GRAPHITE SUBLIMATION TESTS with Inert Gas Mitigation

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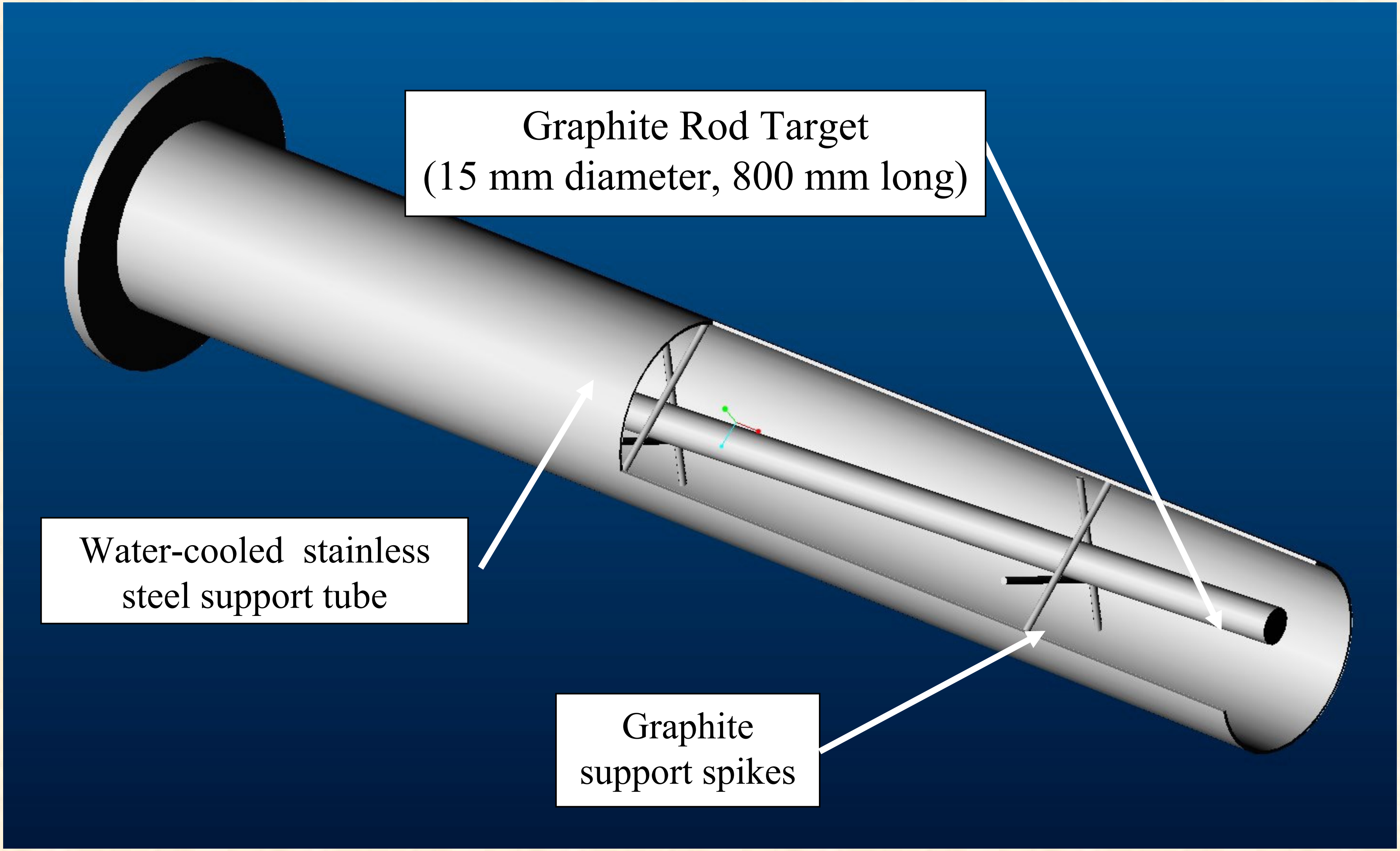
  - **D. E. Schechter for advice on cover gas technique**

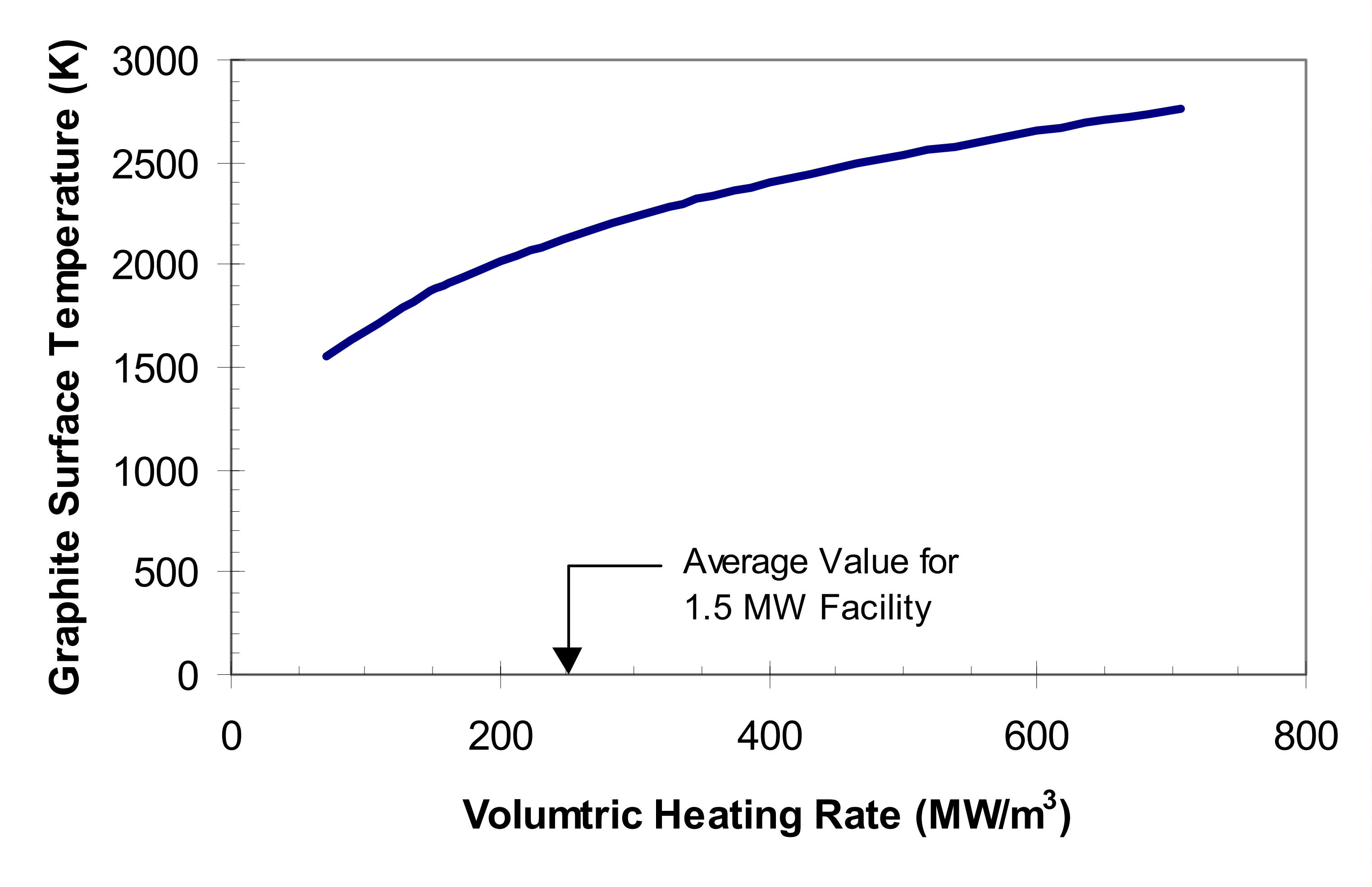
ORNL Proposed Passively Cooled Graphite Target for Neutrino Factories



