Kairos Power

An Overview of Kairos Power and Qualification Programs

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Kairos Power's mission is to enable the world's transition to clean energy, with the ultimate goal of dramatically improving people's quality of life while protecting the environment.

In order to achieve this mission, we must prioritize our efforts to focus on a clean energy technology that is *affordable* and *safe*.

Biography

Ryan Latta

- Principal Engineer - Fuel Qualification
- Expertise
  - Fuel element irradiation and laboratory tests
  - Finite element-based fuel performance models
- Purdue University
  - Masters in Nuclear Engineering

Kairos Power

Overview of Kairos Power

Overview of Kairos Power

- Nuclear energy engineering and design company **singularly focused** on the commercialization of the fluoride salt-cooled high temperature reactor (FHR)
  - Founded in 2016
  - Current Staffing
    - >270 Employees
    - ~90% Engineering Staff
- Private funding commitment to engineering design and licensing program and physical demonstration through nuclear and non-nuclear technology development program
- Schedule driven by US demonstration by 2030 (**or earlier**) and rapid deployment ramp in 2030s
- Cost targets set to be competitive with natural gas in the US electricity market

Kairos Power Headquarters

Kairos Power Team

Kairos Power Locations

HQ / R-Lab / S-Lab
Alameda, CA

T-Facility / Engineering Test Unit
Production Development Facility
Albuquerque, NM

Kairos Power | MATERION

Molten Salt Pilot Plant
Elmore, OH

Hermes Reactor
Oak Ridge, TN

Licensing Office
Charlotte, NC

Kairos Power Facilities

- **RAPID Lab**
- **Salt Lab**
- **Testing Facility**

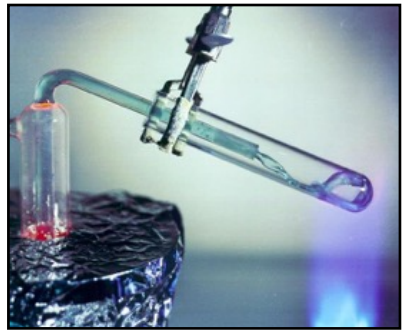
Kairos Power is Uniquely Suited to Supply the Nuclear Technology to Replace U.S. Natural Gas Capacity

- **Robust Inherent Safety**
  - Uniquely large ***fuel temperature margins***
  - Absorption of fission products in primary coolant
  - Low-pressure system
  - Effective passive decay heat removal
- **Lower Capital Costs**
  - Reduce requirements for high-cost, nuclear-grade components and ***structures*** through FHR intrinsic safety and plant architecture
  - Leverage conventional materials, existing industrial equipment, and conventional fabrication and construction methods

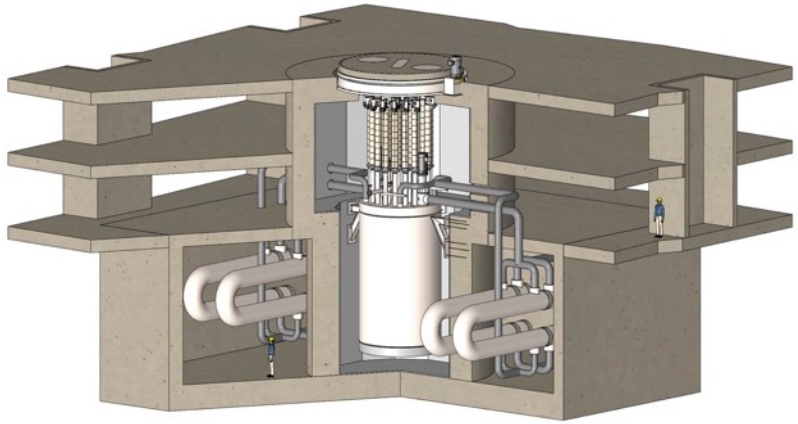
Technology Basis

Coated Particle Fuel
TRISO

Liquid Fluoride Salt Coolant
Flibe ($2LiF\text{-}BeF_2$)

