Heat Transfer

Objective

- Heat transfer in a microreactor overcomes unique challenges due to the compact footprint, radiation field, transportability, and high temperatures present.
- High temperature operation preferred to give higher power production efficiencies.
- Novel concepts explored to transport heat and dampen transients affecting structural integrity and performance of core structures/components.
- Research/testing of nonnuclear components helps increase our understanding of system performance.
- Feasible heat pipe and gas-cooled components plus heat exchanger and power conversion units can be integrated for non-nuclear testing easier than in nuclear demonstrations.
- Techniques for fabricating test articles with these features will also be developed and demonstrated.

MRP Microreactor Program

37 Heat Pipe Test Article

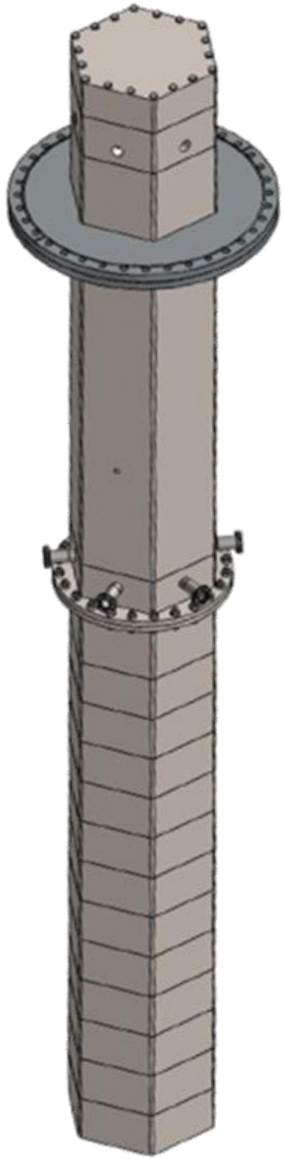
March 3, 2022

Bob Reid, Lindsey Gaspar, Michael Middlemas, and Katrina Sweetland

INL Idaho National Laboratory
OAK RIDGE National Laboratory
MRP Microreactor Program
Los Alamos NATIONAL LABORATORY
Argonne NATIONAL LABORATORY

Presentation Outline

- Overview
- eBlock37
- eXchanger37 Subassembly
- Core37 Subassembly
- eWick37
- eFill37 Subassembly
- eFill37 Charge Subassembly
- eFill37 Laser Weld Subassembly
- Facility Upgrades
- Ongoing and Future Work

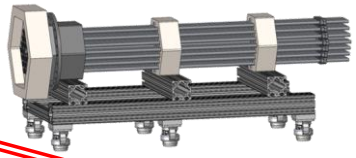


MRP Microreactor Program

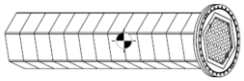
eBlock37 Build

gCart37

Handling Cart

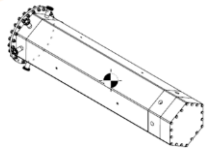


Core37
US DOE S133,464

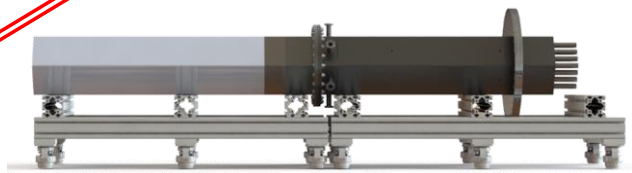


Monolithic
Reactor Core
Block

eXchanger37
US DOE S133,464

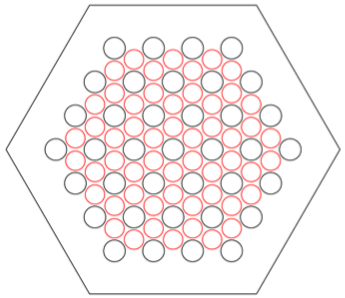


Monolithic
Heat Pipe to
Gas Heat Exchanger

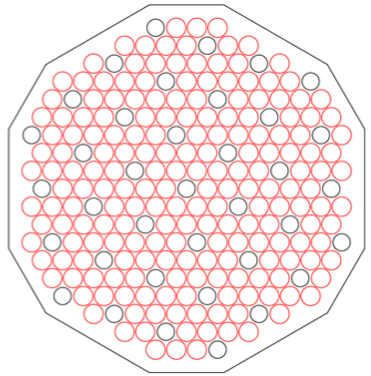


eWick37 (NQA-1)
US DOE S133,680

Mass Produced
NQA-1 Quality
High Capacity
Heat Pipe Wicks



Thermal Hydraulic
Similarity



Nuclear Similarity
(criticality)