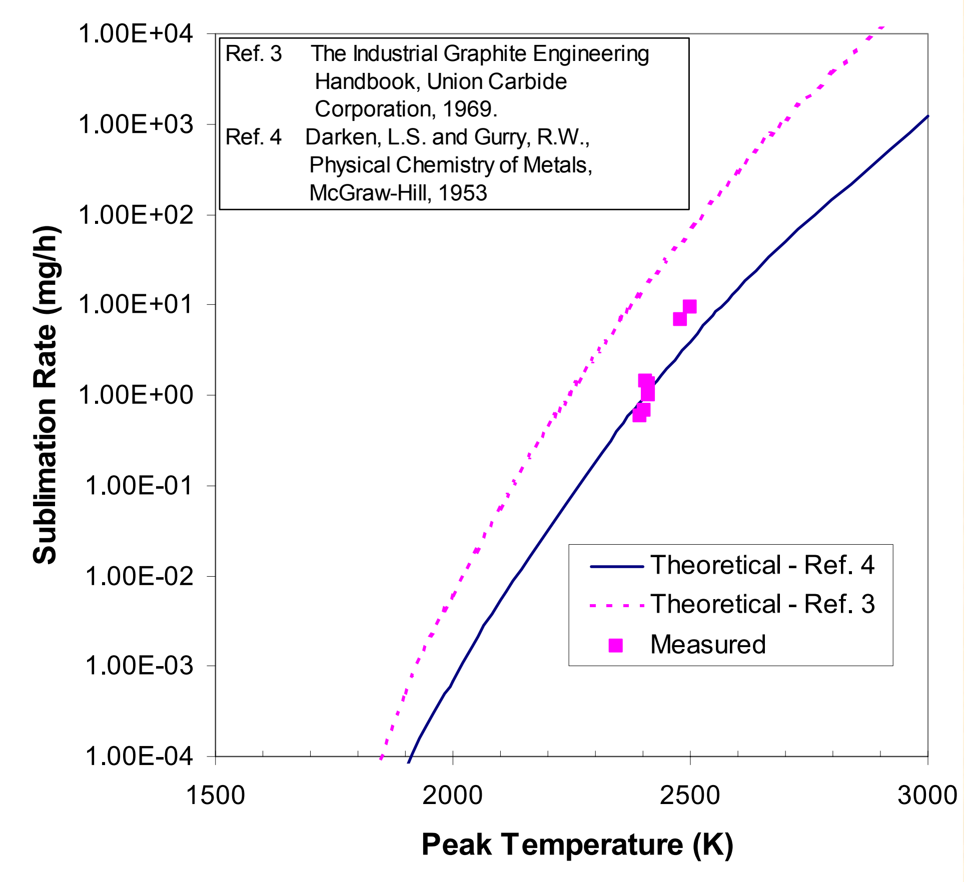
Motivation for Graphite Sublimation Tests

- **A radiatively cooled graphite target was proposed as a candidate for a neutrino factory target**
  - Radiation cooled design is very robust mechanically, but loss of material by sublimation will limit the power
- **We proposed the use of Helium Cover Gas to greatly reduce the net erosion rate**
  - Net erosion of graphite is limited by near surface interactions between sublimated carbon and He (mean-free-path ~ 1 μm), which leads to redeposition of sublimated graphite
- **Graphite sublimation tests are being conducted in an attempt to better establish limits for a vacuum environment and validate the use of helium to suppress sublimation**

