Radiation Effects in a Couple Solid Spallation Target Materials

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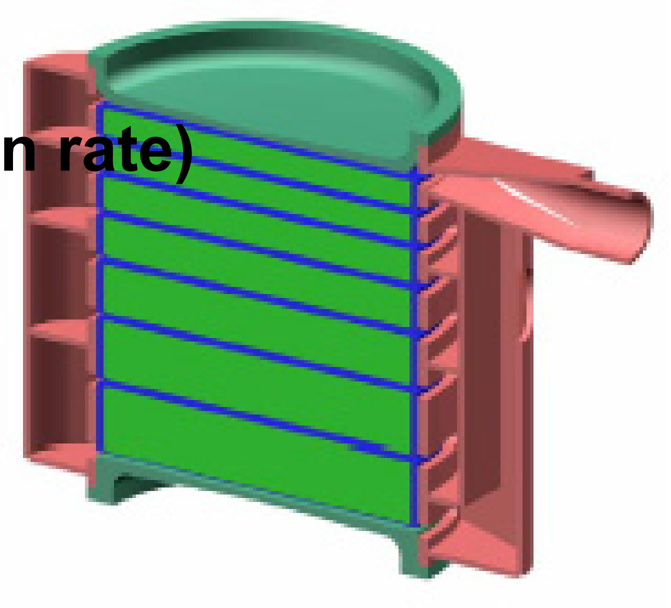
Outline

- Background Experience
- Effects of Irradiation
  - » Tungsten
    - Unirradiated
    - Compression
    - ΔDBTT
    - Corrosion
  - » Tantalum
    - Unirradiated
    - Tensile Properties
- Summary and Conclusions

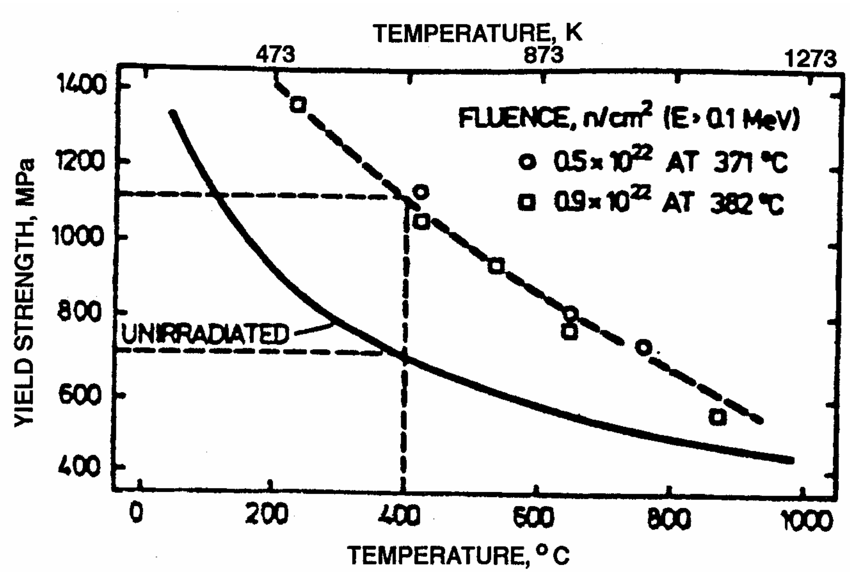
Previous Target Experience

- **LANSCE Target for Neutron Scattering (800 MeV, 100 μA)**
  - **Densimet alloy (high corrosion rate)**
  - **Pure Tungsten**
- **APT (800 MeV, 1 mA)**
  - **Pure Tungsten (high corrosion rate)**
  - **304L and 718 Clad**
- **KENS -Ta clad W**
- **ISIS**
  - **Pure tantalum (99.99%)**
  - **Ta clad W**



Irradiation Damage in Tungsten

AFCI Materials Handbook Shows Examples of Unirradiated Data for Tungsten



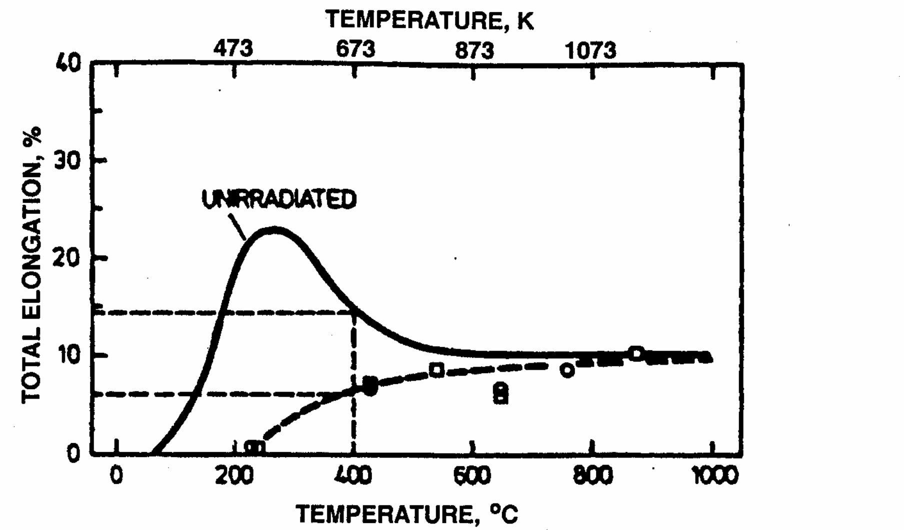


Figure 7-25. Temperature dependence of ductility of unirradiated and irradiated [1.6 dpa at ~658 K (385 °C)] tungsten.

- **Yield stress is high and decreases with increasing temperature**
- **Ductility in tension is low and significantly affected by increasing irradiation dose**

Previous Work Shows Large Increase in DBTT with Increasing Dose

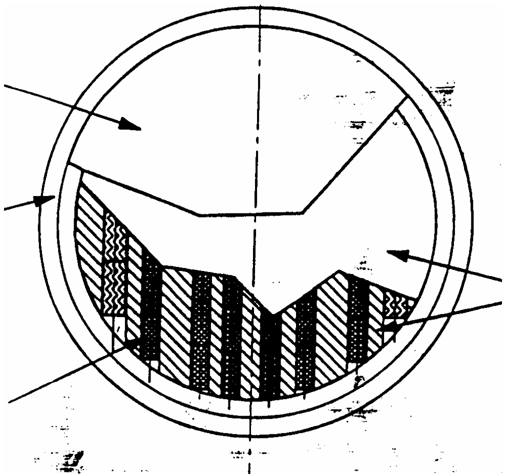
Material	Tirr	Fluence (10^{20} n/cm^2, E>0.1 MeV)	DBTT (C)
Densimet 18	-	-	<RT
	250	5	>800
	250	9.5	>800
W-10% Re	-	-	30
	250	5	185
Tungsten	-	-	75
	250	5	145
	250	9.5	240

Reference: Lohmann, 1986

Experimental Irradiation at LANSCE Shows Alloy Content Strongly Influences Irradiation Effects

Alloy Compositions

Alloy	W, %	Re, %	Cu, %	Fe, %	Ni, %
W-25% Re	75	25			
Kulite 1700	90		2	2	6
Kulite 1850	97		0.5	1-2	1-2



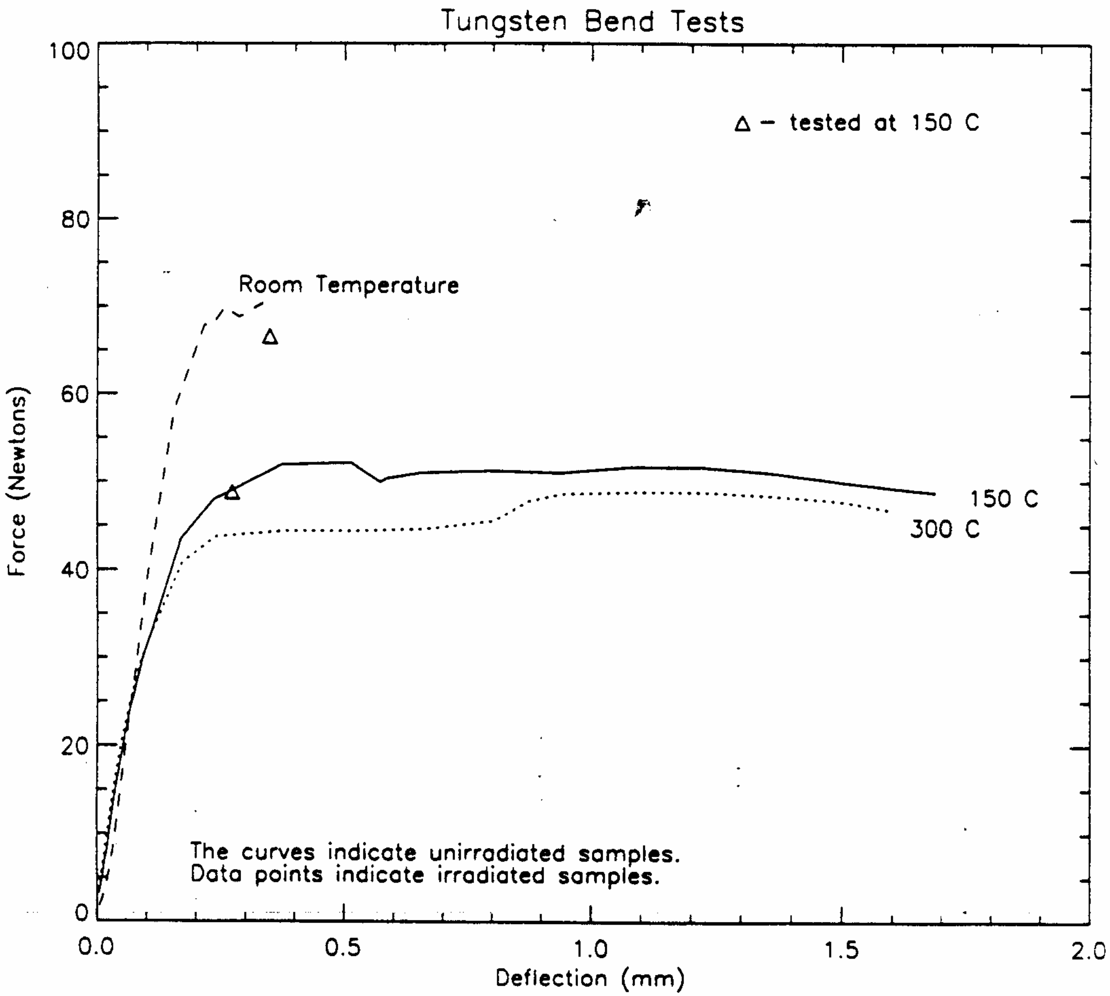
Proton Irradiation Canister (Beam incident on Center)

