Enclosure 2
Presentation Materials for the January 12, 2023, ACRS Kairos Power Subcommittee Meeting
(Non-Proprietary)

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Graphite Material Qualification Topical Report

ACRS Kairos Power Subcommittee Meeting

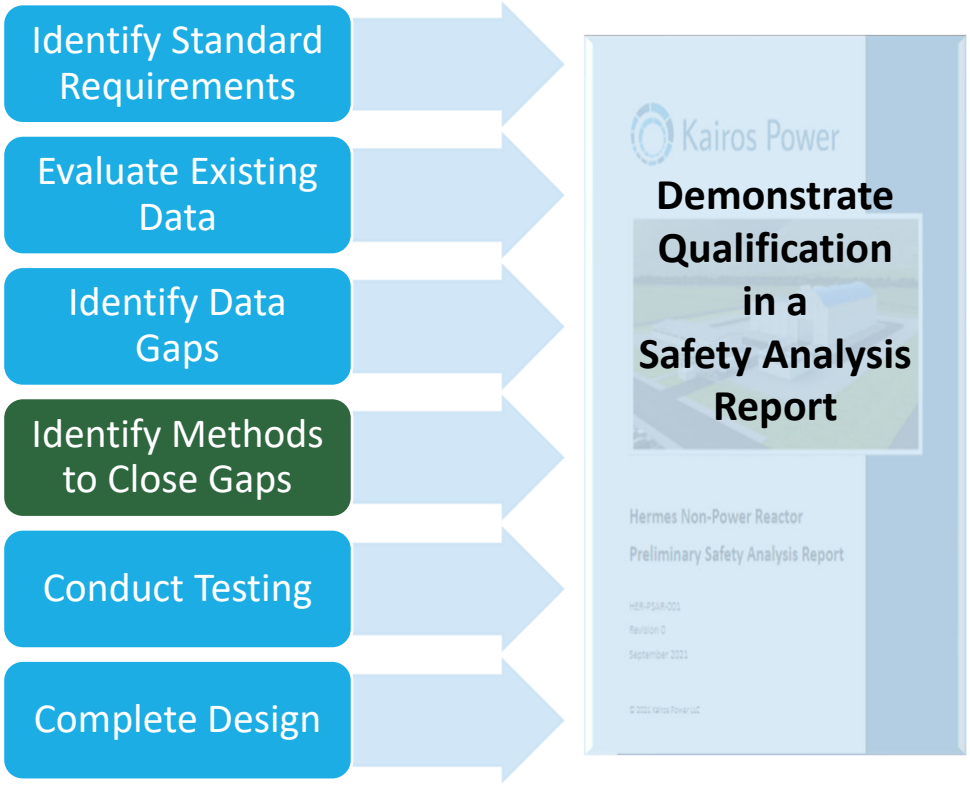
January 12, 2023

OPEN SESSION


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.

