STRUCTURAL & NOZZLE MATERIALS ASSESSMENT

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ARIES EVALUATION OF HYLIFE-II DESIGN

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SUMMARY SLIDE

- **Type 304 Stainless Steel (304SS)**
  - Must tighten specs on Mo and Nb for low activation
  - Swelling limit on lifetime (e.g., 5 vol.% at 25 dpa)
  - Helium embrittlement (650±50°C) limit on T_{max}
  - Creep limit on σ (e.g, 53 MPa at 600°C for 10-y life)
- **Low-activation Ferritic Steel (LAFS)**
  - Creep limit on σ (e.g, 55 MPa at 600°C for 10-y life)
- **Developmental ODS LAFS**
  - Good potential for high T (600-800°C) performance

APPROACH TO MATERIALS ASSESSMENT

- **Materials: 304SS, LAFS, ODS-LAFS**
  - Annealed Type 304 austenitic stainless steel
  - Low-activation (LA) Ferritic Steel (FA): e.g. F82H
  - Oxide Dispersion Strengthened (ODS) LAFS
- **Design Limits used in Assessment**
  - Based on ASME B&PVC, RCC-MR, ITER-ISDC
  - Short-time stress limits for pressure vessels/piping
  - Long-time stress limits based on thermal creep
  - Generic deformation limits (e.g., 5% vol. swelling)

304SS ASSESSMENT

- **Low Activation & Swelling Compositions**

  - Need tighten specs on Mo and Nb for LA

  - Need tight specs on Ni, Cr, P, Si & C to reduce $\Delta V/V_o$

- **Swelling**

  - Incubation ($D<D_o$), transient ($D<D_s$), steady-state ($D \geq D_s$)

- **Helium-Induced Embrittlement**

  - Severe at 650±25°C

- **Thermal Creep Limits on Stresses**

  - Severe for T > 550°C

TYPE 304SS COMPOSITION

- **Activation Considerations**
  - “Off-the-shelf 304SS contains high levels of Mo and Nb
  - Fast Breeder Reactor (FBR) program recommended
    < 0.2 wt.% Mo & < 0.005 wt.%Nb to reduce data scatter
  - Recommend that activation analysis be used to determine
    upper Mo and Nb limits and then assign material cost
- **Swelling Considerations**
  - Specify 304L (0.01-0.03 wt.% C)
  - ≈10.5%Ni, ≈18%Cr, 0.06-0.08%P, ≈0.3-0.4%Si

TYPE 304 STAINLESS STEEL SWELLING

- **General Results for 304SS and 316SS**
  - Incubation phase ($D<D_o$) with negligible swelling
  - Transient phase ($D_o \leq D < D_s$) with R = 0-1 vol.%/dpa
  - Steady state ($D \geq D_s$) with R = 1 vol.%/dpa
  - D_o, D_s and transient R depend on many parameters
- **Specific Results for 304SS and 304L SS**
  - At 390-530°C, D_o = 5-12 dpa, trans. R = 0.2-0.3%/dpa
  - Upperbound correlation for $\Delta V/V_o < 10$ vol. %

    $\Delta V/V_o = 0.33$ vol.%/dpa (D – 10 dpa)

HELIUM EMBRITTLEMENT IN 304SS

- **Low Temperature (<400°C) Behavior**

  - Low uniform (UE) and total (TE) elongation
  - High reduction in area (RA>60%) & fracture toughness

- **High Temperature (>550°C) Behavior**

  - Low UE, TE, RA (40%→10%) at >600°C, 6 dpa, 3 ppm He
  - Results suggest low fracture toughness
  - He migration to grain boundaries reduces tensile ductility
  - Same phenomena will reduce creep ductility and failure time

