Cu-8 Cr-4 Nb Alloy For Reusable Launch Vehicle Combustion Chamber Liners

David L. Ellis and Hee Man Yun

Insights in R&T
April 13, 1999

Outline

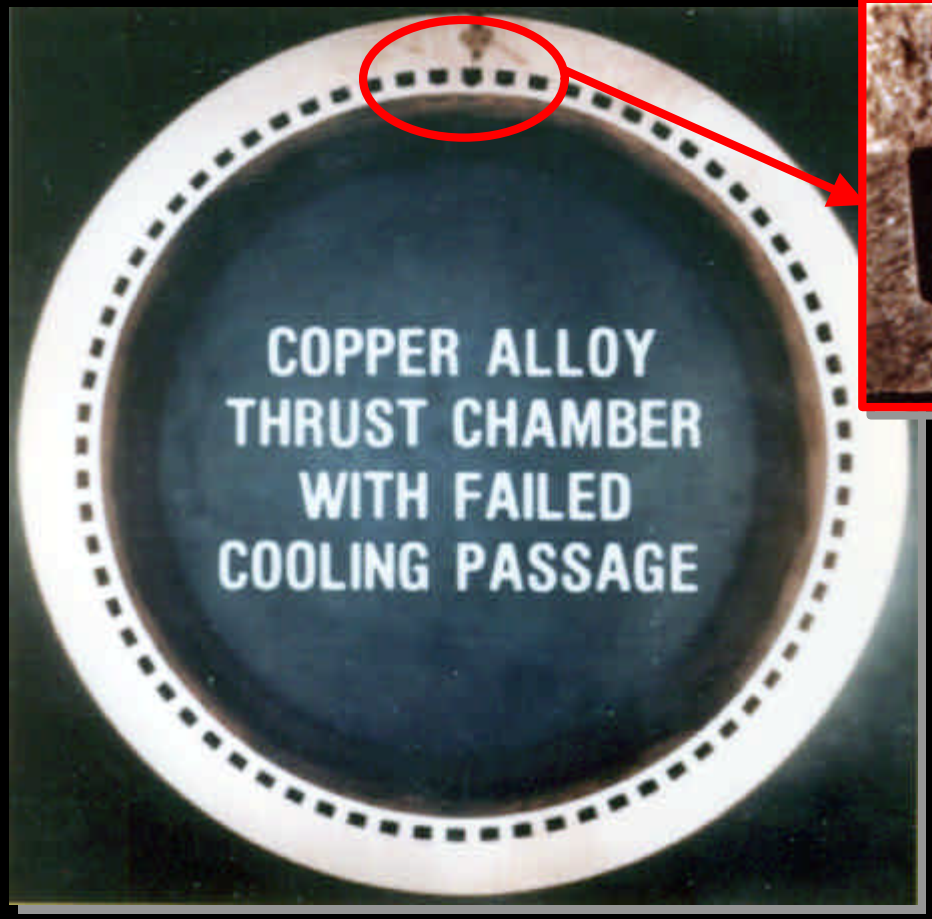
- Development Of Cu-8 Cr-4 Nb At NASA
- Properties And Benefits Of Cu-8 Cr-4 Nb
- Synergies Within NASA
- Transferring Cu-8 Cr-4 Nb To Industry
- Potential Future Uses

Combustion Chamber Liners

- **Used in regeneratively cooled rocket engines such as the Space Shuttle Main Engine (SSME)**
- **Exposed to 5000°F flame on inside, cryogenic hydrogen on outside**
- **Requirements:**
  - High conductivity
  - High strength
  - Good creep resistance
  - Good LCF life
  - Low thermal expansion
  - Good environmental compatibility

Commercially produced Cu-8 Cr-4 Nb chambers

Failure Of Combustion Chamber Liners



- **Complex failure mechanism**
  - Creep
  - Low cycle fatigue
  - Thermal ratcheting
- **Current alloy NARloy-Z (Cu-3 Ag-0.5 Zr) inadequate for RLV**

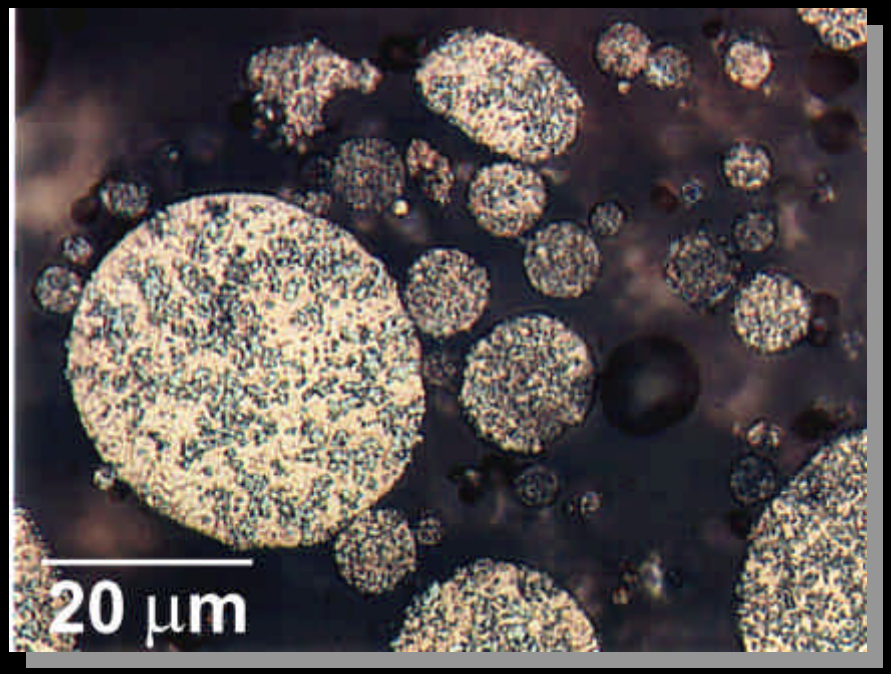
Development Of Cu-8 Cr-4 Nb

- Alloy developed as part of Earth-To-Orbit (ETO) program
- Initial work done at NASA using Chill Block Melt Spinning (CBMS) to make 5-15 grams of ribbon
- Scale-up involved changing production to conventional gas atomization
- Newest technique uses vacuum plasma spray (VPS) to make complex shapes