Irradiation Conditions (LANSCE 800 MeV, 650 μA, proton beam)

Material	Tirr (max) (C)	Fluence (10^{20} protons/cm^2)	Hardness (unirradiated)	Hardness (Irradiated)
Pure W	300	3.7	492	573
K1700	500	3.4	329	460
K1850	850	3.0	348	600
W-25Re	720	3.6	465	784

Sommer et al., 1985

Bend Test Results Show Large Reduction in Ductility with Irradiation Dose

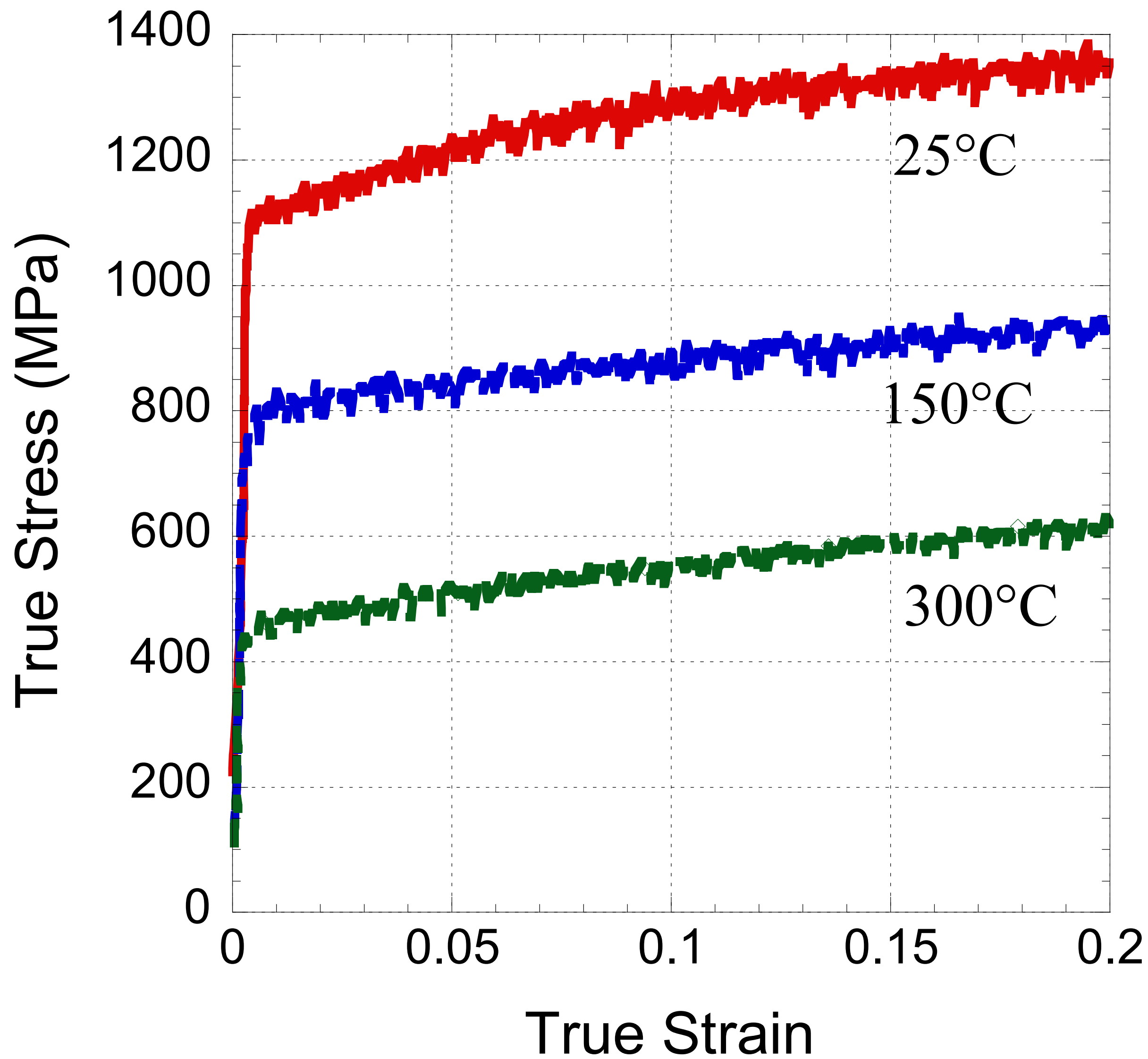


- **Alloy K1850 and alloy W 25% Re show a very large increase in hardness and become extremely brittle after exposure to 3-3.5 x 10^{20} p/cm2.**
- **Pure W is brittle after exposure to 3.7 x 10^{20} p/cm^2 but has some ability to deform.**
- **Alloy K1700 deformed after exposure to 3.4 x 10^{20} p/cm^2 but at a reduced flow stress possibly due to formation of cracks.**

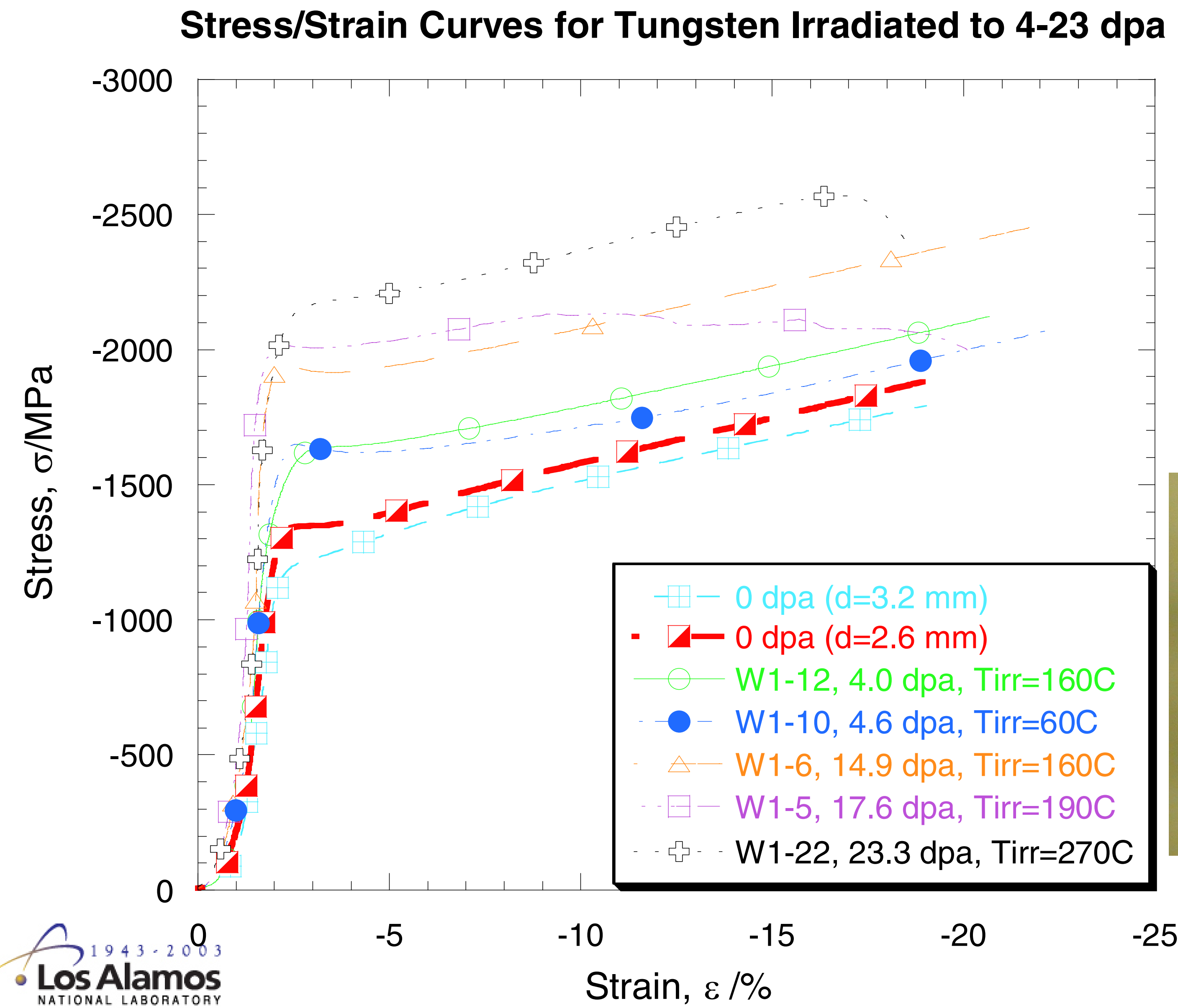
Sommer et al., 1985

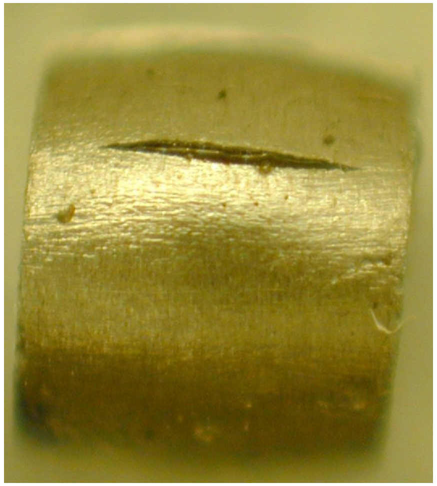
Larger Plasticity Can be Measured by Testing Mechanical Properties of Tungsten in Compression

