4.1 HIGH-HEAT FLUX TESTING USING PLASMA ARC LAMPS OF LOW-LEVEL IRRADIATED MATERIALS

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OBJECTIVE

The objective of this work is testing of irradiated materials that are candidates for use in divertor components and mock-up divertor components under high-heat flux using Plasma Arc Lamps (PAL).

SUMMARY

The high-heat flux testing facility using Plasma Arc Lamps was demonstrated at ORNL for W samples. The test sections were designed by taking into account safety and materials compatibility requirements in order to handle the testing of low level irradiated tungsten articles. An enclosure was designed and fabricated. Test sections for the high-heat flux testing using PAL of low-level radioactive sample were designed and fabricated. The test sections were assembled and proof-of-principle testing was conducted, demonstrating the readiness of the new facility for irradiated samples.

PROGRESS AND STATUS

Introduction

Developing plasma-facing materials is a key challenge to the realization of the steady state high power fusion that will be required in DEMO and future fusion power plants. Based primarily on high temperature performance and plasma poisoning issues the two candidate materials for PFC armor have been tungsten and carbon. However, for the case of ITER, and likely the next generation of deuterium-tritium fueled machines, tungsten appears the material of choice. In order to demonstrate the performance of these new materials and structures, the Plasma-arc-lamp facility at ORNL will be used with minor modification to provide fusion-prototypical steady state heat flux conditions.

This work specifically addresses (1) coupling of the material design effort with material testing, and (2) cost-effective testing, as specifically identified in the Fusion ReNeW roadmap as follows:

- thrust area 11 “Careful *coupling of the material design effort with material testing* will be required to advance a science-based development approach.” and “Such testing will need to proceed in a timely and *cost-effective* manner to ensure that the results are incorporated into improved material designs that will enhance the performance of the developed materials.”
- *thrust area 14* high heat flux testing will be aimed at “Basic materials property information and models of materials behavior in the harsh fusion environment.”

There are several high heat flux (HHF) test facilities that provide thermal loads with power densities ranging from the MW/m^2 to several GW/m^2, and pulse durations ranging from a few hundred microseconds to almost continuous (Hirai et al., 2005; Coenen et al. 2011). For the static high heat flux testing, tests in electron beam facilities, particle beam facilities, IR heater and in-pile tests have been performed (Hirai et al., 2005). In this effort, only high heat flux (HHF) testing will be considered and the primary facility utilized will be the plasma arc lamp facility, a high-intensity infrared lamp. This technology has been successfully demonstrated for this purpose in the past for the High Average Power Laser inertial fusion program. Static heat loads corresponding to cycling loads during normal operation, are estimated to be up to 20 MW/m^2 in the divertor targets in ITER. Tungsten coatings bonded to F82H steel have been successfully tested to greater than 10 MW/m^2 for one thousand cycles using the plasma arc lamp facility at ORNL (Romanoski, et al., 2005; Figure 5).

EXPERIMENTAL PROCEDURE

In this project, as part of the material characterization of divertor armor the testing is undertaken of actively cooled components under fusion specific (a) thermal loading conditions and (b) operational temperatures. The high heat flux testing at ORNL using the plasma arc lamp will aim at obtaining (1) basic materials property information and (2) formulating constitutive equations for models of materials behavior in the harsh fusion environment.

PAL Facility

ORNL has two Plasma-arc lamps available, as illustrated in Figure 1 and described in Table 1.

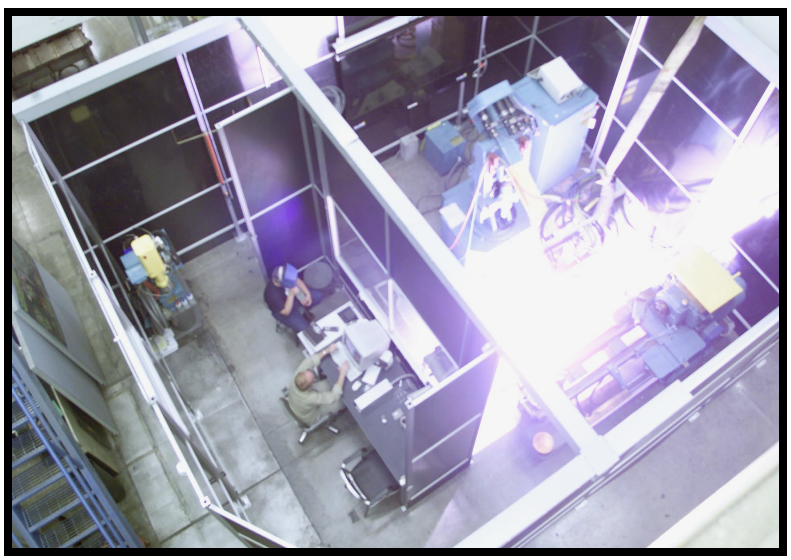


Figure 1. Plasma Arc Lamp available at ORNL for high heat flux testing.

