Status of EVOLVE Design

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Topics Covered

- Power Conversion Efficiency
- Heat Exchangers
- Tritium System
- Thermo-mechanical Analysis
- Helium Embrittlement

Effect of He Concentration on Time to Rupture

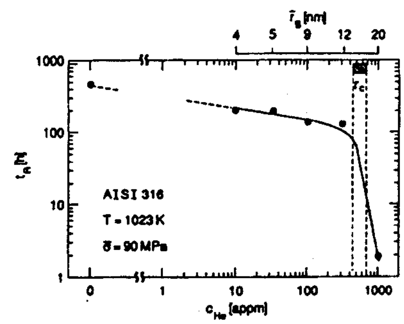

Fig. 5. Time to rupture, t_R, versus He concentration, c_{He}, for creep tests performed after high-temperature α-implantation. When the average radius of grain boundary cavities observed in TEM, $\bar{r}_B$, reaches the critical value $r_c \approx 15$ nm, t_R drops drastically [1].

H.Trinkaus, et.al., J. Nucl. Mater., 215-215, p 303-309, 1994

Effect of He Concentration on Creep Ductility and Fracture

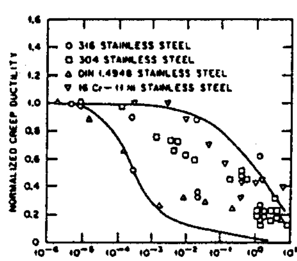

Fig. 6. Collection of normalized creep ductilities for several different austenitic stainless steels versus helium content. Curves represent predicted upper and lower bounds based on grain size and other factors. Data for 316 are for an initial stress of 191 MPa and temperature of 625°C. Conditions for other alloys vary. After ref. [20].

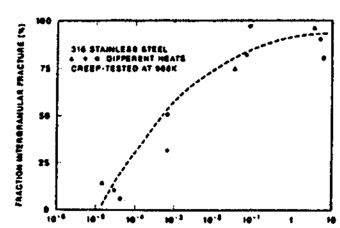

Fig. 7. Fraction of fracture surface of 316 stainless steel that exhibits intergranular failure in creep tests at 625°C versus helium content. After ref. [21].

L.K.Mansur, et.al., J. Nucl. Mater, 155-157, p130-147, 1988

Effect of Strain Rate and He on Creep Ductility

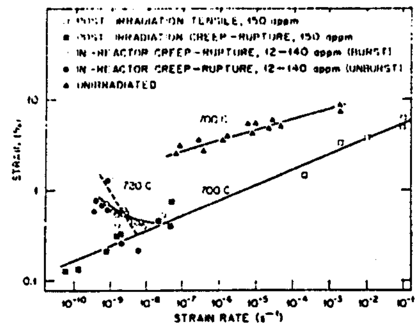

Fig. 15. Strain to failure of alloy 1.4970 irradiated in the BR-2 reactor. Strain rate is varied over a very wide range, with tensile tests results plotted at the higher strain rates and creep-rupture results plotted at the lower strain rates. The latter results include both post-irradiation and in-reactor tests. After ref. [57].

L.K.Mansur, et.al., J. Nucl. Mater, 155-157, p130-147, 1988

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Conclusions

- The EVOLVE design achieves high power conversion efficiency, ~57%
- Heat exchanger sizes and pumping power are modest.
- An acceptable tritium recovery system has been identified. Tritium containment needs to be addressed in more detail.
- High T creep does not appear to be a problem. Finite element analysis is planned.
- Helium embrittlement effects should be addressed in more detail for all high T concepts.

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Power Conversion Efficiency

To, K	Turbine inlet temperature	1273
Ts, K	Compressor inlet temperature	308
To/Ts		4.13
r	Compression ratio	2.0
nx	Recuperator efficiency	0.96
nc	Compressor efficiency	0.92
nt	Turbine efficiency	0.92
Beta	Turbine pressure ratio	1.02
Gamma	Gas heat capacity ratio (Cp/Cv)	1.66
Cycle efficiency		57.7%

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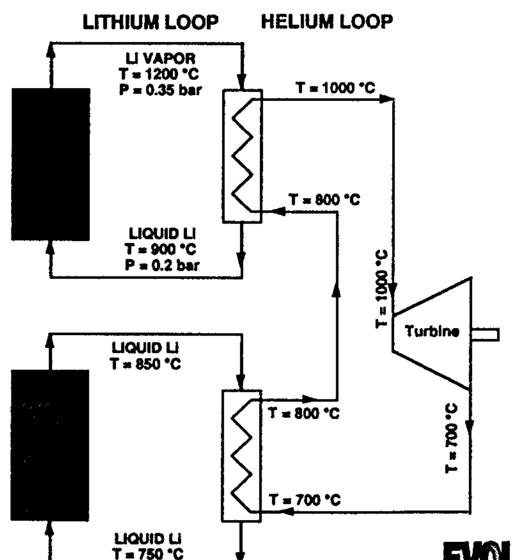
EVOLVE Lithium-Helium Heat Exchanger