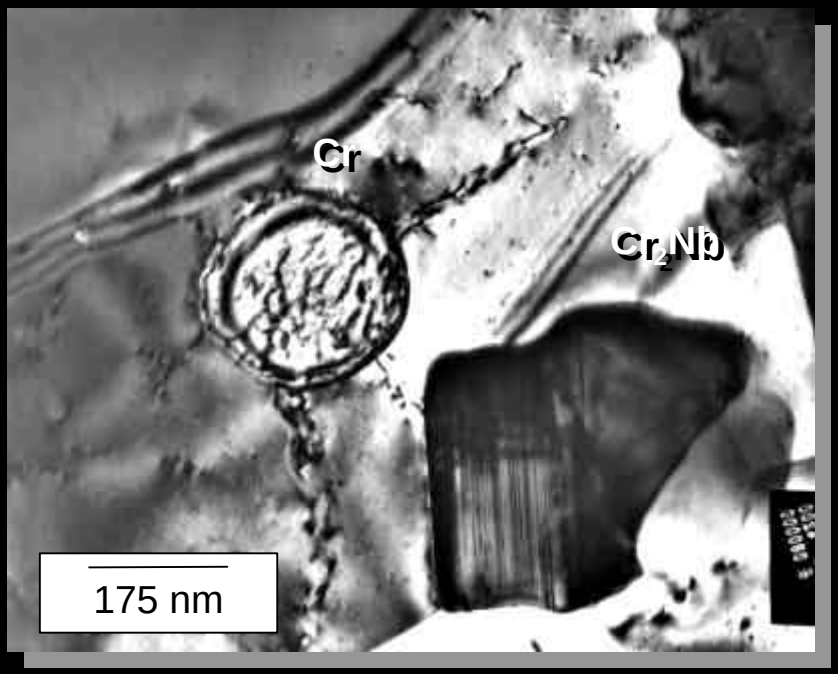
Commercial Extrusion Of Bars

- **NASA**
  - 2” diameter extrusion can with 2 pounds of powder
  - Extruded into 0.5” diameter x 36” long bars (24” good material)
- **CSM Industries (Coldwater, MI)**
  - 6” diameter can with 25 pounds of powder
  - Extruded into 1.1” diameter x 156” long bars (109” good material)