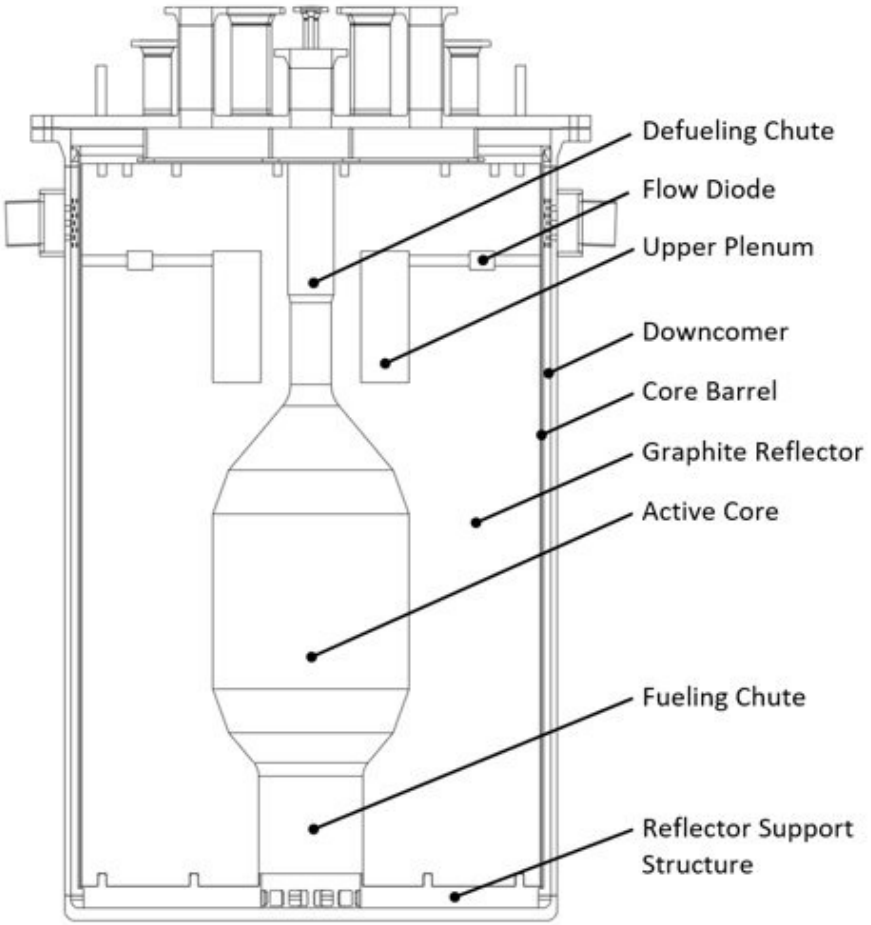


Kairos Power Reactor Nuclear Island



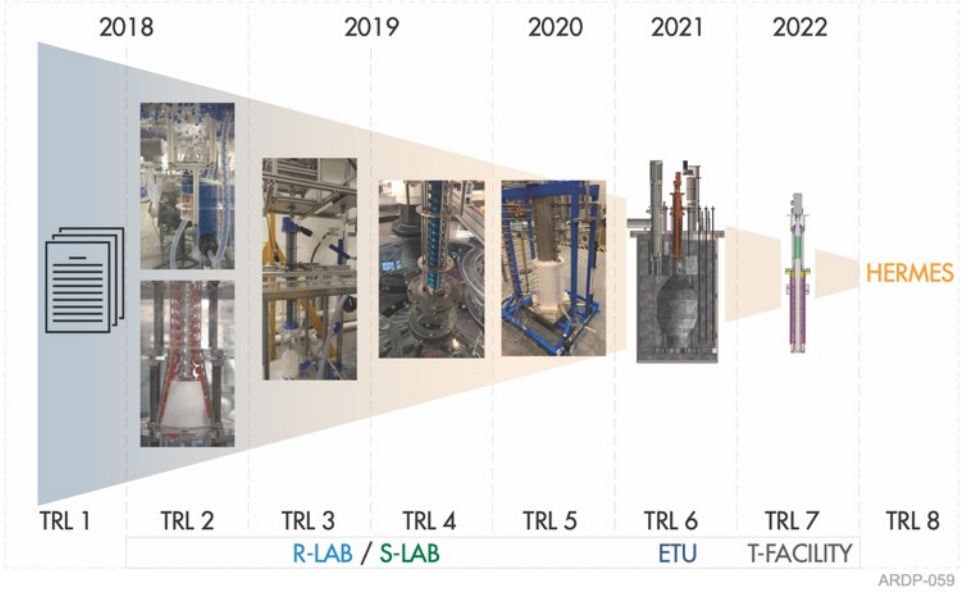
KP-FHR Overview

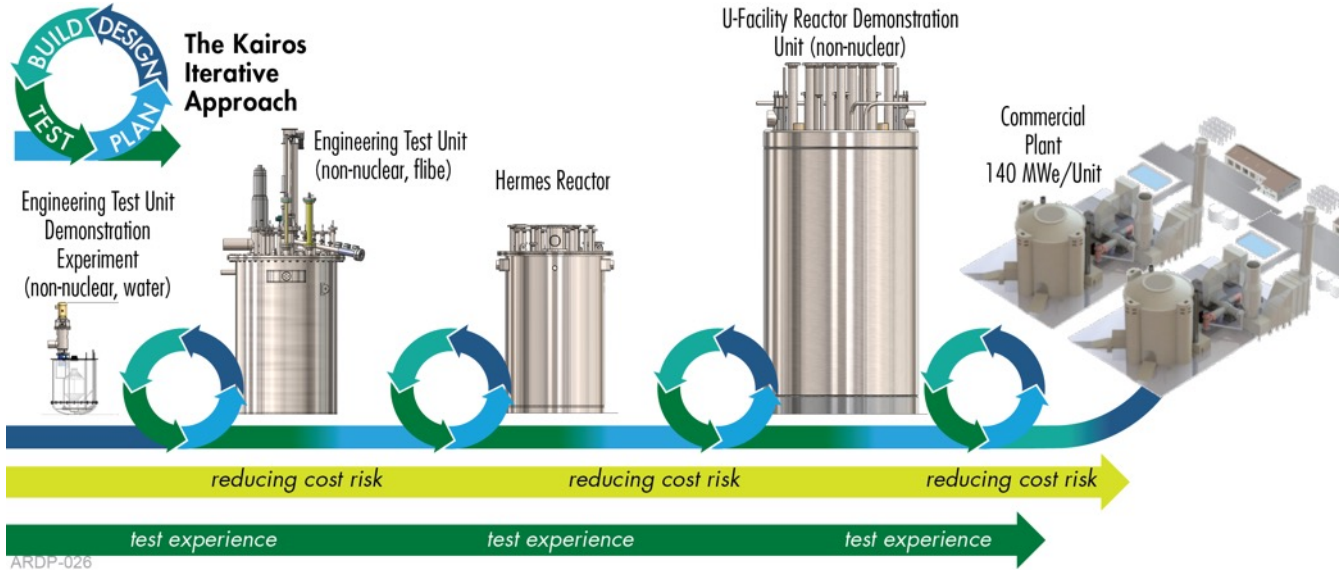
Parameter	Description / Value	
Reactor Type	Hermes	KP-X
Reactor Type	Non-Power Test Reactor	Commercial Electric Power Reactor
Reactor Vessel Size	3 m dia., 4.4 m ht.	4 m dia., 6 m ht.
Reactor Thermal / Electric Power	35 MWth / N/A	320 MWth / 140 MWe
Reactor Operating Pressure	<0.2 MPa	<0.2 MPa
Core Inlet / Outlet Temperature	550°C / 650°C	550°C / 650°C