- **Yield Strength**
  - **25°C ~1100MPa**
  - **150°C ~700MPa**
  - **300°C ~400MPa**

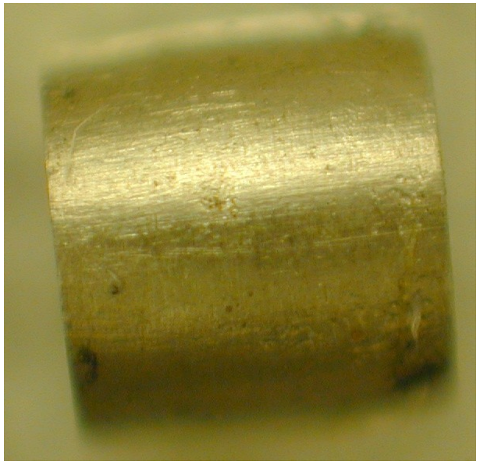


Compression Stress/Strain Results for Irradiated Tungsten Show Increase in Yield Stress with Dose above 4 dpa



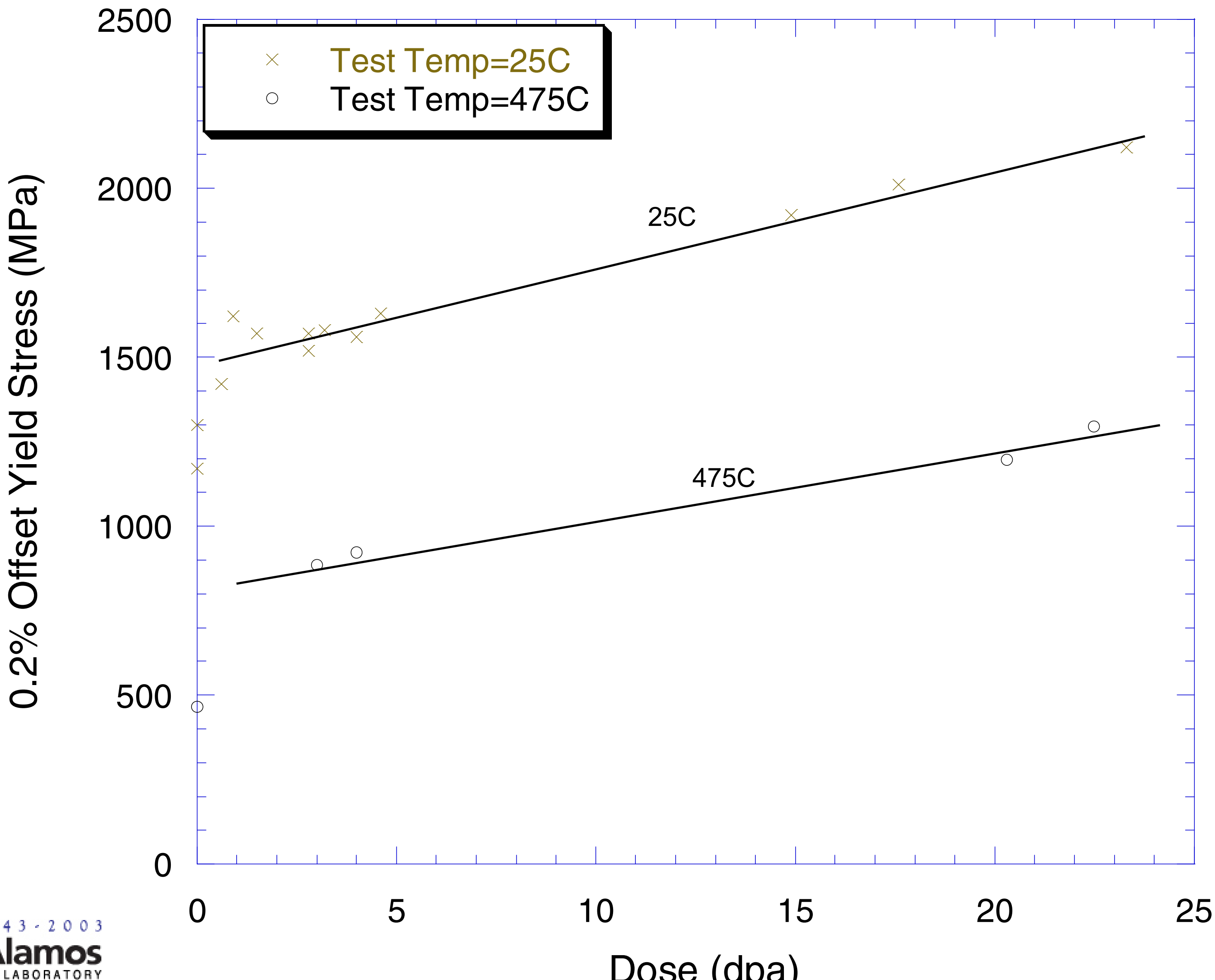


3.2 dpa

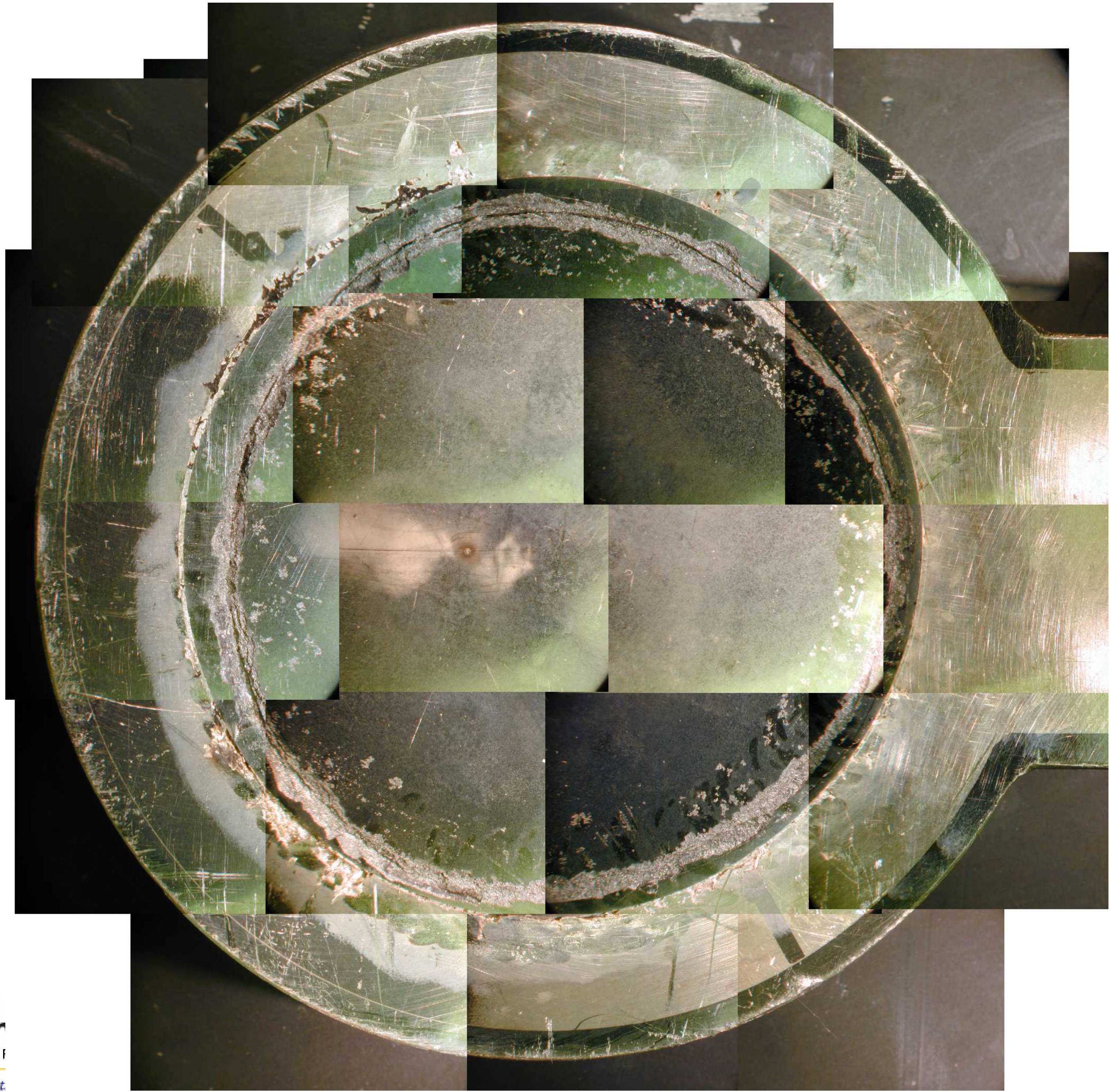


0 dpa

Yield Stress steeply with dose up to 1 dpa and gradually up to 23 dpa

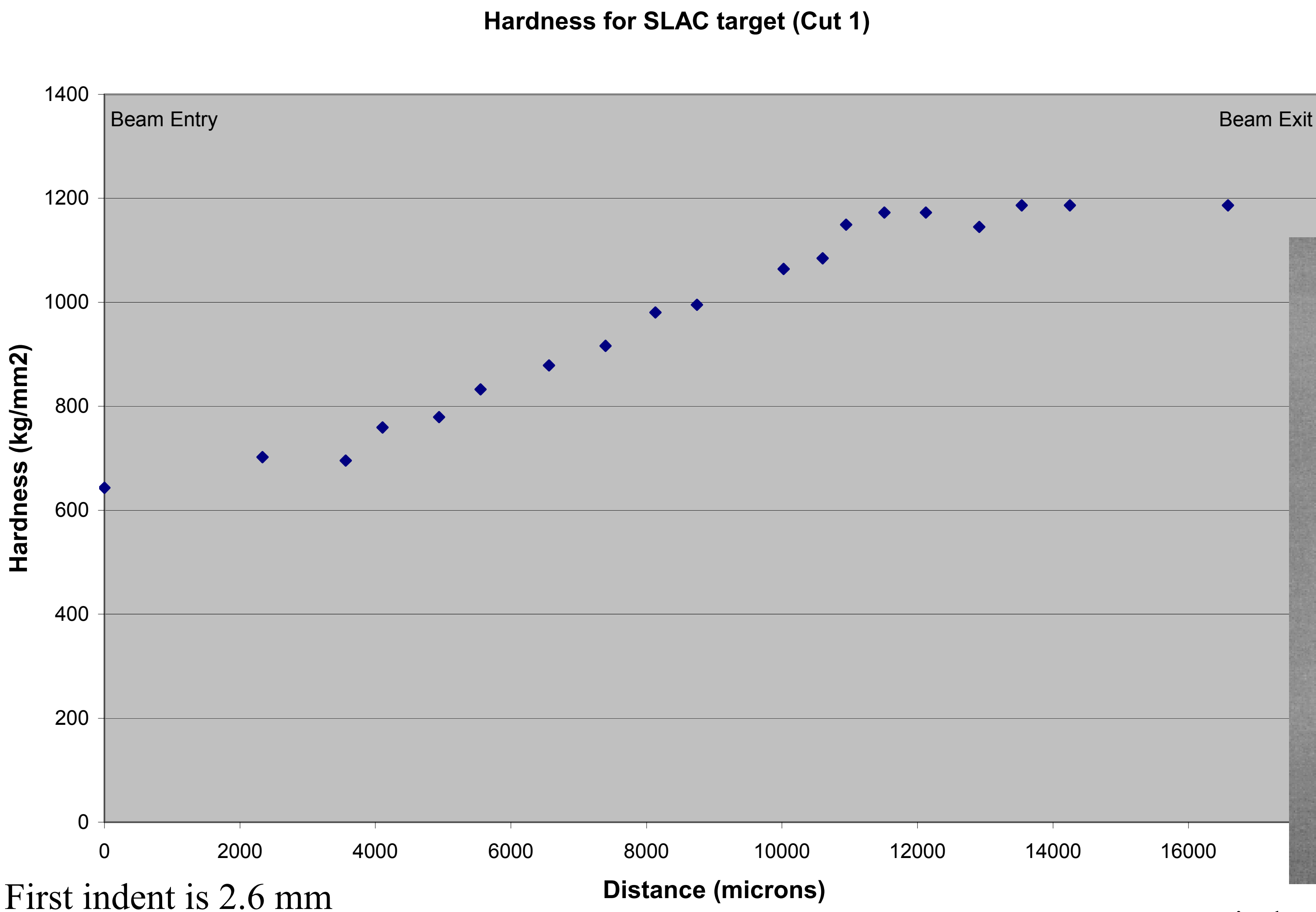


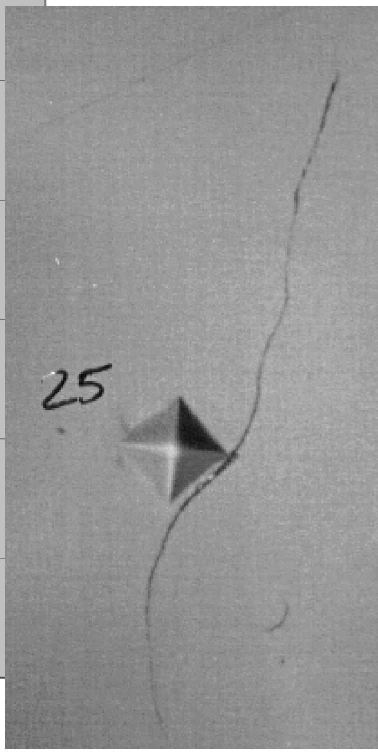