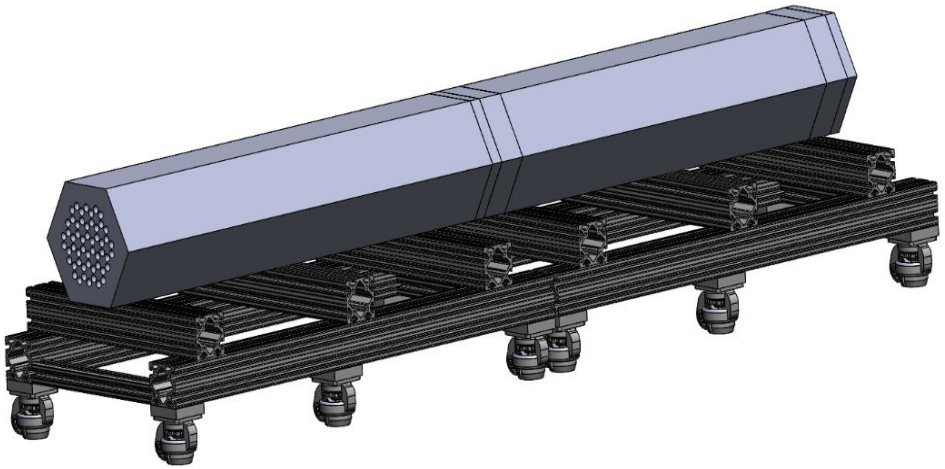
eFill37
US DOE S133,662

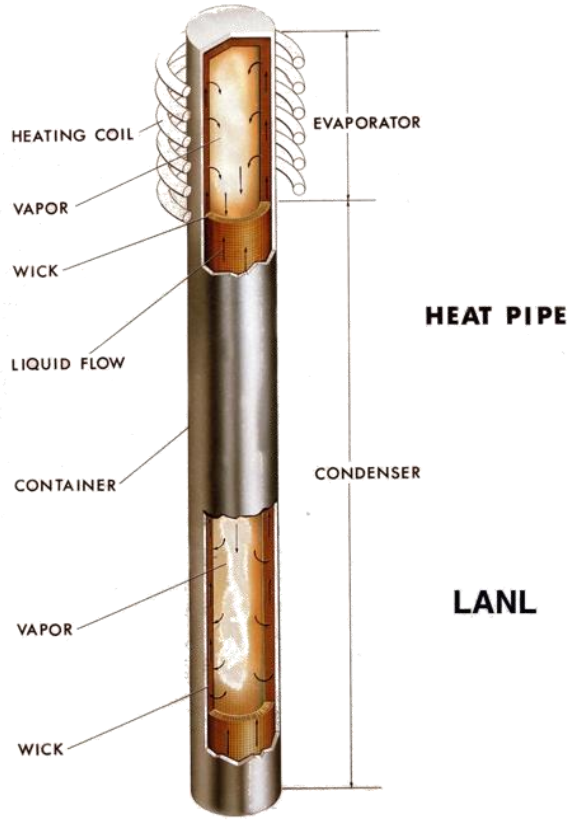
Mass Produced
High Purity
Heat Pipe Fill
And Seal

MRP Microreactor Program

Overview

- Design and fabricate a sub-scale, electrically heated and heat-pipe-cooled prototype of a fast spectrum microreactor
- Testing will be conducted at Idaho National Laboratory MAGNET facility
- Fuel rods will be simulated with cartridge heaters and combined heat pipe/heat exchanger article