Kairos Power Design Approach

- Kairos Power believes **“hardware is worth 1000 calculations”** and ETU will be the proof case for this philosophy since it integrates all the major systems of Hermes in a non-nuclear environment
- Our iterative strategy is supported by capabilities in Material Testing, Tritium Testing, Chemistry Control, Mod/Sim, Core Design and Neutronics, and Instrumentation and Controls





Fuel Qualification

Licensing Strategy

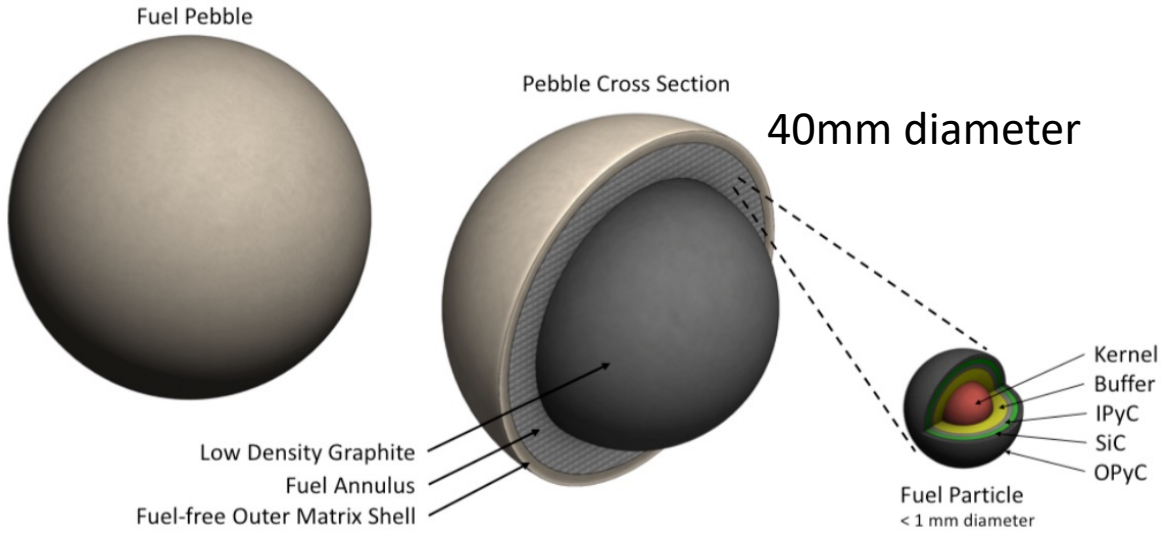
- Reduce licensing risk with early and continued engagement with NRC
- Topical Reports
  - 11 Topical Reports – Fuel, Materials, Source term, QA, etc.
  - 7 Approvals
  - 1 Draft approvals
  - 3 Under final review

KP Fuel Qualification Methodology

- Fuel qualification is focused on the annular fuel pebble form meeting functional requirements
- The DOE AGR program is the foundation for qualification of TRISO fuel particles
  - NRC safety evaluation of EPRI TRISO topical report on AGR tests
  - No irradiation testing if operating within the envelope AGR test data

Parameter	Hermes Non-Power Test Reactor	AGR-1 2009 AGR-2 2013
Particles per Pebble/Compact	~16,000	4,100 / 3,200
Peak Particle Power (mW)	155	104 / 155
Burnup (%FIMA)	~6	19.6 / 13.2
Peak Fuel Time Average Temperature (°C)	<830	800 - 1200 / 850 - 1350

Annular Fuel Pebble



Fuel Qualification Program

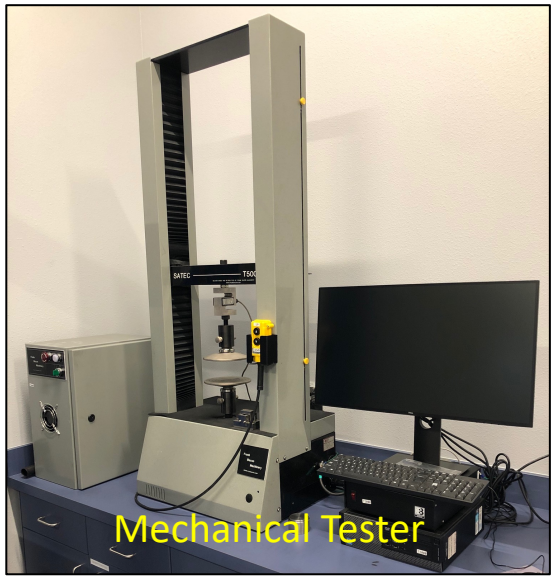
- Fuel Pebble Laboratory Test Program demonstrates that annular fuel pebbles meets functional requirements
- Mechanical
  - Compression
  - Impact
  - Tribology
  - Molten Salt Infiltration
- Material Compatibility
  - Pebble with Flibe
  - Pebble with Air

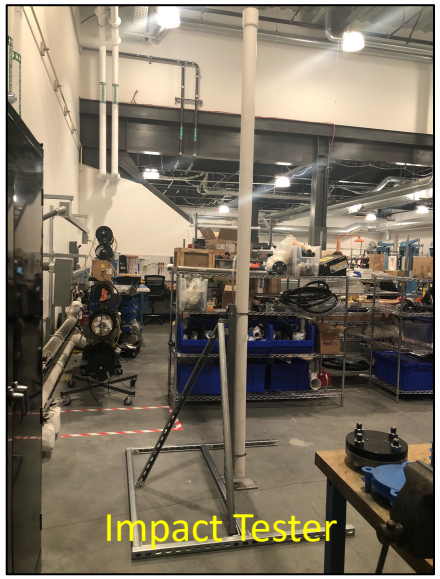
Hermes Fuel Surveillance – Fuel performance confirmation