Similar Embrittlement also Observed Upon Analysis of SLAC W/Re Positron Target



Exit Surface of SLAC positron target after irradiation in a 30 GeV electron beam.

Hardness Measured from Beam Entry to Exit Shows Factor of 2 increase and Strong Embrittlement



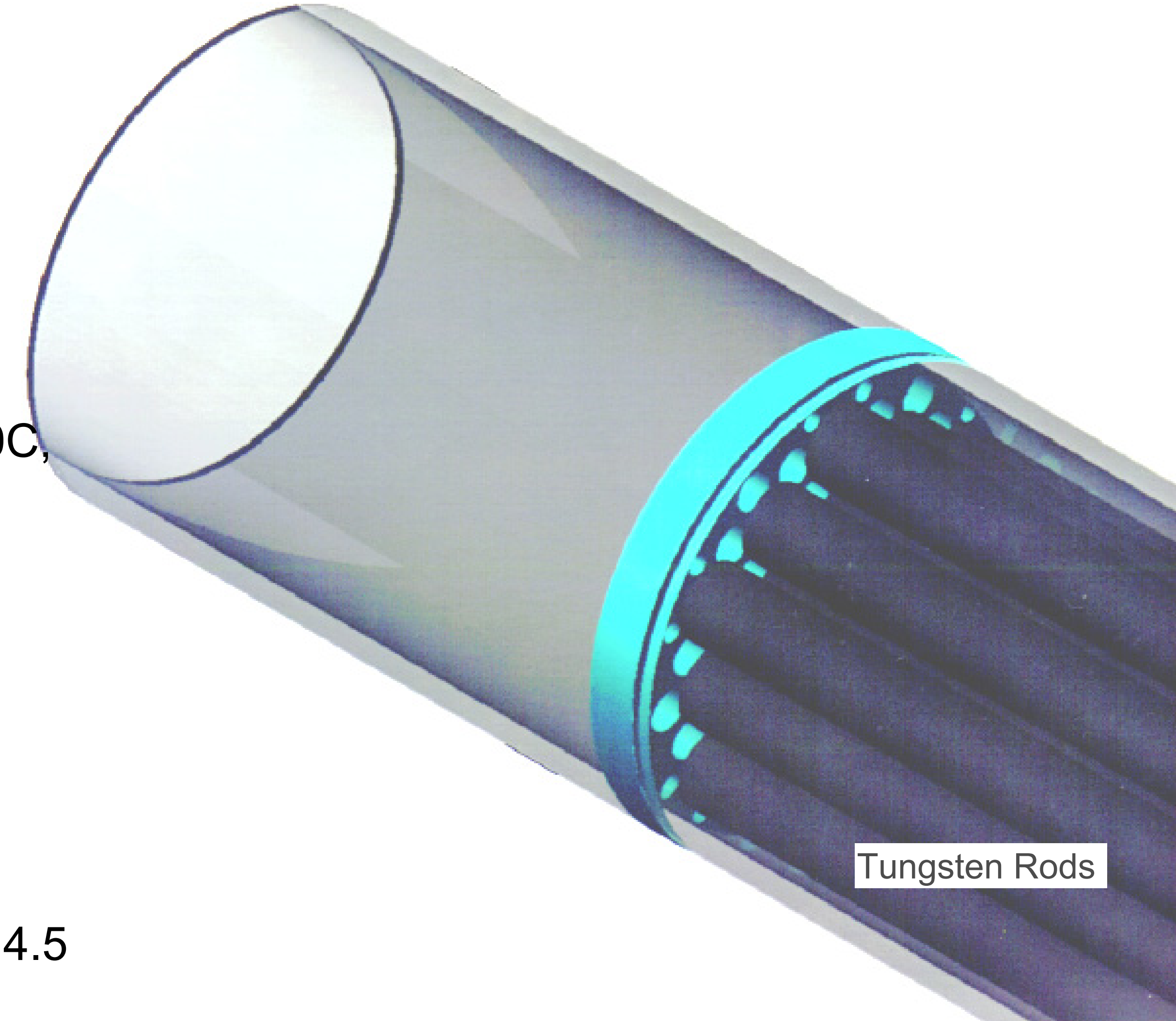


First indent is 2.6 mm from beam entry surface of target

Last indent is 0.4 mm from beam exit surface of target

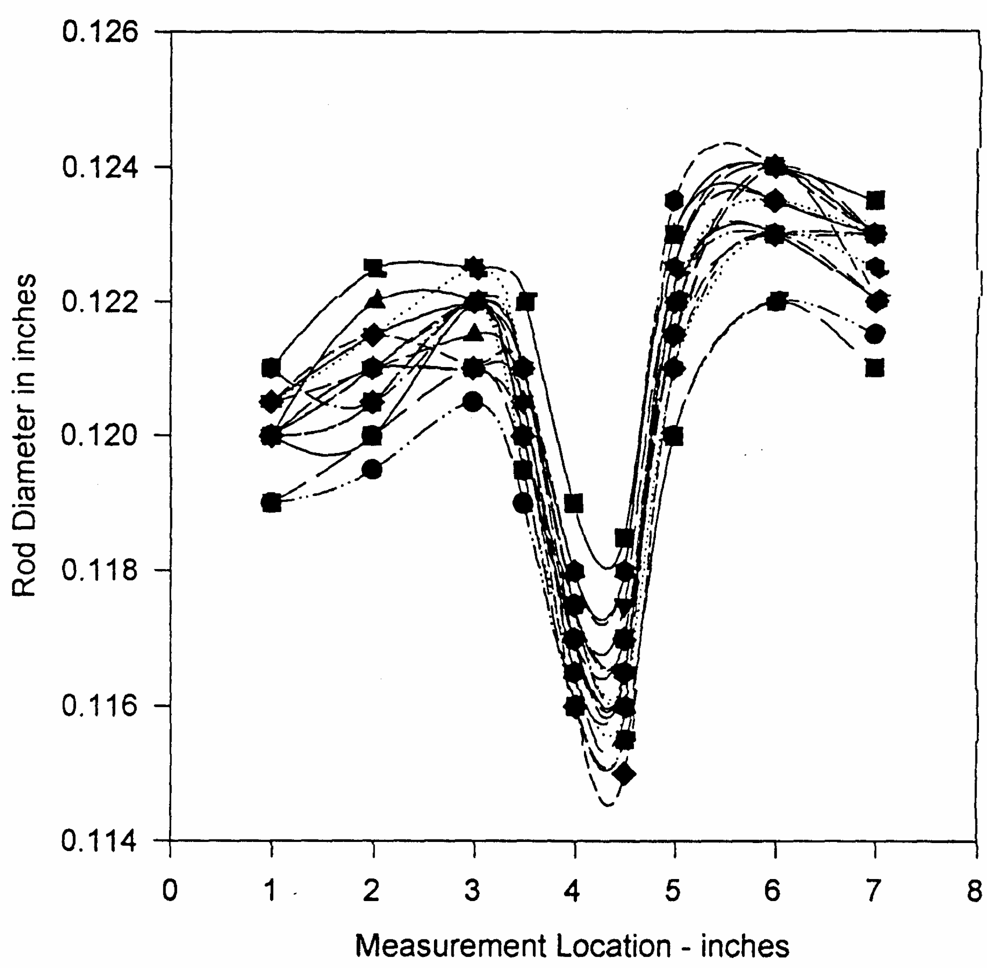
Irradiation of Pure Tungsten in Proton Beam Revealed high Corrosion Rate