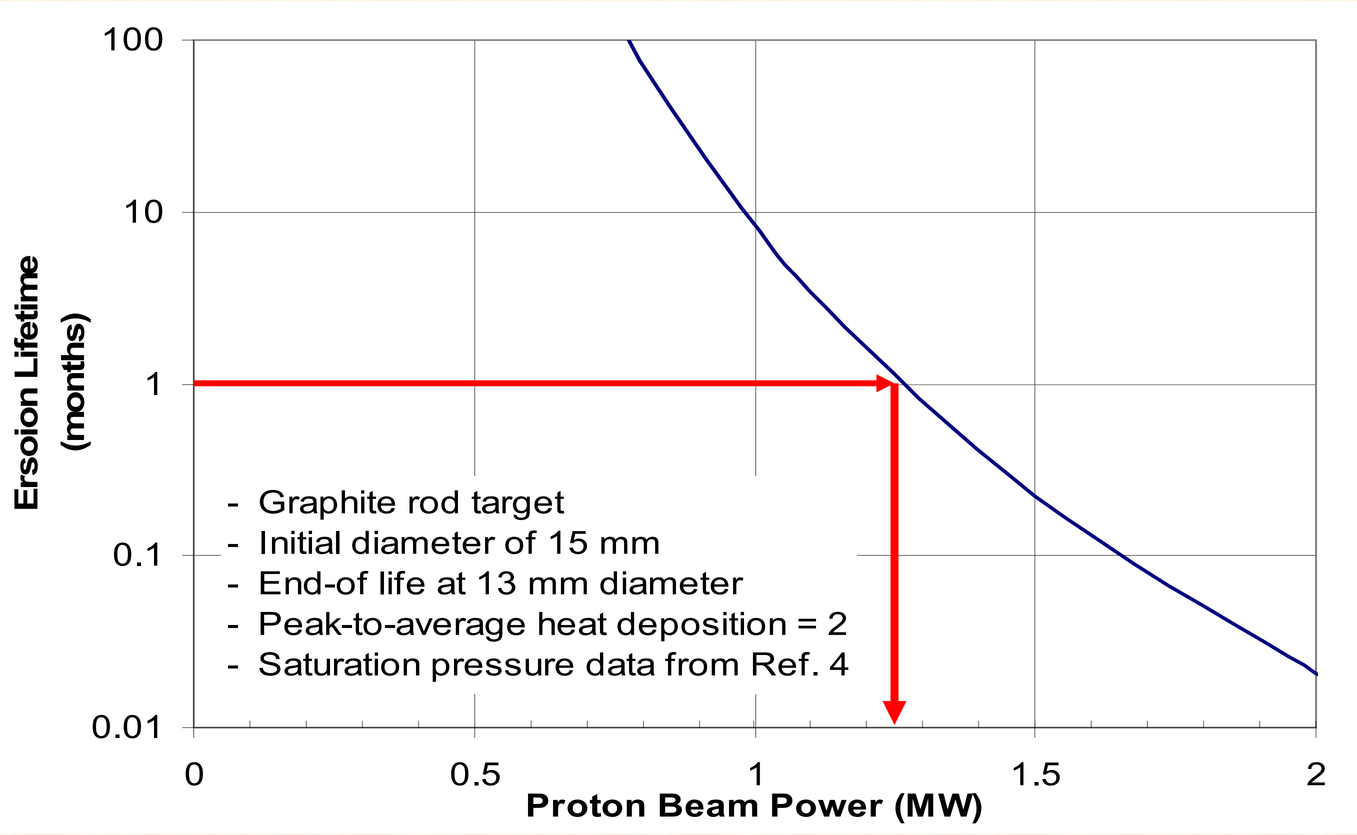
Surface Temperatures Exceed 2000K for Radiatively Cooled Graphite Targets



Test data and theoretical predictions of graphite coupon sublimation



Target Lifetime of One Month Is Possible at Power Levels of 1.2 MW

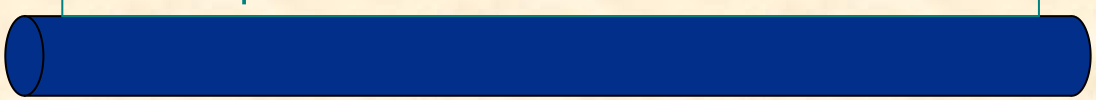


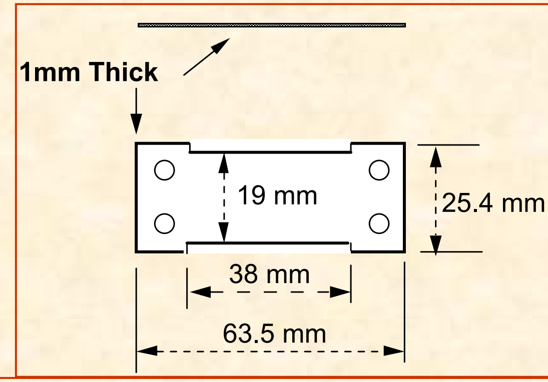
- This lifetime is based on data from previous tests under vacuum conditions
- Hopefully, net erosion rate can be reduced/lifetime extended with He cover gas

Status of graphite sublimation tests

- Vacuum tests on small coupons successfully conducted, but we experienced arcing damage with helium gas
- New tests have been conducted with target rod prototype
  - Joule heating at power densities equivalent to beam deposition
    - Requires high current (~ 1 kA)
    - Use existing facility in ORNL Fusion Energy Division
  - Test specimen
    - 15 mm diameter, 300 mm long
    - Clamped at both ends for current feed
  - Includes water-cooled panel coil shroud and extensive heat shields