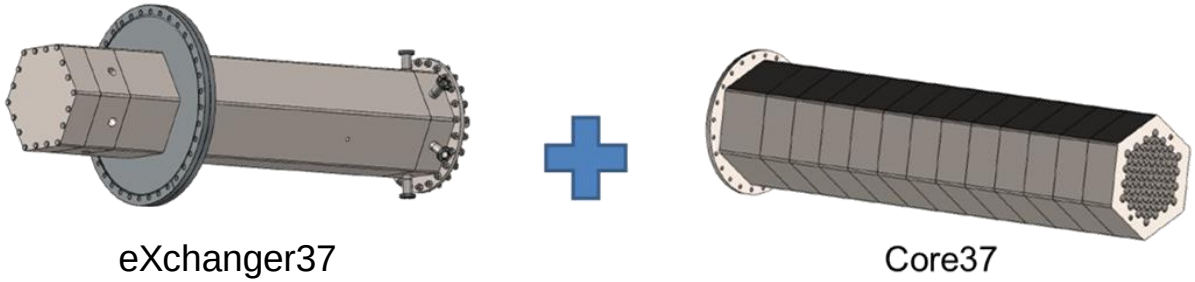




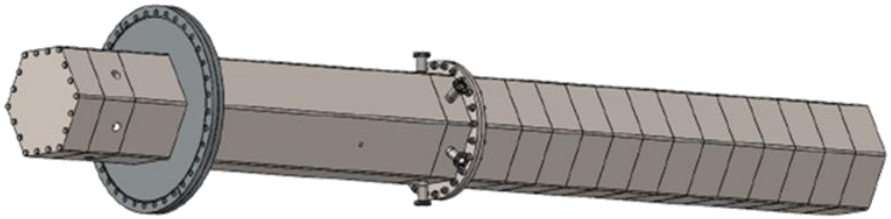
MRP Microreactor Program

eBlock37

- The eBlock37 is a sub-scale, electrically heated and heat-pipe cooled prototype of a fast spectrum microreactor.
- Comprised of a gas-cooled heat exchanger (eXchanger37) and electrically-heated and heat-pipe cooled core (Core37),
- Subassemblies built from stainless steel 316L and thermally linked by and array of 37 sodium heat pipes
- Heat pipes transfer nominal 100 kW from the core at 700°C



eXchanger37 Core37

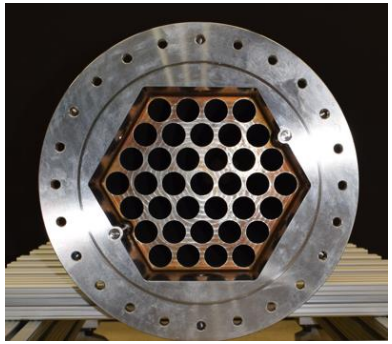


eBlock37

MRP Microreactor Program

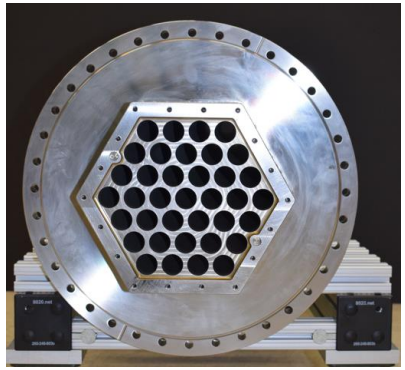
eXchanger37 Subassembly

- Consists of a main body containing axial holes through which the heat-pipe array passes
- Flange on evaporator end links to Core37 Subassembly
- Flange on the condenser end links to the eFill37 and can be removed following heat-pipe fill operations
- Assembly completed CY21



Evaporator End

eXchanger on gCart

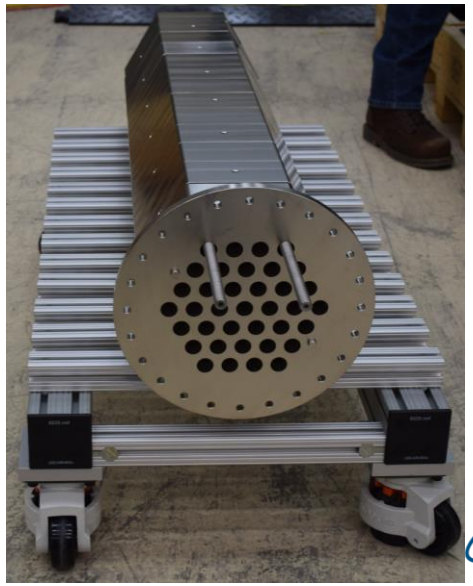


Condenser End

MRP Microreactor Program

Core37 Subassembly

- Consists of 13 segments that will be diffusion bonded together
- Flange on the end links to the eXchanger37 Subassembly
- All 13 segments have been manufactured for full-scale core
- Alignment pins pressed into each segment to ensure alignment during bonding
- Segments packaged for shipment to Bodycote facility for diffusion bonding



MRP Microreactor Program

Core37 Subassembly – Bonding Trials

- Diffusion bonding trials conducted on sub-scale, unit
  - Robust bond, but asperity closure incomplete due to pressure relaxation after initial asperity crush
  - Mismatch in Arrhenius diffusion rate and thermal diffusion rate believed to have resulted in uneven contact
  - Testing of alternate method currently being pursued
- Full-scale core bonding to be performed following assessment of new bonding parameter performance

