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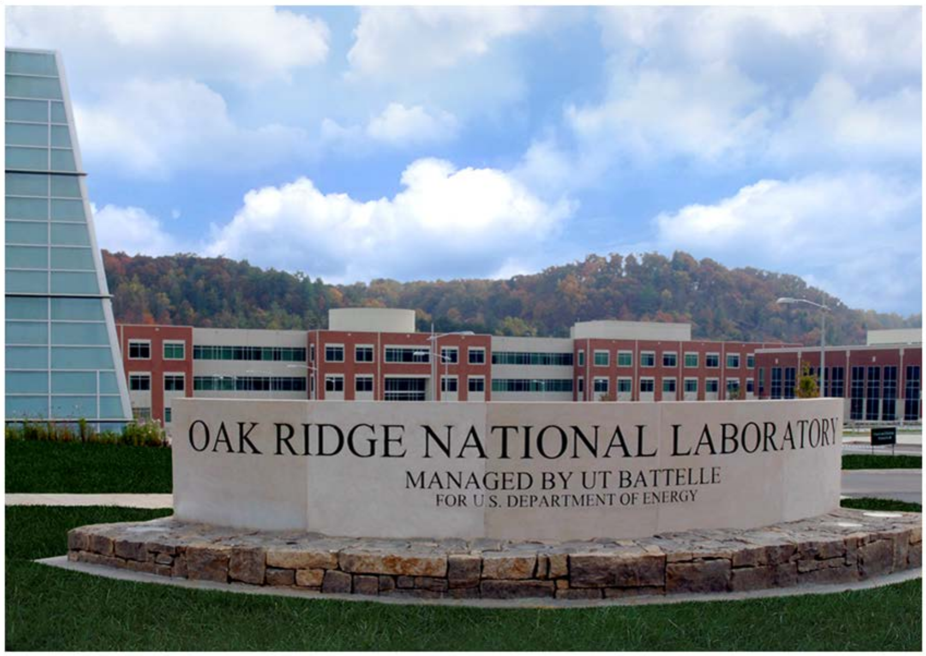
Evaluation of Testing Facilities for a High Temperature Fission Chamber Design



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May 2018

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OAK RIDGE NATIONAL LABORATORY
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Electrical and Electronics System Research Division

Evaluation of Testing Facilities for a High-Temperature Fission Chamber Design

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EXECUTIVE SUMMARY

Oak Ridge National Laboratory (ORNL) developed a first-of-its-kind high-temperature fission chamber (HTFC) prototype that could survive in the harsher environments of advanced reactors with high flux fields up to 10^{13} n/cm^2-s and temperatures upwards of 700°C. The first prototype of the HTFC was demonstrated at the Ohio State University Research Reactor (OSURR) in October 2017. The experiment at the OSURR was designed to demonstrate four regions of operation: low flux and low temperatures, low flux and high temperatures, high flux and low temperatures, and high flux and high temperatures. Although some problems developed during the experiment at the OSURR, data was obtained and the fission chamber was shipped back to ORNL. The problems were diagnosed and documented at ORNL, and the HTFC was reassembled. Testing will proceed at ORNL at temperatures up to 700°C. This report discusses other possible test facilities to demonstrate the HTFC instrument prototype after reassembly.

1. INTRODUCTION

Next-generation advanced nuclear reactors will require instrumentation designed to withstand harsher environments than previous reactors. Fission chambers are one instrument used for monitoring power and in-core fuel management. Existing materials and fill gases used in fission chamber designs cannot withstand the higher temperatures and corrosive environments of high-temperature gas-cooled and molten salt reactors. Although none of these advanced reactors currently exists commercially, the instrumentation prototypes need to be tested and qualified. For the fission chamber part of these tests, it is important to select demonstration facilities with the desired flux and that allow for furnaces to be heated to elevated temperatures.

