Milestone M3FT-15OR0202268: Delivery of completed irradiation vehicles and the quality assurance document to the High Flux Isotope Reactor for irradiation

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1. Introduction

This report details the initial fabrication and delivery of two Fuel Cycle Research and Development (FCRD) irradiation capsules (ATFSC01 and ATFSC02), with associated quality assurance documentation, to the High Flux Isotope Reactor (HFIR). The capsules and documentation were delivered by September 30, 2015, thus meeting the deadline for milestone M3FT-15OR0202268. These irradiation experiments are testing silicon carbide composite tubes in order to obtain experimental validation of thermo-mechanical models of stress states in SiC cladding irradiated under a prototypic high heat flux. This document contains a copy of the completed capsule fabrication request sheets, which detail all constituent components, pertinent drawings, etc., along with a detailed summary of the capsule assembly process performed by the Thermal Hydraulics and Irradiation Engineering Group (THIEG) in the Reactor and Nuclear Systems Division (RNSD). A complete fabrication package record is maintained by the THIEG and is available upon request.

2. Experimental Design

The capsule design uses an embossed aluminum foil to transfer heat from the cladding and sleeve (see Figure 1) to the capsule housing. The foil compresses as the cladding swells under irradiation and keeps the clad surface temperature approximately constant throughout the irradiation. Heat transfer through the embossed foil has been validated experimentally (see Figure 2). This design allows the SiC tubes can be irradiated under a representative light water reactor temperature (300-350 °C outer surface temperature) and heat flux (0.5-1.0 MW/m^2). The molybdenum heaters provide the heat generation required to reach the desired heat flux. Titanium centering thimbles keep both the SiC tube specimens and the molybdenum heaters centered within the capsule housing. Figure 1 shows a stack up of two 16 mm length specimens, one 12 mm length specimen, and one 4 mm length specimen. Alternatively, a stack up of three 16 mm length specimens can be used. This alternate stacking arrangement with three 16 mm length specimens was used for capsules ATFSC01 and ATFSC02, which were assembled and delivered to the HFIR for insertion during cycle 462 (October 2015).

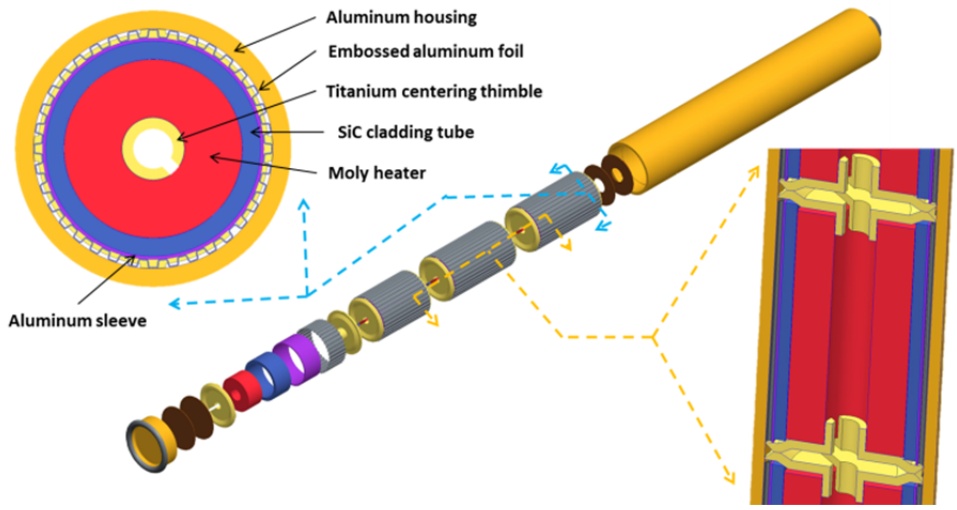

Figure 1. Schematic overview of experimental design

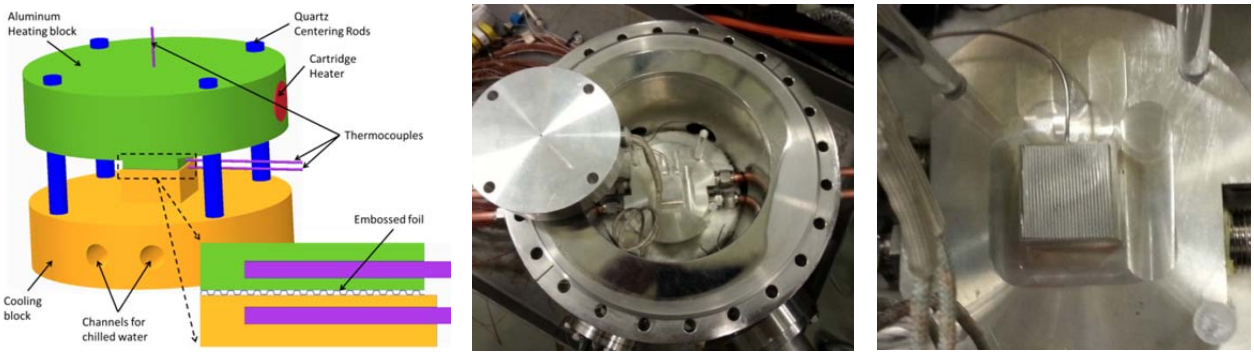

Figure 2. Validation experiment schematic (left), and pictures of the experimental rig (center) and foil loaded inside the rig (right).