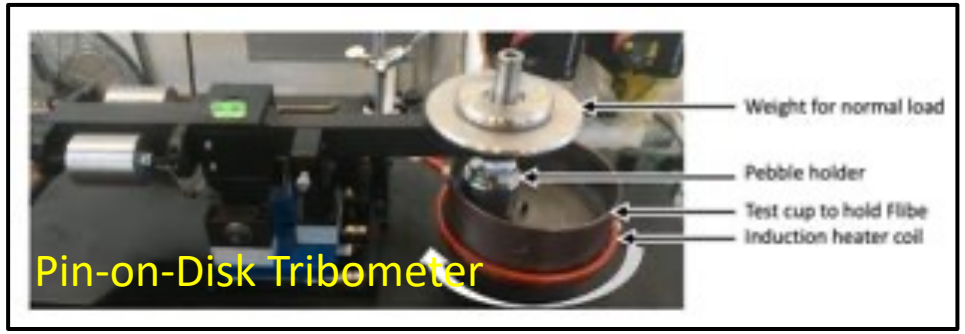
- Fission product monitoring during normal operation
- Pebble inspection in the pebble handling and storage system (PHSS)
- Post irradiation examination (PIE) in a hot cell facility

Mechanical Tests

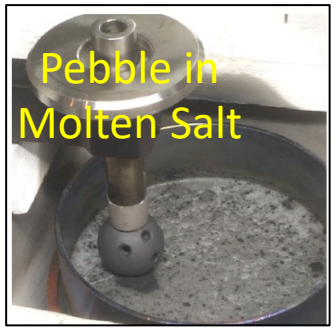
- Demonstrate pebbles do not fracture from static and dynamic loads in the reactor and wear behavior
- Compression test
  - Compression Test (Crush Test)
  - Pebble is loaded in compression until failure
- Impact test
  - Pebble fracture under cyclic impacts
- Tribology
  - Wear rate and coefficient of friction


