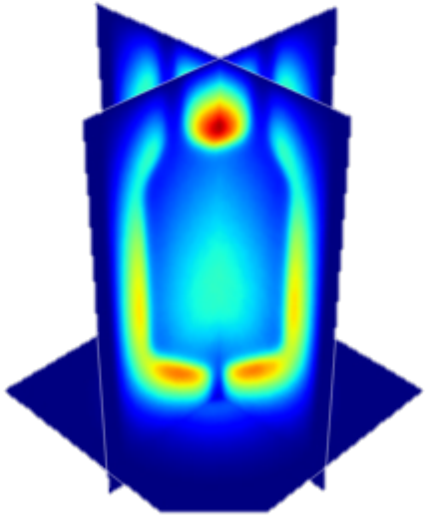
Kairos Power



# Nuclear data for Kairos Power's Fluoride-salt cooled High Temperature Reactor (KP-FHR)

WANDA 2021

NADER SATVAT

MANAGER, REACTOR CORE DESIGN

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.

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

# Kairos Power is Uniquely Suited to Supply the 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

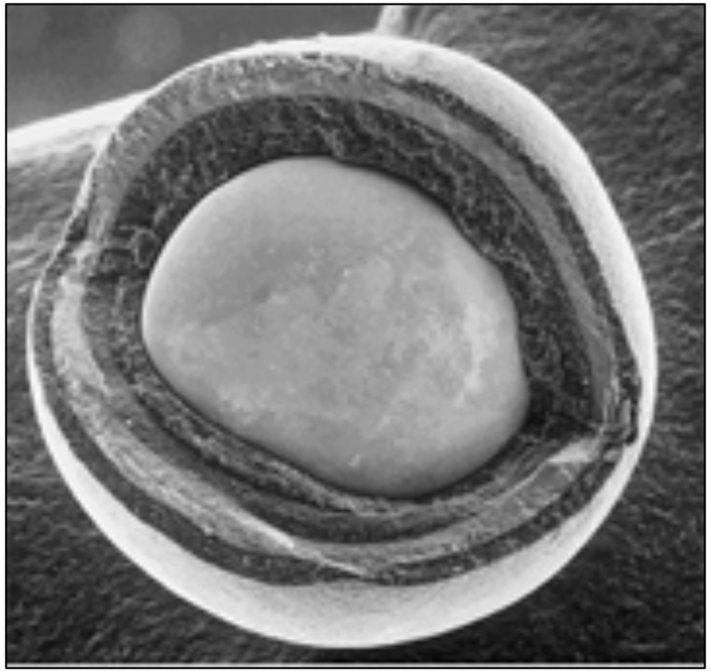
## LOWER CAPITAL COSTS

- Reduce requirements for high-cost nuclear grade components and structures
- Leverage conventional materials, existing industrial equipment, and conventional fabrication and construction methods