Cu-8 Cr-4 Nb Microstructure



Optical Micrograph of
Atomized Powder

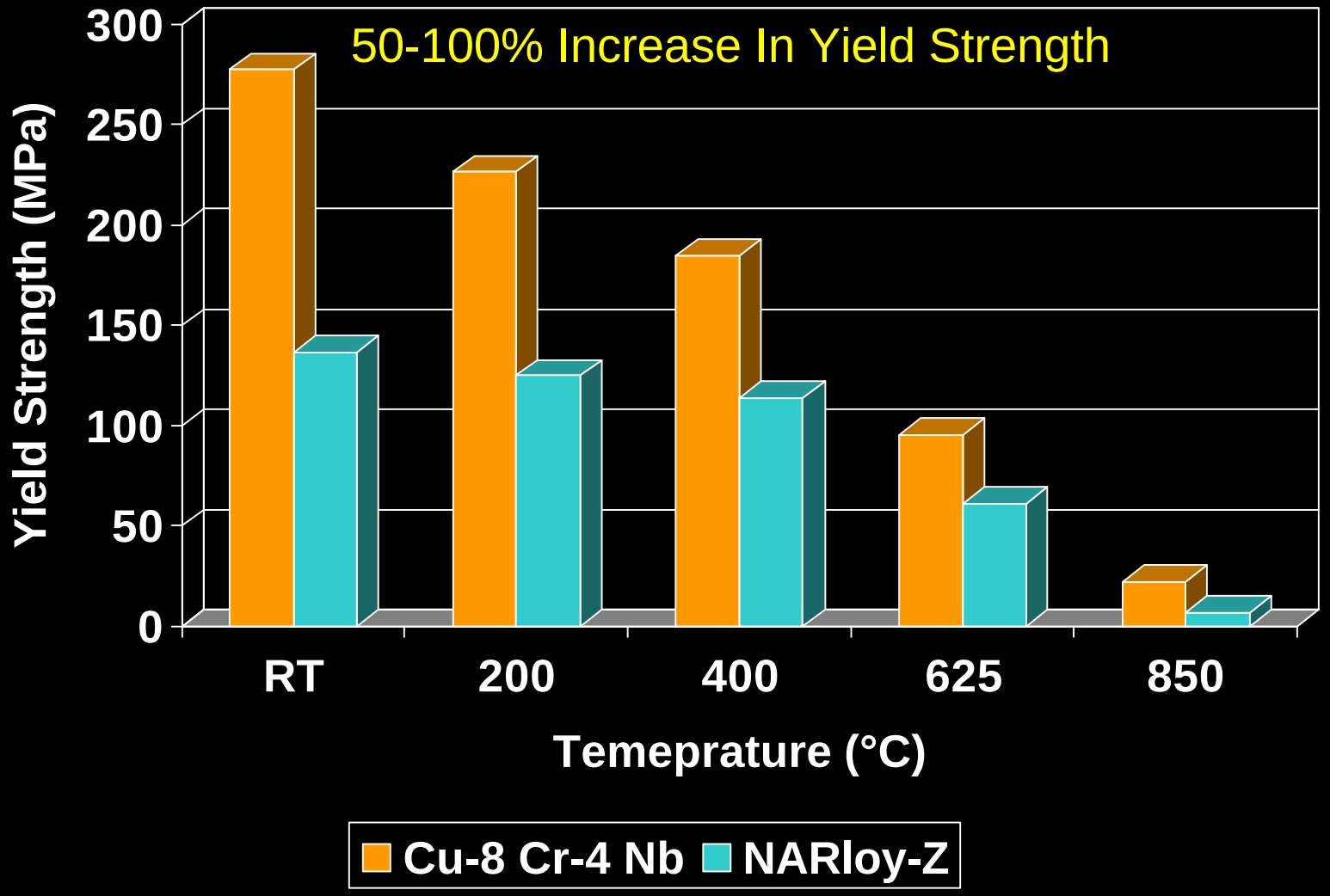


TEM Bright Field Image of
Extruded Bar

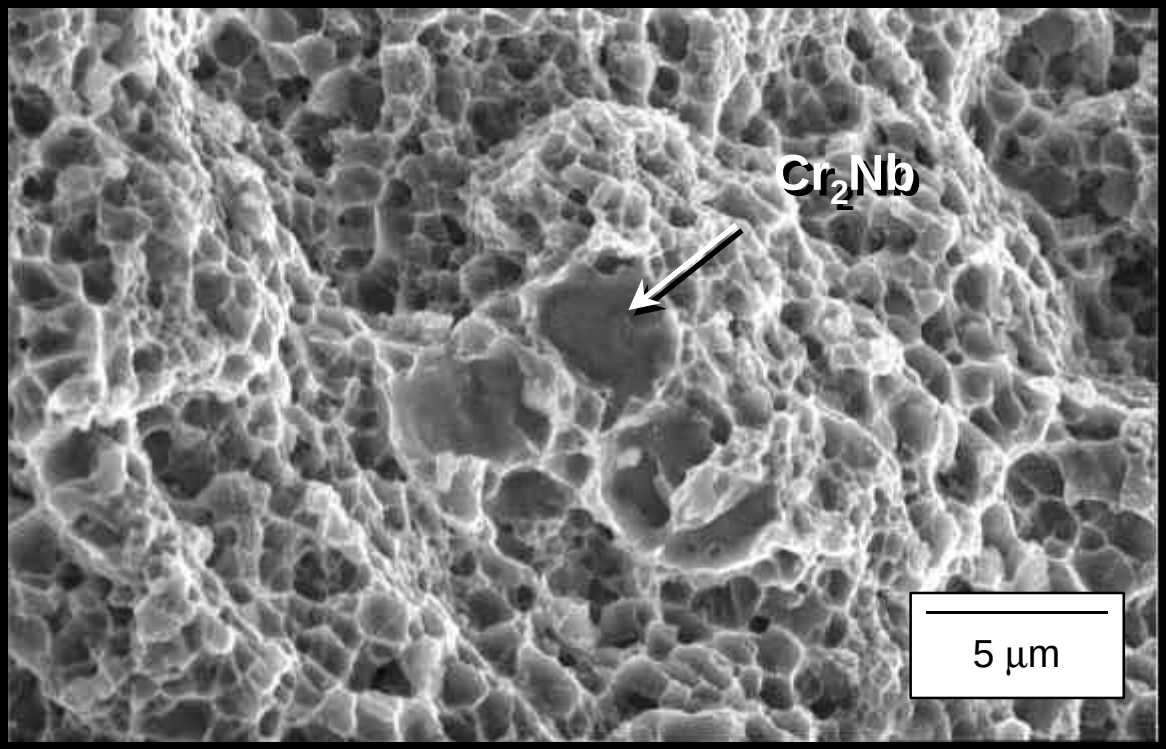
Phases identified:

- Cu matrix
- ~14 volume percent Cr_2Nb precipitates
- Cr precipitate (minor precipitate)
- Some oxides, mainly Cr_2O_3