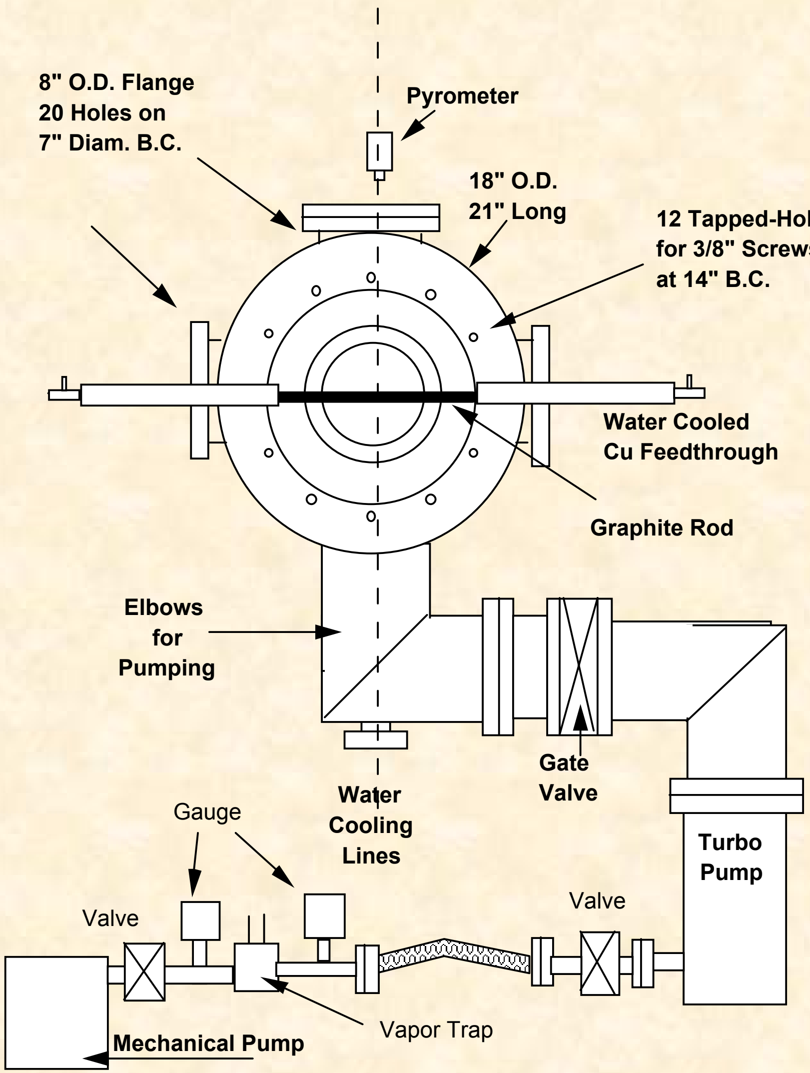
Rod specimen that will be used for new tests