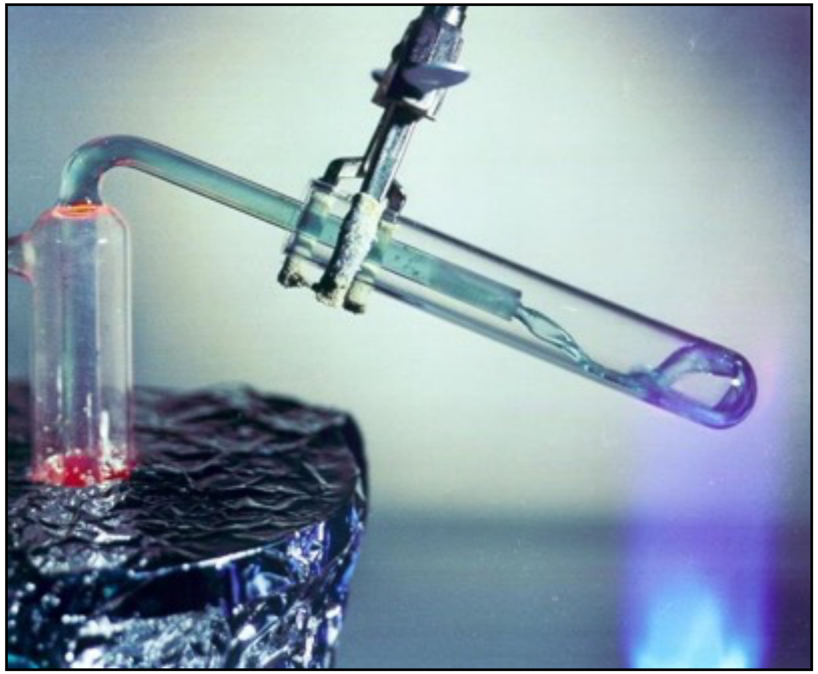
## IMPROVED OPERATING ECONOMICS

- High efficiency
- Flexible deployment of low-cost nuclear heat

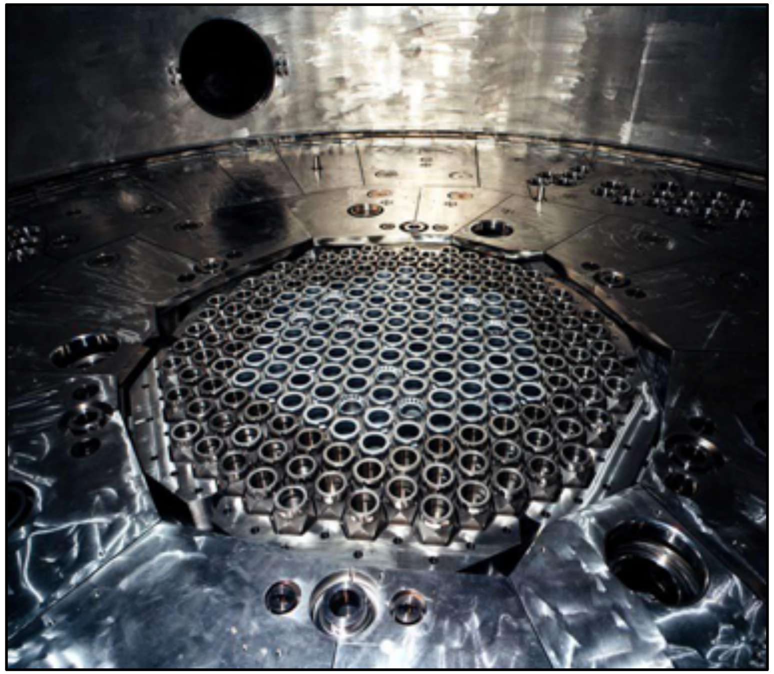
# Kairos Power Fluoride Salt-Cooled High-Temperature Reactor (KP-FHR)



Coated Particle Fuel
[from HTGRs]

