2

ANTER EL-AZAB

LIMITATIONS OF CURRENT CONCEPTS IN HANDLING HIGH POWER DENSITY

APEX STUDY MEETING

University of California, Los Angeles

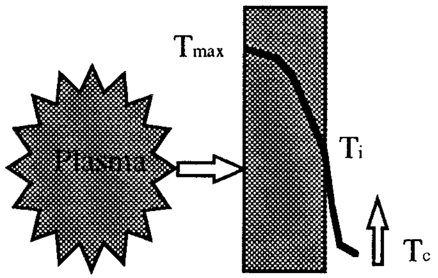
October 15-17, 1997

CURRENT CONCEPTS

- STRUCTURAL MATERIALS:
  - Ferritic Steel
  - Vanadium-Cr-Ti Alloy
  - Silicon-Carbide Composite
- WHAT IS THE IMPACT OF TEMPERATURE AND STRESS LIMITS ON THE MAXIMUM WALL LOADING CAPABILITY:
  - Surface heat flux
  - Neutron wall loading

FIRST WALL CONFIGURATION

A plate subjected surface heat flux and to bulk nuclear heating, and cooled on one side.



THERMOELASTIC PROPERTIES

	k(w/mK)	alpha (/K)	E(GPa)	nu
Ferritic Steel	26	11.8E-6	190E+3	0.26
V-15Cr-5Ti Alloy	28	10.3E-6	118E+3	0.33
SiC Composite	6	3.E-6	220E+3	0.2

TEMPERATURE LIMITS

- **UPPER TEMP. LIMITS**

Steel	**550 °C**	**(ther. creep, swelling)**
Vanadium Alloy	**650 °C**	**(ther. creep, swelling)**
SiC Composite	**? (1000 °C)**	

STRESS LIMITS

- Design stress (allowable) limt:

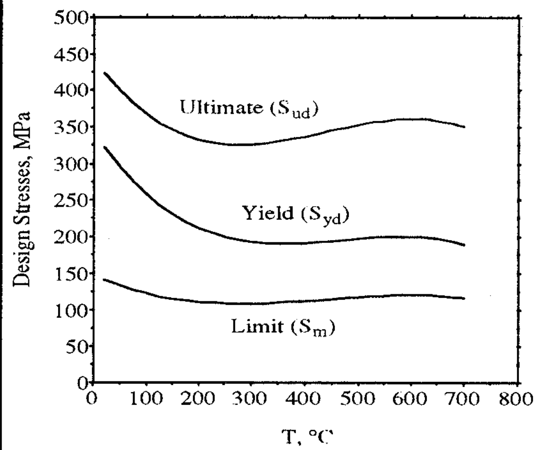
  Sm = min{ (2/3)Sy , (1/3) Su}
- Limit on ave. primary membrane (hoop) stress

  Pm < Sm
- Limit on primary bending stress

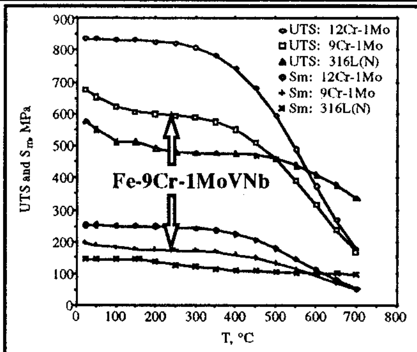
  Pb + Pm <1.5 Sm
- Limit on secondary thermal stress

  Q + Pb + Pm < 3Sm
- Limit on peak stress (fracture mechanics design), fatigue limits, thermal and irradiation creep, etc.

ALLOWABLE STRESS
V-4CR-4Ti



ALLOWABLE STRESS
Ferritic Steel

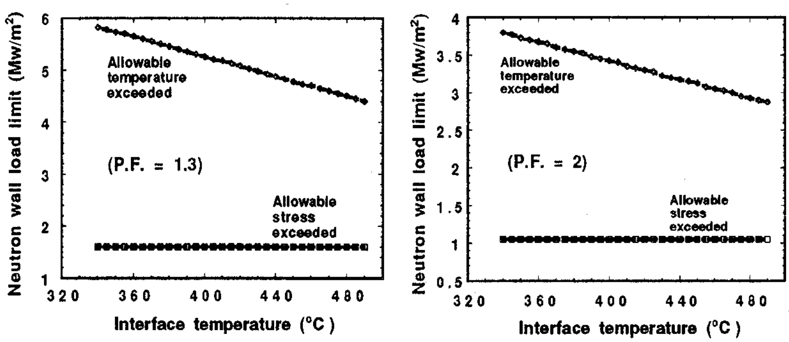


Ultimate tensile strength (UTS) and maximum allowable primary stress, Sm, for unirradiated steels: Fe-12Cr-1MoVW (e.g., HT9), Fe-9Cr-1MoVNb, and annealed 316L(N).

