Kairos Power

OVERVIEW OF THE SAFETY CASE FOR THE KAIROS POWER FLUORIDE SALT-COOLED HIGH TEMPERATURE REACTOR

Presented to the ANS Trinity Local Section

11/24/2020

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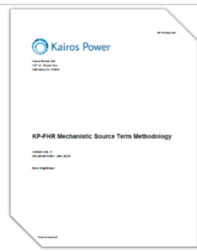
Disclaimer: Non-Proprietary Discussion of Content from a Licensing Submittal

- This presentation discusses content taken from the non-proprietary version of the topical report titled: KP-FHR Mechanistic Source Term Methodology, KP-TR-012-NP (ML20182A785).
- This presentation is intended to demystify Kairos Power's approach to conducting source term analysis.



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Mechanistic Source Term Methodology Outline

KP Overview
- Emphasis on Design-Build-Test loops
- Focus Safety Analysis on the Fuel and Flibe Barriers to Reduce Safety Related SSCs

Safety Basis Overview
- TRISO Fuel
- Flibe Salt
- Low Pressure System

Transport Medium
- Fuel Barrier (TRISO - Building off High Temperature Gas Reactor)
- Flibe Barrier (Building off MSRE and Fusion Experience)
- Gas Space Analysis (Simplified and Conservative Radionuclide transport to the Site Boundary)

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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
    - 158 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

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Kairos Power Recent Progress

S-Lab
Flibe Chemistry and Materials Testing Lab
Operational Sep 2020

New Mexico Expansion
T-Facility **and Manufacturing Development Facility**
Purchased Jan 2020

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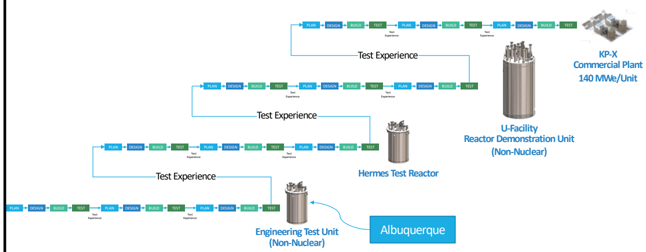
Kairos Power Development Program



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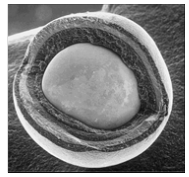
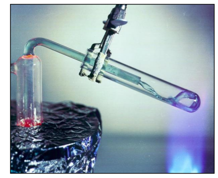
KP-FHR Safety Basis

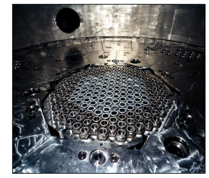
Coated Particle Fuel
Stable fuel to 1600°C



Liquid Fluoride Salt Coolants
Secondary barrier to contain radionuclides



Low-Pressure Pool Vessel
Minimal driving force for mobilization



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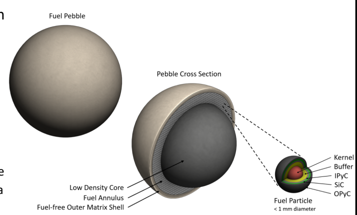
KP-FHR Fuel Element

The Primary Barrier of Radionuclide Retention

- The TRISO fuel form provides the first barrier to radionuclide retention in the KP-FHR for all normal and off-normal operating modes
- TRISO particles utilize a series of diverse barriers to provide robust fuel performance
- Kairos Power's fuel design builds on the AGR fuel development program
  - Extensive industrial fabrication experience
  - Validated irradiation performance under a wide variety of conditions



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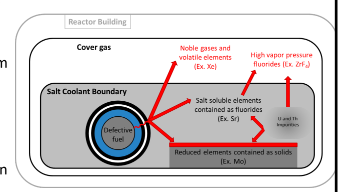
KP-FHR Flibe Salt

The Second Barrier of Radionuclide Retention

- The primary coolant, Flibe, provides the second defense-in-depth barrier to radionuclide retention in the KP-FHR for all in-core normal and off-normal operating modes.
- Flibe can chemically react with fission and activation products, separating them into:
  - Salt soluble compounds,
  - Suspended oxides,
  - Noble metals, or
  - Gas phases
- Kairos Power's Flibe development program builds on radionuclide retention experience in the Molten Salt Reactor Experiment



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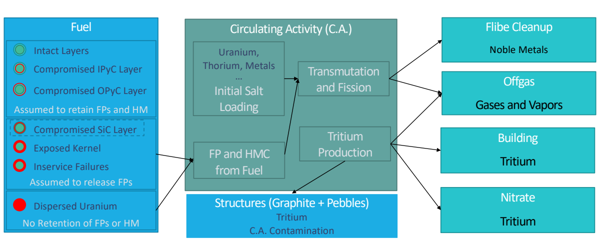
Sources of Steady State Material at Risk (MAR)

Accumulation in the Primary Heat Transport System



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TRISO Barrier

Radionuclide Diffusion

- Incremental TRISO failure due to design basis accident mechanical and thermal stresses will be precluded by design.
- Diffusivity through TRISO layers data exists for:
  - Cesium,
  - Strontium,
  - Silver, and
  - Krypton.
- Compromised layers have their diffusivities set to high values.