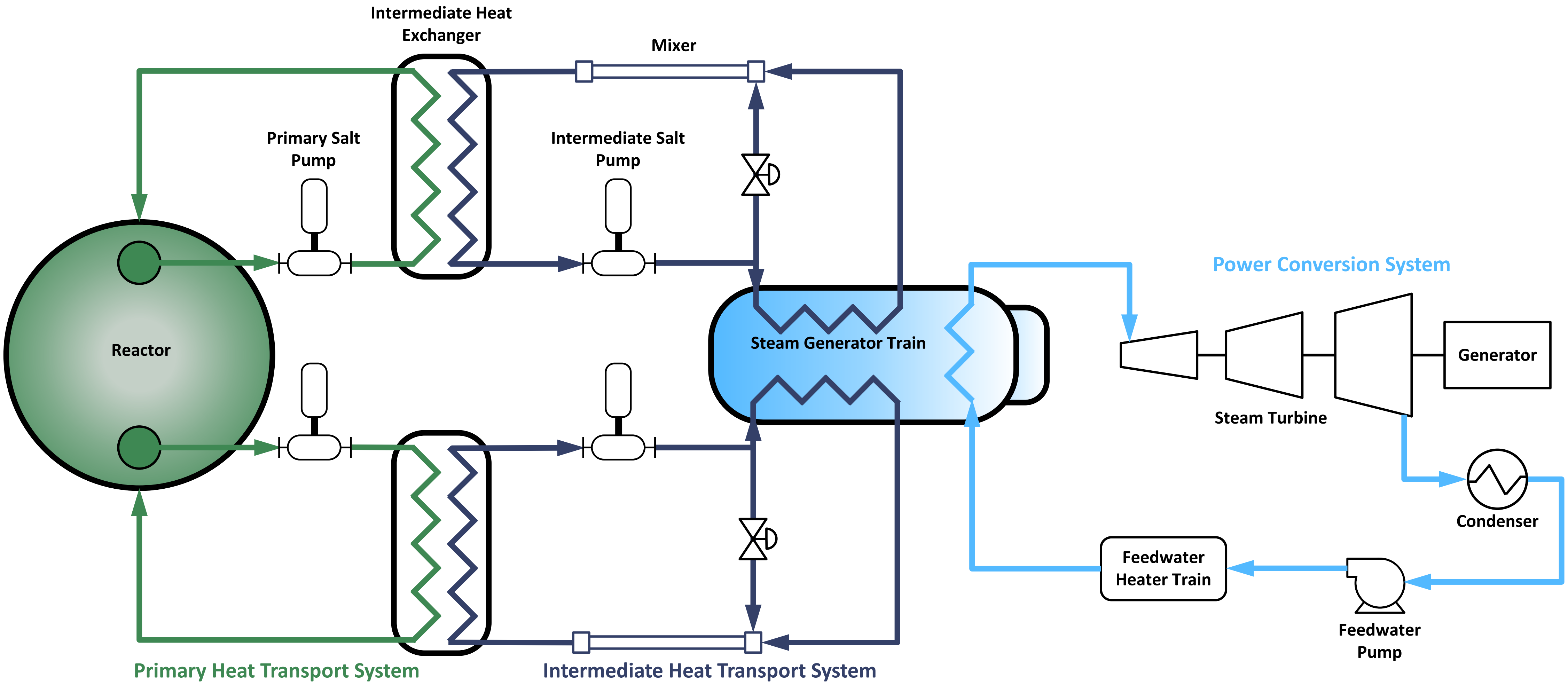


Liquid Fluoride Salt Coolants
[from MSRs]

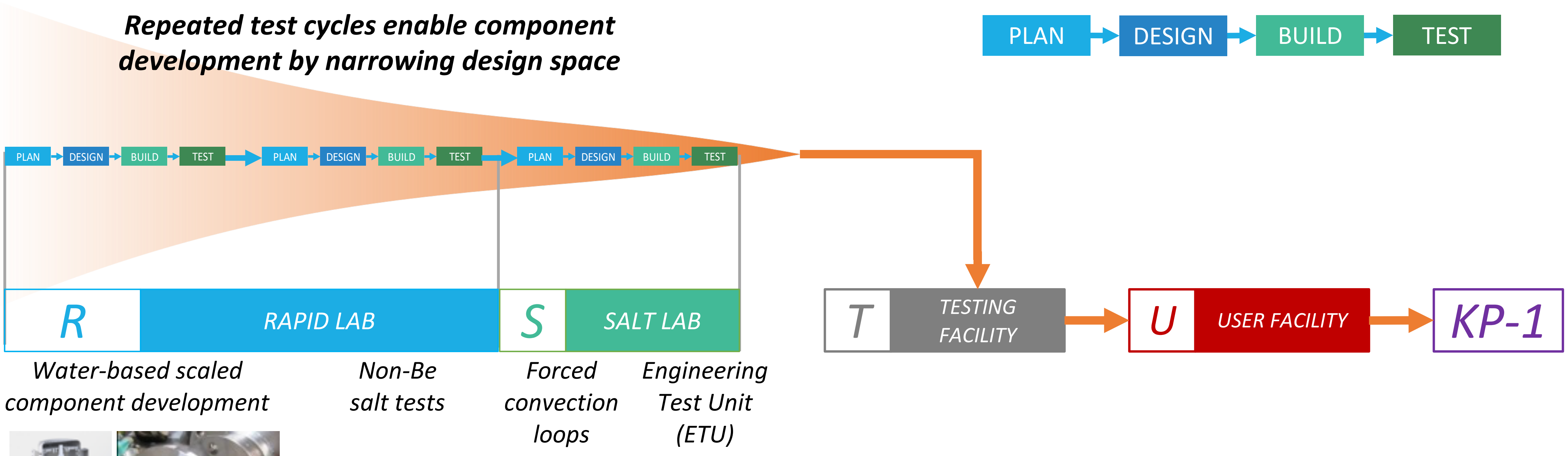


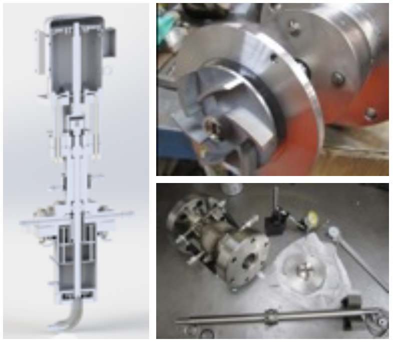
Low-Pressure Pool Vessel
[from SFRs]