University of Wisconsin-Madison



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EVOLVE Lithium-Helium Heat Exchanger

University of Wisconsin-Madison

Parameters of the Lithium-Helium Heat Exchanger

1- Heat Exchanger System Parameters

	Low Temp. HX	High Temp. HX
Heat Capacity (MW)	1000	2000
Number of Heat Exchangers	32	32
Li Inlet Temp.(°C)	850	1200
Li Exit Temp.(°C)	750	900
Li δT (°C)	100	300
Li Mass flow Rate (kg/s)	2380	95
He Inlet Temp.(°C)	700	800
He Exit Temp.(°C)	800	1000
He δT (°C)	100	200
He Mass flow Rate (kg/s)	1923	1923
He Pressure, (bar)	120	120

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EVOLVE Lithium-Helium Heat Exchanger

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2- Single Heat Exchangers Parameters

	Low Temp. HX	High Temp. HX
Tube inside Diameter. (mm)	12.5	12.5
Length of Each Tube (m)	1.5	1.0
Number of Tubes	1912=(44X44)	1912=(44X44)
Li Mass flow Rate (kg/s)	75	2.97
Li Minimum flow Area (m^2)	0.825=(1.5X1.1)/2	0.55=(1.0X1.1)/2
Li Max. Velocity (m/s)	0.2	225
He flow Area (m^2)	0.235	0.235
He Velocity (m/s)	138	138
He Fraction Pressure drop (bar)	0.93	0.62
He Pumping Power (MW)	1.2	0.8

NOTE:

To enhance condensation in the high temperature heat exchanger, fins and flow deflector could be used.

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Tritium System

• Tritium recovery method	Cold trap
• Tritium production rate	
First breeding zone, g/fph	333
Second breeding zone, g/fph	167
• Coolant flow rate	
First breeding zone, Kg/hr	95
Second breeding zone, Kg/hr	2380
• Allowable tritium concentration, appm	1
• Li flow rate to the tritium recovery system	
First breeding zone, Kg/hr	30
Second breeding zone, Kg/hr	15
• Maximun tritium partial pressure, Pa	0.0014

Conclusion: Tritium flow rate to the tritium recovery system is modest. Tritium partial pressure starts to be a concern.

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Time-dependent Primary Stress Allowable (S_{mt})

$$S_{mt} = \mathrm{Min}(S_m, S_t)$$

where

$$S_t(t,T) = \mathrm{Min}\begin{cases} 100\% \text{ stress to } \min(\frac{\varepsilon_c}{5}, 1\%) \text{ creep strain} \\ 80\% \text{ stress to onset of tertiary creep} \\ 67\% \text{ stress to cause creep rupture} \end{cases}$$

and ε_c is the minimum creep ductility

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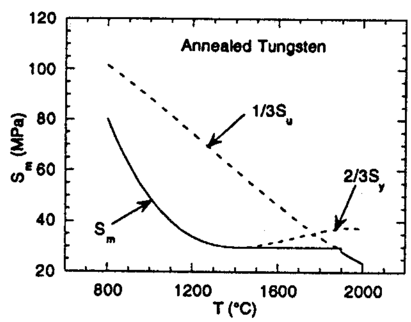
Time-independent Primary Stress Allowable (S_m)

- $S_m = \mathrm{Min}\begin{cases} \frac{1}{3} S_u \\ \frac{2}{3} S_y \end{cases}$



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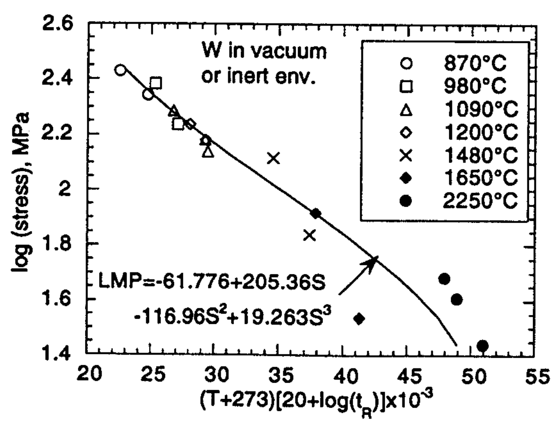
Larson-Miller Parameter for Time to Rupture



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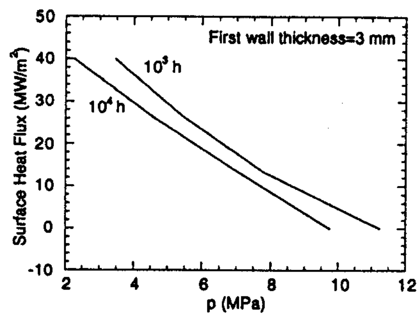
Creep Rupture Effect