3. Component Fabrication

Silicon carbide composite tube specimens were manufactured by General Atomic (GA). Composite tube specimens GA-TGI-1 and GA-TGI-4 were loaded into capsules ATFSC01 and ATFSC02, respectively. Pictures of these specimens are provided in Figure 3. In addition to the composite tube specimens, two CVD SiC tubes (monoliths) were loaded into each capsule to serve as a reference for comparison between the composites and the monoliths. The embossed aluminum foils were fabricated using a custom foil fabrication system (see Figure 4) that allows the foils to be rolled through mating gears without tearing the foil.

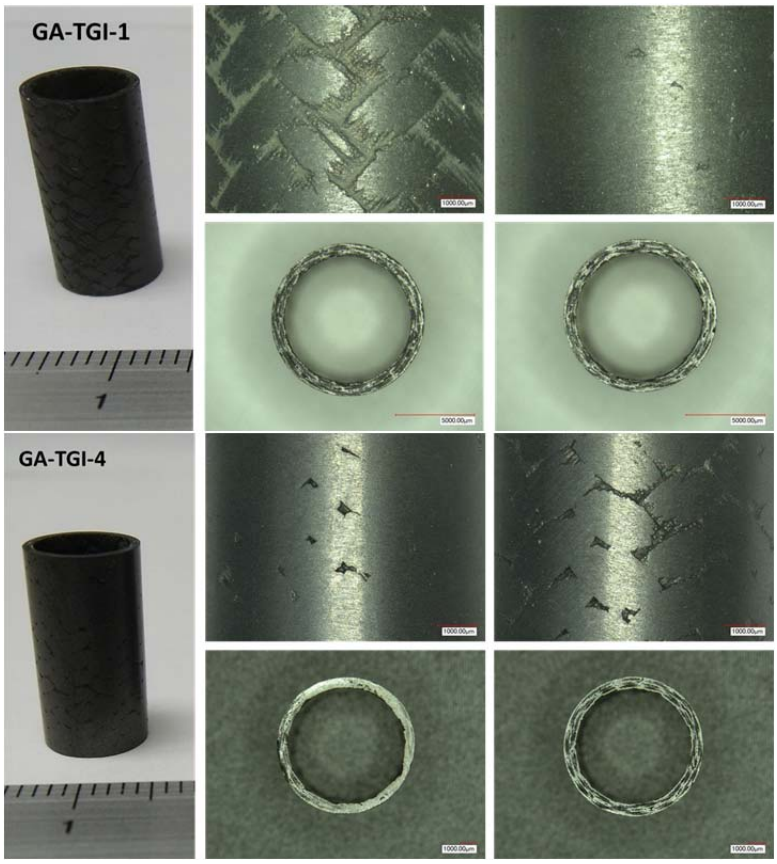

Figure 3. Pictures of SiC composite tube specimens GA-TGI-1 (top) and GA-TGI-4 (bottom)

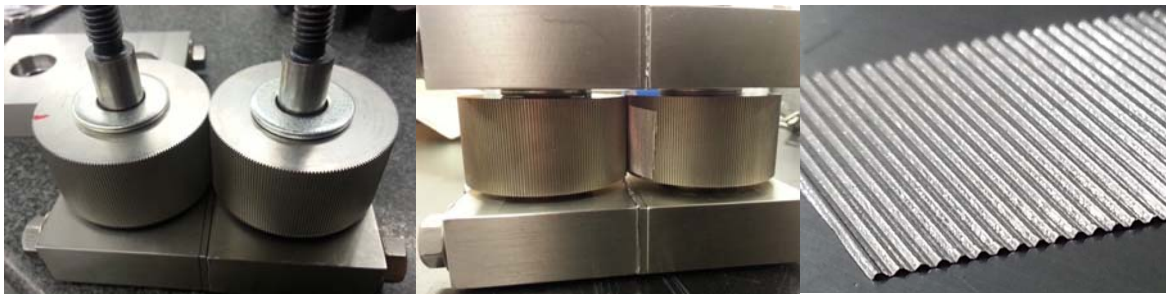

Figure 4. Pictures of the foil fabrication system

4. Capsule Assembly

The centering thimbles were pressed into the molybdenum heaters and the SiC tubes were inserted around the heaters. The sleeve was rolled around gage pins of the appropriate diameter and then wrapped tightly around the SiC tubes. The embossed foils were then wrapped around the sleeve to form the sub-assemblies (i.e. two centering thimbles, a heater, tube, sleeve, and foil). The sub- assemblies were then pressed into the housing. The foils were sized so that they must be compressed during insertion to ensure that there is good contact at the tube/sleeve, sleeve/foil, and foil/housing interfaces. Figure 5 shows pictures taken during the assembly process including the sub-assemblies and the fully assembled rabbit housings.