Table 1. Incident and absorbed heat fluxes in tungsten at current ORNL PAL Capabilities.

Plasma Arc Lamp System	Min. Pulse Time [s]	Max. Pulse Time [s]	Incident Max. Heat Flux [MW/m^2]	*Absorbed Max. Heat Flux in W [MW/m^2] at 1,100 K	Process Area [cm^2]	Size of Max Heat flux [cmxcm]
Vortek 300	0.01	50-400	27	12.7	41	1x10
Vortek 500	0.02	50-400	4.2	2	320	18x18

*Based on W emissivity of 0.47.

Test Section Design

The test sections were designed by taking into account safety and materials compatibility requirements in order to handle the testing of low levels irradiated tungsten articles (Table 2). An enclosure was designed and fabricated (Figure 2). Test sections for the high-heat flux testing using PAL of low-level radioactive sample were designed and fabricated (Figure 3). The test section was instrumented with thermocouples as shown in Figure 3b. I order to handle RAD materials, the facility relies on two levels of containment: (1) a quartz cylinder that contains the sample holder, (2) the Al test enclosure that is vacuum tight including a high-temperature o-ring to support the large quartz window and vacuum-tight thermocouple feedthroughs, (3) Ar evacuation using HEPA vacuum filters.

Table 2. Design considerations and solution adopted for the testing of low-level irradiated tungsten articles.

Design Considerations	Solutions
IR heating	Quartz window
Quartz window seal	High temperature o-ring
Enclosure overheating	Enclosure size larger than area of peak power, water cooled
W testing: No O_2 at high temp.	Evacuation of air in enclosure and backfill with Ar
Quartz window integrity during air evacuation	Secondary chamber for equalizing pressure on both sides of window
Liftoff of quartz window	Vent & Pressure gauge
Avoid overheating & cracking of Q-window during high-heat flux	Air knife to cool the quartz
High-heat flux	Impingement water cooling
Containment of RAD volatilization compounds	1. HEPA filter vacuum 2. Testing section enclosed in quartz cylinder 3. Vacuum tight thermocouple feedthroughs 4. No water connections within the enclosure
Temperature measurements	K, S, R thermocouples; pyrometer

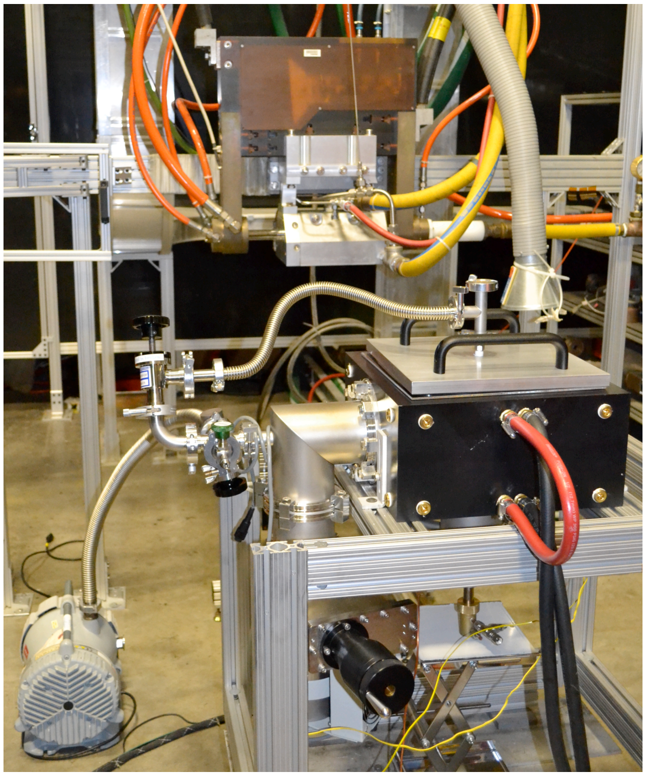


Figure 2. Aluminum enclosure (black anodized) as prepared for the evacuation procedure, showing vacuum pump and top chamber.

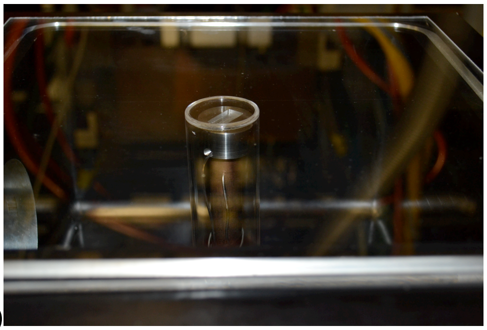
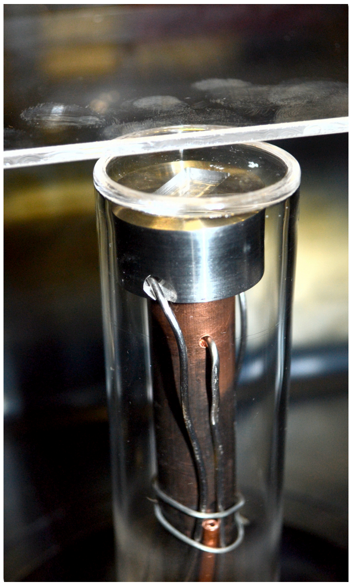
(a)  (b) 

Figure 3. Test section (a) panoramic top view and (b) test stand composed of quartz cylinder for containment of volatile RAD gases, water cooled rod, Mo sample holder, and thermocouples.