# Basic System Configuration with Steam Cycle

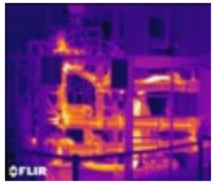


# Kairos Test Program Enables Component Development by Narrowing the Design Space

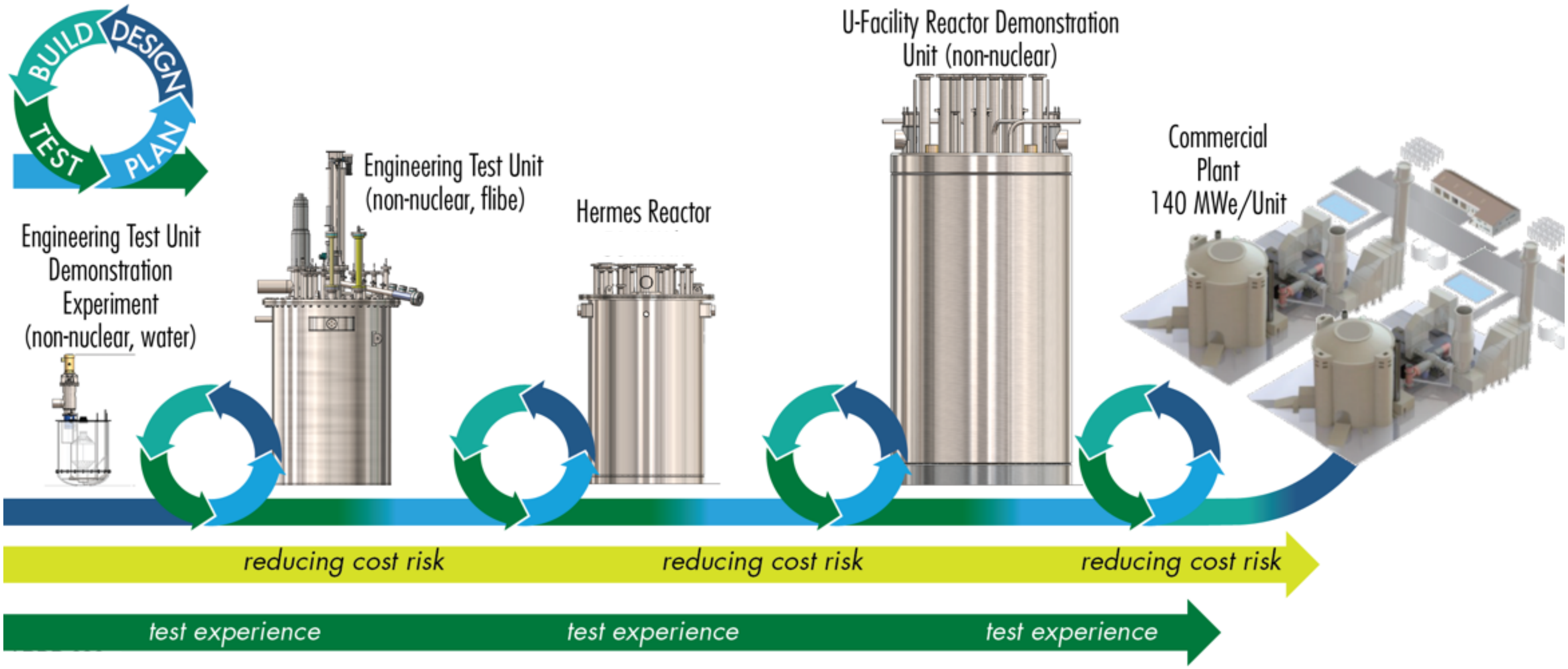


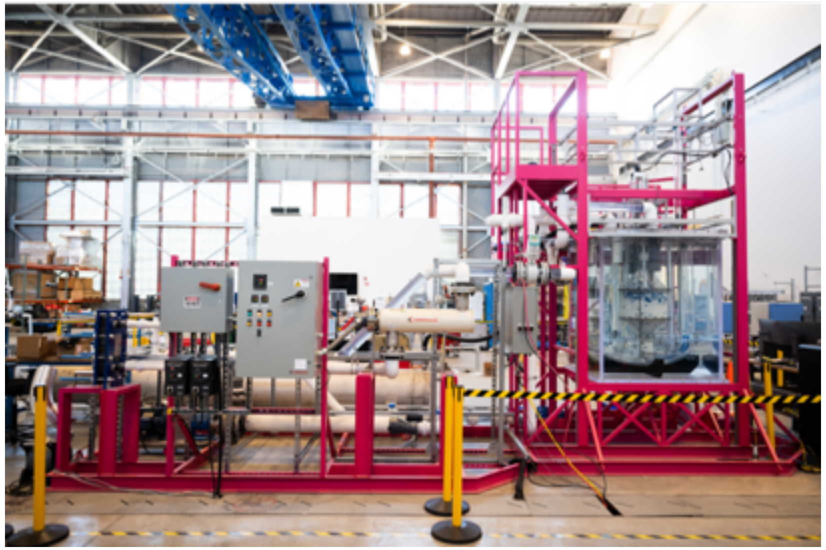
FCL-0 Pump



# Development Strategy - Iterative Development Approach



# Kairos Power's RAPID-Lab for Iterative Testing for Design, Safety, Validation



# Kairos Power Recent Progress

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