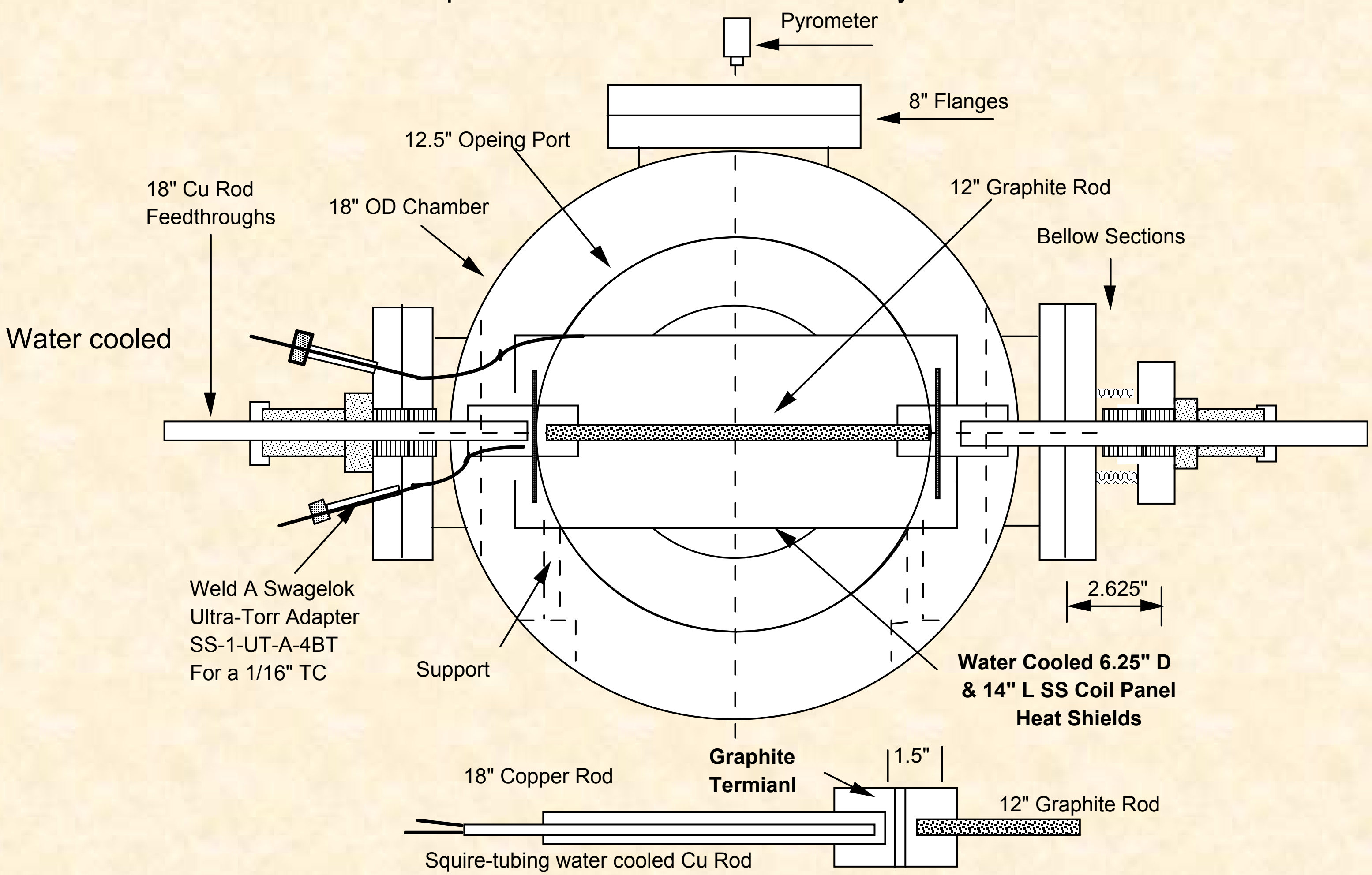


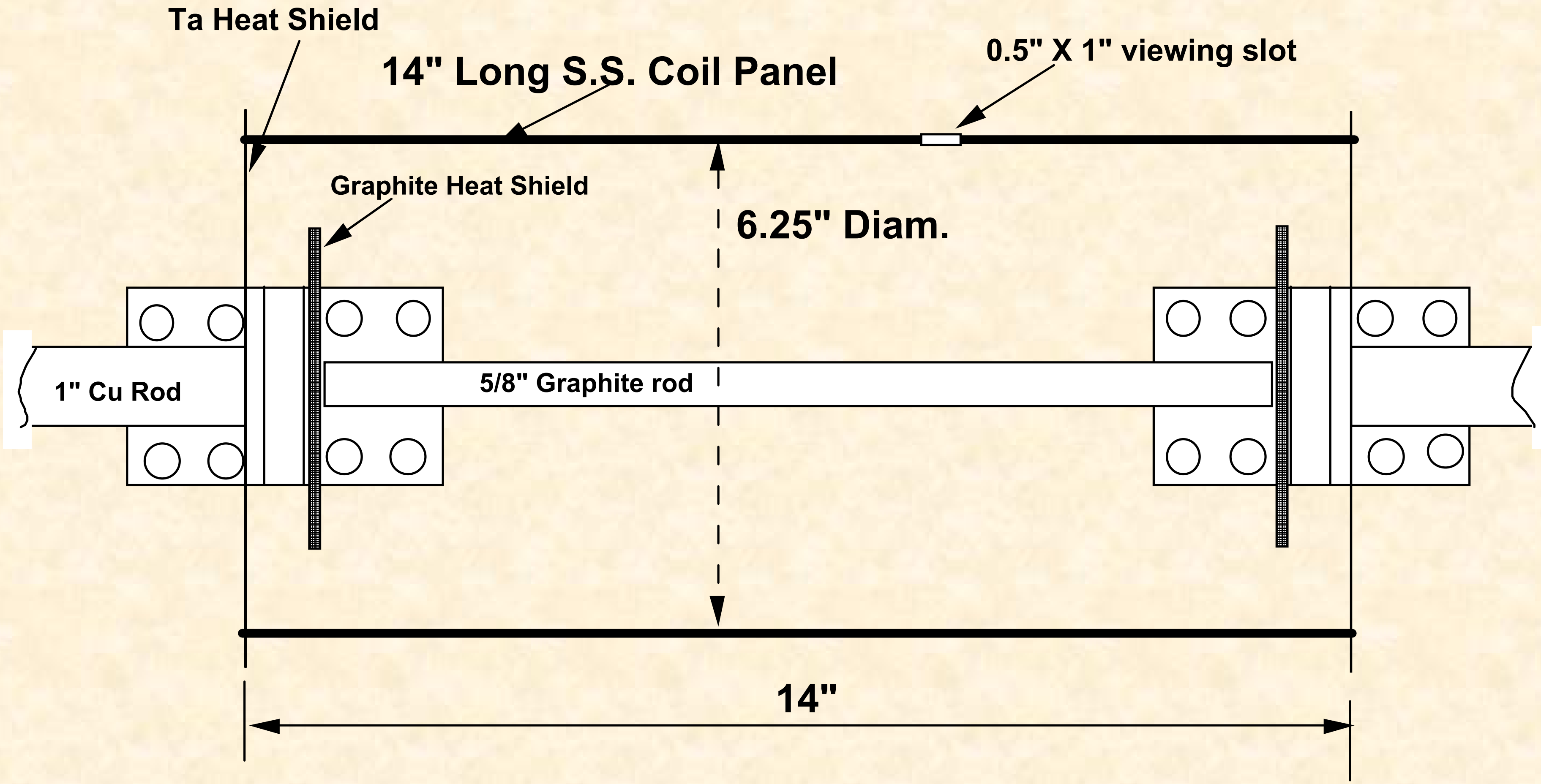
Small coupons used in previous tests

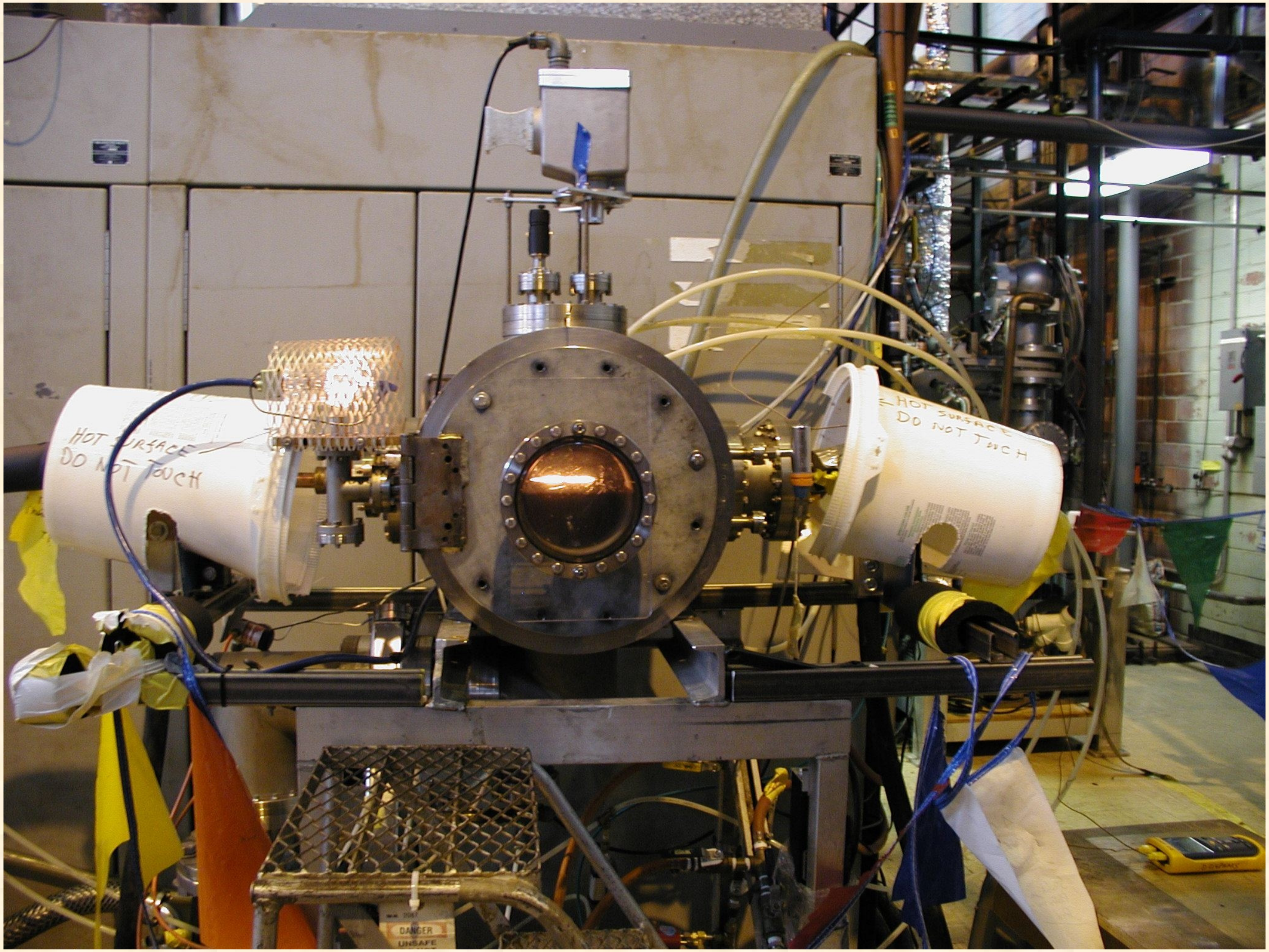
Graphite Rod Sublimation
Test Device