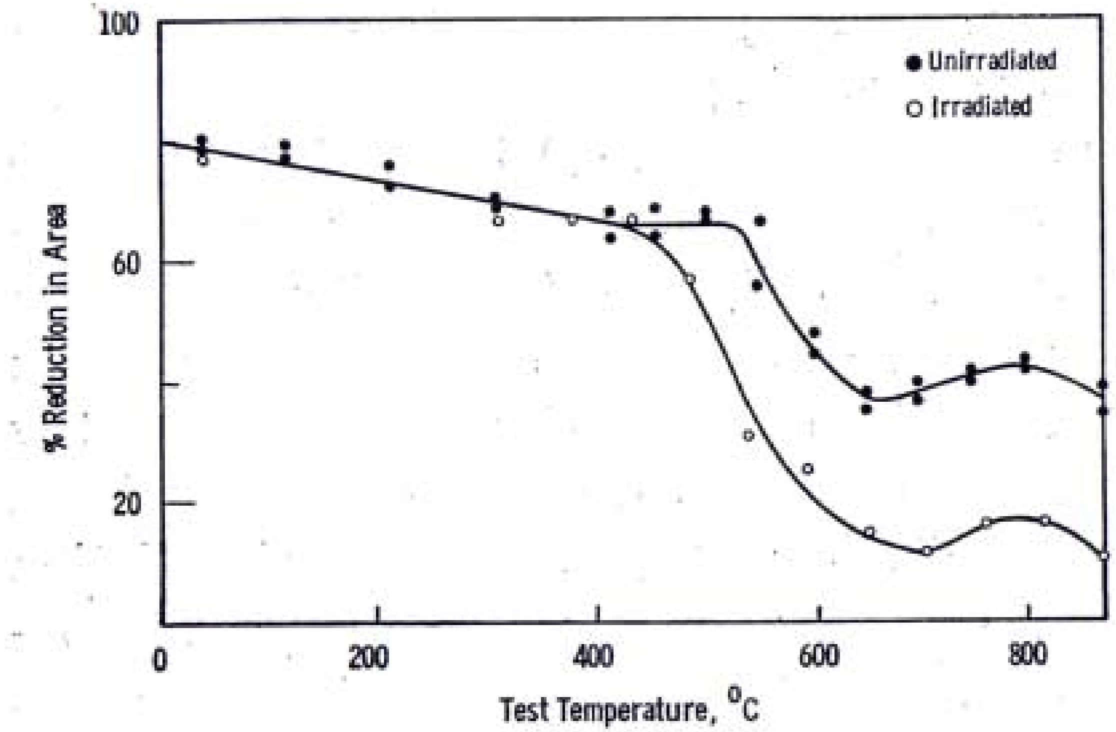

Fig. 5. Reduction in area for 304 stainless steel irradiated to 1.1×10^{22} n/cm^2 ($E > 0.1$ MeV) at 540 ± 50 °C.

TYPE 304SS THERMAL CREEP LIMITS

- **Design Stresses based on Tensile Properties**
  - S_m limits primary membrane stresses P_m
  - Primary bending stress (P_B) limit: $P_B+P_m \leq 1.5\ S_m$
  - Thermal & swelling stress (Q) limit: $Q+P_B+P_m \leq 1.5\ S_m$
- **Thermal Creep Limits S_m for given T & time**
  - Limits based on creep strain, rupture and tertiary creep
  - 600°C and 10 yrs: S_m = 93 MPa → S_{mt} = 53 MPa
  - 650°C and 10 yrs: S_m = 88 MPa → S_{mt} = 35 MPa
  - He embrittlement will reduce failure time at >600°C

LOW-ACTIVATION (LA) FERRITIC STEEL (FS) ASSESSMENT

- **Low Activation**

  - IEA heat (modified F-82H) is satisfactory

- **Swelling**

  - Not an issue: $\Delta V/V_o \leq 0.015$ vol.%/dpa

- **Helium-Induced Embrittlement**

  - Never been observed at high T for ferritic steels
  - High He production at 100 dpa may be an issue???

- **Thermal Creep Limits on Stresses**

  - Severe for T > 550°C

TENSILE & THERMAL CREEP LIMITS FOR LOW-ACTIVATION FERRITIC STEELS

- **Yield (YS) & Ultimate Tensile (UTS) Strength**

  - High for T < 450°C; rapid decrease for T > 450°C

  - S_m = 128 MPa (550°C), 103 MPa (600°C), 73 MPa (600°C)

- **Thermal Creep Limits based on 10-year Life**

  - S_{mt} = 100 MPa at 550°C

  - S_{mt} = 55 MPa at 600°C

  - S_{mt} = 23 MPa at 650°C

LOW-ACTIVATION (LA) ODS FERRITIC STEEL (FS) ASSESSMENT

- **Commercial Alloys (M956, M957)**
  - Mo content (0.3 wt.%) too high; Nb content not specified
  - Highly anisotropic: strong only in extruded direction
- **Developmental Alloys**
  - LAF-3 (mod. F-82H plus fine Y_2O_3 & TiO_2 particles)
  - Japanese 12YWT (12-13% Cr vs. 8.6% for F-82H)
  - Japanese PNC 1DS (11% Cr, higher Y_2O_3 than 12YWT)
  - Ongoing effort to optimize chemical composition and and heat treatment for high strength in all directions

TENSILE PROPERTIES FOR ODS LAFS ALLOY LAF-3

T °C	YS MPa	UTS MPa	TE %	S_m MPa
500	730	970	13	268
650	380	480	22	133
700	290	400	17	111

MATERIALS SELECTION FOR HYLIFE-II IFE DESIGN (1994)

- FSW: Ti-modified 316SS (PCA), 304SS, other
  - Tubes (1994); allowed to leak flibe into chamber
  - Current design ??? (2002)
- Flow Guide Structures: 316SS (PCA), 304SS
  - Current: low-stress, swelling-tolerant, corrugated sheets
- Liquid Nozzle Systems: unspecified
- Vacuum Vessel: PCA, 304SS, C-C composites

RECOMMENDED MATERIALS FOR HYLIFE-II IFE DESIGN (2002)

- FSW: ODS LAFS (e.g., LAF-3) if tubes
  - 304SS would limit lifetime and T_{max} (≤600°C)
  - V alloys are limited to Li coolant; C-C or SiC-SiC ???
- Corrugated Flow Guide Structures
  - LAFS if stresses are low and leaks are OK???
- Liquid Nozzle Systems: ODS LAFS
- Vacuum Vessel: ODS LAFS
  - Fabricability and joining (welding) are issues