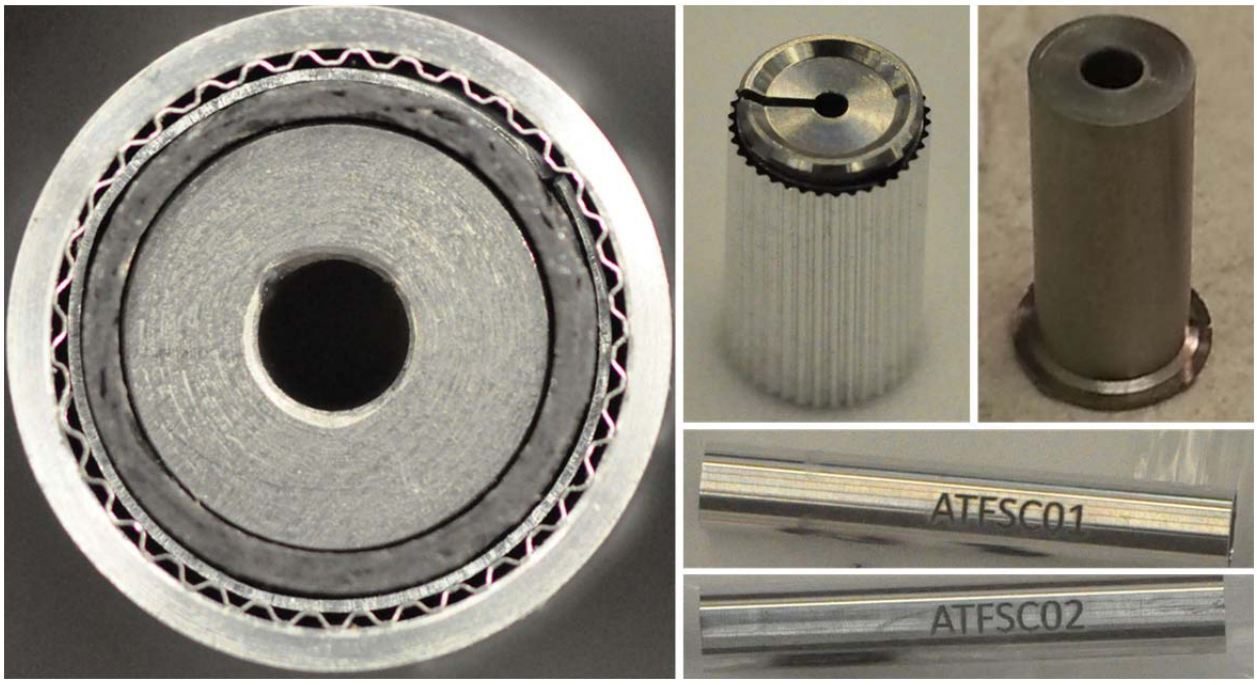

Figure 5. Pictures of sub-assembly in capsule housing (left), building of sub-assemblies (top right), and fully assembled capsules (bottom right)

5. Final Capsule Welding and Testing

Upon successful assembly of the capsules, the end caps were electron beam welded to the housings. Preliminary non-destructive examination (NDE) was performed on the end cap trepan welds to ensure that the weld joints were hermetically sealed. A final sealing weld was then made for each capsule, providing an inert helium internal atmosphere for all capsules. A formal helium leak rate test and external hydrostatic compression test were performed on the capsules to ensure they were properly sealed. THIEG engineering staff used the final loading and assembly data to perform the necessary evaluations required to ensure that each capsule is bounded by existing HFIR safety basis calculations and meets the requirements of the ORNL Research Reactor Division's Experiment Authorization Bases Document EABD-HFIR-2009-004 Rev. 11. Upon completion of the THIEG review, the capsules were delivered to the HFIR for final quality assurance review and insertion for irradiation.

