Performance of a Clad Tungsten-Rod Spallation-Neutron-Source Target

Walter F. Sommer[1], Stuart A. Maloy[1], Mcintyre R. Louthan[2], Gordon J. Willcutt[1], Phillip D. Ferguson[3], Michael R. James[1]

1. **Los Alamos National Laboratory**
2. **Savannah River Technology Center**
3. **Oak Ridge National Laboratory**

Contributors-LANL

Materials Core Team: Laurie Waters, Stuart A. Maloy, Frank Gac, Michael R. James, Bob Johnson, Mike Paciotti, Larry Quintana, Walter F. Sommer Jr.

Tungsten Rod Bundles Michael R. Barbe, Marvin J. Barney, Richard D. Bramlett, George I. Keel, Leo Sanchez, Frank M. Smith, Brian G. Smith

Insert Assembly, Facility Prepararations and Facility Operations: James P. Abernathey, Robert D. Brown, Steven B. Cushing, John C. Eddleman, Julian I. Garcia, Mike P. Geelan, Manfred E. Gehrmann, Jeffrey Hannaford, Johnny A Herrera, Joseph C. Ivie, John J. Jarmer, William S. Johnson Jr., Robert E. Jones, James N. Knudson, Michael A. Madrid, Joseph D. Medina, Stephen L. Morgan, Theodore E. Newlin, Peter D. Olivas, Felix R. Olivas, Joseph L. Raybun, John E. Roberts, Jake C. Salazar, Ivan K. Taylor, Joe E. Vasquez, Manuel Velarde, Richard D. Werbeck, Willliam B. Wilson

Water Chemistry Studies: Luc L. Daemen, Virginia Hamilton, David J. Jamriska, Gary S. Kanner

Corrosion Studies: Darryl P. Butt, Scott R. Lillard, Donald L. Pile

APT Target/Blanket Design: Ron Barber, Michael Cappiello, Richard J. Kapernick, Ronald B. Parker

Thermal Hydraulics Analysis: Brent Faulkner, David I. Poston, Tom Sena, Donald A. Siebe, Jonathan Teague, Gordon J. Willcutt, Keith Woloshun

Specimen Preparation: Lawrence B. Dauelsberg, Vincent B. Hesch

Irradiation Control: Michael A. Oothoudt, Chandra Pillai

Physics Calculations: Phillip D. Ferguson, Mike James

Specimen Retrieval: James Fitzgibbons, Jeff Keddy, James Ledbetter, Manuel R. Lopez, Tobias Romero, Jay Thorne

Activation Foil Counting: Don Dry, Malcolm Fowler

Contributors-Other Laboratories

Brookhaven National Laboratory

Carl Cjakowski, George Greene, Lewis Snead

Lawrence Livermore National Laboratory

Edward Dalder, Richard Howell, Dennis Slaughter, Richard Vandervoort

Oak Ridge National Laboratory

Dave Alexander, Ken Farrell, Orville Kimball, Janet Robertson, Phil Rittenhouse, Glenn Romanowski, Lance Snead, Mikhail Sokolov

Pacific Northwest National Laboratory

Elaine M. Dieffenbacher, Ruby M. Ermi, Frank A. Garner, Larry Greenwood, Margaret L. Hamilton, Brian M. Oliver, Mychailo B. Toloczko, Gary K. Whiting

Sandia National Laboratories

Rion Causey, Don Cowgill, Steve Wright, Kristen Kurz

Butler Services

Ralph E. Lomax

Ray Rashkin Associates Inc,

Jan K. Novak, Eugene L. Zimmermann

Westinghouse Savannah River Company

Greg Chandler, Frank A. Cheek, Carla Dinkins, Kerry Dunn, Don Fisher, Robbie Garritano, Natraj Iyer, Ross Lathrop, Doug Leader, McIntyre Louthan, Tom McCoy, Harold Peacock, Tom Spatz, Scott West, Max Zaslawsky