Yield Strength Of Cu-8 Cr-4 Nb



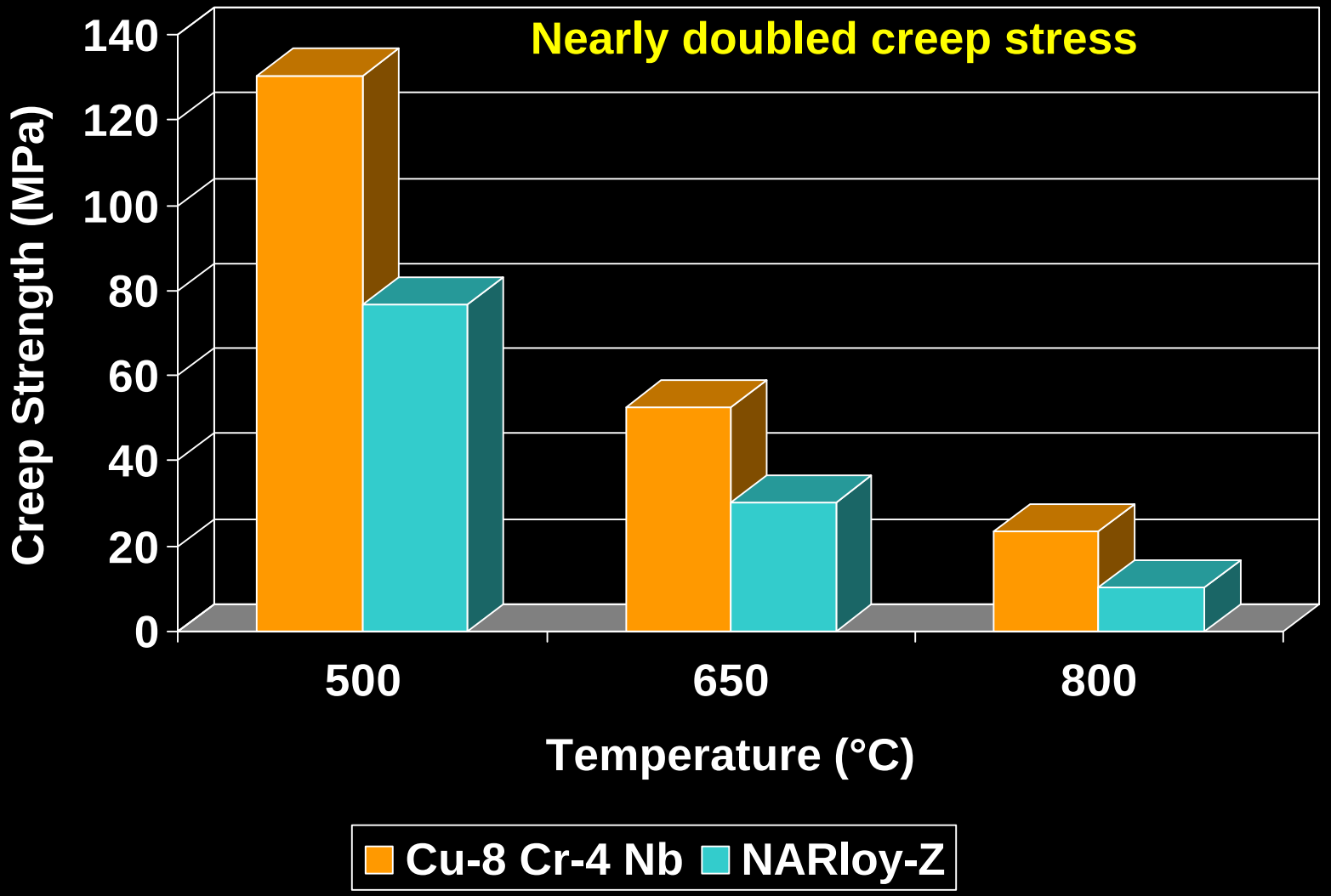
Fracture Surfaces



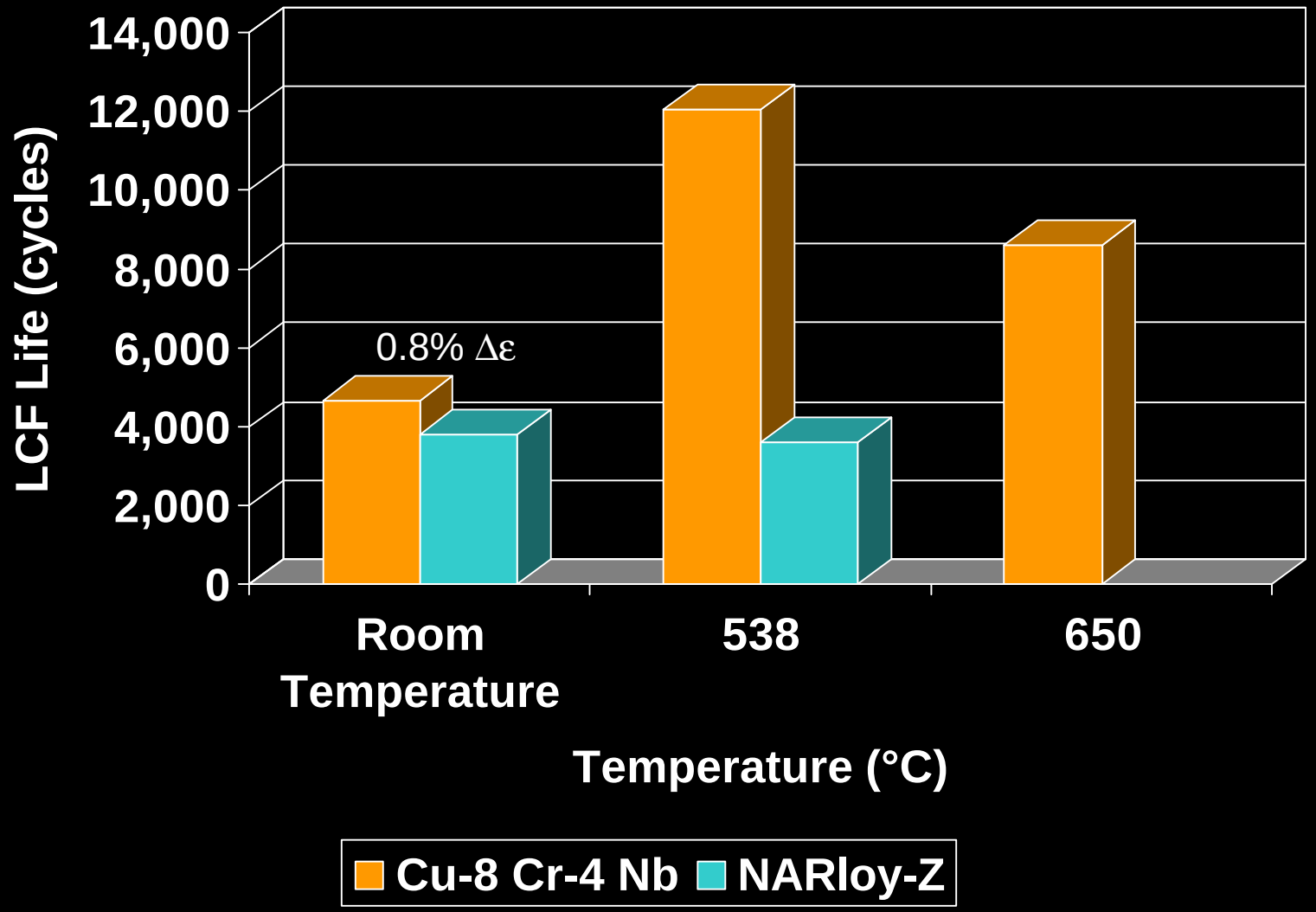
RT Cu-8 Cr-4 Nb Tensile Test

- **Evidence of ductile failure**
- **No cleavage observed**
- **No debonding around precipitates observed**
- **No change in mode with temperature observed**