- 1/8 in. diameter rods
- 19 rods per bundle
- Cooled with flowing water
- Water inlet Temperature ~30C, Delta T~10C
- Max. W surface T-~166C
- System pressure = 13bar
- Coolant velocity ~ 2.9 m/s
- Water ph during operation ~ 4.5



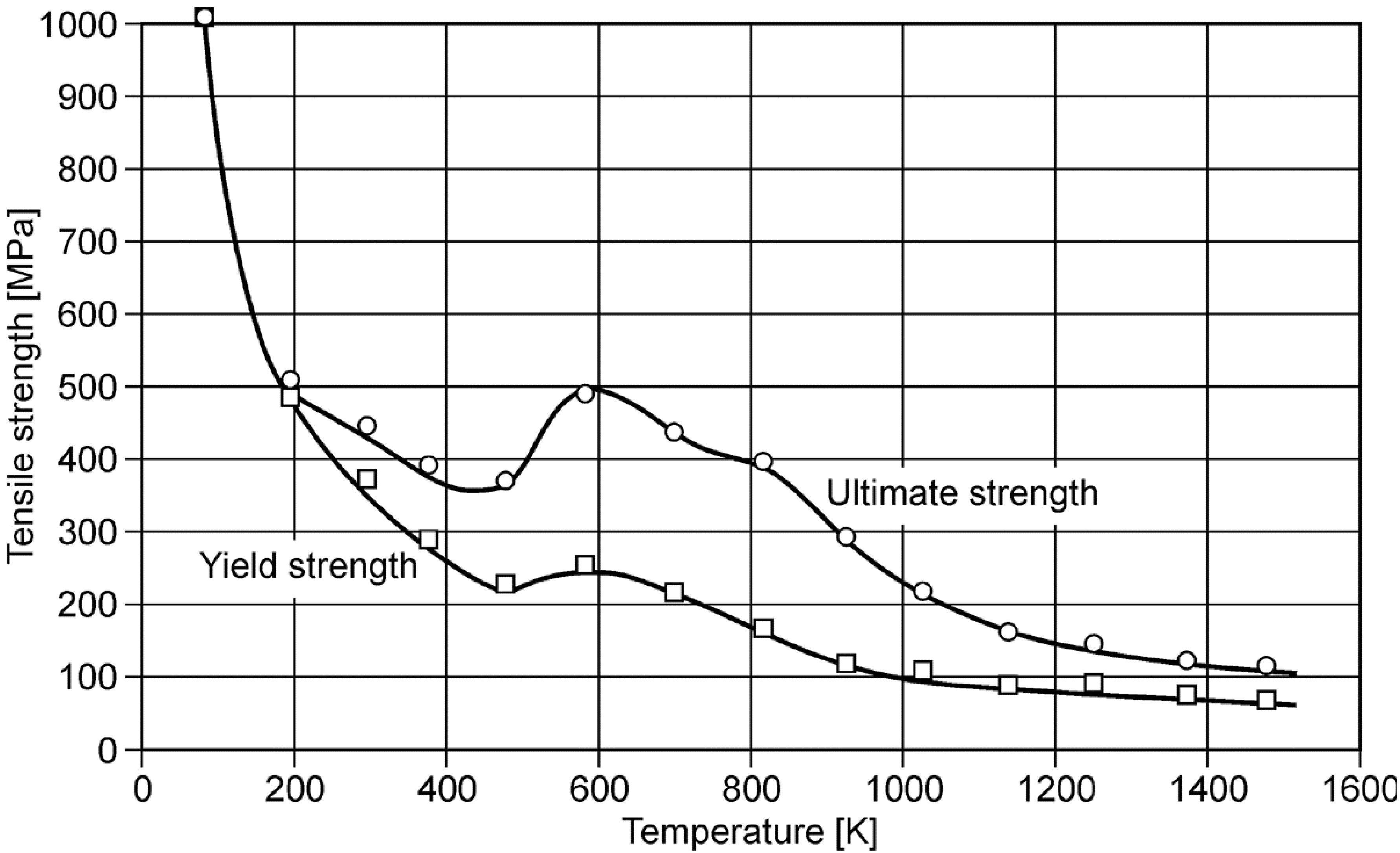
Decrease in Diameter of Bare Tungsten Rods Confirmed Tungsten Corrosion Rate

- Capsule irradiated for 2 months in 800 MeV, 1 mA proton beam (~2×10^{21} p/cm^2)
- Measured the diameter of all 19 tungsten rods in the leading rod bundle.
- The loss of tungsten on rods scaled with Gaussian beam shape.
- Implied corrosion rate of ~1 mm /year.
- Measured Helium concentration of ~740 appm



Irradiation Damage in Tantalum

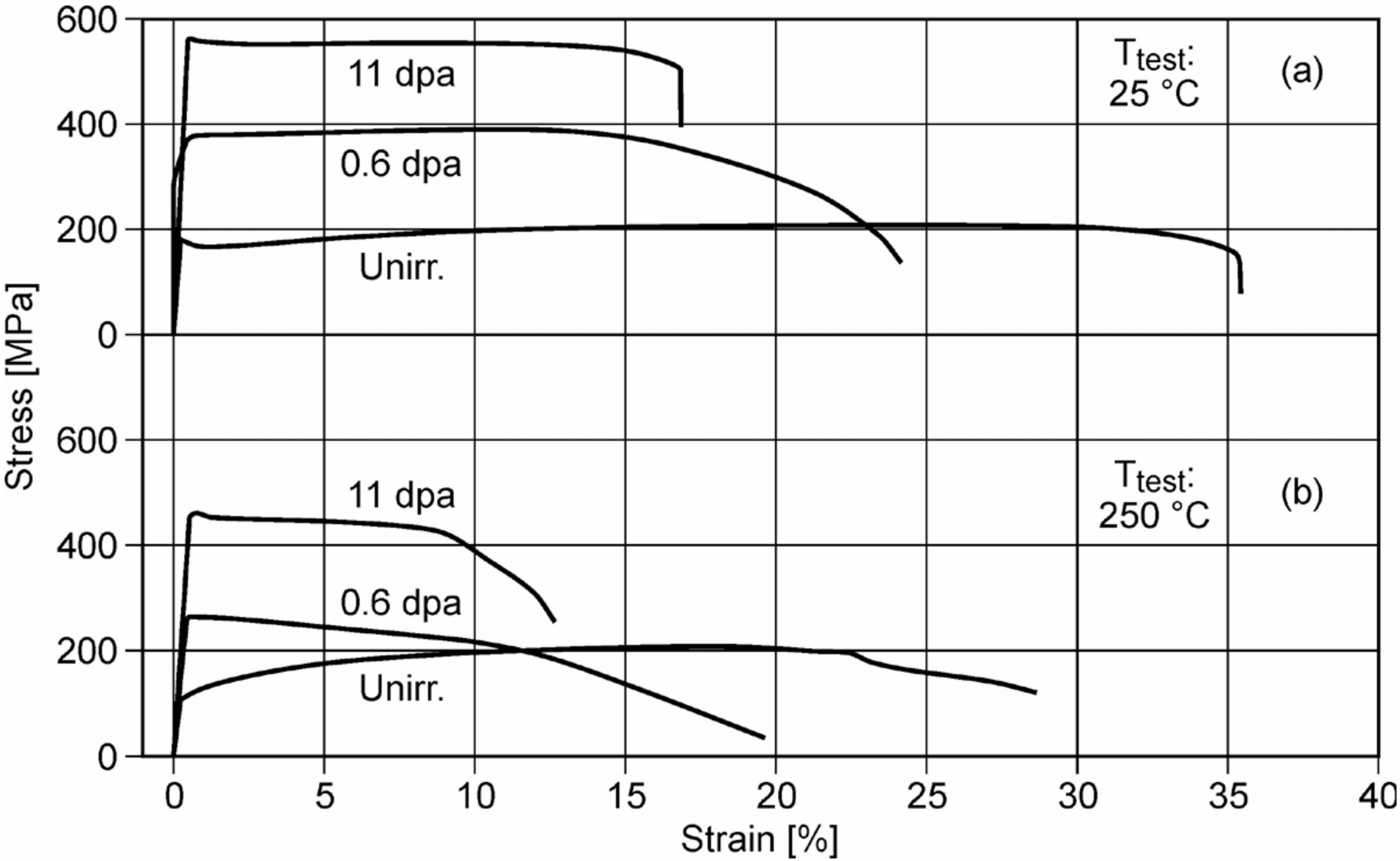
Yield Stress vs. Temperature for Tantalum



Temperature dependence of yield strength and ultimate tensile strength of low purity Ta

