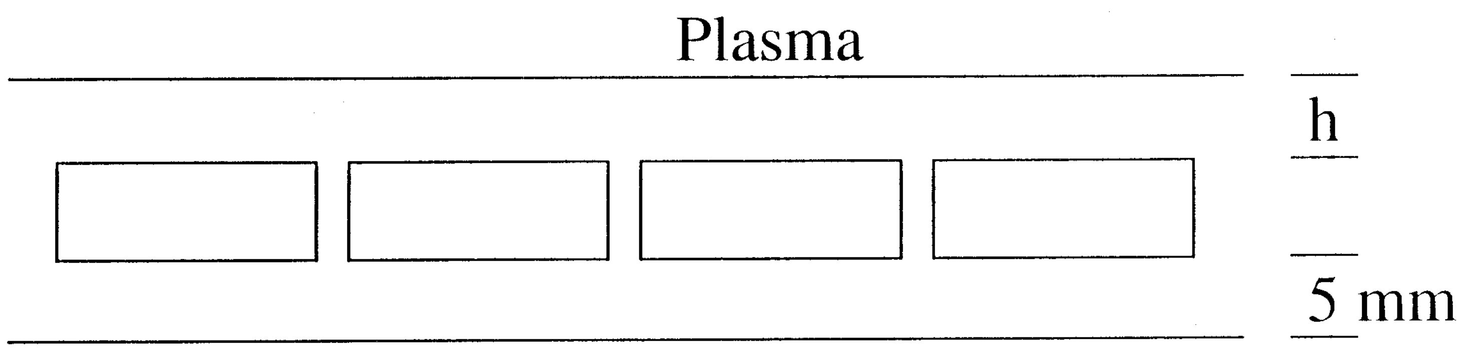
Damage	Level A	Level C	Level D
Immediate plastic collapse and instability (IRB 3211.1)	$S_m(\theta_m, \phi t)$	$\min\begin{cases}1.2S_m(\theta_m,\phi t)\\ S_{y,min}(\theta_m,\phi t)\end{cases}$	$\min\begin{cases}2.4S_m(\theta_m,\phi t)\\ 0.7S_{u,min}(\theta_m,\phi t)\end{cases}$
Immediate plastic strain 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