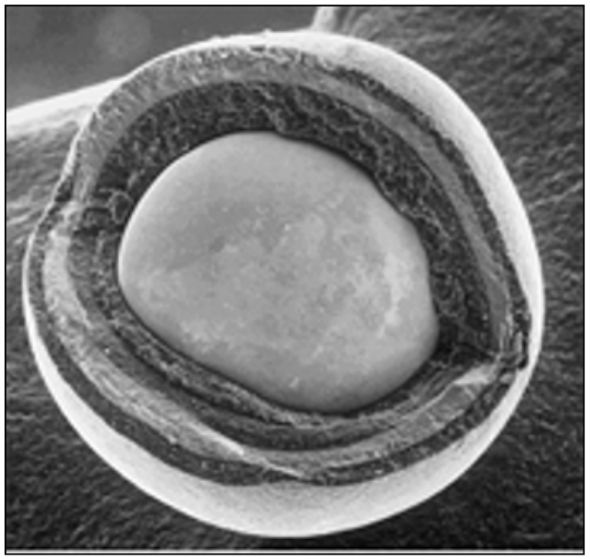
Introduction

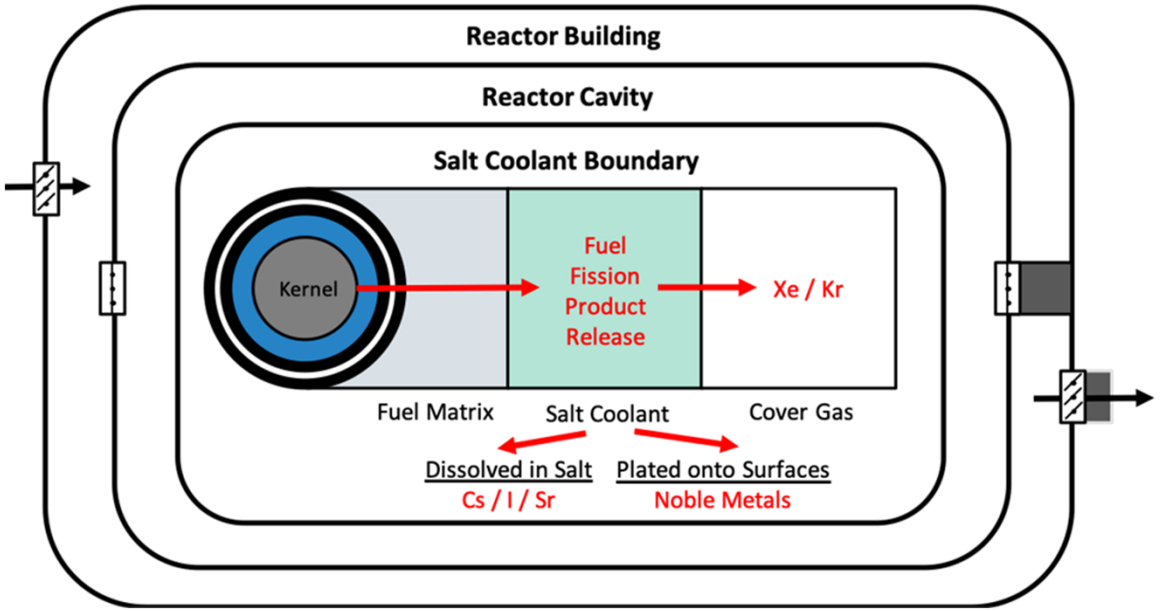
- This report presents the methods for qualifying structural graphite for use in KP-FHRs
  - Qualification is subject to the conditions in topical report
- This report is applicable to a test or power KP-FHR provided that the report conditions are met



Fission Product Retention in the KP-FHR

Coated Particle Fuel
[High Temperature Gas Reactors]





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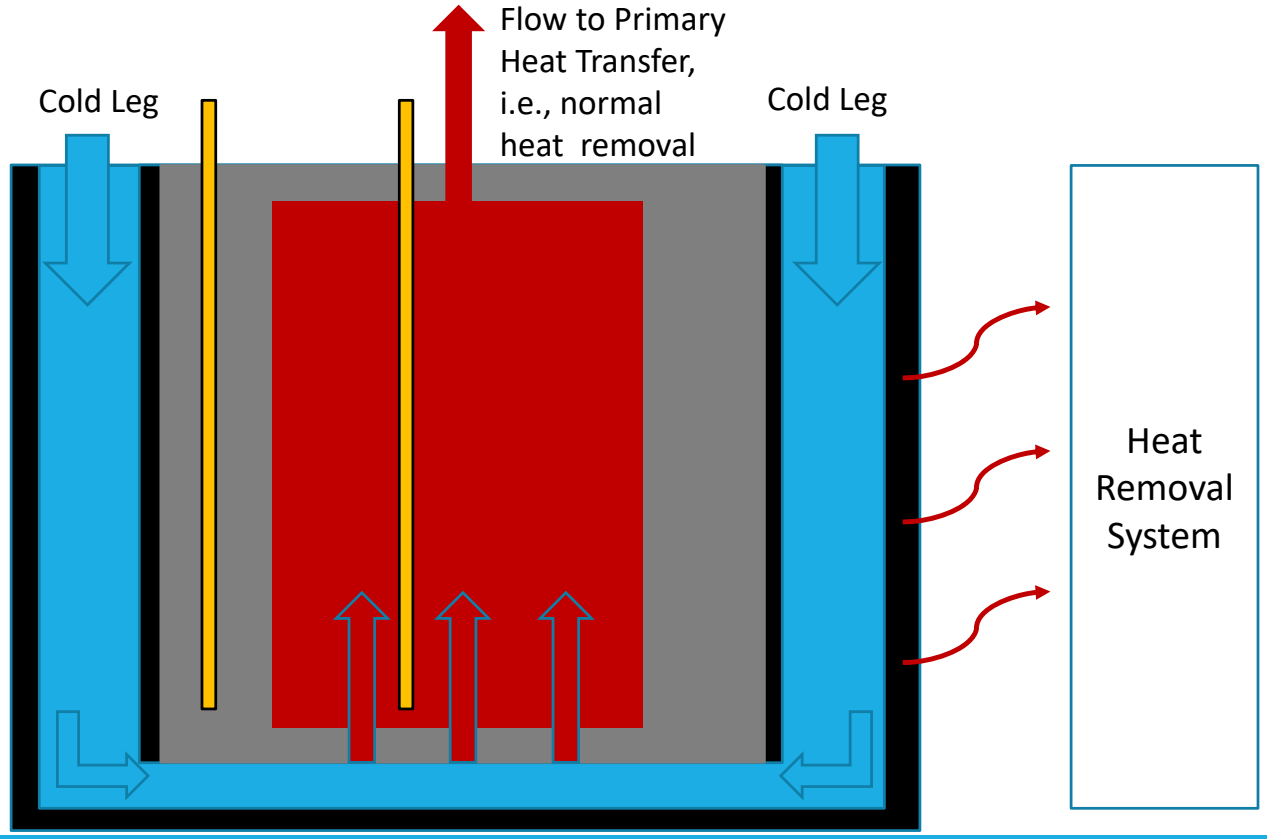
Test and Power KP-FHRs