North Carolina State University

Don Dudziak, Jose Velez, Monroe Wechsler

University of Illinois

James Stubbins

US DOE

Steve Stack

New Mexico Tech

Gillian Bond, Bulent H. Sencer

General Atomics

Bob Johnson

Paul Scherrer Institute

Guenter Bauer, Yong Dai

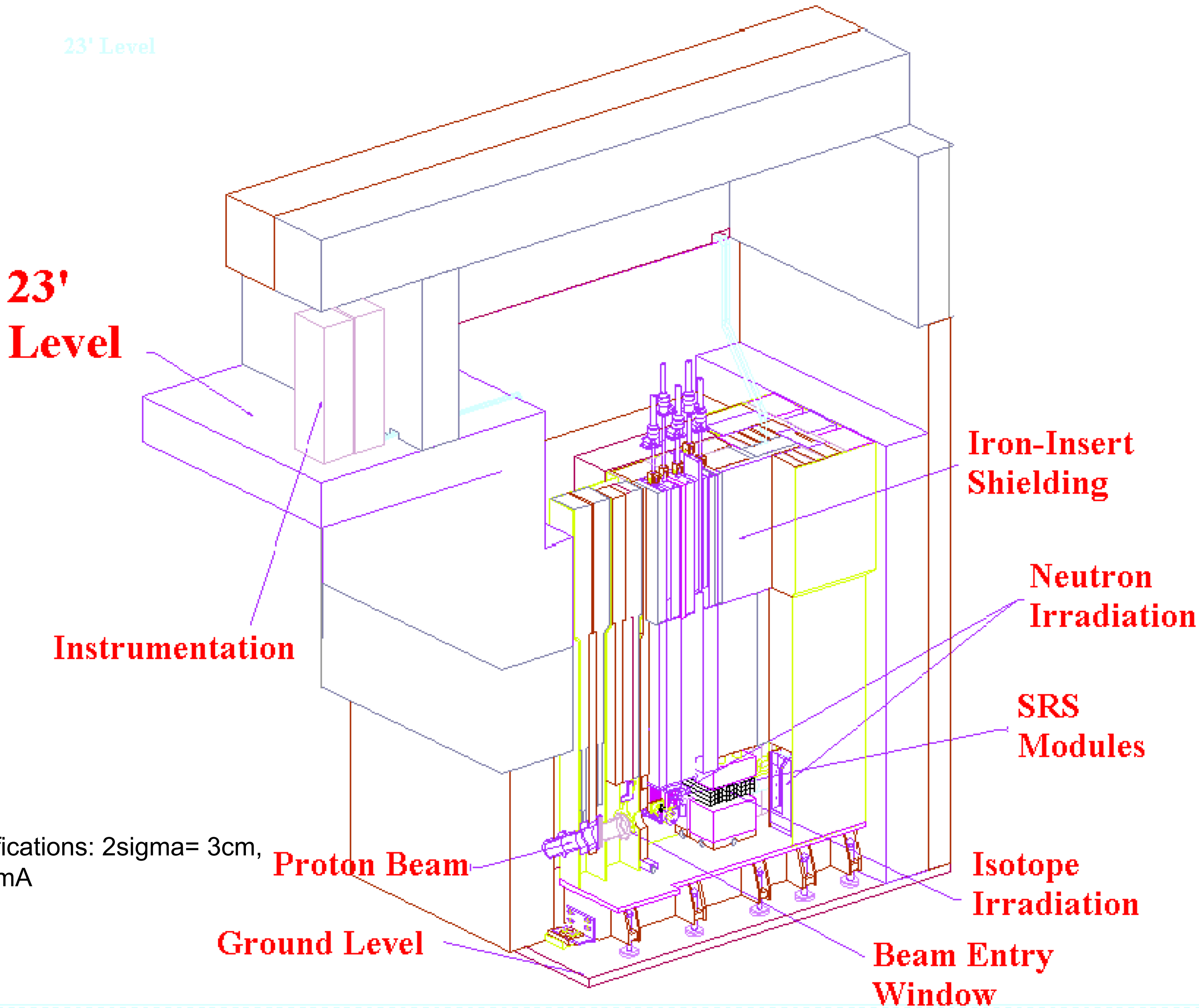
Forschungszentrum - Juelich

Flavio Carsughi, Guenter Pott, Hans Ullmaier, Jiachao Chen

Outline

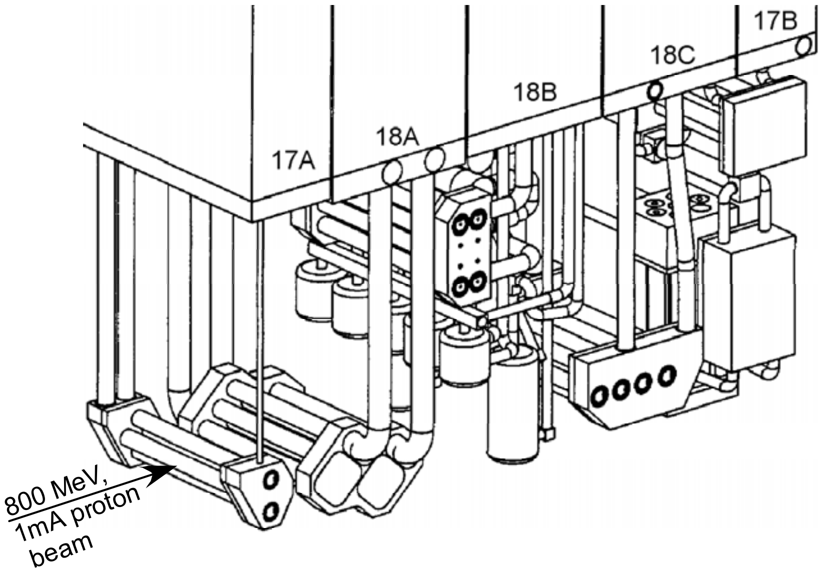
- Irradiation Design
- Thermal Hydraulics Analysis
- Insert Replacement
- Design and Assembly
- Performance of Neutron Source and Materials
  - » Mechanical Properties
  - » Surface Condition
- Conclusions

A-6 Experimental Area (LASREF)

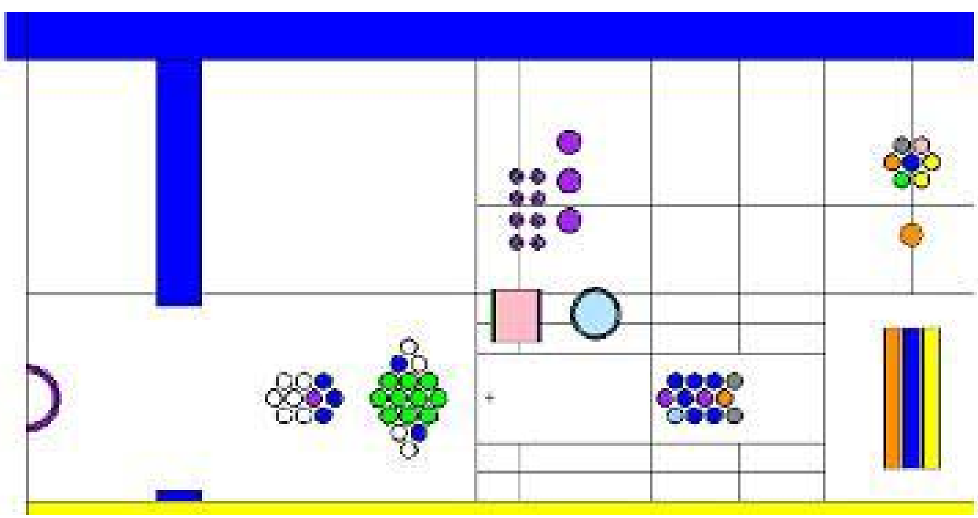


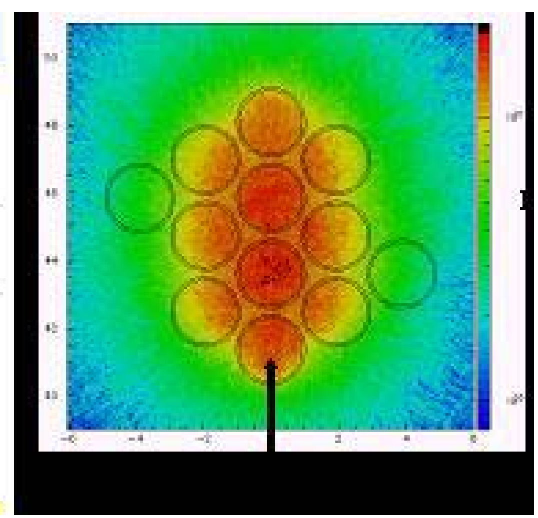
Beam Specifications: 2sigma= 3cm,
800 MeV, 1 mA

Physics Calculation Performed to Determine Power Deposition for each Insert



- **Used LAHET to model all 5 inserts in proton beam.**
- **Power densities used for design of inserts to be irradiated at prototypic temperatures.**





Thermal Hydraulic Analysis Performed on Tungsten Rod Bundles

• Water inlet Temperature ~27.5 °C, Max Δ T~10 ° C.