- Creep rupture does not limit allowable surface heat flux unless coolant pressure is very high
- Creep rupture effect may become more pronounced in the presence of He embrittlement

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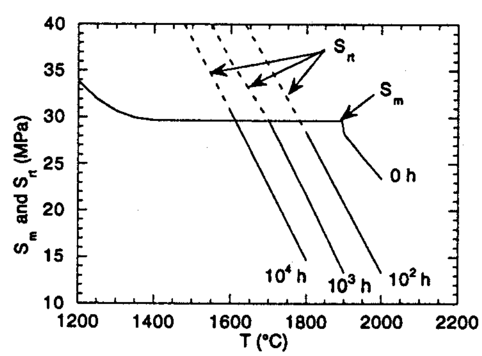
S_m and S_{rt} for Tungsten



- Need creep strain and ductility data
- Need data for onset of tertiary creep

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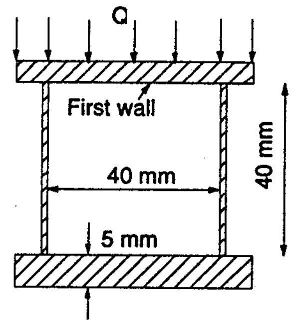
Rectangular Channel Design



T (coolant)=1200°C

p (coolant) =0.04 MPa

T_{max} for W=1400°C

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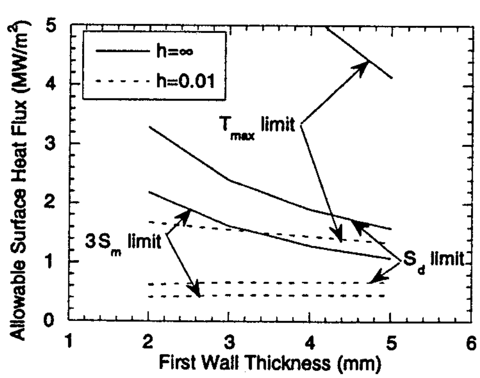
Allowable Surface Heat Flux



- Allowable surface heat flux depends strongly on coolant/first wall heat transfer coefficient h (w/mm^2/°C)

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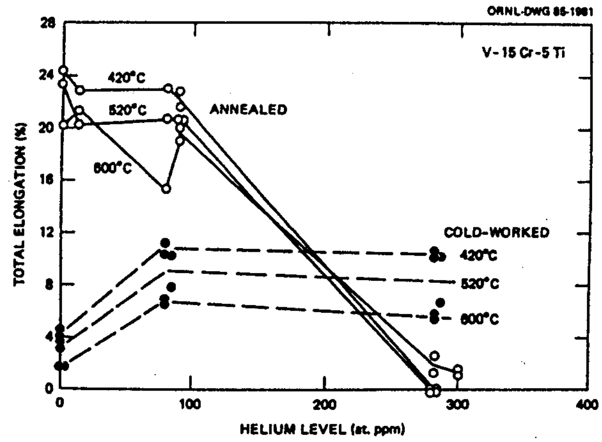
What Is He Embrittlement?

- High T (>0.45 T_m) loss of ductility due to He bubble formation and growth at grain boundaries
- Failure is intergranular.
- Uniform and total ductilities along with reduction in area are all reduced.
- Tensile strength is generally unaffected.

He Embrittlement Considerations

Embrittlement	Microstructure	He Implantation	Strain Rate	Temperature	Content
Slight	Cold-worked fine ppts.	Low T + Rad dam.	High	Low	Low
↓	↓	↓	↓	↓	↓
Severe	Annealed few ppts.	T Trick @ high T	Low (creep)	High	High

Effect of TM Treatment on He Embrittlement



D.N.Braski, AP DIP Report, DOE/ER-0045-15, p 83, 1985

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Effect of Temperature on He Embrittlement

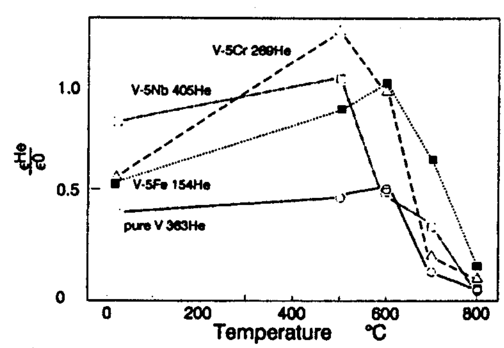

Fig. 3. Helium embrittlement (represented by the elongation of helium-doped specimen divided by that of the helium-free specimen) of alloys as a function of temperature.

H.Matsui, et. al.,J. Nucl. Mater, 191-194, 919-923, 1992

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