Mechanical Tester


Impact Tester



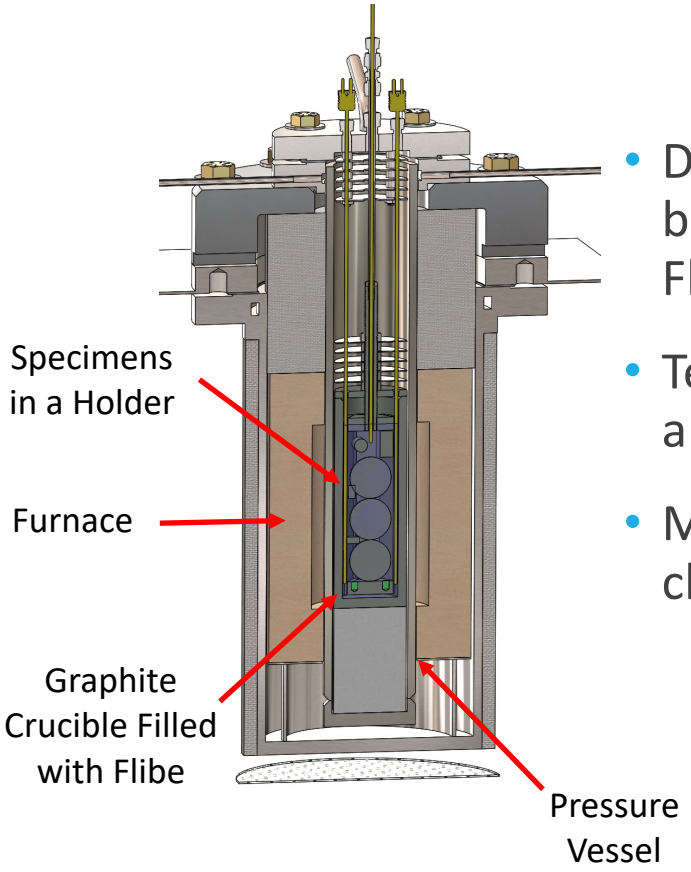
Pin-on-Disk Tribometer


Pebble in Molten Salt


Crush Tested Pebbles

Material Compatibility and Molten Salt Infiltration (MSI) Tests

MSI Test Device



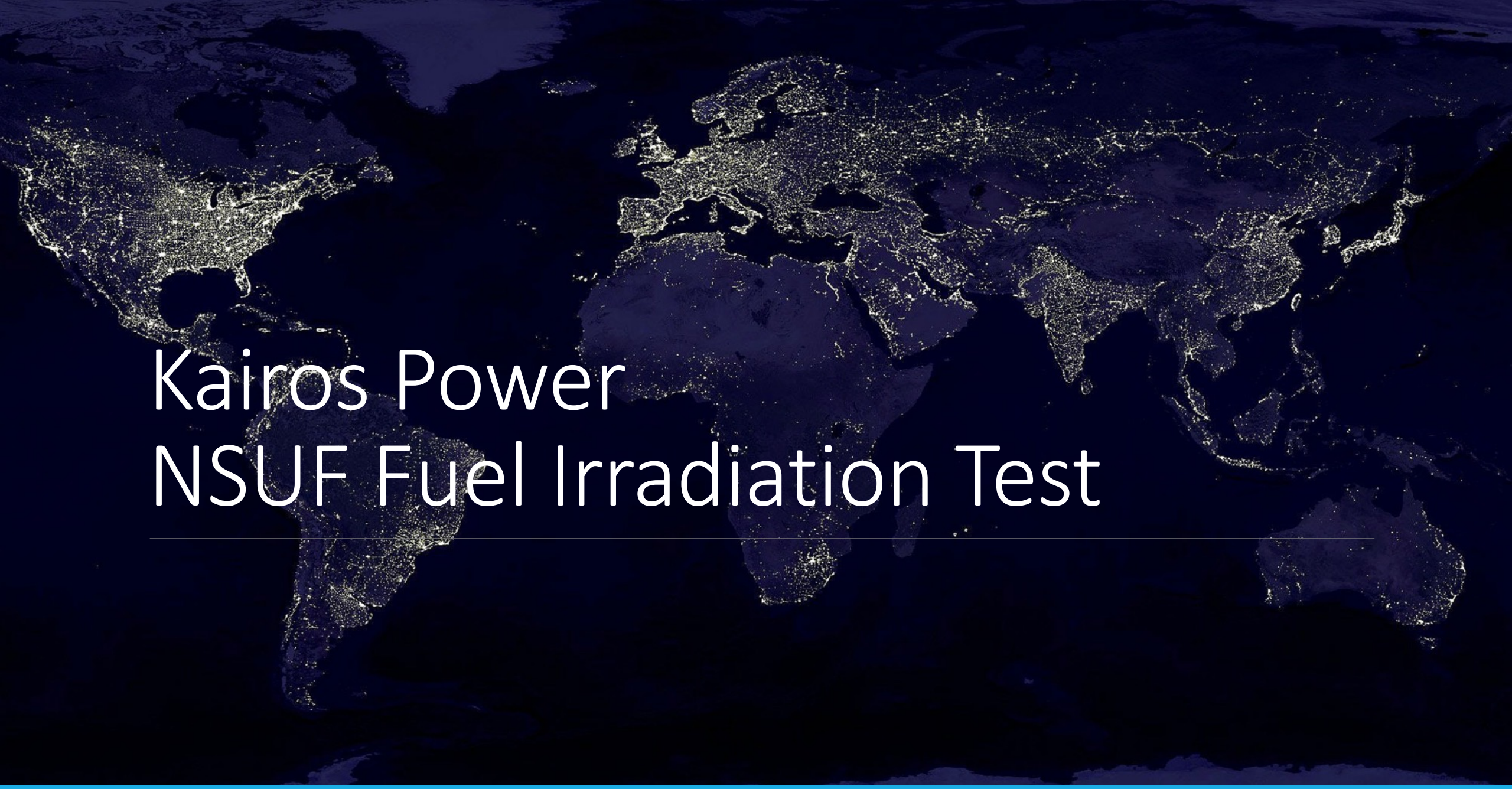
- Demonstrate pebbles are buoyant and compatible with Flibe
- Test temperature up to 900°C and pressure up to 500 kPa
- Measurement of weight change

Vertical Furnace for Oxidation Tests

- Demonstrate oxidation rate behavior of pebbles
- Oxidation tests in the temperature range 450-700C
- Measurement of mass loss with time to create an Arrhenius correlation

Hermes Fuel Surveillance

- Fuel surveillance in Hermes confirms fuel performance
- Fission Product Monitoring
  - Cover gas
  - Flibe coolant
- PHSS Pebble Inspection System
- Post Irradiation Examination
  - TRISO particle failure fraction
  - Pebble surface wear
  - Molten salt infiltration



Kairos Power
NSUF Fuel Irradiation Test

Kairos Power NSUF Project
HFIR Irradiation of TRISO Fuel at High Powers

- Investigate fuel performance of TRISO fuel particles at powers considerably greater than the DOE AGR irradiation tests to demonstrate significant margin.
- Project award ~$3M over 5 years
- Timeline
  - Test Design/Fabrication 10/19 – 6/21
  - Irradiation 6/21 – 1/21
  - PIE 6/22 - 2024

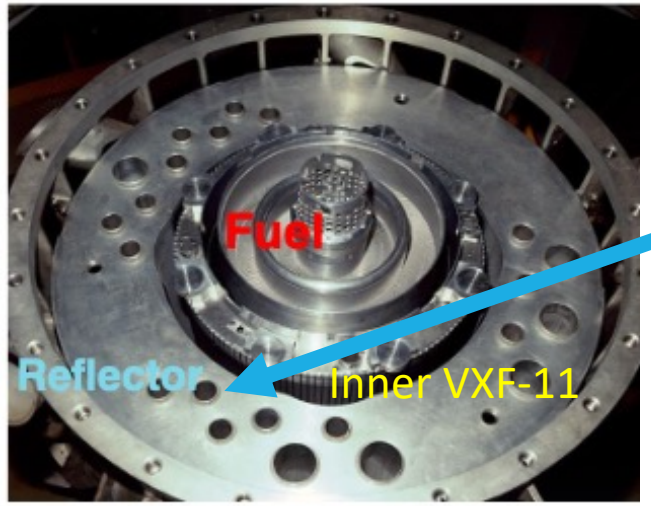
Project Reports

Characterization of Minifuel Compacts
ORNL/TM-2021/5 January 2021

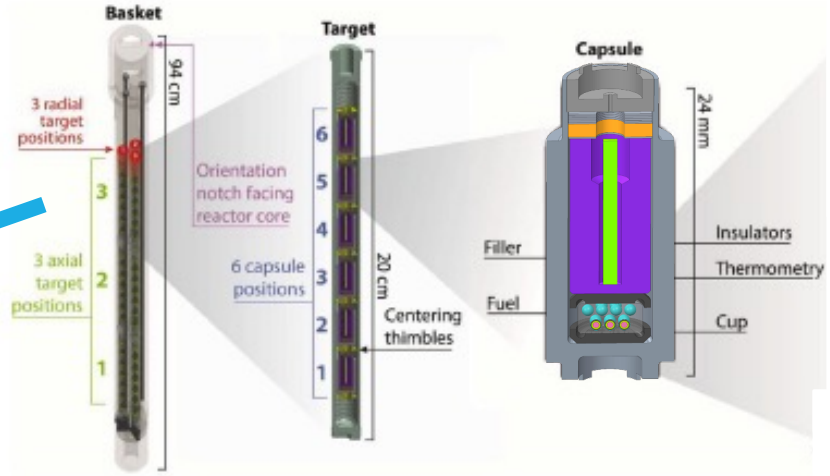
HFIR Irradiation Test Design
ORNL/TM-2020/1658 June 2021