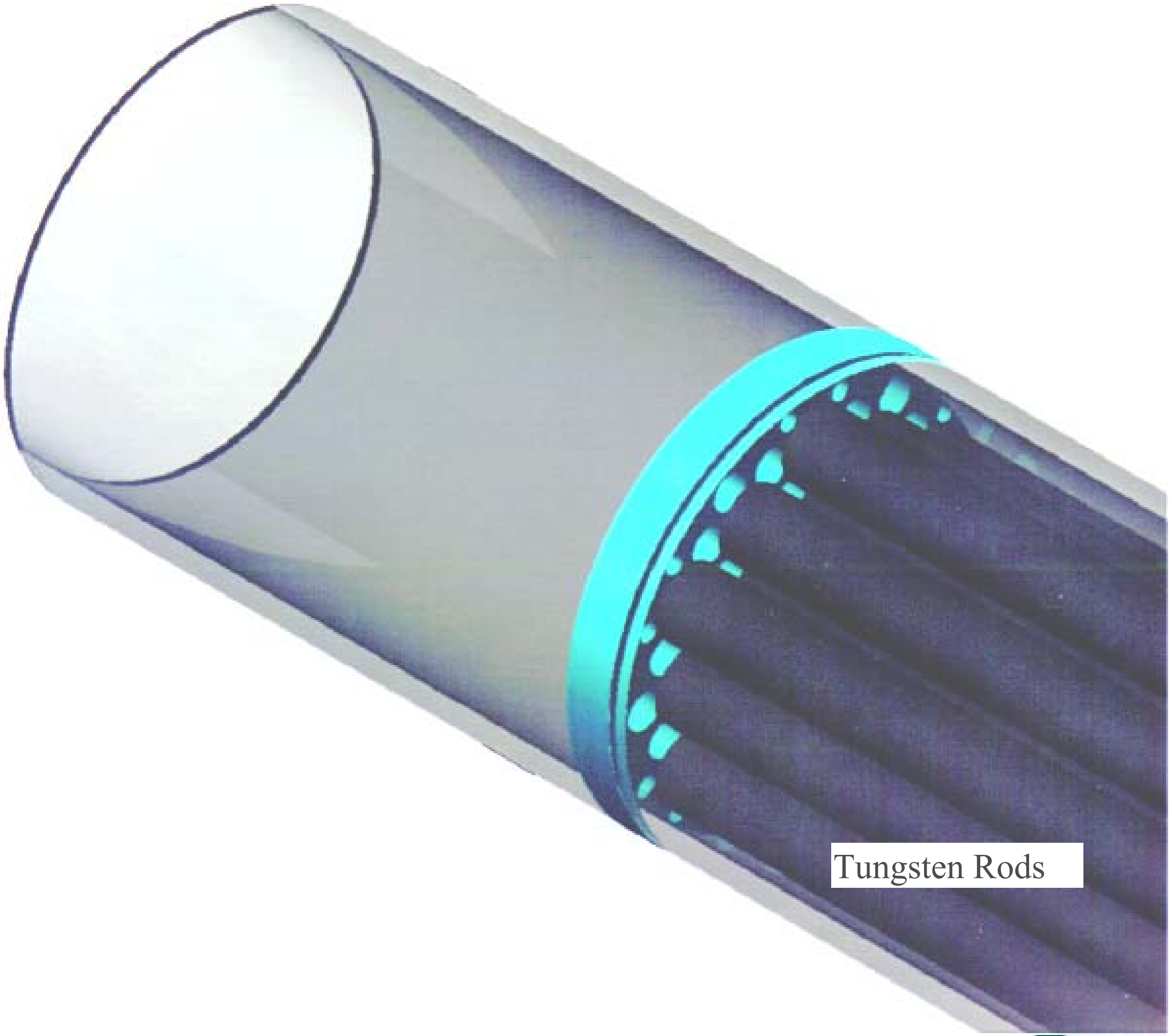
• Peak power densities varied from 2.25 kW/cm^3 to 1.19 kW/cm^3

•Total Deposited Power varied from 8 to 15 kW.