	D_1 (m^2/s)	Q_1 (kJ/mol)	D_2 (m^2/s)	Q_2 (kJ/mol)
Cesium				
Kernel	5.6×10^{-8}	209	5.2×10^{-4}	362
Buffer & Buffer-IPyC Gap	10^{-8}	0	-	-
PyC	6.3×10^{-8}	222	-	-
SiC	$5.5\times10^{-14}\times e^{1.1\times\phi/5}$ ϕ is the fast neutron fluence ($\times10^{25}$ n/m^2, $E_n > 0.18$ MeV)	125	1.6×10^{-2}	514
Matrix	3.6×10^{-4}	189	-	-
Strontium				
Kernel	2.2×10^{-3}	488	-	-
Buffer & Buffer-IPyC Gap	10^{-8}	0	-	-
PyC	2.3×10^{-6}	197	-	-
SiC	1.2×10^{-9}	205	1.8×10^{6}	791
Matrix	1.0×10^{-2}	303	-	-
Silver				
Kernel	6.7×10^{-9}	165	-	-
Buffer & Buffer-IPyC Gap	10^{-8}	0	-	-
PyC	5.3×10^{-9}	154	-	-
SiC	3.6×10^{-9}	215	-	-
Matrix	1.6	258	-	-
Krypton (Iodine, Xe)				
Kernel - Normal Operation	1.3×10^{-12}	126	-	-
Kernel - Accident	8.8×10^{-15}	54	6.0×10^{-1}	480
Buffer & Buffer-IPyC Gap	10^{-8}	0	-	-
PyC	2.9×10^{-8}	291	2.0×10^{5}	923
SiC - T>1625.9 K	3.7×10^{1}	657	-	-
SiC - T≤1625.9 K	8.6×10^{-10}	326	-	-
Matrix	6.0×10^{-6}	0	-	-

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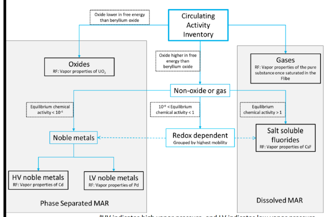
Flibe Barrier

Evaporation or Mechanical Aerosolization



[a]HV indicates high vapor pressure, and LV indicates low vapor pressure.

- Evaporation is a function vapor pressure, p_i, of radionuclides above the reactor coolant:
  - $p_i = a_i K_i$
  - $w_i = \frac{h_i \; p_i \; A}{R \; T}$

K_i is the temperature dependent vapor pressure equilibrium constant
a_i is the activity of phase i
w_i is the molar flow rate of phase i in moles per second,
h_i is the mass transfer coefficient of species i,
A is the area of the Flibe pool,
R is the universal constant,
T is temperature.

- Aerosolization due to pipe breaks are primarily determined via jet breakup correlations:
  - It is assumed the droplets produced by jet breakup follow Rosin-Rammler's distribution

$$f_D = 1.0 - exp\left(-(\frac{p_D}{X})^q\right)$$

where: $X = \left[\Gamma\left(1 - \frac{1}{q}\right)\right]$ SMD

  - The fraction of droplets/aerosols, f_D, is determined for a cut-off diameter $p_D = 50\ \mu m$.
  - The SMD is obtained from capillary size of droplets that balance the surface tension and pressure due to kinetic energy:

$$\text{SMD} = \frac{36.6}{C_D^{4/3}}\left(\frac{\mu_f^2 \sigma \rho_f}{\rho_g^2 (\Delta P)^2}\right)^{1/3}$$

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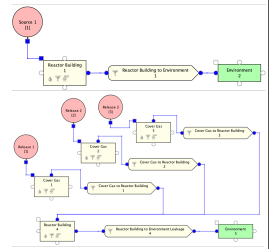
Gas Space Analysis

Simple and Conservative

- Codes: RADTRAD and ARCON96
  - Gas space transport
  - Dose calculations
  - Existing models are accepted as-is.
- Key Inputs:
  - Mobilized material-at-risk activities
  - Depletion mechanisms
    - Radioactive decay and/or
    - Henry correlation for aerosol settling.
  - Leakage rates (Conservative)
  - $\frac{\chi}{Q}$ (Input from ARCON96 code calculations)



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Summary

- Kairos Power's combination of TRISO fuel and Flibe coolant contained within a low-pressure system provides for a diverse and redundant set of radionuclide retention barriers that can enable a simplified safety case.
- By defining a simplified, conservative, and scrutable source term methodology, the number of safety related SSCs can be significantly reduced to the subset of systems required to support the Fuel and Flibe radionuclide retention safety functions.
- Kairos's design-build-test paradigm will lead to significant improvements in cost certainty and continue to provide a wealth of knowledge that will lead to continued design improvements.

ANS Trinity Takeaway
Albuquerque's Engineering Test Unit is Central to Kairos Power's Iterative Learning Roadmap

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