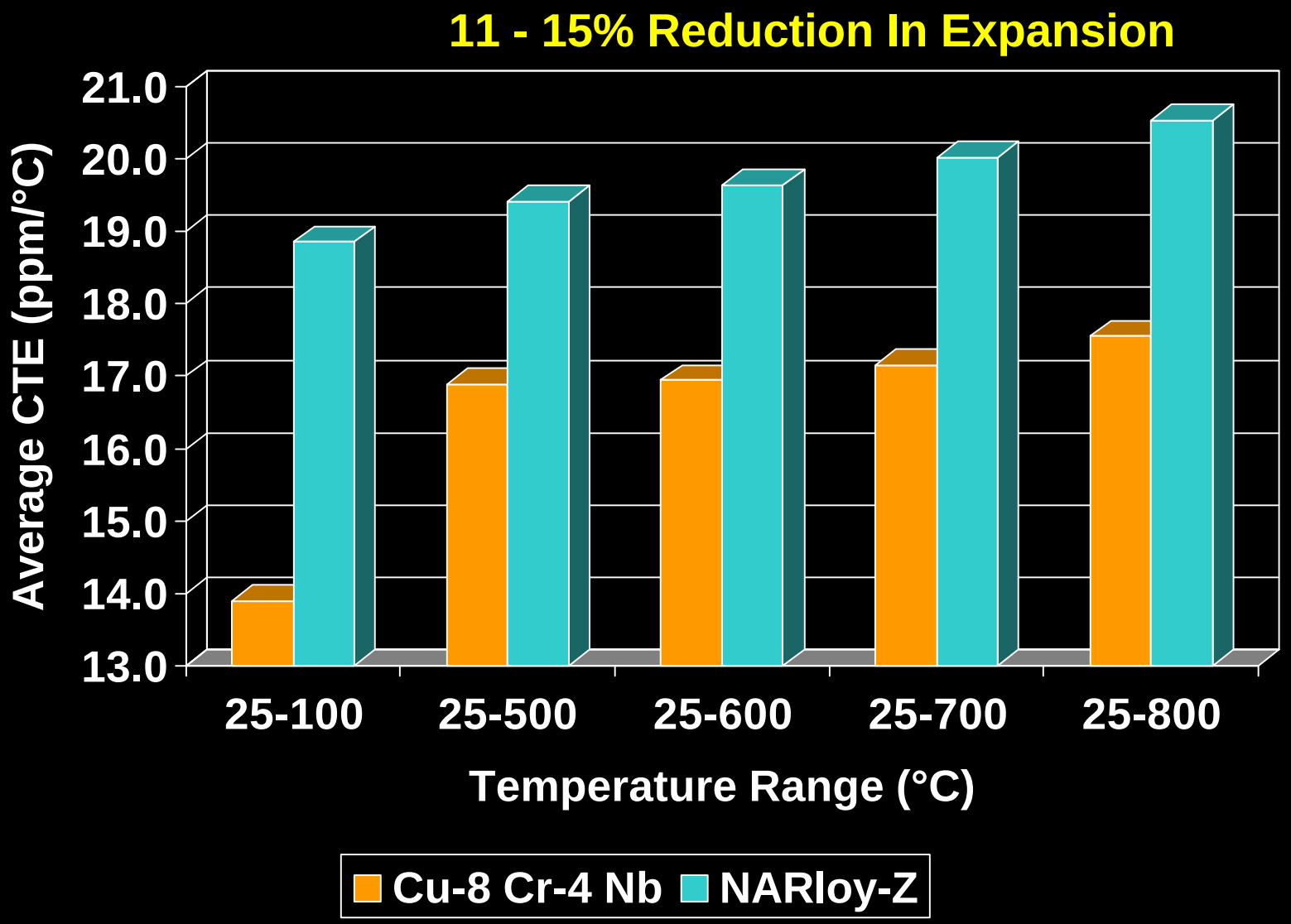
Fifteen Hour Life Creep Strength Of Cu-8 Cr-4 Nb



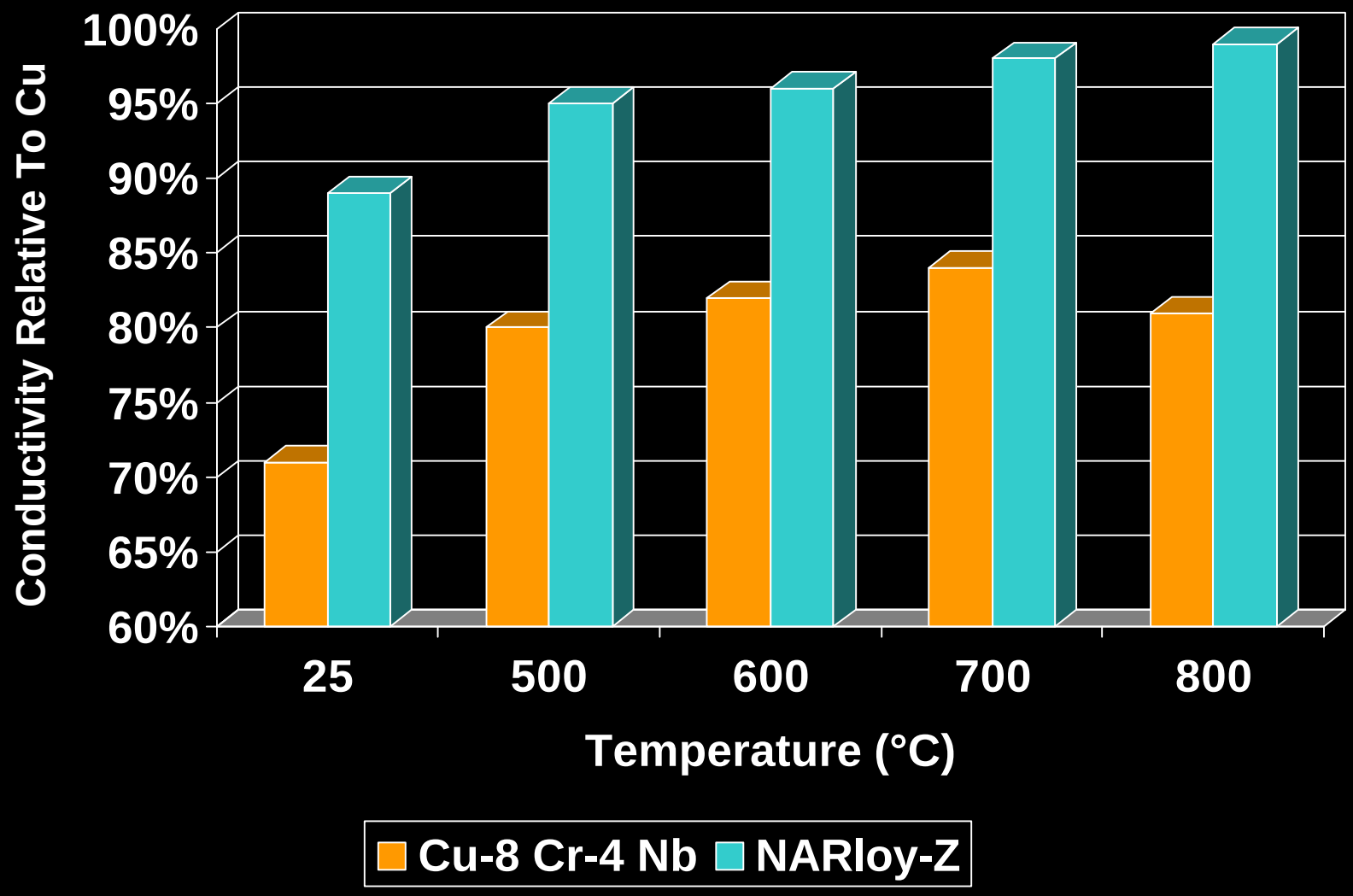
0.7% Strain Range Low Cycle Fatigue Lives Of Cu-8 Cr-4 Nb