2. DEMONSTRATION FACILITIES

The high-temperature fission chamber (HTFC) prototype was designed to meet the following conditions: (1) sensitivity of 1 nv (or $n/cm^2/s$); (2) harsh environments like FLiBe (molten salt) at 1 atm or helium (gas-cooled) at 79 atm; (3) temperatures from 700°C (FLiBe cooled) to 800°C (helium cooled); (4) thermal neutron flux equivalent to 10^{13} nv; and (5) a lifetime expectancy of approximately 2 years. Although some of these conditions are easily met in conventional reactors, some conditions must be implemented through other means. For example, to reach 700 to 800°C, a furnace must be installed with the fission chamber. Many facilities were asked to complete a table of specifications about their facilities (see Table 1). Several inquiries were made to help identify the best demonstration facility for the experiment specifications

Table 1. Description of facility capabilities

Specification	Description
Management	Facility operator
City	Facility location
Reactor Type	Type or reactor or other facilities on site
Maximum thermal flux ($x10^{14}$ $n/cm^2 \cdot s$)	Maximum thermal neutron flux
Maximum fast flux ($x10^{14}$ $n/cm^2 \cdot s$)	Maximum fast neutron flux
Coolant inlet temperature (°C)	Coolant temperature is the temperature (heat sink) where experiments will be exposed to on their outer boundary
Operating pressure (MPa)	How much pressure the experiment will be exposed to if there is any pressure boundary
Experiment facility diameter (mm)	The experiment location, your upper limit for the outer dimension of your experiment
Experiment active length (mm)	Your boundary length for the experiment
Experiment cabling/rack installation	How do users need to design experiment electronics for installation at the facility?
Typical operating fraction	Is the reactor operating on demand or continuously? That schedule may affect your irradiation time/removal
Existing flow loops	Are there built in flow loops? Is there restriction put in one?
Existing salt facility	Are there built in salt loops? Is there restriction to put one?
Hot cell capability	Are there hotcells within the facility?
Activity restrictions	What is the activity restriction, safety margin? Worst case scenario margin.
High temperature restrictions	Are heaters allowed? Do they already have heaters? What is the temperature limit on heated experiments?
Web link	Website or contact information

Although several facilities were contacted as potential demonstration locations, only a few were able to meet the needs of the experiment. The few things considered important for this experiment are

- reactor type and instrumentation feedthrough/instrumentation installation,
- reactor power range and availability to change power, and
- availability to install furnaces with the instrument.

The information received from the facilities is shown in Table 2. The reactor facilities are ordered alphabetically in the table. The information in these tables was provided by the individuals running the facilities. The websites in the tables are for contact information only because most of the information is not available on the websites or in the user manuals. For the future, it is recommended that these facilities be contacted individually for updated information.