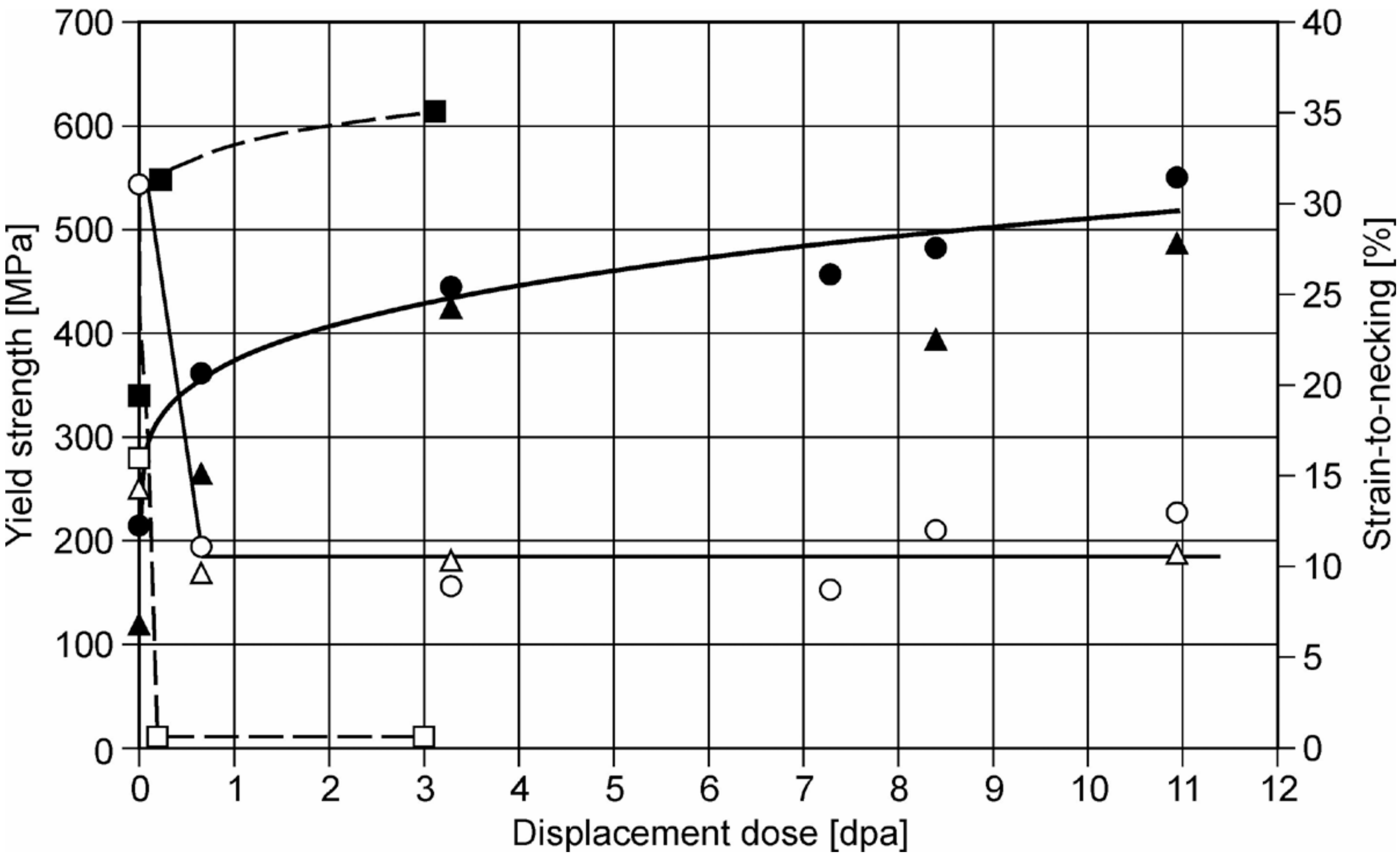
Total Elongation between 20 and 40%

Irradiation of 99.95 % Ta in a High Energy Proton Beam at ISIS Retains 10% Ductility to 11 dpa



Chen, Ullmaier et al., 2001

Yield Strength and Strain-to-necking vs. Dose for Irradiated Tantalum

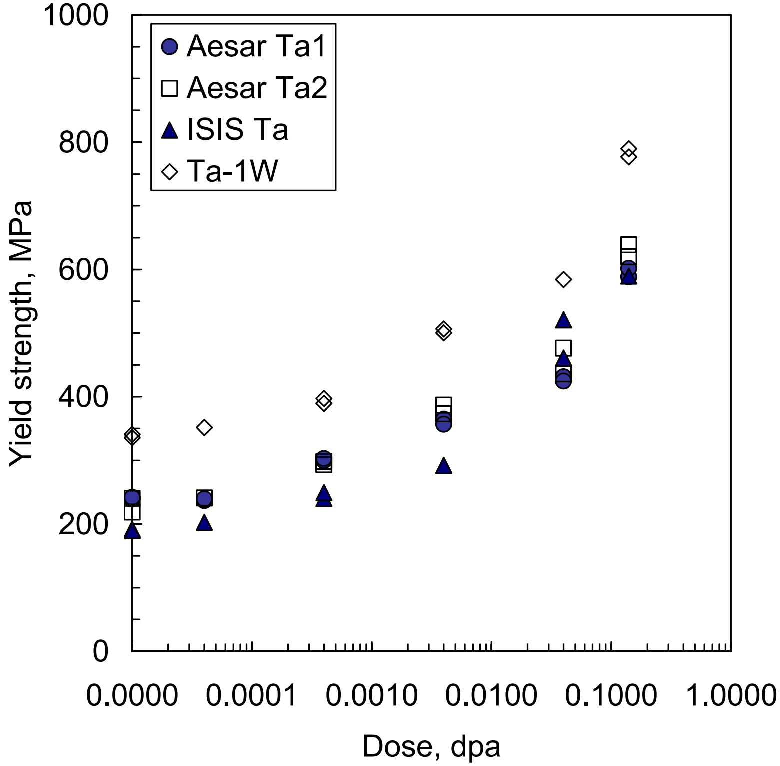


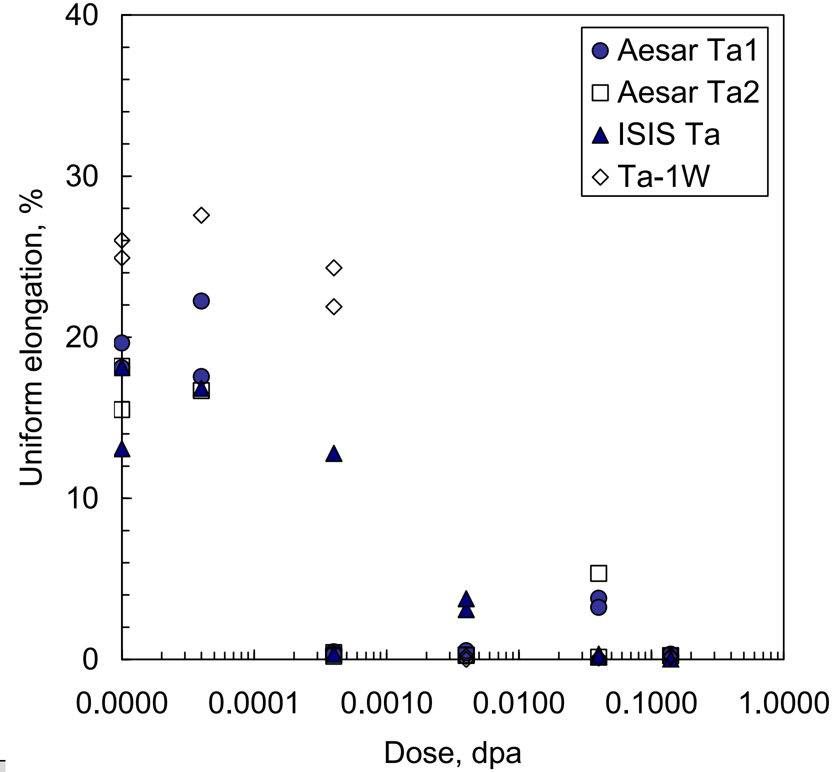
Chen, Ullmaier et al.

Sommer et al.

Yield strength (filled symbols) and strain-to-necking (open symbols) of Ta irradiated with 800 MeV protons. The circles and triangles refer to high purity material, irradiated below 200°C (473 K) and tested at 25 (298 K) and 250°C (523 K). The squares refer to impure Ta irradiated below 400°C (673 K) and tested at 25°C (298 K). Whereas the high purity material retains a high ductility up to displacement doses of 11 dpa (*Fig. 21-50*), strong embrittlement is observed even at low doses in impure Ta and Ta-W alloys (*Fig. 21-32*).

Recent Results at ORNL on Effects of Irradiation on Tantalum with various Purity Levels