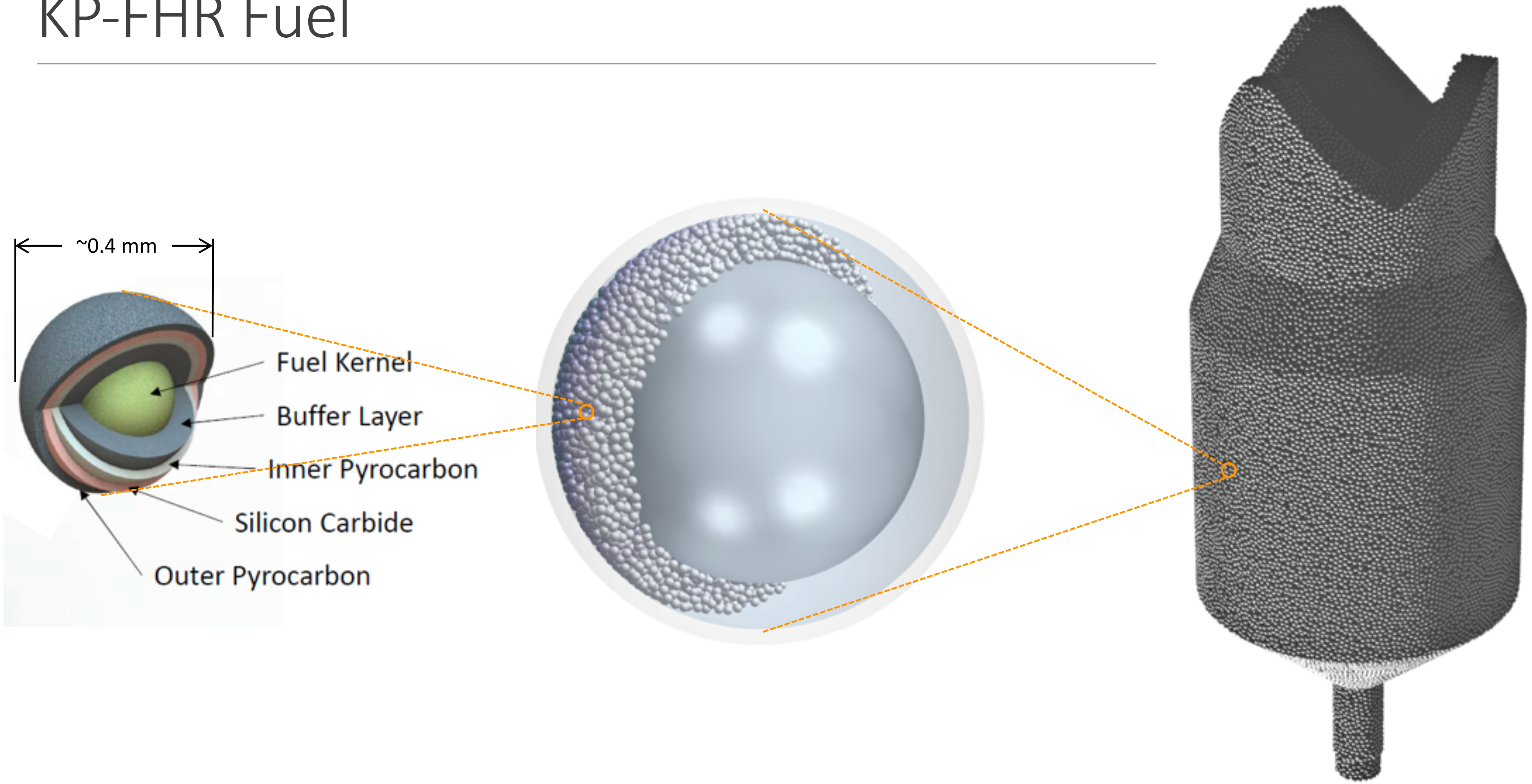
**New Mexico Expansion**
**T-Facility and Manufacturing Development Facility**
**Purchased Jan 2020**

**K-33 Hermes Site**
**Test reactor site in Tennessee**
**Nov 2020**

# KP-FHR Core

- 280-320$MW_{th}$
- Packed-bed: PF ~60%
- Pebbles inserted from the bottom and are removed at the top
- Control system is combination of in-bed and in-reflector