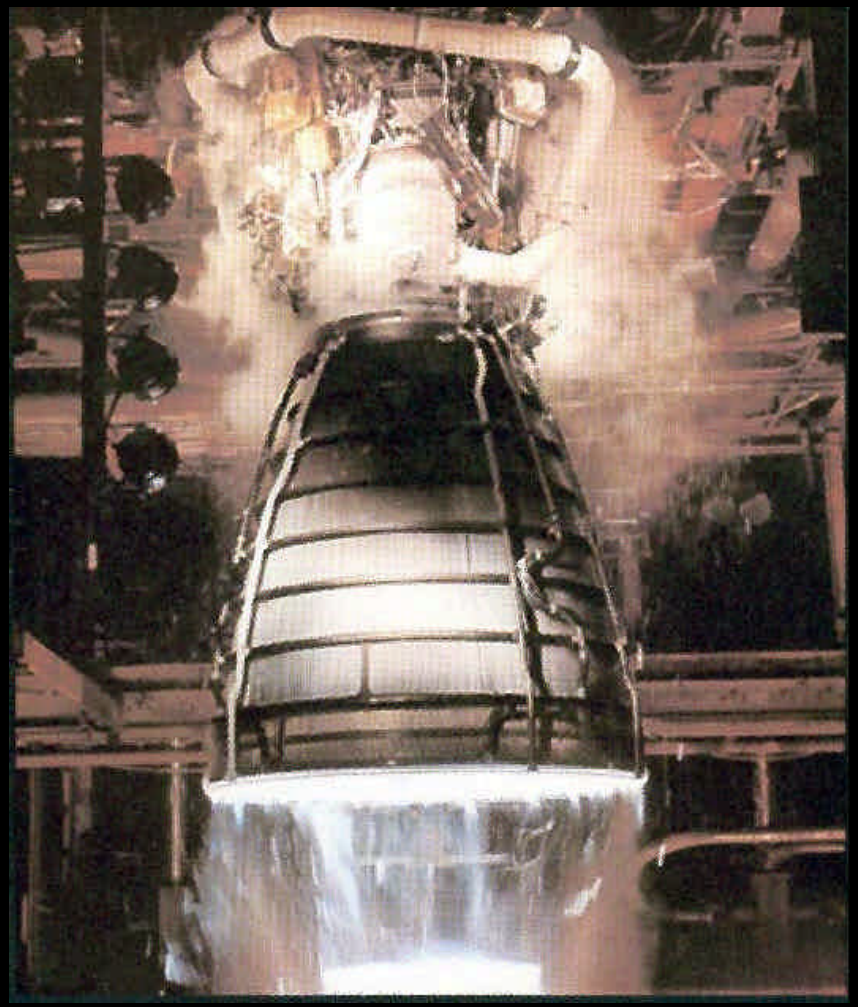
Thermal Expansion Of Cu-8 Cr-4 Nb



Thermal Conductivity Of Cu-8 Cr-4 Nb



Increased Materials Capabilities Spark Interest For Various Aerospace Applications



Space Shuttle Main Engine (SSME) test firing

- **National Aerospace Plane (NASP)**
  - Combustor section as alternative to metal matrix composite or refractory alloy
- **NASA**
  - Marshall Space Flight Center for SSME and RLV engines
- **Rocketdyne**
  - Several rocket engine applications could benefit

Co-operative Development Within NASA

VPS spool piece with cooling channels

- **NASA Marshall Space Flight Center (MSFC) has developed Vacuum Plasma Spray (VPS) process for NARloy-Z**
- **Developed VPS for Cu-8 Cr-4 Nb using internal funding source**
- **Currently working with NASA GRC on testing of existing spool piece**
- **Lightweight jacket for RLV will make and test at least 4 VPS liners**