• Peak Clad Temperature was 141ºC and Peak Tungsten temperature was 271 º C

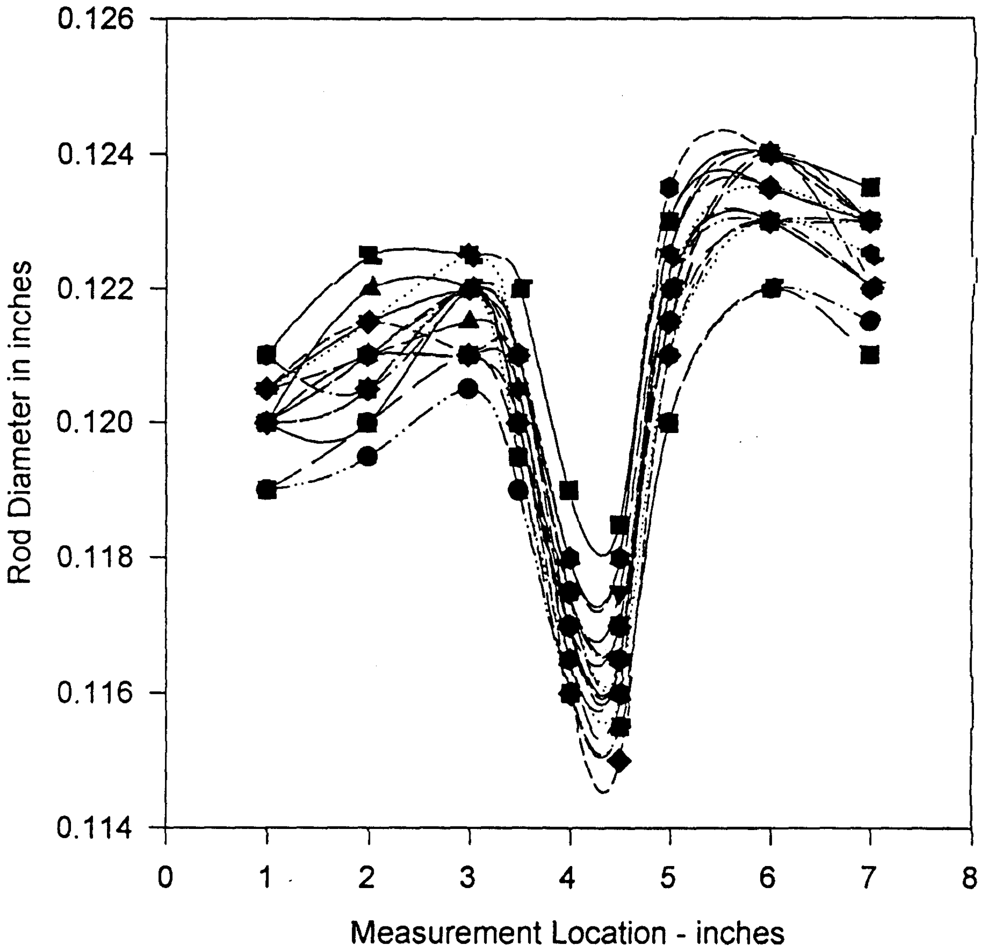
• System pressure = 13bar

• Coolant velocity ~ 2.9 l/s



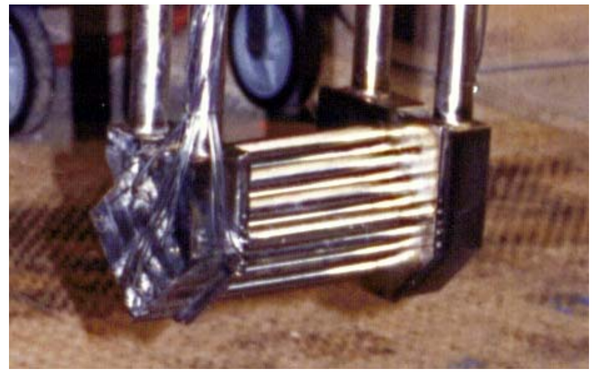
Decrease in Diameter of Bare Tungsten Rods Confirmed Tungsten Corrosion Rate

- Bare tungsten initially chosen because of better results than alloys
- 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