MRP Microreactor Program

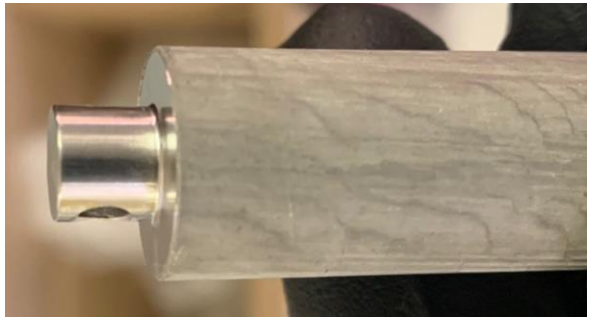
eWick37

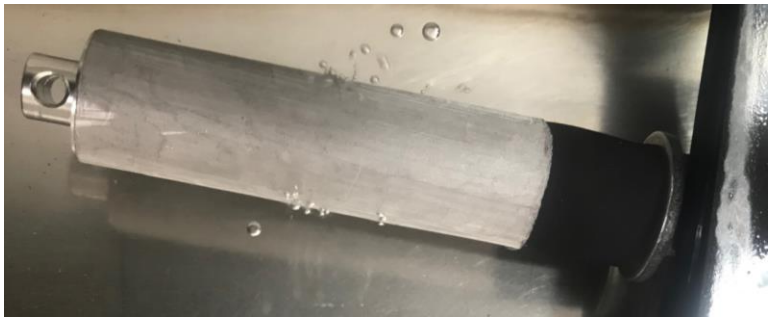
- Ultimate Hydroforming, Inc. (UHI) is fabricating and completing a scaled-up production of LANL eWick37
  - Nadcap accredited
  - AS ISO 9001:2015 9100D registered
  - Fully validated and controlled process for wick manufacture consistent with NQA-1 quality standards
- A total of 54 stainless steel wicks are being produced
- Wicks required to be suitable for producing a minimum axial heat transfer rate of 2.7 kW at 1000 K

MRP Microreactor Program

eWick – Fabrication Process

7. Bubble point testing used to determine pore distribution and size
8. Steel plug bonded to end of wick
9. Repeat bubble point test with plug installed

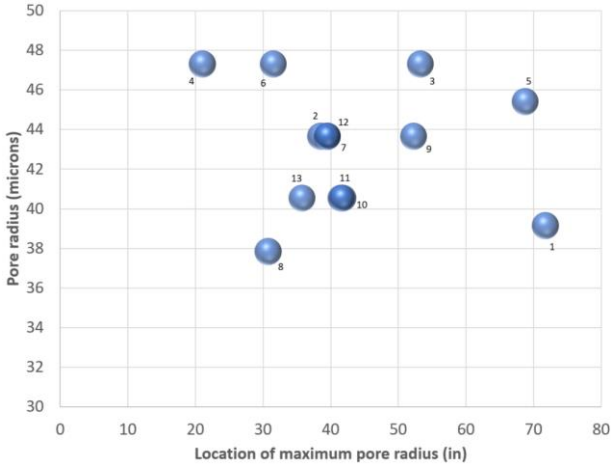




MRP Microreactor Program

eWick37 – Status

- Wicks produced to date have consistently been manufactured with < 50 micron effective pore radius
  - Suitable for axial heat transfer rates of at least 8.0 kW at 1000 K with selected heat pipe design and materials (2.7 kW maximum test article requirement)
  - 13 assemblies completed through bubble point testing (1/22)
  - 22 assemblies in copper tubes and are being sized (1/22)
  - Remaining screen material will be cleaned and assembled once copper has been etched away from remaining assemblies



MRP Microreactor Program

eFill37 Subassembly

- The eFill37 is a scalable heat pipe charging and sealing apparatus developed with the intent of easing and automating the manufacture of heat-pipe-cooled microreactors
- Interfaces directly with eBlock37 via vacuum flange, providing inert gas or vacuum conditions to mitigate hazards associated with alkali metal handling and prevent contamination
- Theta-theta stage manipulation enables access to every heat pipe in the array

MRP Microreactor Program

eFill37 Subassembly

- eFill37 uses multiple configurations for completing distinct steps of the manufacturing process
  - Charging
  - Plug insertion
  - Sealing
- Fill system represents a significant departure from earlier approaches for alkali metal heat pipe fill methods that only allowed for fill of a limited number of heat pipes at a time