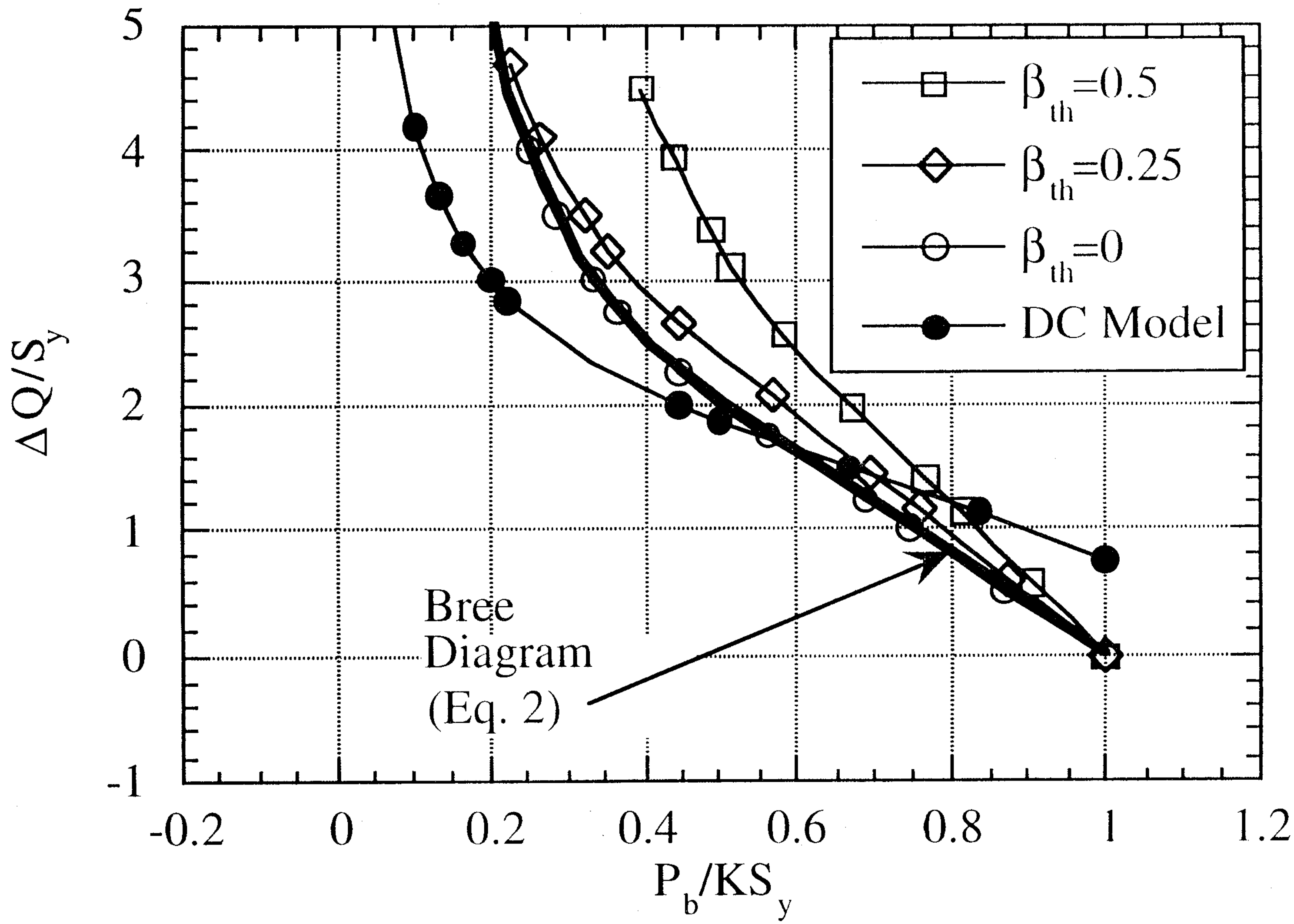
First Wall Examples

- Design

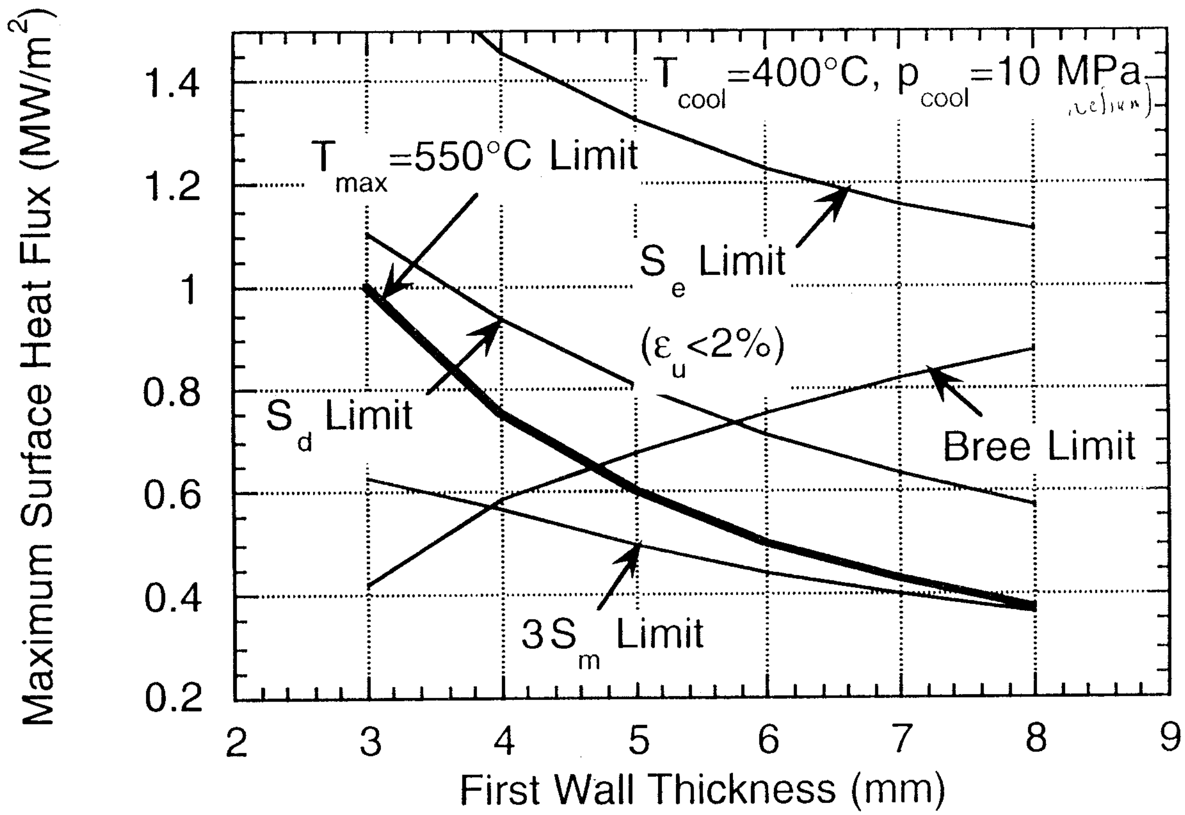


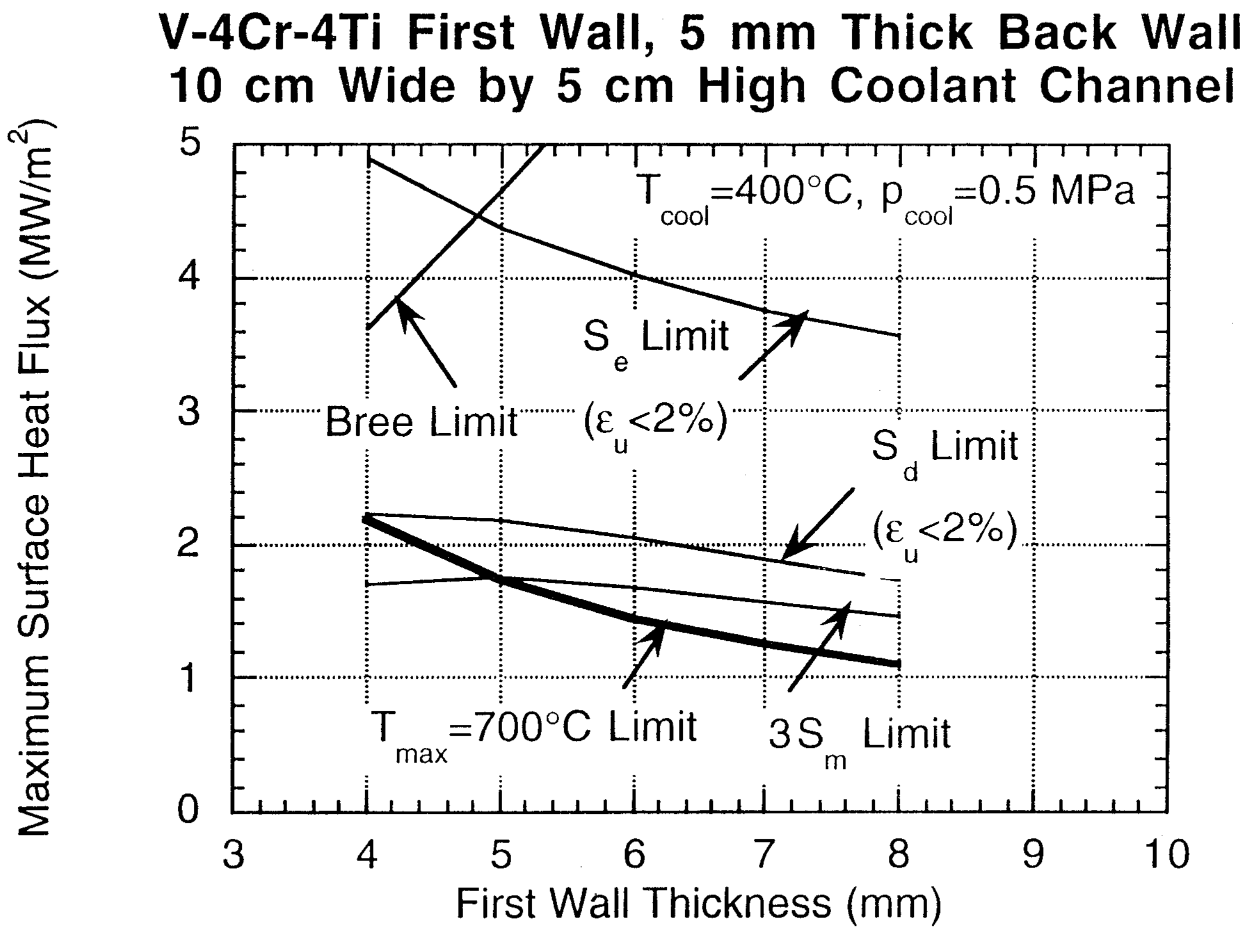
- Assumptions
  - First wall allowed to expand but not bend
  - No nuclear heating
  - No ΔT between coolant and structure
  - Fatigue/crack growth not included
  - Thermal creep not included
  - Saturation of radiation effects on tensile properties assumed

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





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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