Table 2. Contacted reactor facilities and their capabilities

Specification	Advanced Test Reactor (ATR)[1]	High Flux Isotope Reactor (HFIR)[2]	HTTR (Japan)[3]	MIT Reactor (MITR)[4]
Management	Idaho National Laboratory	Oak Ridge National Laboratory	Japan Atomic Energy Agency	Massachusetts Institute of Technology
City, State	Idaho Falls, ID	Oak Ridge, TN	Oarai-machi, Japan	Cambridge, MA
Reactor type	Light water	Light water	High-temperature gas cooled	Heavy water reflected
Maximum thermal flux (x10^{14} n/cm^2·s)	NE/NW flux trap 4.4 Other flux traps 4.4 A-1 to A-8 1.9 A-9 to A-12 2.0 B-1 to B- 8 2.5 B-9 to B-12 1.1 H positions 1.9 Large I 0.17 Medium I 0.34 Small I 0.84	21	Standpipe hole 0.7 (< 2.38 eV) Basket in fuel block region 0.5	0.6
Maximum fast flux (x10^{14} n/cm^2·s)	NE/NW flux trap 2.2 (> 1 MeV) Other flux traps 0.97 A-1 to A-8 1.7 A-9 to A-12 2.3 B-1 to B- 8 2.3 B-9 to B-12 0.81 H positions 1.7 Large I 0.013 Medium I 0.013 Small I 0.032	11	Standpipe hole 0.2 (> 0.18 MeV) Basket in fuel block region 0.2	1.2
Coolant inlet temperature (°C)	52	50	395	42
Operating pressure (MPa)	2.5		4	0.1
Experiment facility diameter (mm)	NE/NW flux trap 133 Other flux traps 76 A-1 to A-8 40 A-9 to A-12 16 B-1 to B-18 22 B-9 to B-12 38 H positions 16 Large I 127 Medium I 89 Small I 38	16-69	I-type test train used in the past for material testing fits into a standpipe hole of 200 mm diameter. Graphite basket can replace a fuel block in the core and has a hole diameter of about 300 mm.	50.8
Experiment active length (mm)	1220	508	I-type test train specimen region has a length of 100 mm, but the hole in which the train is inserted runs the length of the core. (about 2,900 mm). The graphite basket has a length of 580 mm	560
Experiment cabling/wrack installation	Instrument leads exit through the top of a capsule. Cables run out of the vessel and into experiment cubicles below the reactor enclosure		Unknown. We would have to discuss reactor tech specs with JAEA.	MIT-NRL will work with users on electronics and cabling for lead-out experiments.
Typical operating fraction	75%	0.46	Currently shutdown; awaiting restart authorization from regulatory. Restart anticipated in 2019.	60%; operating 24/7; each cycle lasts 8-10 weeks. Can reduce cycle length as necessary.
Fuel restrictions	Nothing is explicitly forbidden. All items introduced into the core are subject to analysis of reactivity and thermo-mechanical performance to determine whether safety limits are challenged.		Likely. We would have to discuss with JAEA.	< 100 g U^{235}
Existing flow loops	Independent flow loops (InPile Tubes) are installed in 6 of the 9 flux traps.	Unknown	No	1 pressurized water loop. New loop can be designed and built to meet experiment specifications.
Existing salt facility	No, other than the usual tech spec limits.	Unknown	No	Yes
Hot cell capability	Yes, but most PIE is performed in the HFEF or FCF hot cells at the Materials and Fuels Complex down the road.	Unknown	On the Oarai site, probably.	2 full hot cells and 1 hot box with manipulators in reactor containment building.
Activity restrictions	See the ATR Users Guide.	Unknown	Unknown. We would have to discuss reactor tech specs with JAEA.	Activity restrictions are primarily determined for postirradiation handling. This is unlikely to be an issue for fission chambers/detectors.
High-temperature restrictions	Conditions in the loop experiments are independent of the primary coolant conditions that are specified during the experiment design phase (negotiations between User Requirements and ATR Engineering). For drop-in capsules (locations not in the loops), heating is by irradiation only; temperatures are controlled via capsule design (and regulation of insulating gas composition).	Unknown	The HTTR operates in the range suitable for testing this instrument.	Heaters are allowed for in-core and beam port irradiation facilities. The heater can be designed to meet experiment requirements.
Web link	https://nsuf.inl.gov/Home/PartnerFacility/652	https://neutrons.ornl.gov/hfir	https://httr.jaea.go.jp/eng/index.html	https://nrl.mit.edu/
Point of contact	Hans Gougar	Don Raby	Hiroyuki Sato	Lin-Wen Hu

Table 3. List of reactor facility and their capabilities (continued)