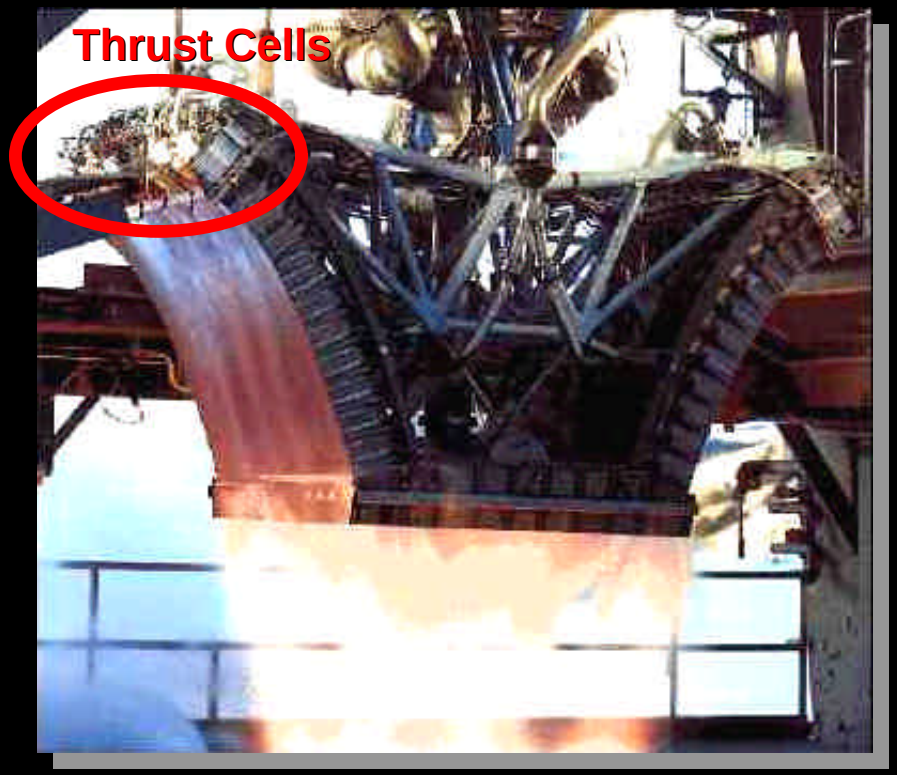
Vacuum Plasma Spray (VPS) Offers Way To Make Complex Parts Quickly And Cheaply

- VPS can rapidly deposit thick, dense layers onto tooling to make complex, near-net shape parts
- Properties of VPS Cu-8 Cr-4 Nb are equal to slightly better than prior extruded material
- VPS can also apply functional gradients for environmental and wear protection

Successful Transfer To Industry In Progress

VentureStar combustion chamber liners to be made from Cu-8 Cr-4 Nb

Aerospike Engine



Test firing of XRS-2200 engine

- **Rocketdyne Division of Boeing developing RS-2200 aerospike engine for Lockheed-Martin Skunk Works for use in VentureStar**
- **Baseline thrust cell liner material is Cu-8 Cr-4 Nb**

Welding Electrodes

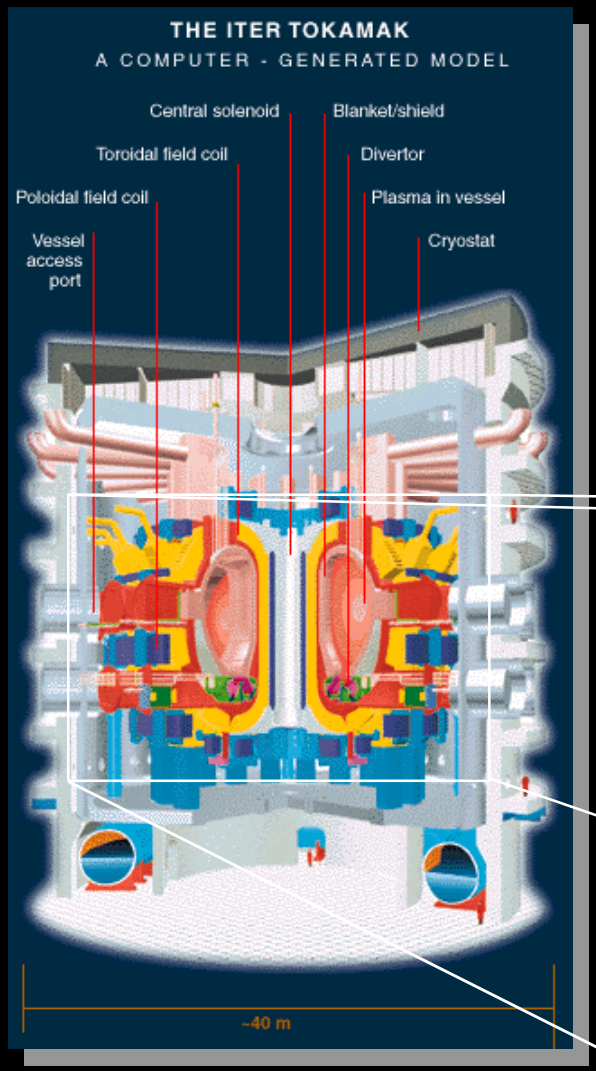
- **Replacement for spot and resistance welding electrodes**
- **Potential to increase life of electrodes and quality of welds**
- **Major hurdles**
  - Resistance to using higher initial cost material particularly in automotive industry
  - Need to prove ability to weld galvanized steel