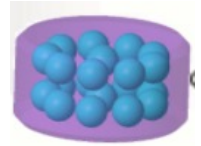
Assembly of Irradiation Targets
ORNL/TM-2021/2057 July 2021

HFIR Core at ORNL



ORNL MiniFuel Test



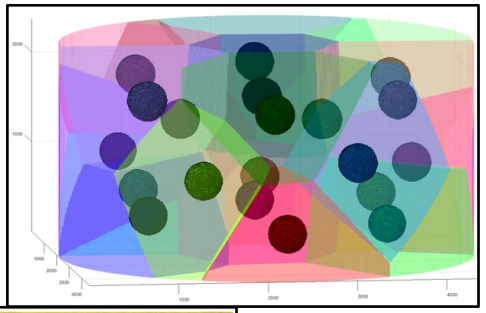


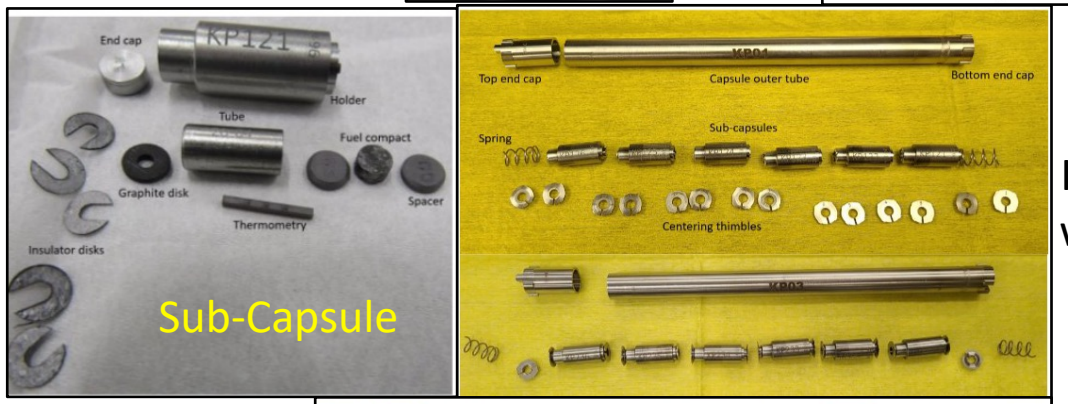
Irradiation Test in HFIR at ORNL

- Miniature fuel compacts
  - 20 TRISO particles in a 4.6mm dia. x 2.3mm ht. carbon matrix compact
  - Kernel types – UCO, Natural UCO, UO_2
- Capsules
  - 30 sub-capsules in 5 irradiation targets
- Irradiation
  - Power 80-1050 mW/particle
  - Burnup up to 12 %FIMA in 96 days
  - SiC layer temperatures - 500°C, 700°C, 900°C

MiniFuel Compact

MFC X-ray Tomography



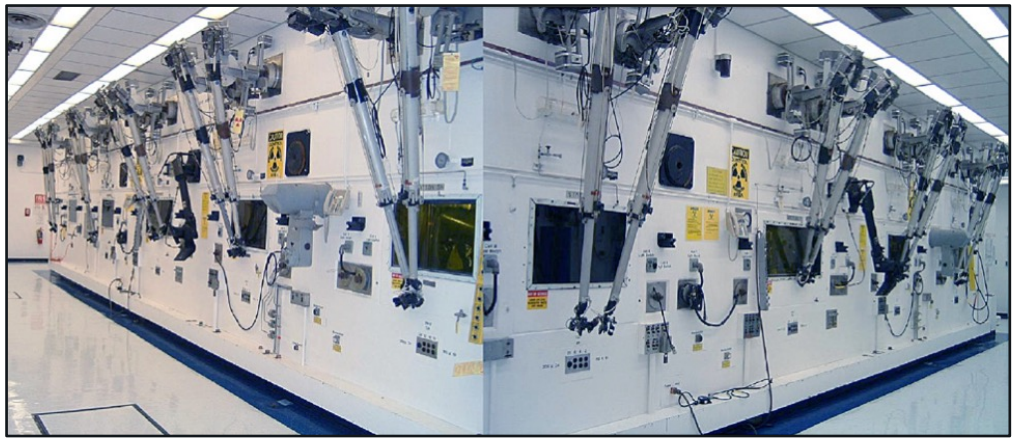


Irradiation Targets with Sub-Capsules

Basket Assembly with Irradiation Targets

Post Irradiation Examination (PIE)

- ORNL Building 3525 Hot Cells
- Non-Destructive
  - Sub-capsule Gas Puncture
  - Gamma Scan
- Destructive
  - Deconsolidation Leach Burn Leach (DLBL)
  - Irradiated Microsphere Gamma Analyzer (IMGA)
  - X-ray Tomography
  - SEM/EDS