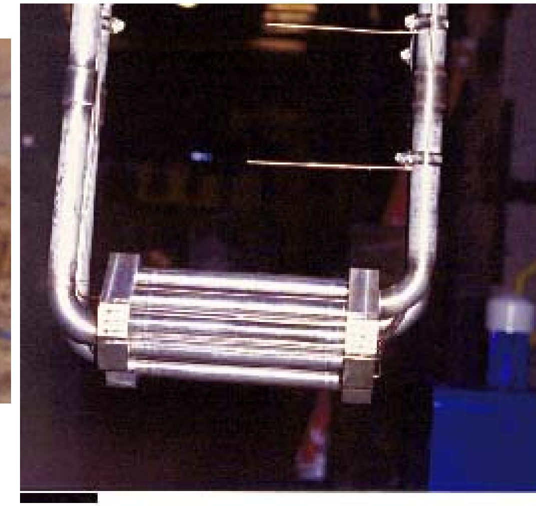


Replacement of Tungsten Neutron Source

Bare Tungsten Neutron Source Capsule

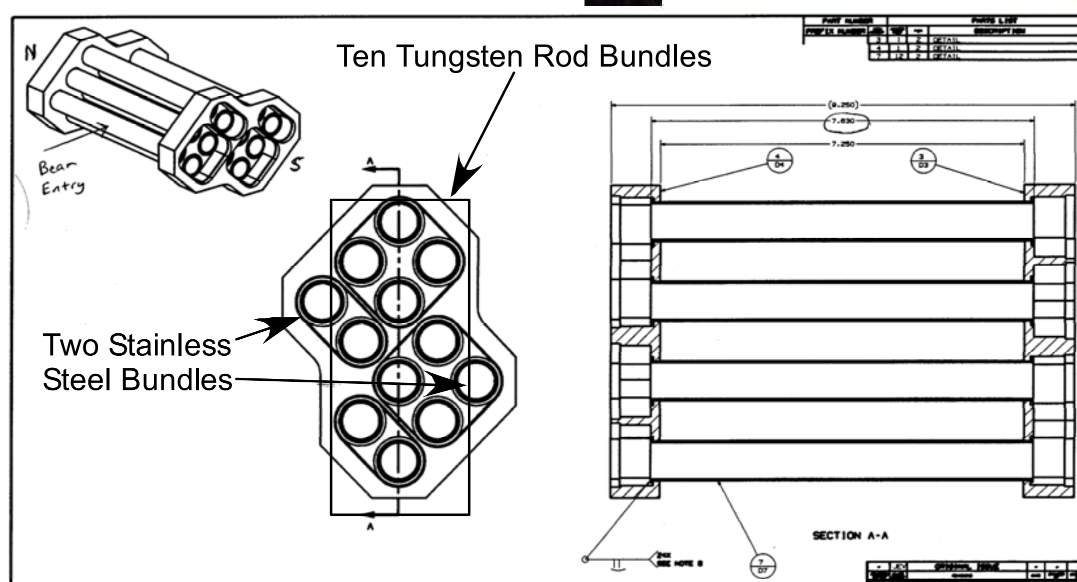


Clad Tungsten Neutron Source Capsule

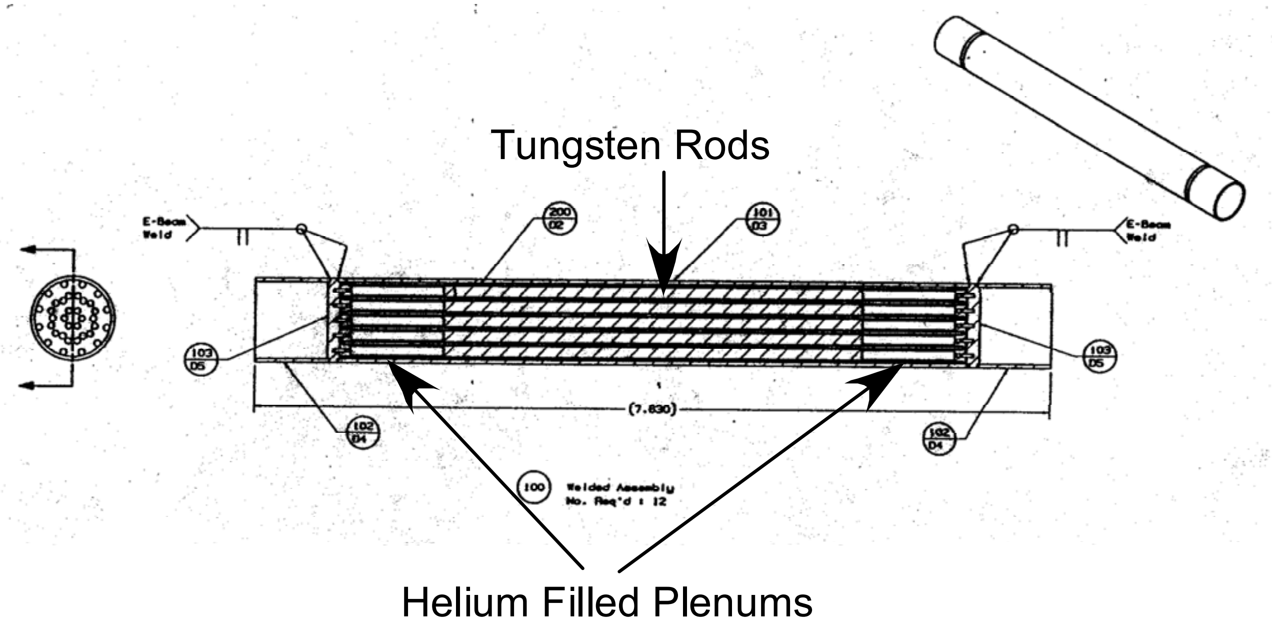


Improved design of tungsten neutron source module

- Used 304L stainless steel to clad tungsten rods.
- No brazes used to seal around thermocouples.
- Thermocouples do not penetrate into water passage.
- Placed thermocouples in air to check for water leaks during irradiation.
- Changed manifold design to avoid possibility of cross flow.



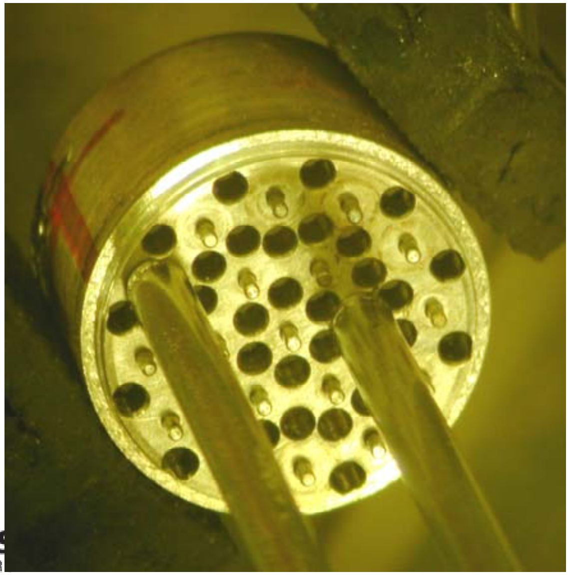
Clad Tungsten Design

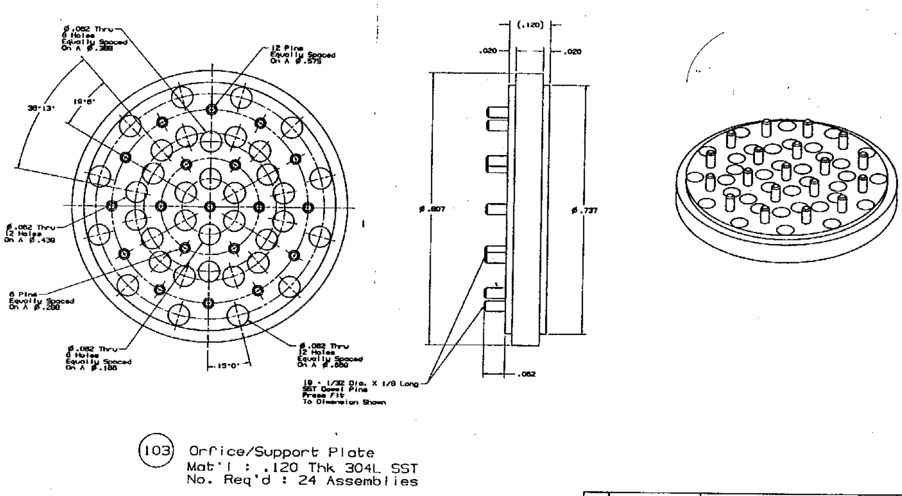


- **Each 2.642 mm diameter tungsten rod was slip clad within a Type 304L stainless steel tube that had a 2.667 mm inner diameter and 2.921 mm outer diameter.**
- **The nominal 0.012 mm radial gap between the tungsten and the cladding was filled with helium at room temperature and atmospheric pressure.**
- **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.**