Plastic Injection Molds

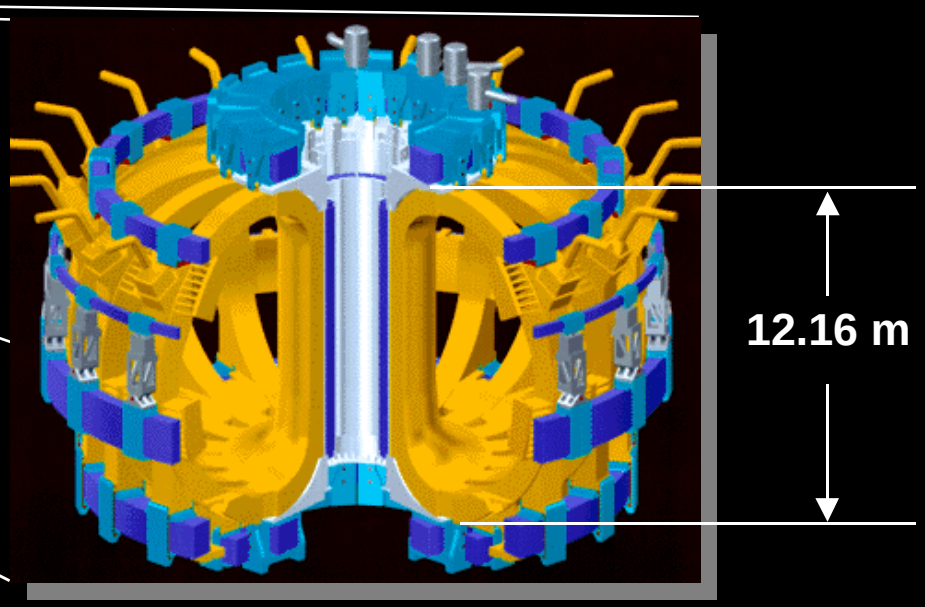
- **Molds require high thermal conductivity and strength**
  - Potential to increase throughput and decrease total cost of molds
- **Major hurdles**
  - Initial cost of producing molds
  - Proving that Cu-8 Cr-4 Nb molds give lower total cost and better wear resistance over the life of the mold




Fusion Generators And High Field Magnets



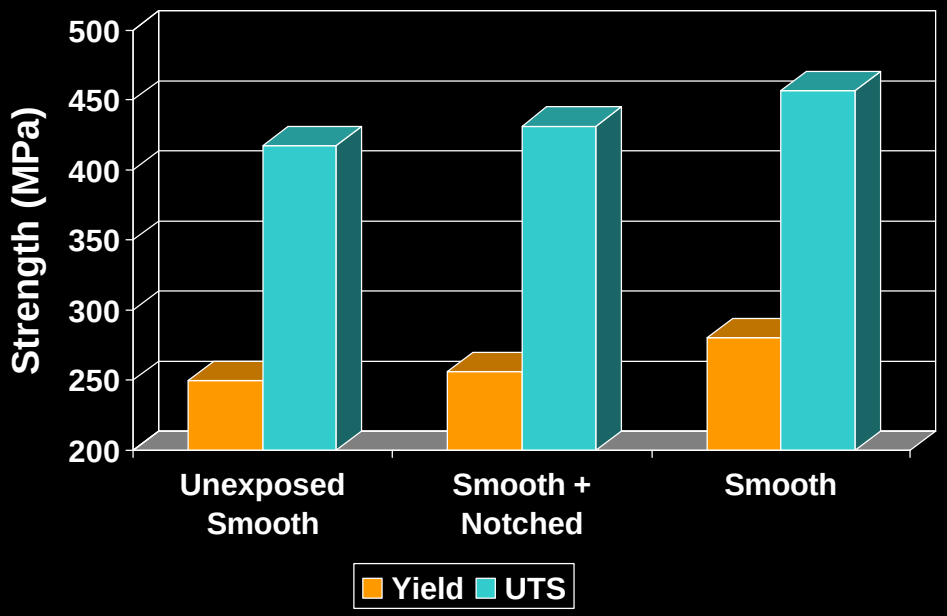
- **International Thermonuclear Experimental Reactor (ITER) uses very large superconducting magnets reinforced with steel and superalloys**
  - Maximum field 12.5 Tesla
- **Cu-8 Cr-4 Nb possible reinforcement or first wall material**

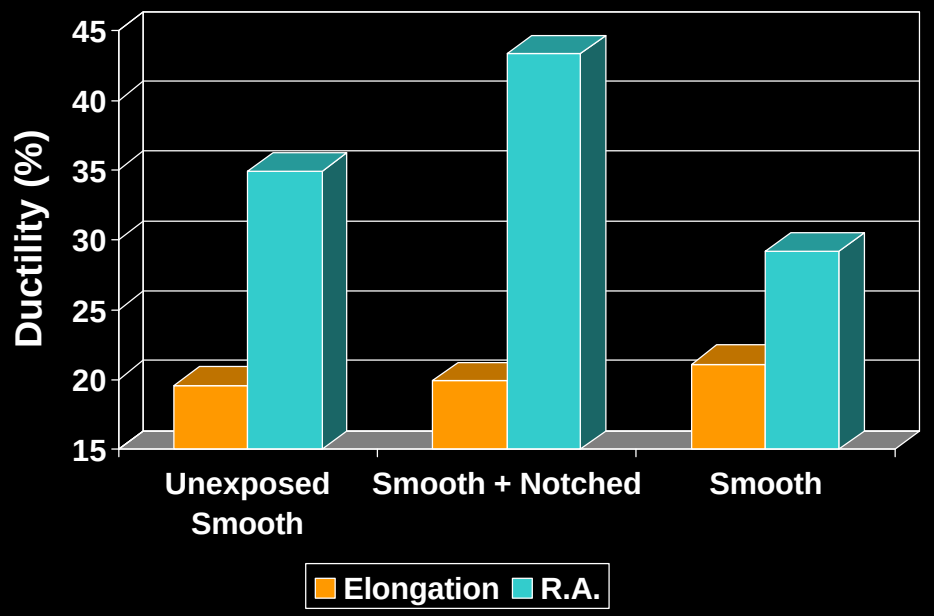


Summary

- Cu-8 Cr-4 Nb has been successfully developed and scaled up
- Mechanical and thermophysical properties are significantly improved over NARloy-Z
- Work is currently underway to transfer the alloy into VentureStar / RLV combustion chamber liners and other uses

Effect Of Hydrogen Exposure On Strength and Ductility Of Cu-8 Cr-4 Nb





- No significant change in elongation or reduction in area after exposure to high pressure hydrogen
- No evidence of notch sensitivity