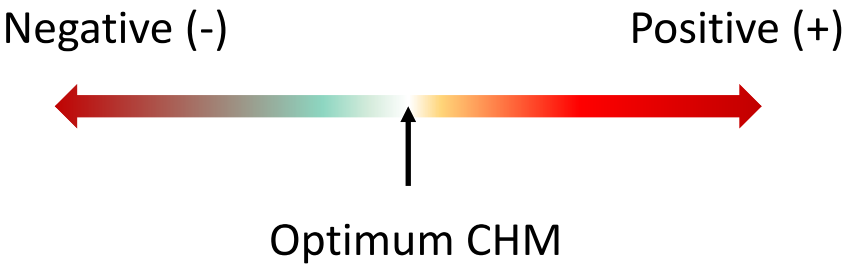
# KP-FHR Fuel


~0.4 mm
Fuel Kernel
Buffer Layer
Inner Pyrocarbon
Silicon Carbide
Outer Pyrocarbon

# KP-FHR Coolant

- Flibe is both absorber and moderator
- Li-7 enrichment is important for operation (coolant reactivity coefficient)
- Carbon-to-heavy metal (CHM) ratio
  - Coolant reactivity coefficient
  - Discharge burnup
  - Time to Li-6 equilibrium

Coolant Temperature Reactivity Coefficient

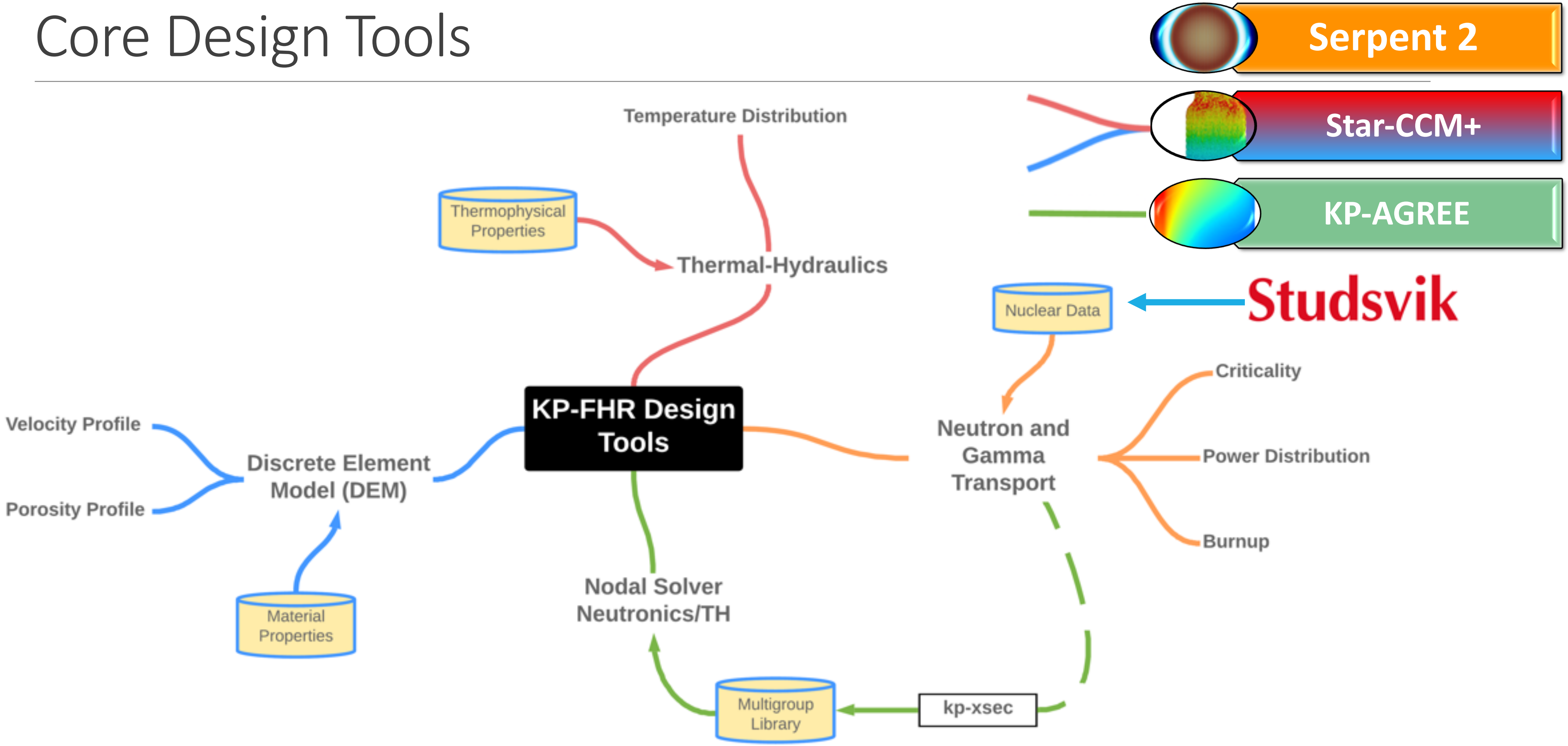



$$^{6}\mathrm{LiF} + n \rightarrow {}^{4}_{2}\mathrm{He} + {}^{3}_{1}\mathrm{HF}$$

$$^{9}_{4}\mathrm{BeF}_2 + n \rightarrow {}^{4}_{2}\mathrm{He} + {}^{6}_{2}\mathrm{He} + 2\mathrm{F}$$