Graphite Rod Erosion Test Assembly Side View

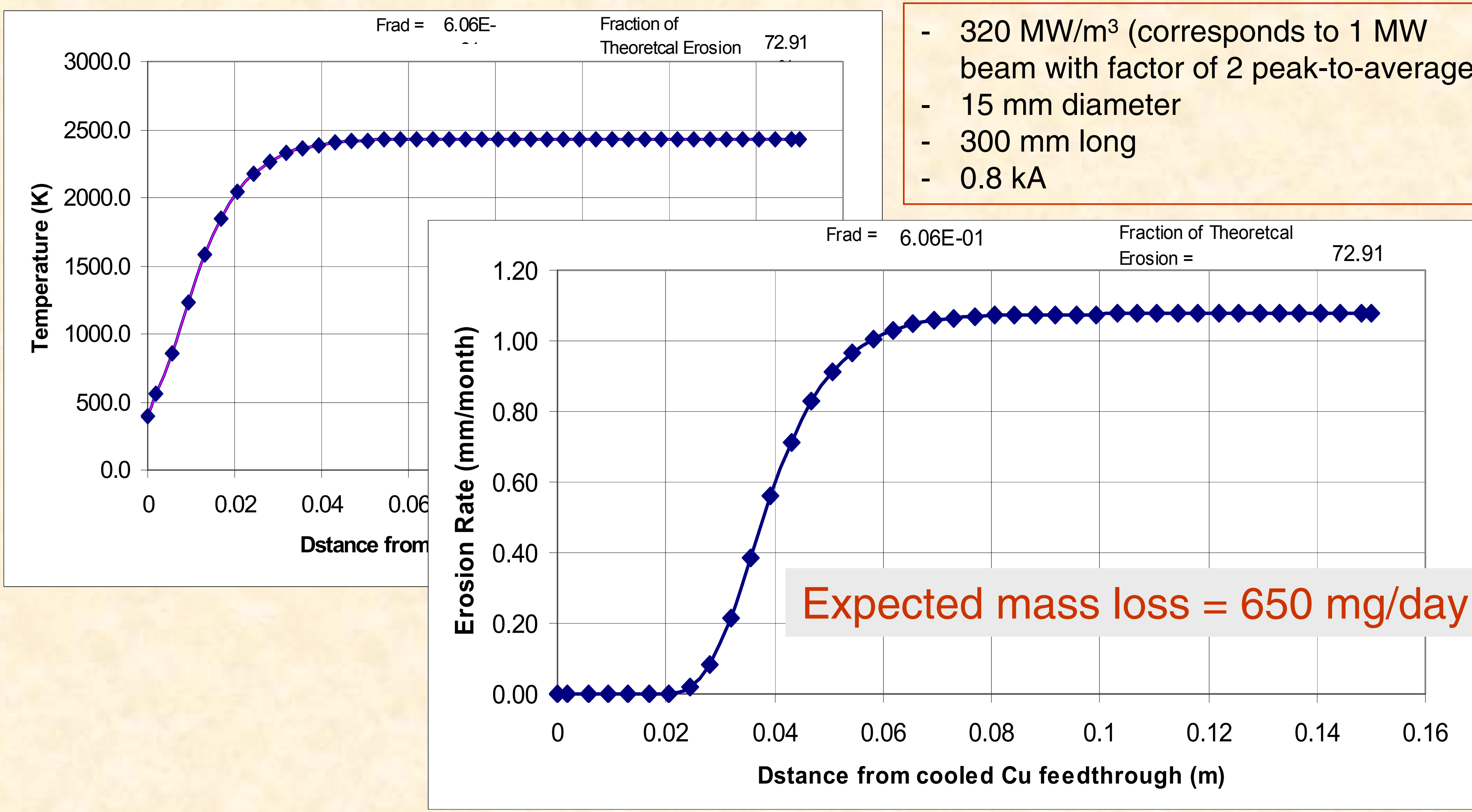



Ta Heat Shield
14" Long S.S. Coil Panel
0.5" X 1" viewing slot
Graphite Heat Shield
6.25" Diam.
1" Cu Rod
5/8" Graphite rod
14"