3525 Hot Cells

IMGA

Graphite Qualification

ET-10 Graphite Qualification Program

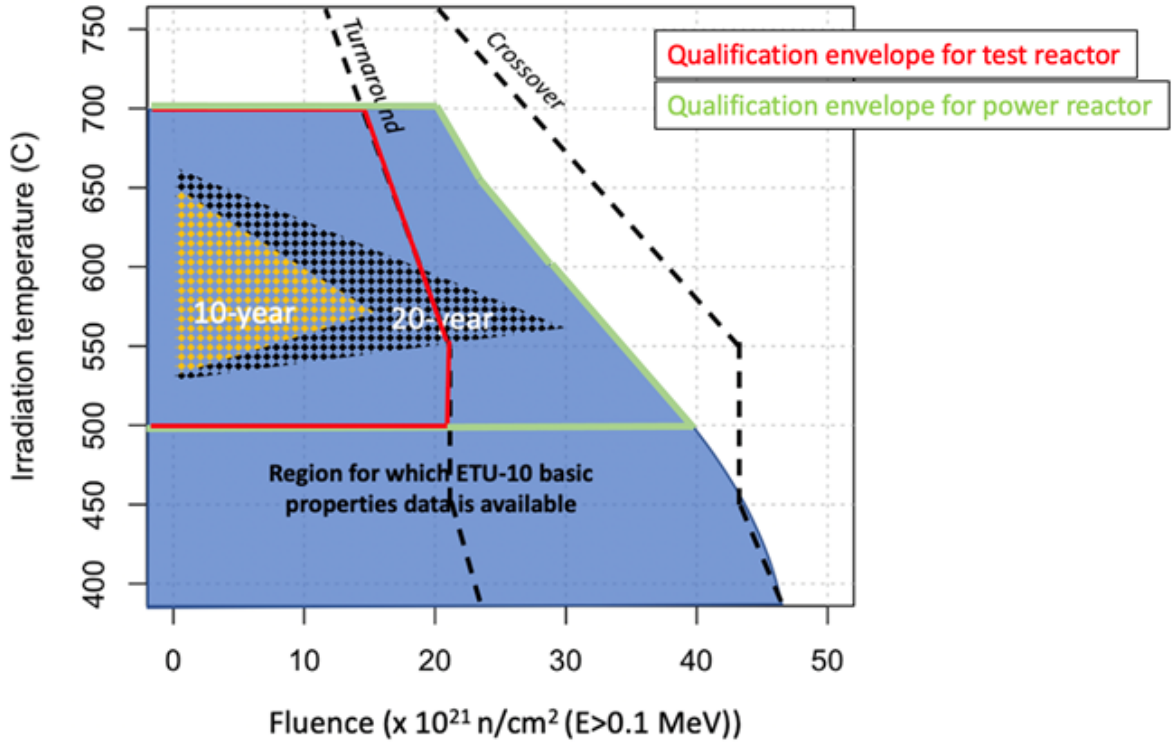
Kairos will pursue an irradiation test program to supplement existing data

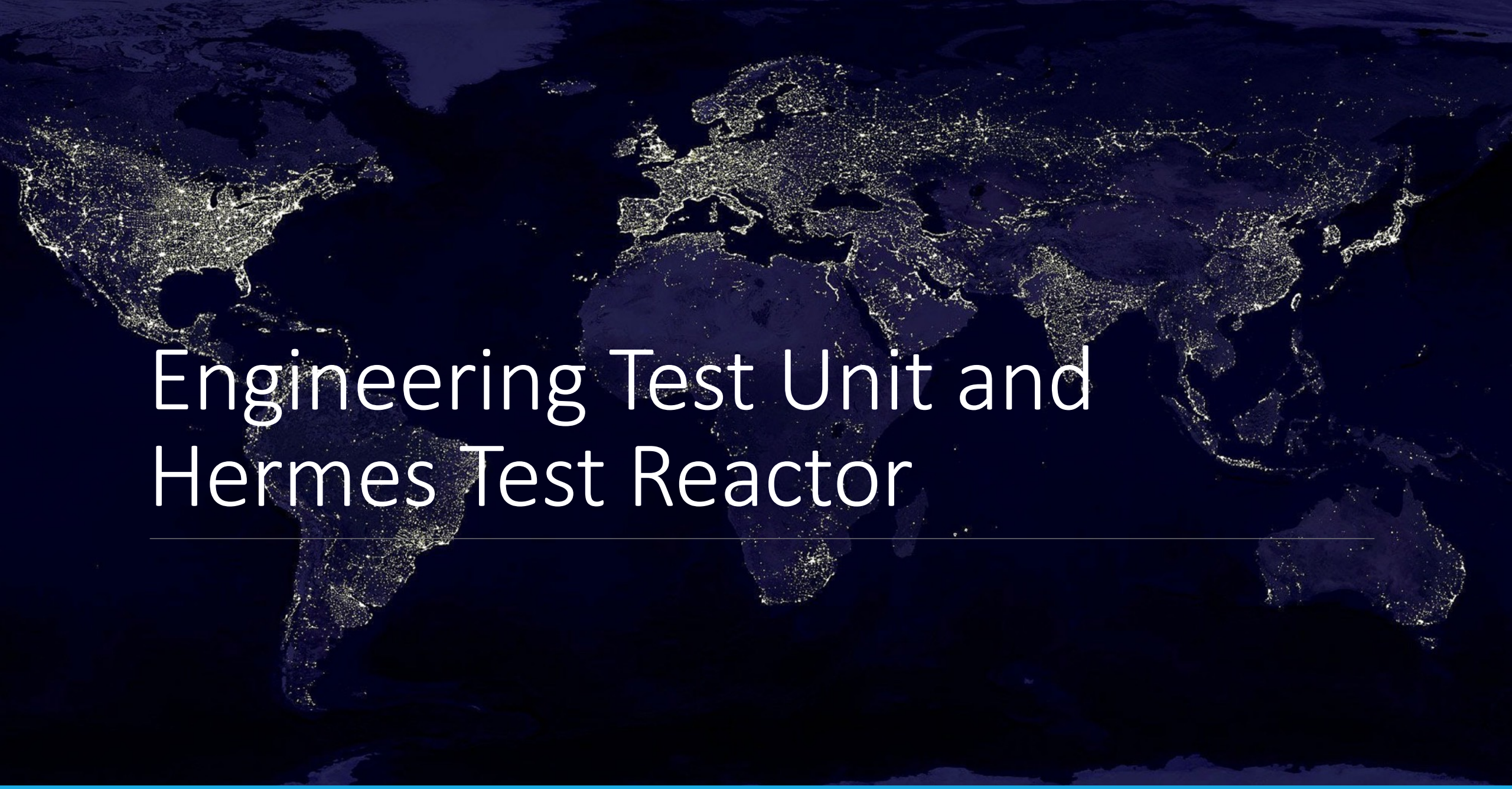
Hermes

- Graphite end-of-life is generally between turnaround and crossover for swelling behavior
- No irradiation test for pre-turnaround graphite life (<10y)