MRP Microreactor Program

eFill37 Charge Subassembly

- eFill37 charge subassembly sits atop the eFill37 rotating stages, enabling transfer of high-purity sodium into each heat pipe
- Gate valves linking the eFill37 with the charge subassembly help maintain vacuum environment during filling operations and allow for changing out subassemblies for subsequent process steps
- A vertical lifting column and expandable bellows provides method of fill stem insertion

MRP Microreactor Program

eFill37 Laser Weld Configuration

- eFill37 laser weld subassembly sits atop the eFill37 rotating stages, enabling sealing of the heat pipe array after fill
- Gate valves linking the eFill37 with the laser weld subassembly help maintain inert environment (0.1 mbar helium) during sealing operations

- Custom bellows attaches to the laser head on one end and chamber viewport window on the other, creating a light-tight environment through which the laser beam travels
- Full-beam enclosure allows system to be treated as Class 1 laser system

MRP Microreactor Program

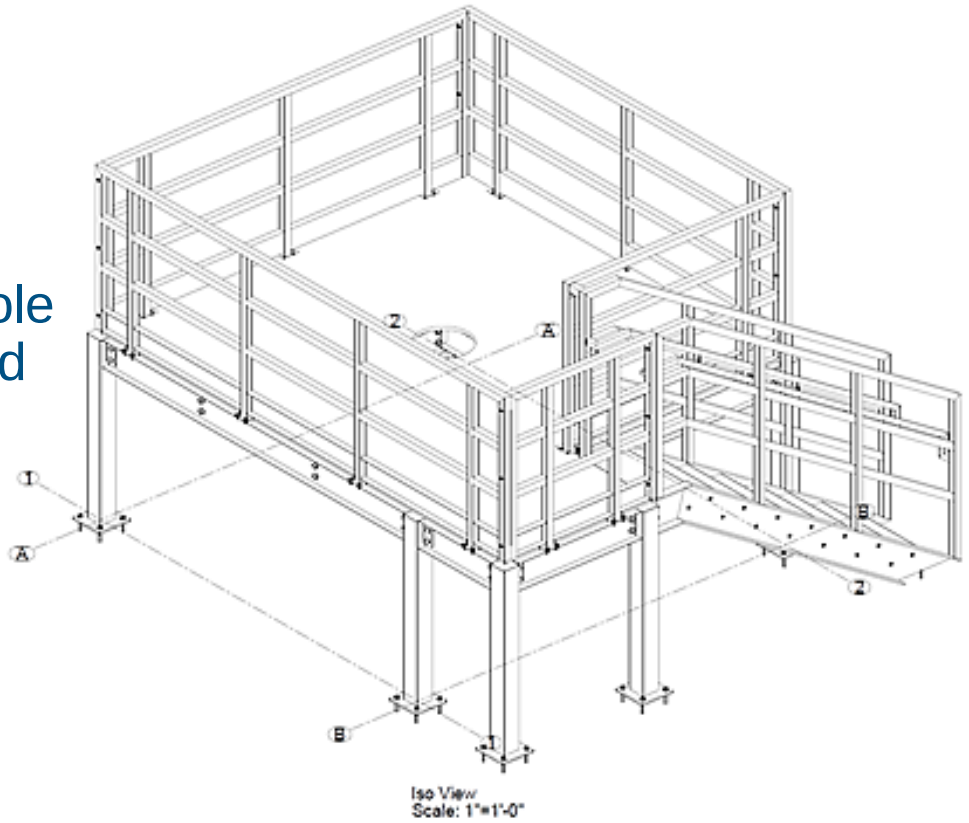
eFill37 Laser Weld Configuration

- Support stand allows for x and y-coordinate positioning, while linear motion stage enables more precise vertical positioning to account for design tolerances
- IPG Photonics YLS-4000 laser and D50 wobble head will be used for weld operations
- All necessary components have been purchased

MRP Microreactor Program

Facility Upgrades

- A mezzanine has been designed to facilitate heat-pipe filling operations using the eFill37
- Penetrating radar has been used to survey floor of installation area for footings
- eBlock37 will be placed through a centrally located hole in the mezzanine and secured to the floor and



MRP Microreactor Program

Ongoing and Future Work

- Core37
  - Diffusion bonding of sub-scale core to verify new bonding parameters
  - Diffusion bonding of full-scale Core37
  - Weld heat-pipe tubing to Core37
- eWick37
  - Complete wick fabrication
- eFill37
  - Assemble plug and laser weld configuration subassemblies
  - Laser installation
- Facility Upgrades
  - Procure and install mezzanine
- Insert wicks; fill article with sodium and weld shut.
- Ship to INL for non-nuclear demonstration.

MRP Microreactor Program