- The reflector provides a physical pathway for maintaining core cooling and a physical pathway for reactivity control element insertions.
- Structural integrity ensures the safety functions can be met.

Downcomer Region
Active Core Region
Negative Reactivity Insertion
Graphite
Vessel/Core Barrell

* not to scale



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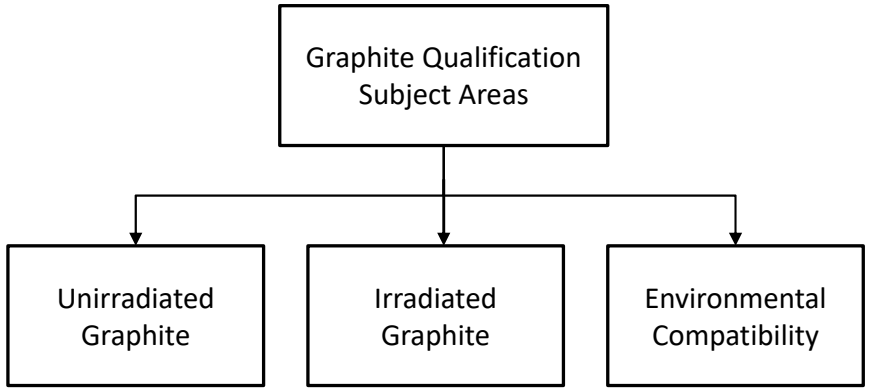
Structural Graphite Topical Report Organization

- Introduction
  - KP-FHR Technologies
  - Regulatory Information
- Nuclear Graphite
  - Background
  - Phenomena Identification and Ranking
- Unirradiated Graphite
- Irradiated Graphite
- Environmental Compatibility
- Conclusions and Limitations
- Appendix A: Data Analysis
- Appendix B: ETU-10 Demonstration of Historical Data Applicability
- Appendix C: Parameter Estimation and Uncertainty Assessment
- Appendix D: Comparison of IG-110 and ETU-10 Material Properties
- Scope:
  - The report applies to both a test reactor and a power reactor.
  - Seismic qualification is out of scope for the report.