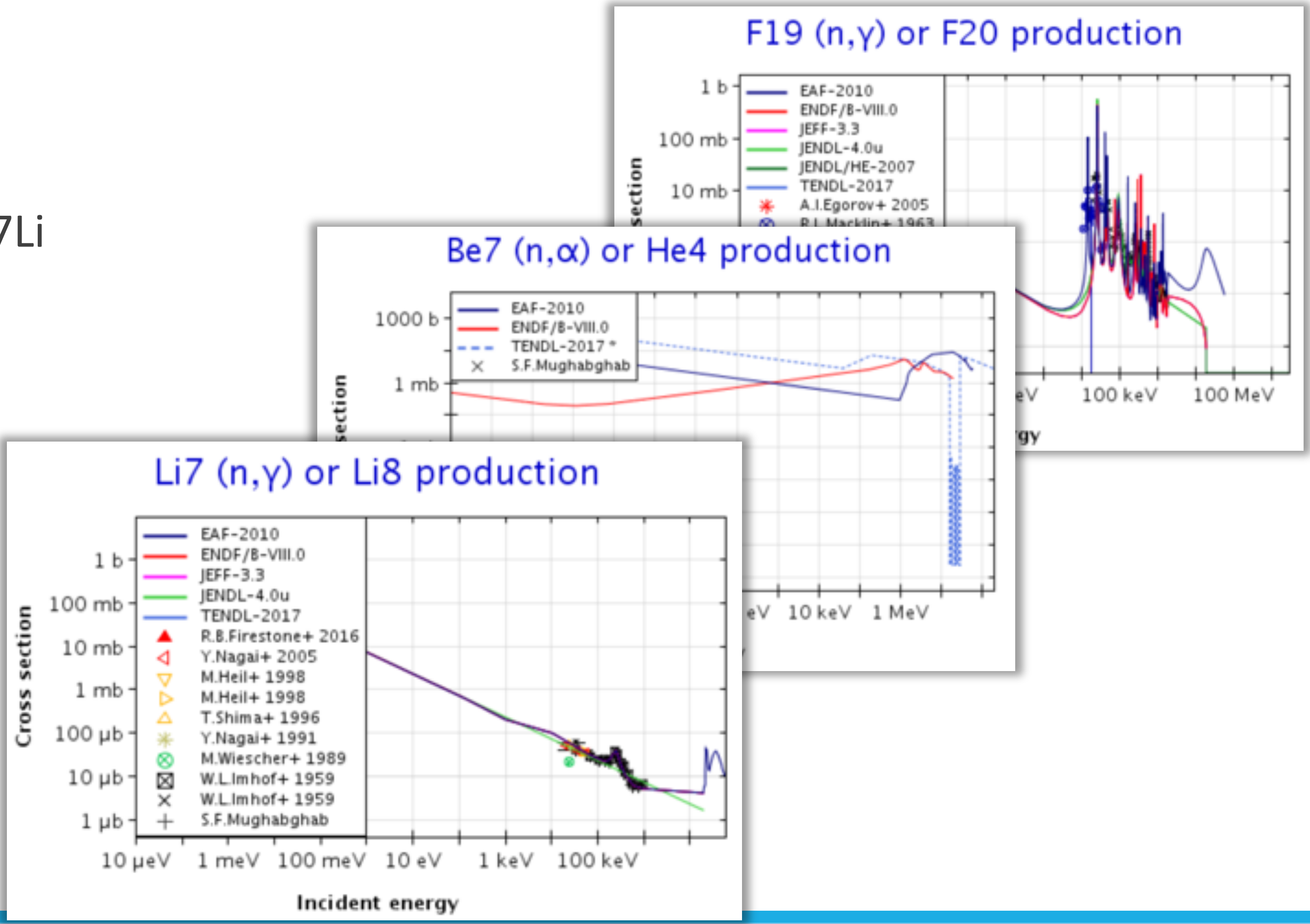
$$^{6}_{2}\mathrm{He} \rightarrow {}^{6}_{3}\mathrm{Li} + e^{+} + \bar{\nu}_e \quad \left(t_{1/2} = 0.8\,\mathrm{sec}\right)$$