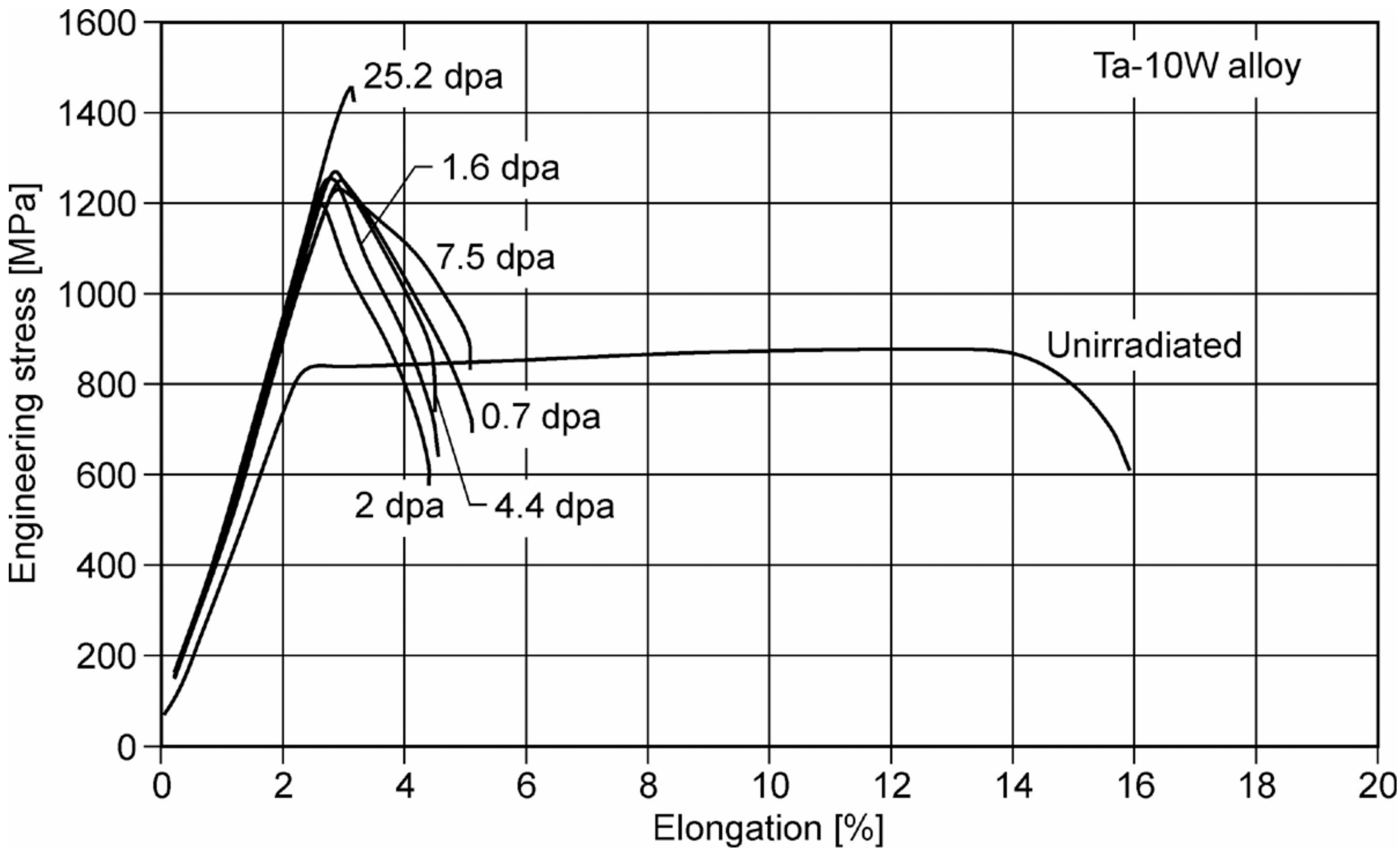




Elements (wt.ppm)	C	Mn	Si	Cr	Ni	W	Nb	Ta	Ti	Cu	O	N	Remarks
S (ISIS Ta)	<30	<10	<10	<10	<5	<20	<400	Bal	<1	<5	<40	<5	From H. Ullmaier. KFA, Jeulich
D (Aesar Ta1)	10	<5	<5	<5	<5	<25	<25	Bal	<5	<5	25	20	Alfa Aesar Co. 99.90%
E (Aesar Ta2)	<10	<5	<5	<5	<5	<25	65	Bal	<5	<5	25	<10	Alfa Aesar Co 99.95%
W (Ta-1W)						1.2		98.8					(wt.%) J.R. Distefano, ORNL

T.S. Byun et al.

Stress/Strain Curves Measured for Ta-10W in Tension Show Strong Reduction of Ductility with Increasing Dose



Irradiation in a 800 MeV proton beam.

Farrell et al.

Summary and Conclusions

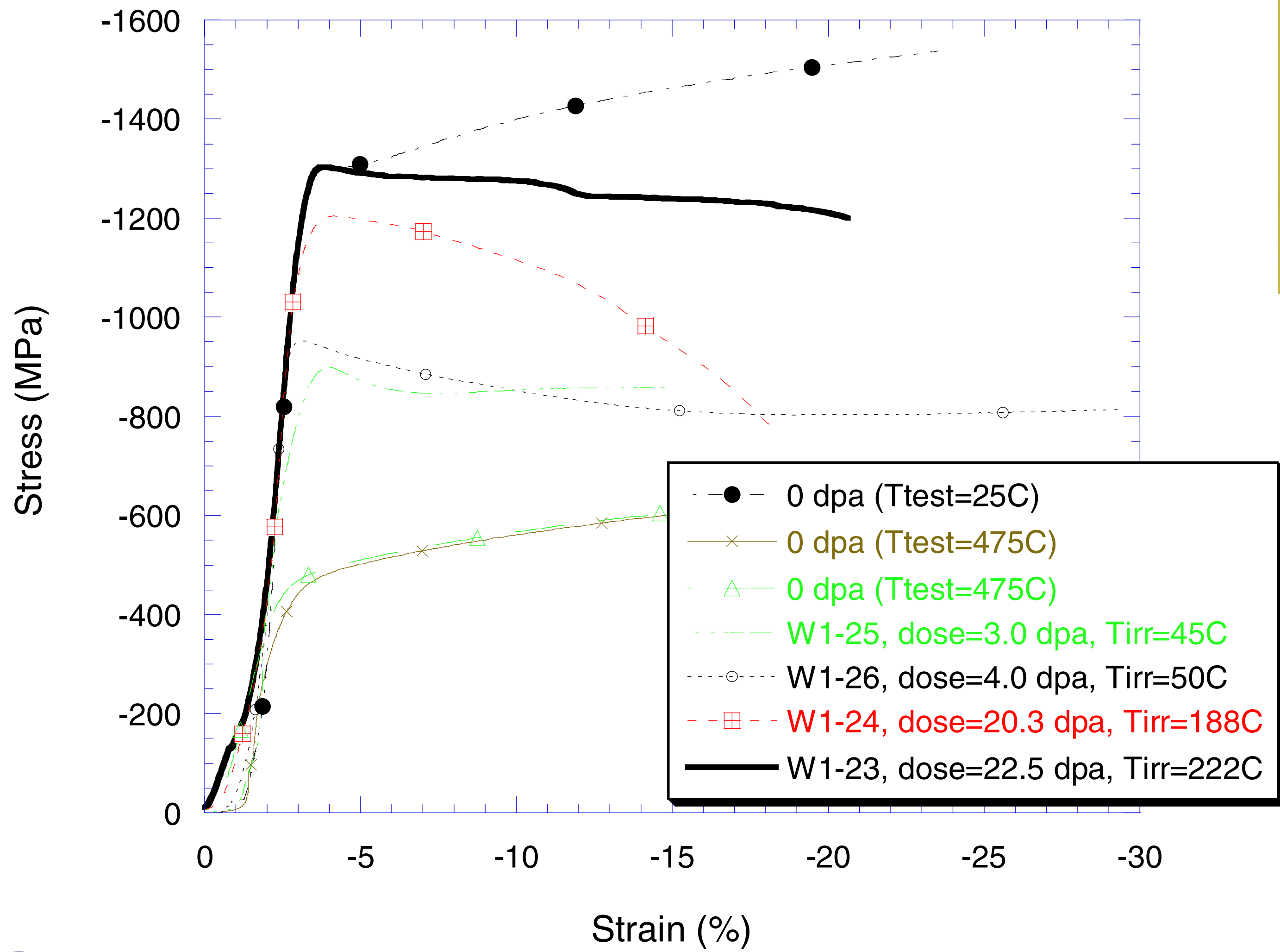
Irradiation Effects in Tungsten

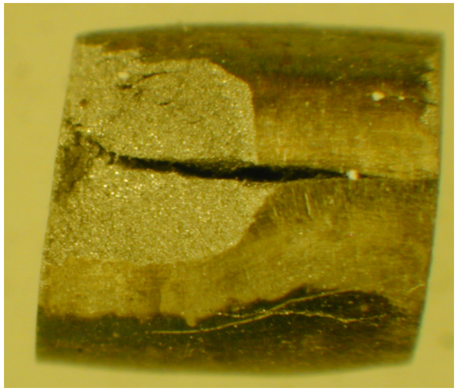
- Tungsten exhibits low ductility at room temperature in unirradiated condition.
- Irradiation strongly increases DBTT and yield stress.
- High purity tungsten shows best resistance to irradiation embrittlement
- Stronger embrittlement observed in machinable tungsten and W-Re alloys
- Significant corrosion also observed under irradiation.

Irradiation Effects in Tantalum

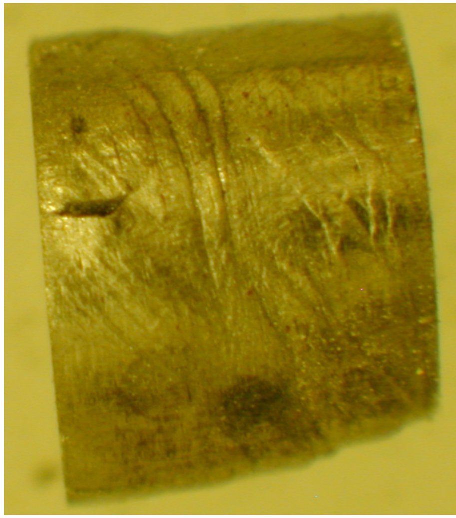
- High Ductility and low yield stress observed in tantalum at room temperature.
- Mechanical testing after irradiation at ISIS showed retention of ductility to doses up to 10 dpa.
- Stronger embrittlement observed for Ta-W alloys over high purity tantalum.
- Recent Results show strong reduction of ductility after irradiation in HFIR to doses greater than 0.1 dpa.
- Very low corrosion rate observed under irradiation.