CALCULATIONS

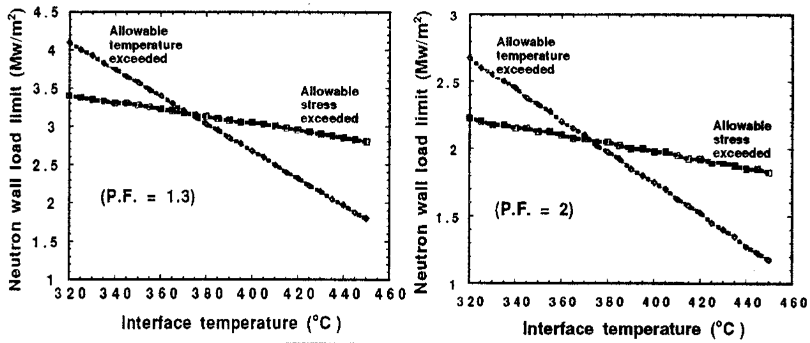
- Boundary conditions+ bulk heating:
  - q" = 0.2Mw/m2 per 1Mw/m2 (NWL)
  - T_i = Coolant-structure interface temp. (variable)
  - q''' = 10w/cm3 per 1Mw/m2 (NWL)
- Peaking factors 1.3 and 2 are considered.
- Stress limits $S_m = S_m(T_{ave})$ --> from data.
  For SiC-SiC S_m = 145 MPa (matrix cracking)
- $P_m + P_b$ = 20MPa (assumed)

NWL Limit for SiC Composite



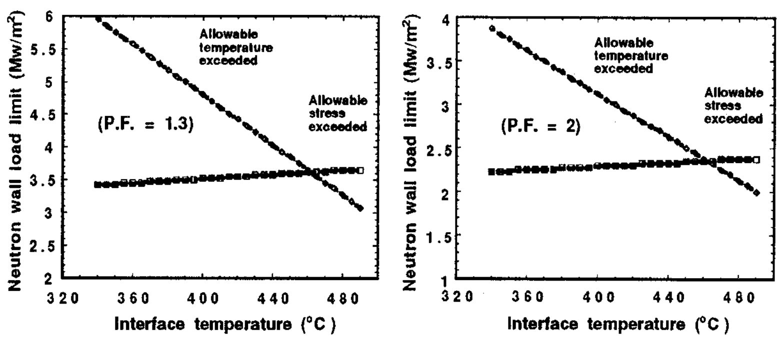
3mm thick first wall

NWL Limit for Ferritic Steel



5mm thick first wall

NWL Limit for V-Cr-Ti Alloy



5mm thick first wall

CONCLUSIONS

Current concepts are inherently limited in handling high power density

INNOVATION THROUGH PURSUIT OF ENGINEERING SCIENCE LOGIC

EXAMPLE & APPROACH

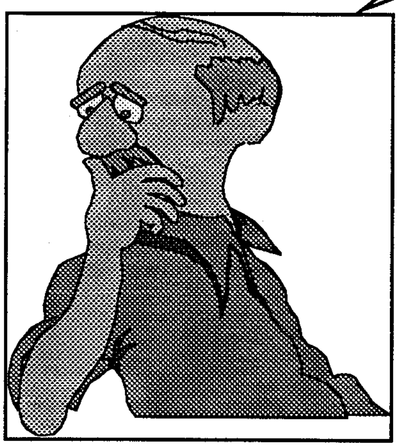
UCLA Team

WHAT IS THE PROBLEM?

- Need to conduct heat through the structure.
- Establish temperature gradients, leading to thermal stresses.
- Operating temperatures and stresses exceed material limits.
- Limits are reached faster when

k	is lower
alpha	is higher
E	is higher

CAN WE DEAL WITH THIS PROBLEM ?



$\cancel{E = m a^2}$

$\cancel{E = m b^2}$

$E = mc^2$

Reduce E
Increase k

HOW: Example

<u>SiC-BASED STRUCTURES</u>:

- Use porous SiC, reduce the effective modulus -> more compliant structure.
- Infiltrate with liquid metal, increase the effective thermal conductivity -> reduce temp. drop and thermal stress.
- Other benefits:
  Higher thermal inertia, better thermal fatigue characteristics.

GENERAL APPROACH

- Eliminate large temp. drops across solid walls by enhancing conduction and reducing stiffness.
- Minimize the need to conduct heat through solid walls by creating efficient alternate or complimentary heat transport paths (flowing films).
- Reduce film temperature drop in coolant, e.g., by adding particulates to gaseous coolants.
- Transporting heat at nearly fixed temperature, e.g., by relying on phase changes or using high heat capacity coolants.

Other ideas are invited here.