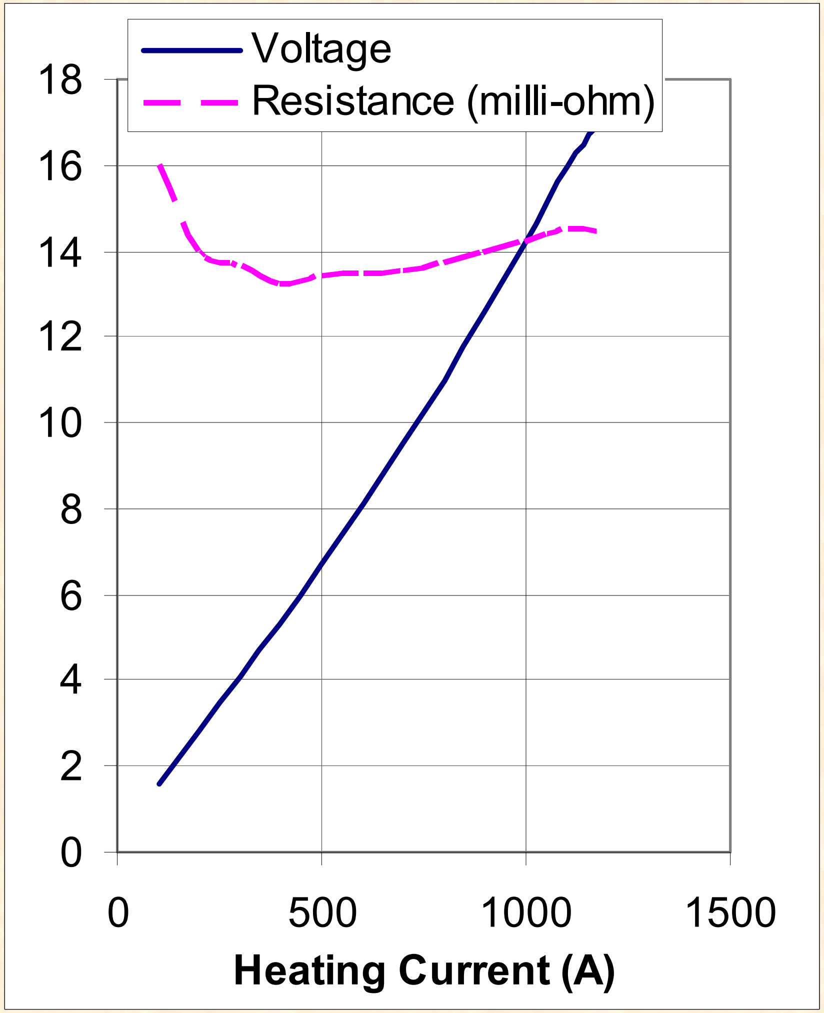

HOT SURFACE
DO NOT TOUCH
HOT SURFACE
DO NOT TOUCH
DANGER

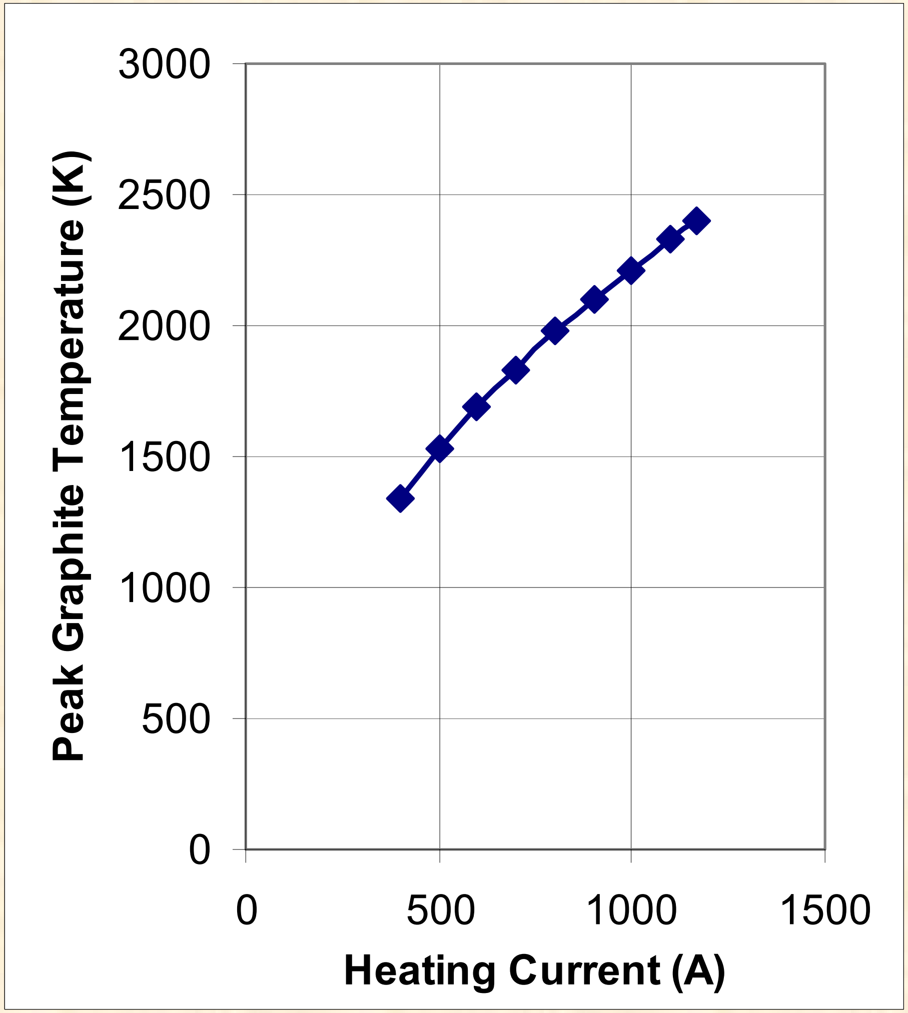
Heat loss through Cu current feedlines is acceptable - Sublimation rate > 70% of theoretical

- 320 MW/m³ (corresponds to 1 MW beam with factor of 2 peak-to-average)
- 15 mm diameter
- 300 mm long
- 0.8 kA