Test Results on Compression Testing of Tungsten at 475C





Dose=22.5 dpa



Dose=3.0 dpa

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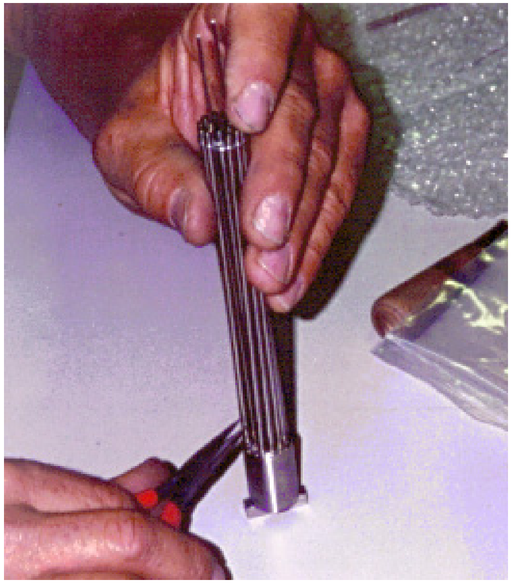
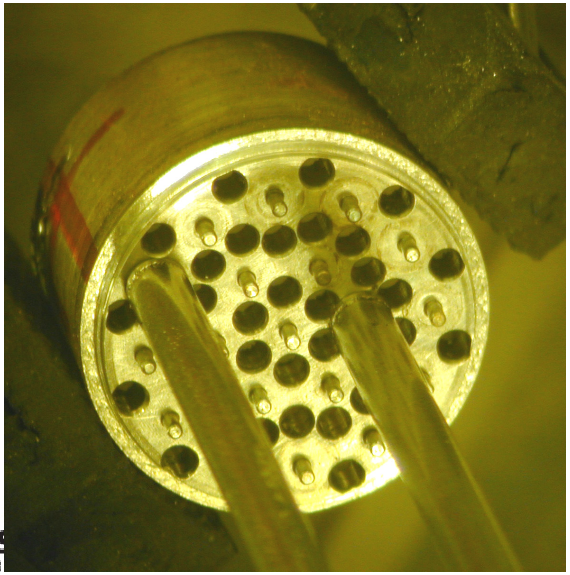
Previous Results on Proton Irradiated Tungsten

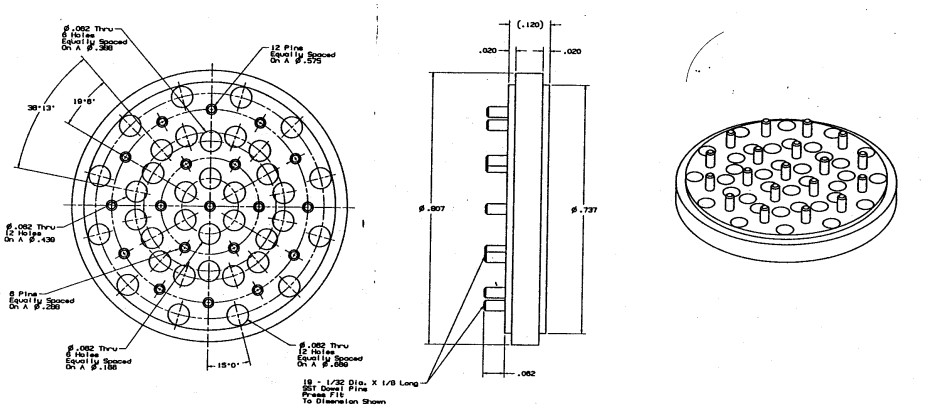
Material	Hardness (kg/mm^2)	Hardness (kg/mm^2) after irradiation	Dose (dpa)/ Irradiation Temperature (ºC)
Tungsten (Sommer et al. 1995)	489	583	2 dpa /300
W-25Re (Sommer et al. 1995)	482	784	2 dpa /720
Tungsten (Maloy et al. 2001)	480	724	20 dpa /180

Assembly of Clad Tungsten Rod Bundles

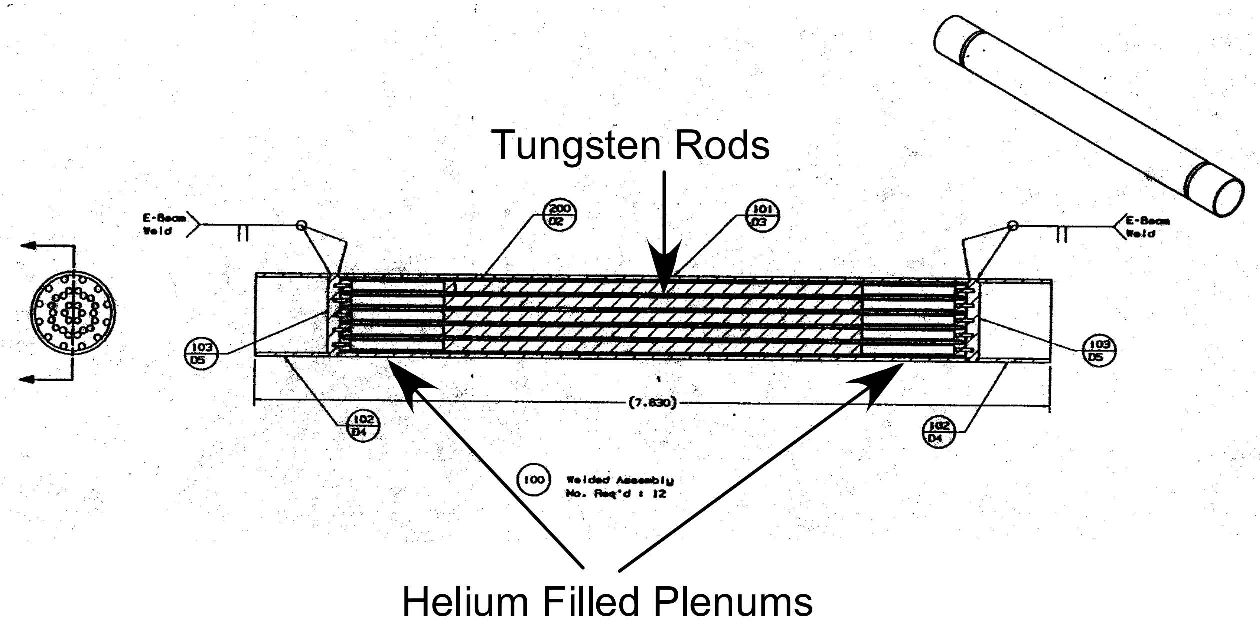
- Rods placed on orifice plate.
- Held in position with removable spacer.
- Frozen in water and spacer removed.
- Attached second orifice plate.
- E-beam welded orifice plates to outer tubes.





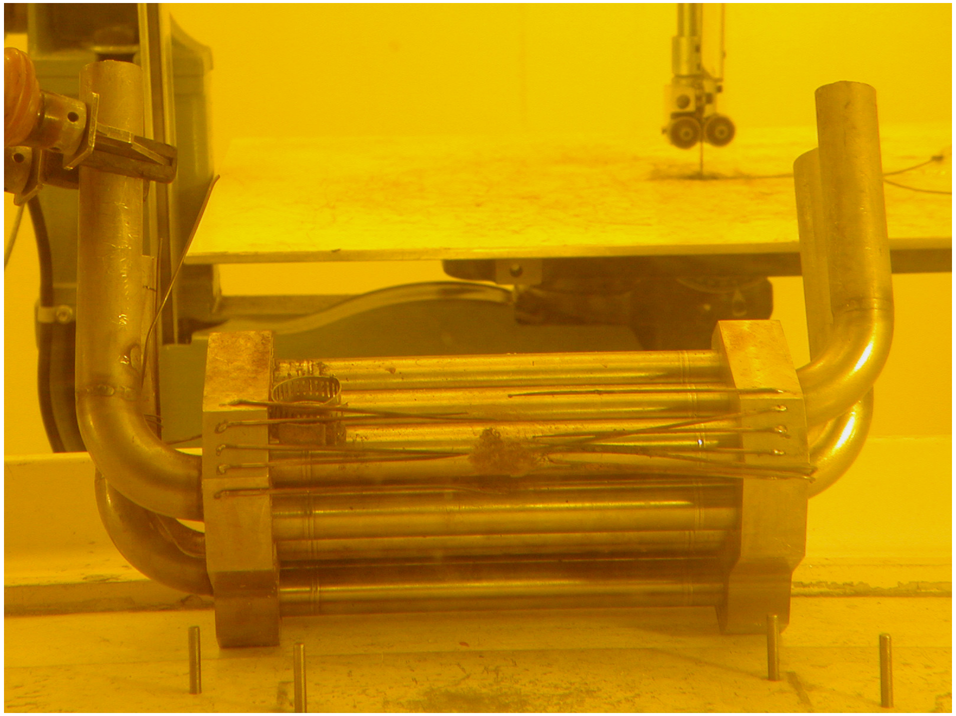


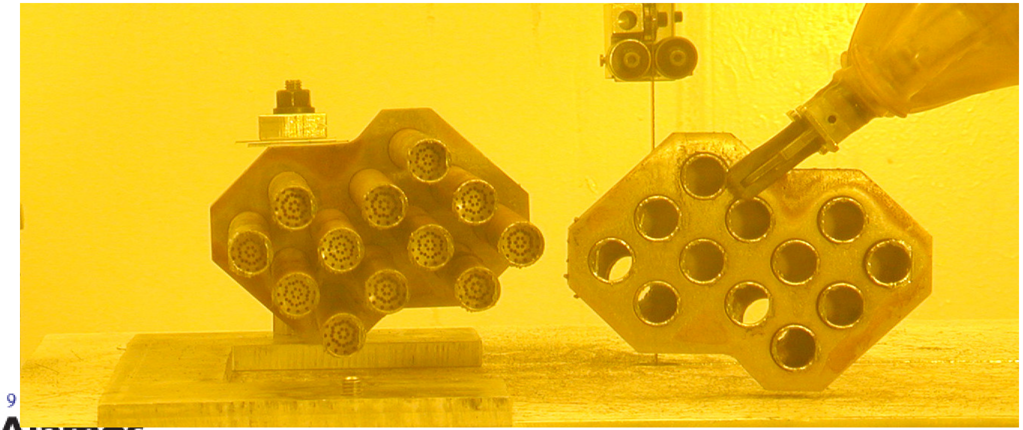
Clad Tungsten Design



- **Each 2.642 mm diameter tungsten rod was slip clad within a Type 304L stainless steel tube that had a 2.667 mm inner diameter and 2.921 mm outer diameter.**
- **The nominal 0.012 mm radial gap between the tungsten and the cladding was filled with helium at room temperature and atmospheric pressure.**
- **The plenums were included to accommodate gaseous spallation products sized so that if all the gasses were to be released, the resulting pressure would not cause yielding in the stainless steel clad.**
- **Gas release results show that plenums are not needed. So, geometry could be further optimized.**

Removal of Tungsten Neutron Source After Irradiation





- Clad Tungsten Source cut from Insert and transported to CMR Hot Cells
- Bandsaw in hot cells used to cut manifolds from tubes
- Helium leak test performed in hot cells showed clad rods still leak tight after irradiation.
- Discoloration on outside surface due to high nitric acid irradiation environment.