Attachments – Fabrication Request Sheets

Capsule Fabrication Request Sheet

Date 9/23/2015

Capsule Number: ATFSC01

Irradiation Conditions

Irradiation Location	TRRH- 4
Target Fluence	2.3E+21
First Cycle Goal	462
Irradiation Time	1.0 cycle
Irradiation Charge Number	N/A
Fill Gas	Helium

Approvals

	Request	Build
Performed by:		
Checked by:		

Capsule Fabrication

	Drawing	Rev.	Part	Material	Count	Comment	MAT IR	FAB IR	ID	Mass (g)
Housing	X3E020977A634	A	1	Al 6061	1		20483	20483	18-1	4.2941
End Cap	X3E020977A634	A	2	Al 4047	1		20157	20157	14-5	0.5139
Centering Thimble	S15-28-SIC-CLAD-02	B	2	Ti6Al4V	6		20369	20419	35,49,62,63,66,67	1.0153
Cladding #3	S15-28-SIC-CLAD-02	B	3	SiC	3	GA-TGI-1 -> ARM00002	20380 20470	20380 20470	GA-TGI-1 CVD-T1 CVD-T2	2.5754
Heater #4	S15-28-SIC-CLAD-02	B	4	Mo	3	Note the pairing of cladding and heaters shown above	20153	20420	ARM00002 ARM00003 ARM00004	16.3004
Sleeve #5	S15-28-SIC-CLAD-02	B	5	Al 1100	3	Sleeves for the CVD tubes must have ~8 µm RMS surface roughness. Sleeves for GA-TGI-1 tube can use standard surface roughness	20378 20379	20471	2 from S02 1 from S01	0.4290
Foil #6	S15-28-SIC-CLAD-02	B	6	Al 1100	3		20388	20473	3 total	0.1950
Insulator Disc with Hole	S15-28-SIC-CLAD-02	B	17	Grafoil	2		19812	19812	2 total	0.0155
Insulator Disc w/o Hole	S15-28-SIC-CLAD-02	B	18	Grafoil	2		19812	19812	2 total	0.0160
Quartz Wool	S15-27-SIC-CLAD-01	0	NA	Quartz	AR		20224	20279	NA	0.0866
Small Thermometry	X3E020977A540	0	3	SiC	3		19502	20469	01,02,03	0.0528
									Total Mass	25.4940
									Specimen Mass	2.5754
									Internal Mass	20.6860

Assembly

	Drawing	Rev.	Comment
Assembly Drawing	S15-27-SIC-CLAD-01	0	
Welding & Cleaning	X3E020977A633	0	
Fill Gas	Helium		

Capsule Fabrication Request Sheet

Date 9/23/2015

Capsule Number: ATFSC02

Irradiation Conditions

Irradiation Location	TRRH- 4
Target Fluence	2.3E+21
First Cycle Goal	462
Irradiation Time	1.0 cycle
Irradiation Charge Number	N/A
Fill Gas	Helium

Approvals

	Request	Build
Performed by:		
Checked by:		

Capsule Fabrication

	Drawing	Rev.	Part	Material	Count	Comment	MAT IR	FAB IR	ID	Mass (g)
Housing	X3E020977A634	A	1	Al 6061	1		20483	20483	18-2	4.2908
End Cap	X3E020977A634	A	2	Al 4047	1		20157	20157	14-96	0.5111
Centering Thimble	S15-28-SIC-CLAD-02	B	2	Ti6Al4V	6		20369	20419	14,43-45,48,56	1.0214
Cladding #3	S15-28-SIC-CLAD-02	B	3	SiC	3	GA-TGI-4 -> ARM00007	20380 20470	20380 20470	GA-TGI-4 CVD-T6 CVD-T7	2.5696
Heater #4	S15-28-SIC-CLAD-02	B	4	Mo	3	Note the pairing of cladding and heaters shown above	20153	20420	ARM00007 ARM00008 ARM00009	16.2954
Sleeve #5	S15-28-SIC-CLAD-02	B	5	Al 1100	3	All sleeves must have surface roughness of ~8 µm RMS	20379	20471	3 total from S02	0.4290
Foil #6	S15-28-SIC-CLAD-02	B	6	Al 1100	3		20388	20473	3 total	0.1950
Insulator Disc with Hole	S15-28-SIC-CLAD-02	B	17	Grafoil	2		19812	19812	2 total	0.0155
Insulator Disc w/o Hole	S15-28-SIC-CLAD-02	B	18	Grafoil	2		19812	19812	2 total	0.0160
Quartz Wool	S15-27-SIC-CLAD-01	0	NA	Quartz	AR		20224	20279	NA	0.0757
Small Thermometry	X3E020977A540	0	3	SiC	3		19502	20469	04,05,06	0.0528
									Total Mass	25.4723
									Specimen Mass	2.5696
									Internal Mass	20.6704

Assembly

	Drawing	Rev.	Comment
Assembly Drawing	S15-27-SIC-CLAD-01	0	
Welding & Cleaning	X3E020977A633	0	
Fill Gas	Helium		