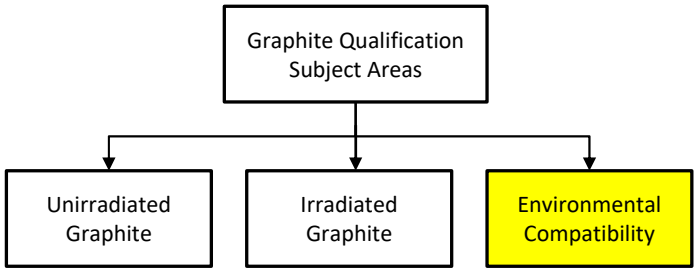
ASME Code Application

- The qualification plan follows the ASME BPV, Section III, Division 5 code (the "Division 5 Code")
  - A portion of the code specifically addresses graphite materials
- The Division 5 Code organizes qualification into three elements:
  - Characterization of as-manufactured graphite mechanical and thermal properties,
  - Characterization of graphite properties under irradiation
  - Environmental compatibility



Background on Graphite

- Characteristics of graphite (vs metallic material)
  - All graphite grades are 99.9%+ carbon.
  - Thermally stable in inert environment, as high as ~3,200°C
  - Mechanical strength increases with temperature
  - Low coefficient of thermal expansion
  - Anisotropic property
  - Up to ~20% porosity
  - High property variability
  - Graphite billet size limitation, difficult to make large-billet, superfine grain graphite.
- Graphite has been used in nuclear reactors for decades and extensive knowledge has accumulated about the material.
  - The topical report also references relevant data about other grades of graphite, for example IG-110 (isomolded, superfine) and CGB grades (extruded, medium grain).
- ET-10 is a superfine grain graphite with nearly isotropic properties that will be qualified for use in a KP-FHR.



Environmental Compatibility

Chapter 5: Environmental Compatibility

- Five phenomena relevant to interaction between Flibe and ETU-10
- Physical Factors
  - Infiltration (See Section 5.1.1) - Closed Session
  - Stress (See Section 5.1.2)
    - Graphite reflector bears no structural loads, unlike the HTGR.
  - Erosion and Abrasion (See Section 5.2)
- Chemical Factors
  - Chemical compatibility with Flibe (See Section 5.1.3)
  - Oxidation (See Section 5.3)

Abrasion and Erosion

- Kairos Power will perform confirmatory tribology testing in Flibe to demonstrate that no significant abrasion of the structural graphite occurs due to contact between the reflector and pebbles
  - No abrasion expected as contact forces are low and ET-10 is harder than the pebbles
- Kairos Power will perform confirmatory erosion examination of ET-10 specimens exposed to long-term Flibe flow in rotating cage loop (RCLs):
  - Erosion is an issue for gas-cooled reactors where the gas flow velocity was 1-2 orders of magnitude higher than the flow velocity of Flibe in a KP-FHR
  - MRSE experience: No obvious signs of erosion on graphite surface after 3 years of operation

Chemical Compatibility with Flibe

There are no known chemical reactions between graphite and Fluoride leading to degradation.

- MSRE experience: No graphite degradation was observed after 3 years of operation
- Intercalation: Theory and literature data indicate it cannot occur under KP-FHR operating conditions
- Fluorination: Kairos Power has evaluated available literature results and found that although there was indication of trace surface fluorination, no bulk fluorination was observed. Bulk fluorination would be necessary to affect graphite mechanical properties.

Oxidation during air ingress event

- Oxidation may occur at the top of the reflector (inert gas space) under air ingress events, which could potentially reduce graphite strength.
  - The effect of air oxidation will be assessed:
    - Measure the ET-10 oxidation kinetic parameters
    - Determine the weight loss vs strength
    - Determine oxidation depth profile
- Oxidation of graphite submerged in Flibe will also be assessed to determine if oxidation occurs. If so, the associated strength reduction will be assessed.

Summary

- The qualification plan in the Graphite Material Qualification Topical Report describes the plan to qualify ET-10 for safety-related structural graphite component design for use in a KP-FHR.
- The qualification plan conforms with the ASME BPV, Section III, Division 5, Code with limited departures.
  - Quantification of mechanical properties as-manufactured ET-10 at room temperature which is conservative for use in future modeling.
  - Fracture toughness will not be measured.
- The qualification plan will use existing data and data from new tests.
  - Existing data for basic irradiation properties and irradiation creep support design of a graphite reflector with a 4-year lifetime (pre-turnaround conditions).
  - A combination of existing basic irradiation properties data and quantification of existing irradiation creep data will support design of a graphite reflector with a lifetime under beyond turnaround conditions.
  - A combination of confirmatory testing and use of existing data to demonstrate environmental compatibility of ET-10 in Flibe.
- Seismic qualification of the reflector structure is outside the scope of the topical report.