RESULTS

The test sections were assembled and proof-of-principle high-heat flux testing was conducted, demonstrating the readiness of the new facility. The locations of the thermocouples are shown in Figure 4. The temperature data during demonstration test was obtained using the uniform reflector of the 750kW PAL at an estimated heat flux of 2 MW/m^2 at an offset distance of 3.2cm. The heat flux measured at 2cm offset was 2.35 MW/m^2. It is estimated that the incident heat flux into the sample was approximately 1 MW/m^2. A typical temperature evolution during a demonstration test is shown in Figure 5. The test duration was 30 s.

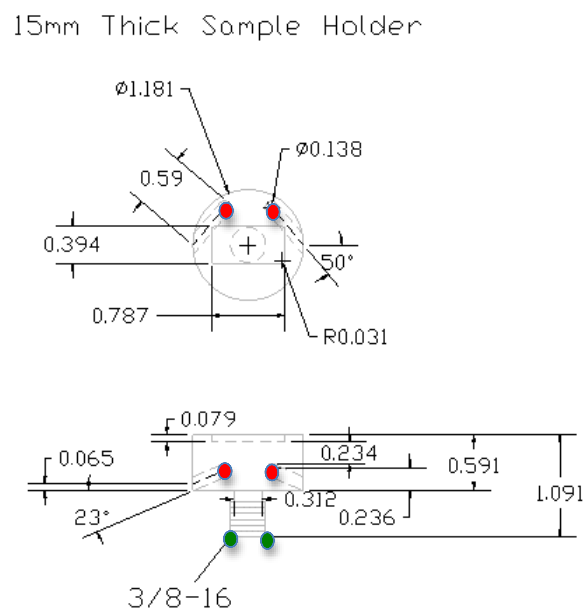


Figure 4. Location of thermocouples in the sample holder (red dots) and cooled rod (green dots).

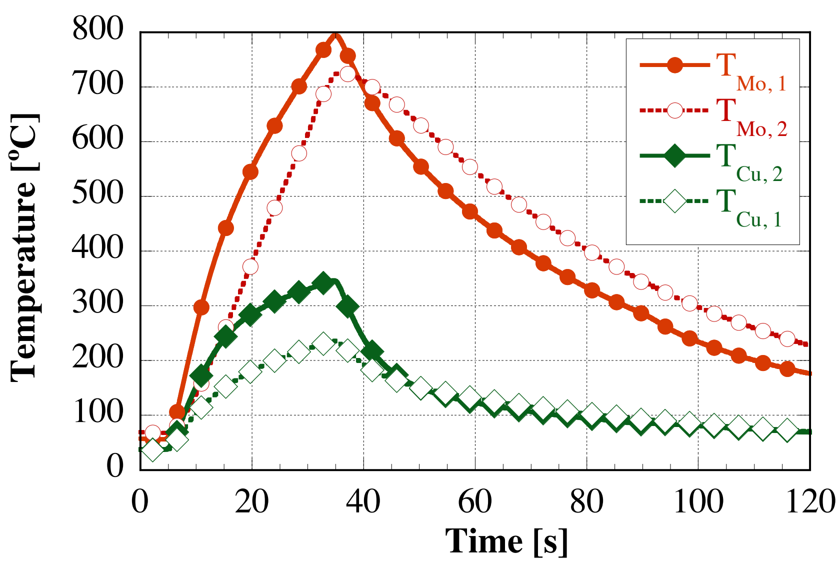


Figure 5. Typical temperature evolution during a demonstration test showing temperatures in the Mo sample holder (circle symbols) and in the Cu water-cooled rod (diamond symbols).

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REFERENCES

[1] T. Hirai, K. Ezato, and P. Majerus, "ITER Relevant High Heat Flux Testing on Plasmas Facing Surfaces," *Mater. Trans.* **46**, 3 (2005) 412.
[2] J. W. Coenen, V. Philipps, S. Brezinsek, B. Bazylev, A. Kreter, T. Hirai, M. Laengner, T. Tanabe, Y. Ueda, U. Samm, and the TEXTOR Team, "Analysis of Tungsten Melt-Layer Motion and Splashing Under Tokamak Conditions at TEXTOR," *Nucl. Fusion* **51**, 083008 (11pp) 2011.
[3] G. Romanoski, L. Snead, A. Sabau, J. Kelly, and S. Zinkle, "Bonding Tungsten to Low Activation Ferritic Steel, *HAPL Workshop*, LLNL, June 20-21, 2005.