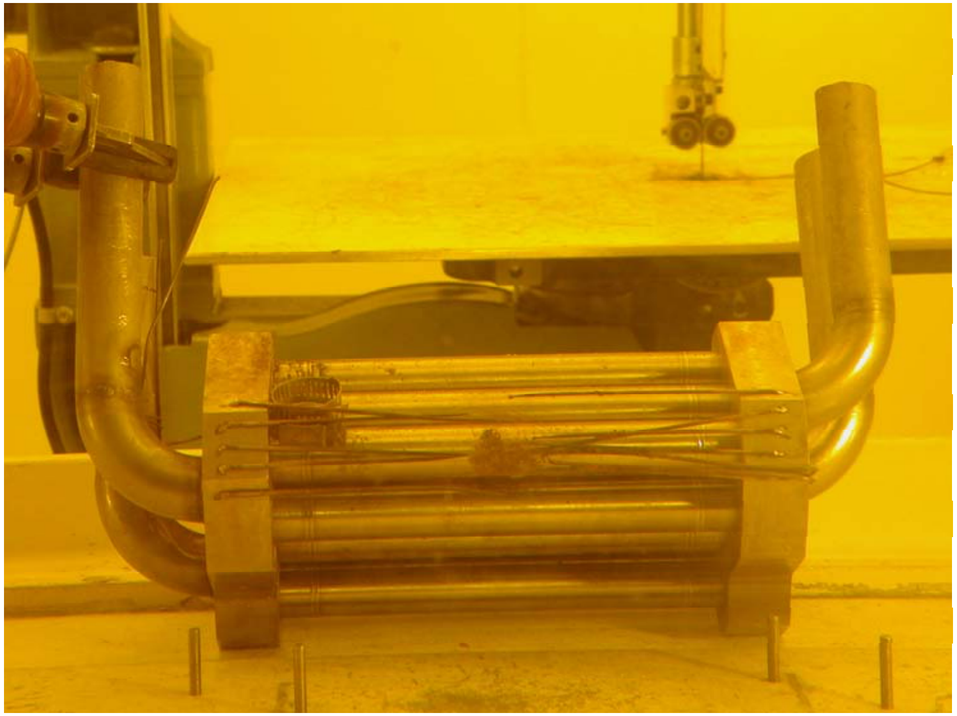
Assembly of Clad Tungsten Rod Bundles

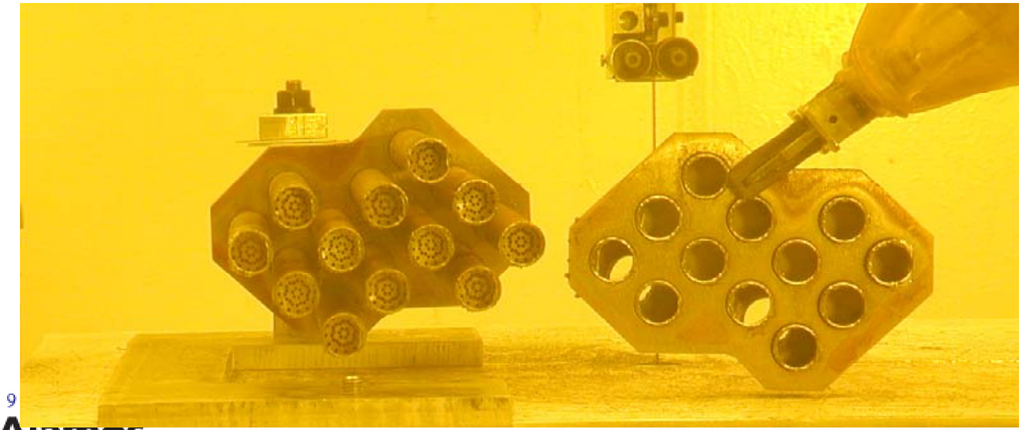
- Rods placed on orifice plate.
- Held in position with removable spacer.
- Frozen in water and spacer removed.
- Attached second orifice plate.
- E-beam welded orifice plates to outer tubes.





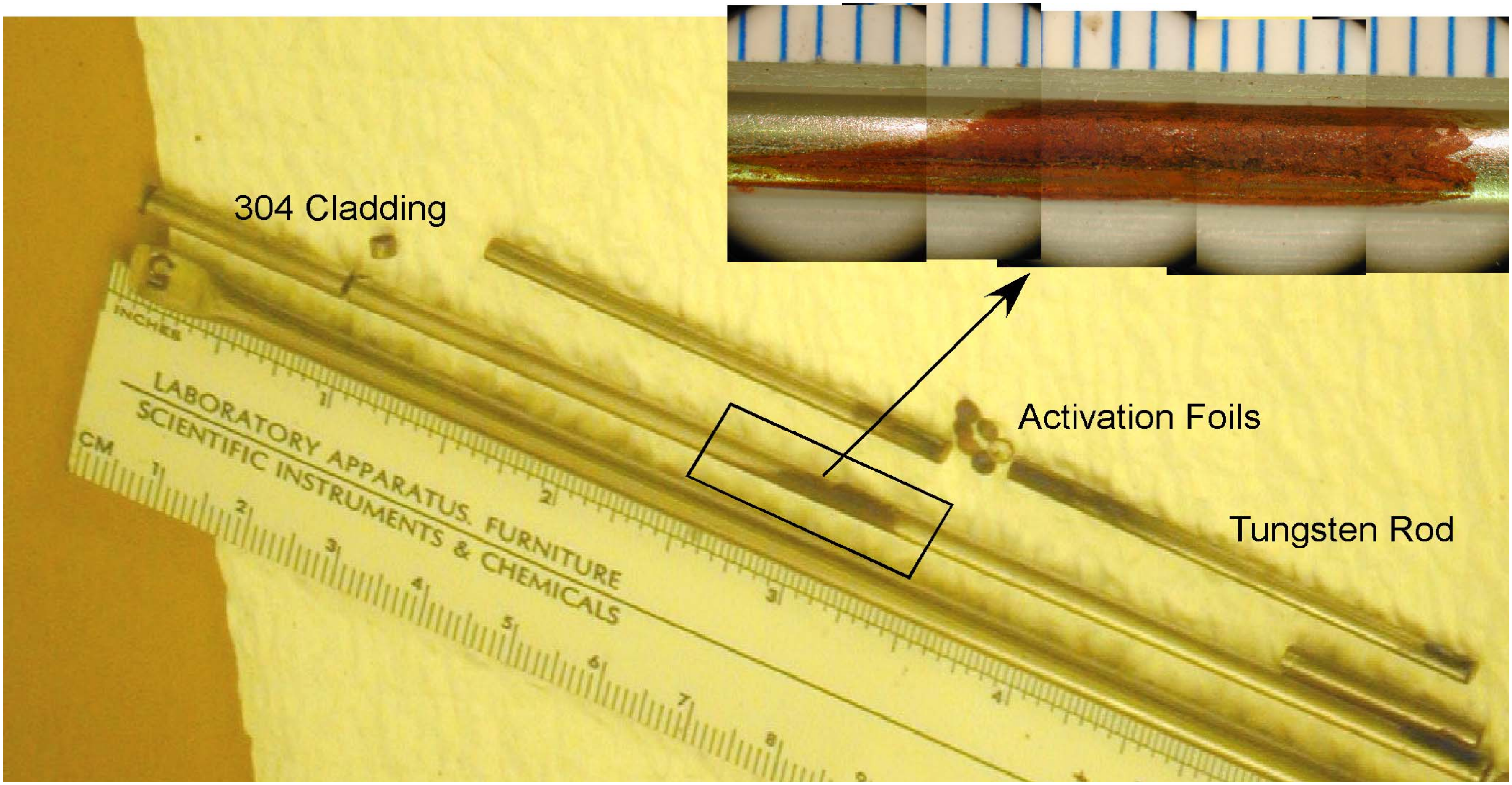
Removal of Tungsten Neutron Source After Irradiation