KP-X

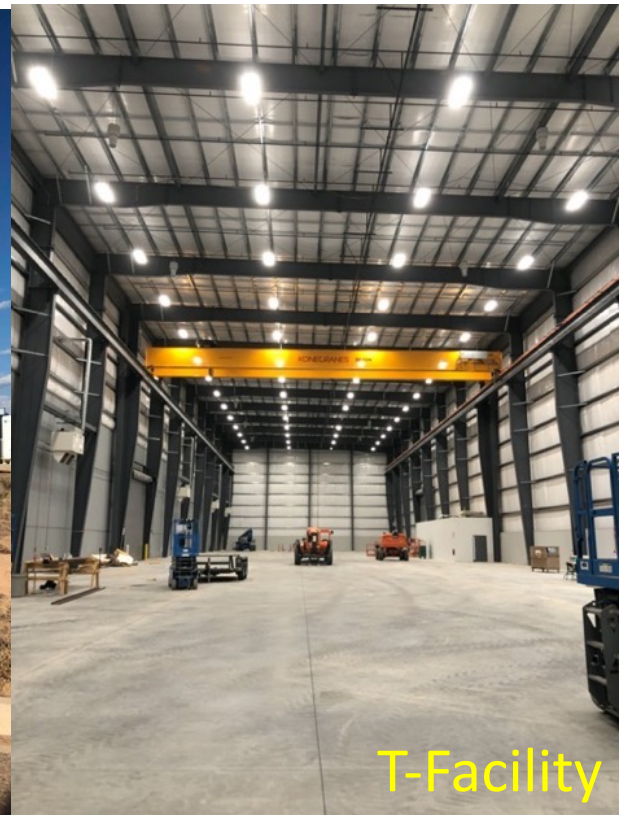
- Irradiation test for post-turnaround fluence (>10y)
- Irradiation creep test at a range of fluence, temperature, and stress

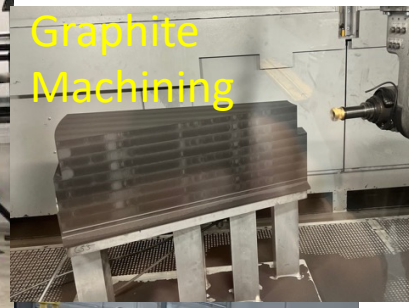


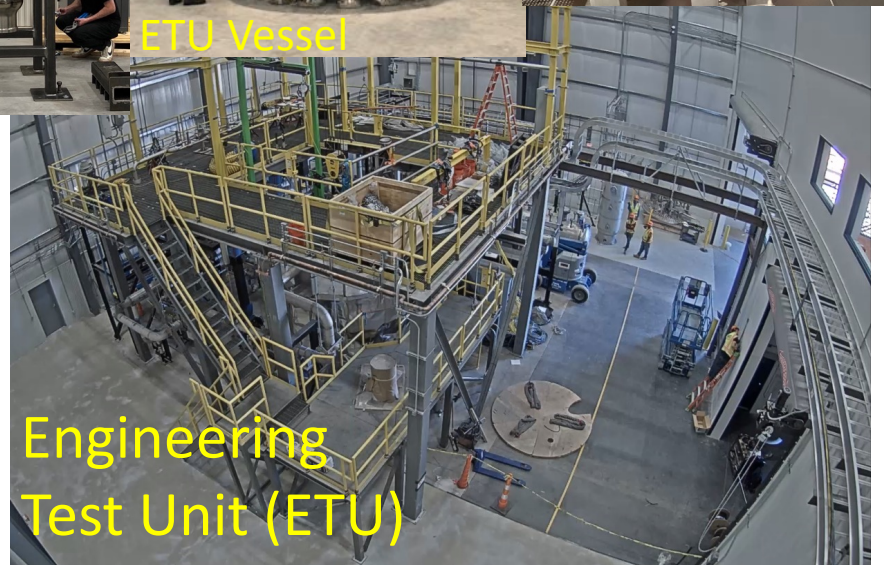


Engineering Test Unit and Hermes Test Reactor

KP-Southwest T-Facility Annex and ETU







40,000 sq ft high bay annex to support state-of-the-art, large-scale Flibe development and qualification testing

Kairos Power Receives U.S. DOE ARDP Award

- Kairos Power is a recipient of an **Advanced Reactor Demonstration Program (ARDP)** award for Risk Reduction funding to support development of the Hermes reactor
- This is a cost-shared partnership between the DOE and industry to demonstrate advanced nuclear technology in the United States
- The total award value over the next seven years is **$629 million** (DOE share is $303 million)
- Kairos Power is partnering with Materion Corporation, Oak Ridge National Laboratory, Idaho National Laboratory, and Electric Power Research Institute on this project

Hermes Construction Permit Application (CPA) Submittal

NRC accepted Kairos Power's CPA for review

- Anticipated Construction Permit issuance in October 2023.
- First CPA for a new, non-water-cooled reactor since 1967 (Fort St. Vrain HTGR application to AEC)
- Supported by Advanced Reactor Demonstration Program award for Risk Reduction funding; Cost-shared partnership btw/ DOE and industry; $629M over the next seven years

Hermes Low Power Test Reactor

Artist's rendering of the Hermes facility