New sublimation Test Apparatus Was Commissioned in Dec '04





TEST PROCEDURE

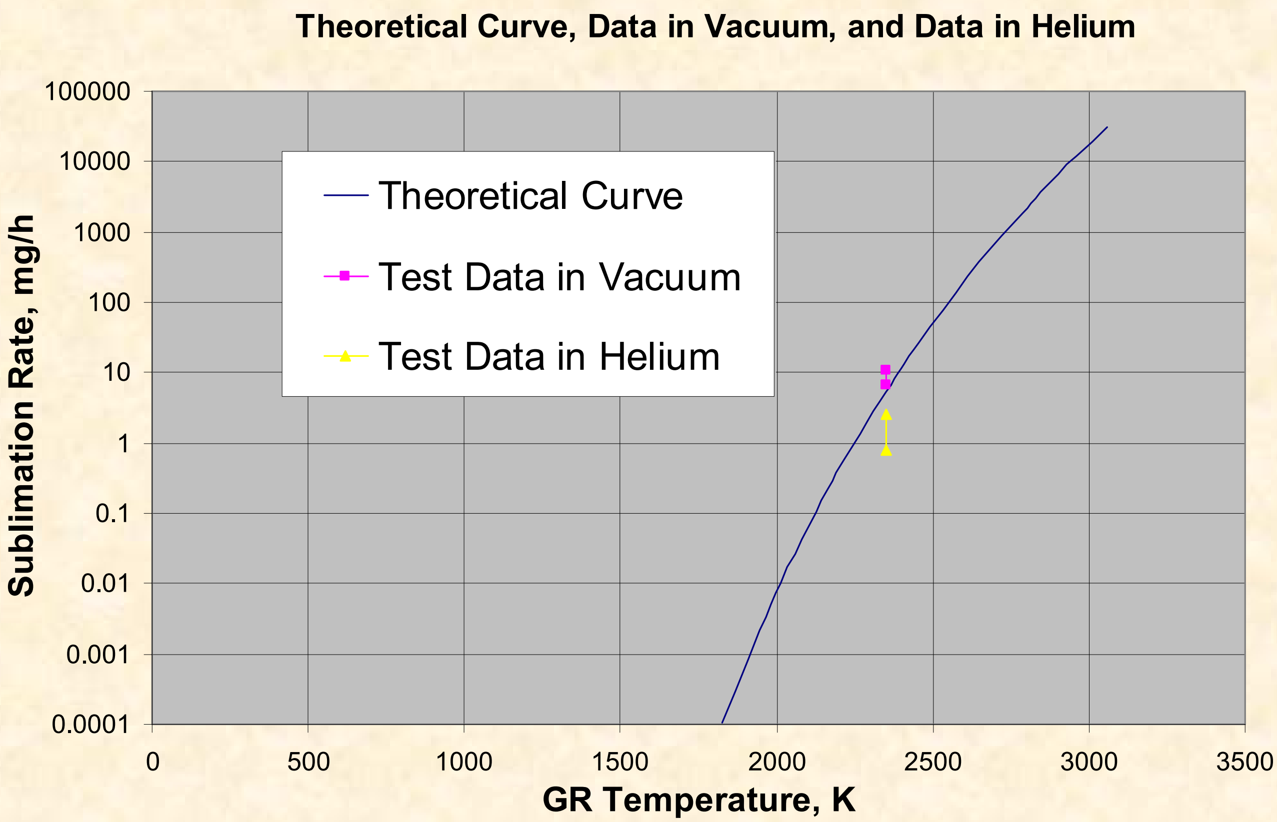
- Heat up a new graphite rod (GR) under vacuum
- Measure Vh / Ih (or resistance) and temperature of GR and use the recorded data to guide subsequent tests
- Measure initial GR mass in an electronic balance after removing the GR from 1-bar He test chamber
- Bake GR at 2000 K for 3 hours under vacuum
- Conduct GR sublimation test at desired temperature (e.g. 2350 K) for a long period of time (5 to 20 hours) under VACUUM or 1-bar HELIUM (Flowing or Static)
- Wait overnight for GR to cool down and fill the test chamber with 1-bar helium
- Remove and measure GR mass to estimate sublimation mass loss rate

Significant Test Results

- The high temperature oven can be operated continuously under vacuum or 1-bar inert cover gas such as helium, Argon, etc.
- GR Resistance character is similar in vacuum or in cover gas.
- The heating power in 1-bar inert cover gas is slightly higher than that under vacuum
- GR mass loss rate (mass loss in mg / test duration in hour) in 1-BAR HELIUM cover gas is lower than that under VACCUM conditions
- Argon cover gas works as well as helium cover gas for mitigating the GR sublimation erosion; measured mass loss rate is 1.7 mg/h for Ar and 2.56 mg/h for He.
- The following observed features could be due to gas impurity

1. The mass loss rate in the static helium cover gas lower than that in the flowing helium cover gas.
2. The mass loss rate decreases with the increase of the test duration under the static helium cover gas.

Theoretical Curve of Graphite Rod with Test Data



Graphite Rod Sublimation Test Parameters

Mass Loss Rate (mg/h)	Test Duration (h)	Vh (V)	Ih (A)	Rh (milli-ohm)	Cover Gas (Vacuum or He)
5.82	5	18.6	1214	15.32	Vacuum
3.4	5	18.9	1230	15.37	Flowing He
2.56	5	18.9	1230	15.37	Static He
0.78	20	18.9	1230	15.37	Static He

Static Helium Cover Gas Mitigates Sublimation of Graphite Rod To 1/30 Of That Under Vacuum

- Average mass loss rate of 2.56 mg /h for a test duration of 5 hours
- Average mass loss rate of 0.78 mg/h for a test duration of 20 hours
- If the test conditions are identical for the above 2 cases, the average mass loss rate for the last 15 hours of the 2nd case is 0.19 mg/h
- Ratio of 0.19 mg/h to 5.82 mg/h (mass loss rate under vacuum) is 1/30

Effective Sublimation Erosion Rate Measured Could be 0.025 g/h/m²

- Graphite Rod (GR): 305 mm Long & 15.88 mm in Diameter
- 38 mm long at each end of the GR was mounted to GR terminal.
- ~38 mm long at each end of GR yields insignificant sublimation.
- Effective length of the GR center section contributing to sublimation erosion is ~153 mm.
- Effective surface area of the GR is 76.3 cm^2.
- Effective sublimation erosion rate of the GR, equivalent to a mass loss rate of 5.82 mg/h under vacuum conditions, is 0.77 $g/h/m^2$.
- If the test conditions for the 2 static helium cases are identical, the mass loss rate during the last 15 hours could be 0.19 mg/h or the effective sublimation erosion rate to be 0.025 $g/h/m^2$.

Concluding Remarks

- Graphite sublimation tests have demonstrated and proven that 1-bar inert cover gas could substantially mitigate graphite sublimation erosion rate
- Gas impurity increased the average sublimation erosion loss rate
- Additional tests with pure inert cover gas should yield better data for designing high power and long life targets