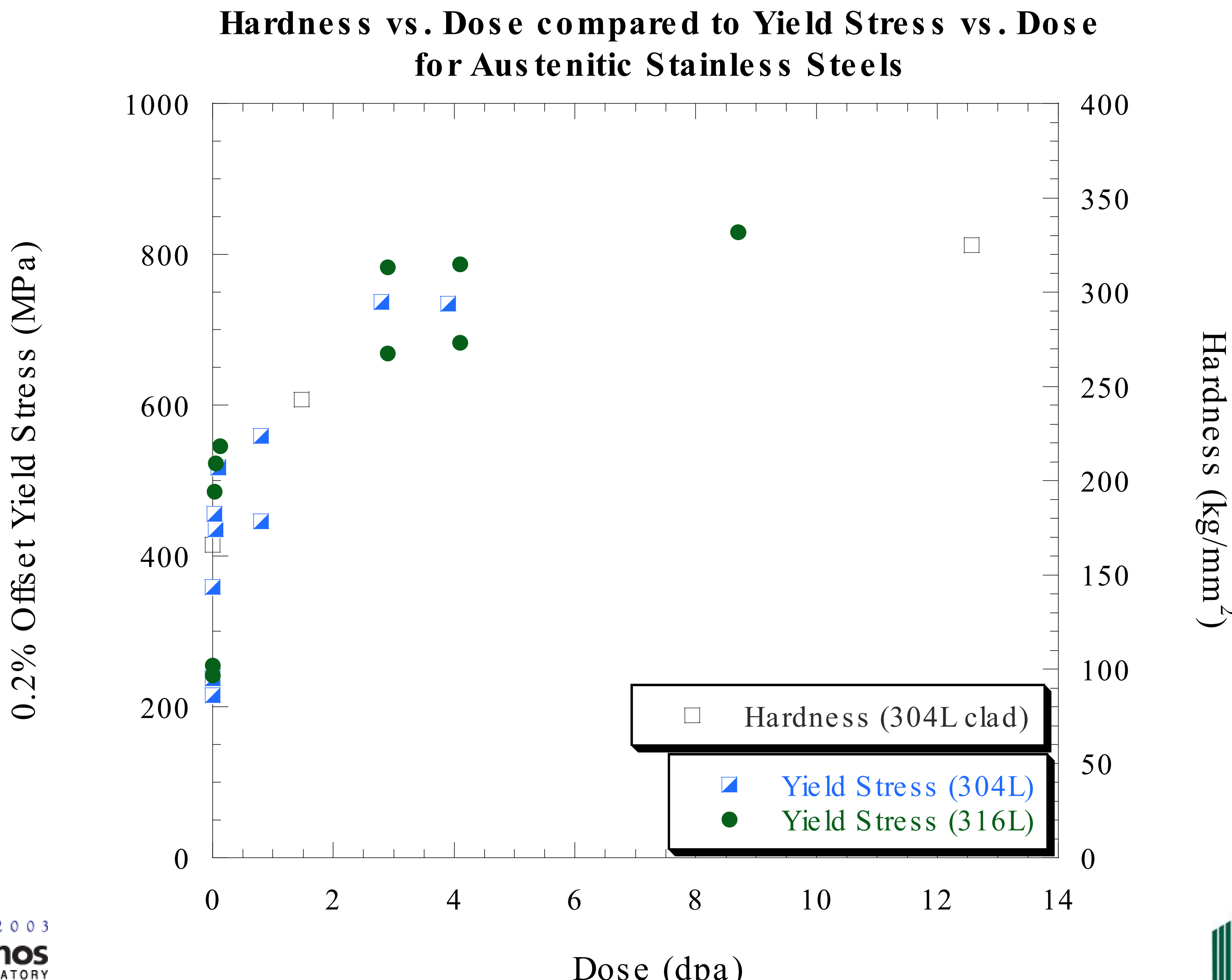
- Clad Tungsten Source cut from Insert and transported to CMR Hot Cells
- Bandsaw in hot cells used to cut manifolds from tubes
- Helium leak test performed in hot cells showed clad rods still leak tight after irradiation.
- Discoloration on outside surface due to high nitric acid irradiation environment.