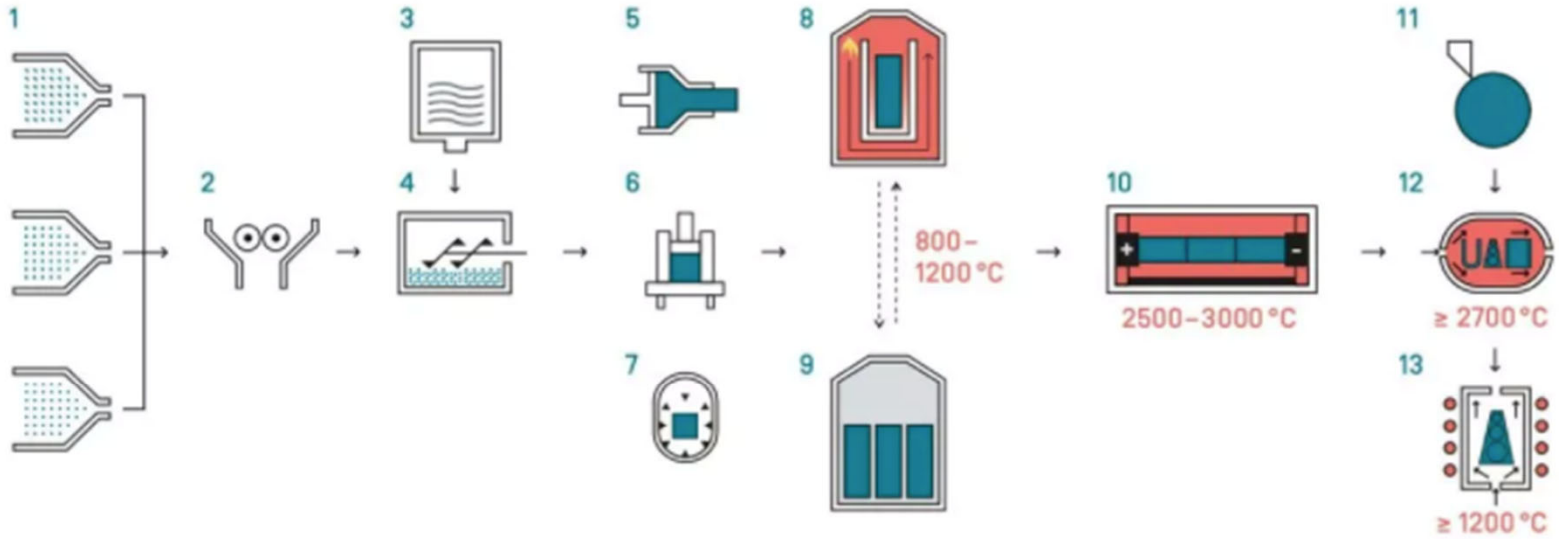
Limitations

- Flibe infiltration is not a consideration for the KP-FHR when limited to reactor vessel fluid heights up to 4m.
- Additional irradiation creep data from testing of ETU-10 is not required when the turnaround fluence is greater than the component lifetime.
- Graphite qualification presumes the reflector does not undergo freeze-thaw cycles.
- A future license application will evaluate and justify the effects of unplanned intermediate salt infiltration into the primary loop, if the reactor design uses intermediate salt in an interfacing heat transfer loop.
- The reflector structure and reactor vessel design preclude the coincident effects of oxidation and irradiation such that the structural integrity of the top of the reflector would be unable to perform its safety function.

Limitations (continued)

- A future license application will demonstrate that ET-10 unirradiated fatigue response follows the same trends as H-451 and PGX.
- A future license application that relies on the qualification program in this report will demonstrate that the data relied on for qualification bounds the analysis for irradiated properties.
- A design specific analysis of the effect of weight loss due to graphite block oxidation on structural integrity of the reflector material will be provided in a future license application that references the qualification program described in this report.

Backup: Graphite Manufacturing Process



1 Coke, graphite
2 Grinding
3 Binder pitch
4 Mixing
5 Extruding
6 Vibro molding
7 Isostatic pressing
8 Carbonizing
9 Pitch impregnation
10 Graphitizing
11 Machining
12 Purifying
13 SiC coating

Source: SGL Carbon website. https://www.sglcarbon.com/en/markets-solutions/material/sigrafine-isostatic-graphite/

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