Specification	University of Missouri Research Reactor (MURR)[5]	The Ohio State University Research Reactor (OSURR)[6]	Penn. State Breazeale Nuclear Reactor (RSIC)[7]	VFTR
Management	University of Missouri	The Ohio State University	Penn. State University	
City, State	Columbia, MO	Columbus, OH	University Park, PA	
Reactor type	Tank	Pool	TRIGA	
Maximum thermal flux (x10^{14} n/cm²·s)	4	0.1	Up to 0.33 (central thimble)	
Maximum fast flux (x10^{14} n/cm²·s)	0.7	0.07	Up to 0.16 (central thimble)	
Coolant inlet temperature (°C)	50	n/a (dry facility)	25-35	
Operating pressure (MPa)	0.176 Mpa (25.5 psi at 25 feet underwater)	0.1	No pressure boundary; open pool reactor	
Experiment facility diameter (mm)	Depends on the experiment (willing to customize for collaborator needs)	10 in. dry tube; 7 in. dry tube, 2.4 in. dry tubes (2), 1.3 in. dry tube	Central thimble: 32 mm; other facilities are available up to 100 mm, with lower flux limits.	
Experiment active length (mm)	765	2 ft	N/A, fuel length is 380 mm (experiments > 75 mm will have nonuniform axial flux).	
Experiment cabling/wrack installation	Depends on the type, size, and space availability	30-35 ft of cabling to stand-alone equipment (e.g., we just installed at the top of the storage pool and did not have to conform to racks)	Experiments need to be reviewed for safety. Electronics must not interfere with reactor control system	
Typical operating fraction	Operates at 10 MW 24 hours per day and 6.5 days per week	On demand, first shift only	Reactor ops are on demand, typically 4-6 hours/day	
Fuel restrictions	Yes, depending on experiment	We do have a license limit for SNM on site.	NU and DU can be irradiated. Enriched uranium irradiations require a license amendment	
Existing flow loops	No, depending on experiment	No built-in flow loops. No restrictions, but approval of the Reactor Oversight Committee might be required.	There are no built-in flow loops, although one can be installed	
Existing salt facility	No, depending on experiment	No built-in salt loops. No restrictions, but approval of the Reactor Oversight Committee might be required.	There are no built-in salt loops, although one can be installed	
Hot cell capability	Yes	No	Yes	
Activity restrictions	Determined by Safety Analysis and Health Physics	No specific limit for what we activate using the reactor, but we are limited in what doses we can safely handle.	See user note below.[a]	
High-temperature restrictions	No heaters exist. Heaters and limits would depend on experiment.	Heaters are allowed, but we do not have any for use. The limit would be a maximum temperature on the facility tube wall.	There is no specific limit on heated experiments. However, experiments must be reviewed to ensure that fuel temperature limits will not be exceeded. The maximum heater power would be heavily dependent on experiment location relative to the fuel.	
Web link	http://www.murr.missouri.edu/operations.php	https://reactor.osu.edu/	www.rsec.psu.edu	
Point of Contact	Rob Hall	Andrew Kauffman	Jeffery Geotherm	Sacit Centiner

[a]*User Note 1:*
From user guide:
e. Experiment materials, except fuel materials, which could off-gas, sublime, volatilize, or produce aerosols under (1) normal operating conditions of the experiment and reactor, (2) credible accident conditions in the reactor, or (3) possible accident conditions in the experiment, SHALL be limited in activity such that the airborne concentration of radioactivity averaged over a year SHALL NOT exceed the limit of Appendix B Table 2 of 10 CFR Part 20.

When calculating activity limits, the following assumptions will be used:

1) If an experiment fails and releases radioactive gases or aerosols to the reactor bay or atmosphere, 100% of the gases or aerosols escape.
2) If the effluent from an experimental facility exhausts through a holdup tank which closes automatically on high radiation level, at least 10% of the gaseous activity or aerosols produced will escape.
3) If the effluent from an experimental facility exhausts through a filter installation designed for greater than 99% efficiency for 0.3 micron particles, at least 10% of these vapors can escape.
4) For materials whose boiling point is above 130˚F and where vapors formed by boiling this material can escape only through an undisturbed column of water above the core, at least 10% of these vapors can escape.

f. Each fueled experiment SHALL be controlled such that the total inventory of iodine isotopes 131 through 135 in the experiment is no greater than 1.5 curies. In addition, any fueled experiment which would generate an inventory of more than 5 millicuries (mCi) of I-131 through I-135 SHALL be reviewed to ensure that in the case of an accident, the total release of iodine will not exceed that postulated for the MHA (see Safety Analysis Report, Chapter 13).

3. CONCLUSIONS

This document describes possible demonstration facilities for testing of the HTFC. Each facility was contacted to help build a table of facility capabilities. This data is subject to change in the future as the facilities are updated and their capabilities are modified. After review of the tables, only a select few facilities were identified that will fit the demonstrate needs of the HTFC. Discussion of future testing of the HTFC is under way.

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