Tungsten Removal from Cladding

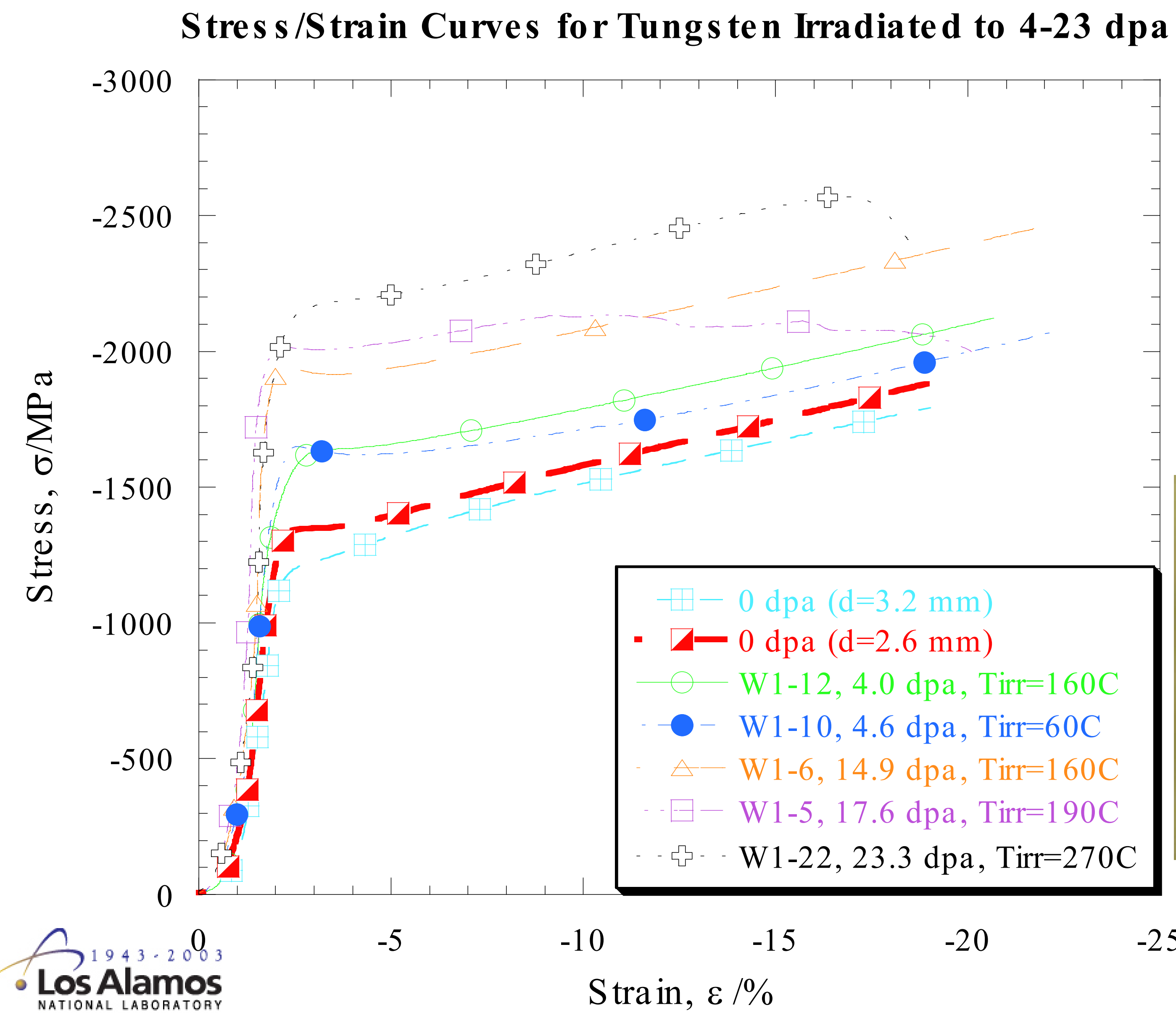


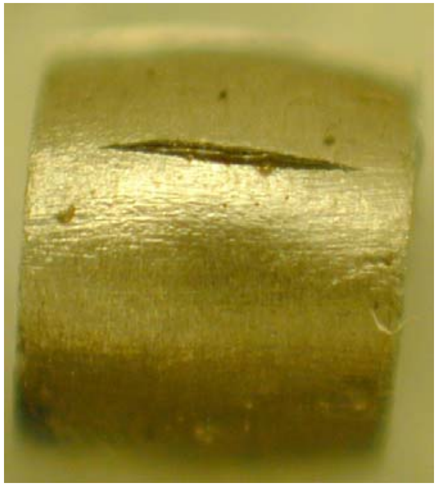
- **Some discoloration observed but no change in diameter seen from measurements accurate to ± 5 microns.**

Hardness increase in cladding agrees well with Yield Stress increases measured on irradiated tensile specimens

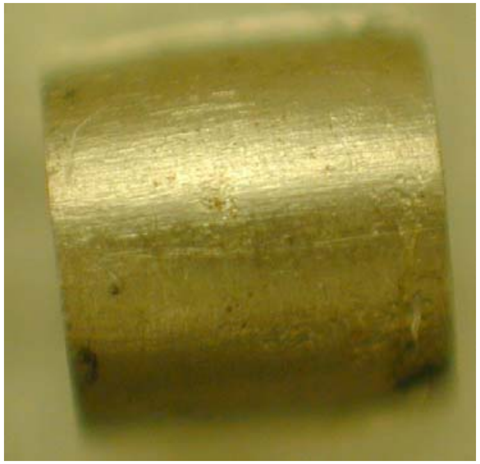


Compression Stress/Strain Results for Irradiated Tungsten Show Increase in Yield Stress with Dose above 4 dpa





3.2 dpa



0 dpa

Conclusions

- The success of the irradiation of slip clad tungsten rods as a spallation neutron target is based on the following observations:
  - The spallation target performed without incident at a peak power density of 2.25 kW/cm^3 and a peak heat flux of 148 W/cm^2. Peak fluence reached 4×10^{21} $particles/cm^2$.
  - The target design produced very low stress and post irradiation testing showed that the properties of the target materials far exceeded design requirements throughout the irradiation.
  - Target geometry is not restricted, especially with further verification that the hydrogen gas created by spallation will not overpressure the volume between the tungsten rod and the clad.
- These observations, coupled with the extensive use of slip clad technology other nuclear applications, demonstrate that future spallation neutron sources should seriously consider using water cooled, slip clad tungsten rod bundles in the target assembly.