# Core Design Tools



# Nuclear data important to KP-FHR

- Thermal scattering data
  - Graphite
  - Flibe
- Cross sections of 19F, 9Be, 6Li, 7Li



# Sources of uncertainty to multiplication factor

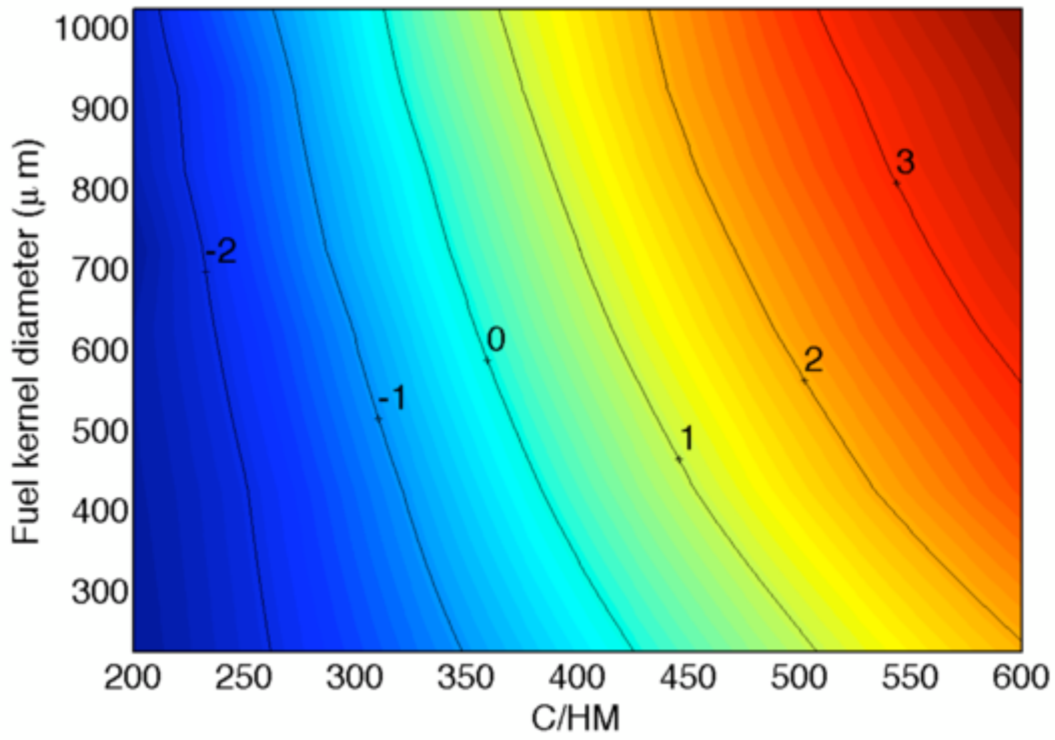
| Reaction | Uncertainty, pcm |
|---|---|
| $^{7}Li$ capture | 1,240 |
| $^{235}U$ nu | 379 |
| $^{238}U$ capture | 214 |
| $^{19}F$ capture | 172 |
| $^{235}U$ capture | 157 |
| $^{235}U$ fission | 138 |
| $^{12}C$ capture | 138 |
| $^{12}C$ elastic | 121 |
| Total | 1,380 |

The major source of uncertainty in Flibe is $^{7}Li$ capture cross section

Shi et al. - 2018 - Sensitivity and Uncertainty Analysis of the Pebble-Bed Fluoride-Salt-Cooled High-Temperature Reactor (PB-FHR)

# FHRs feature relatively small coolant density reactivity coefficients

- Coolant density (temperature) reactivity feedback in FHRs is a fine balance between flibe absorption and moderation
  - Positive feedback from reduced absorption
  - Negative feedback from reduced moderation (spectrum hardening)
- Coolant temperature feedbacks can only be achieved if flibe has a significant contribution to moderation




*Coolant temperature reactivity feedback (pcm/K) as a function of carbon-to-heavy metal ratio*

# Uncertainty in the coolant density feedback is also dominated by $^{7}Li$ capture

| Reaction | Relative uncertainty, % |
|---|---|
| $^{7}Li$ capture | 31.30 |
| $^{19}F$ capture | 4.33 |
| $^{19}F$ elastic | 2.10 |
| $^{7}Li$ elastic | 1.67 |
| $^{9}Be$ capture | 0.99 |

# FHR and fluoride molten salt reactors share similar data needs

Uncertainty from nuclear data for the effective multiplication factor of the Molten Salt Reactor Experiment

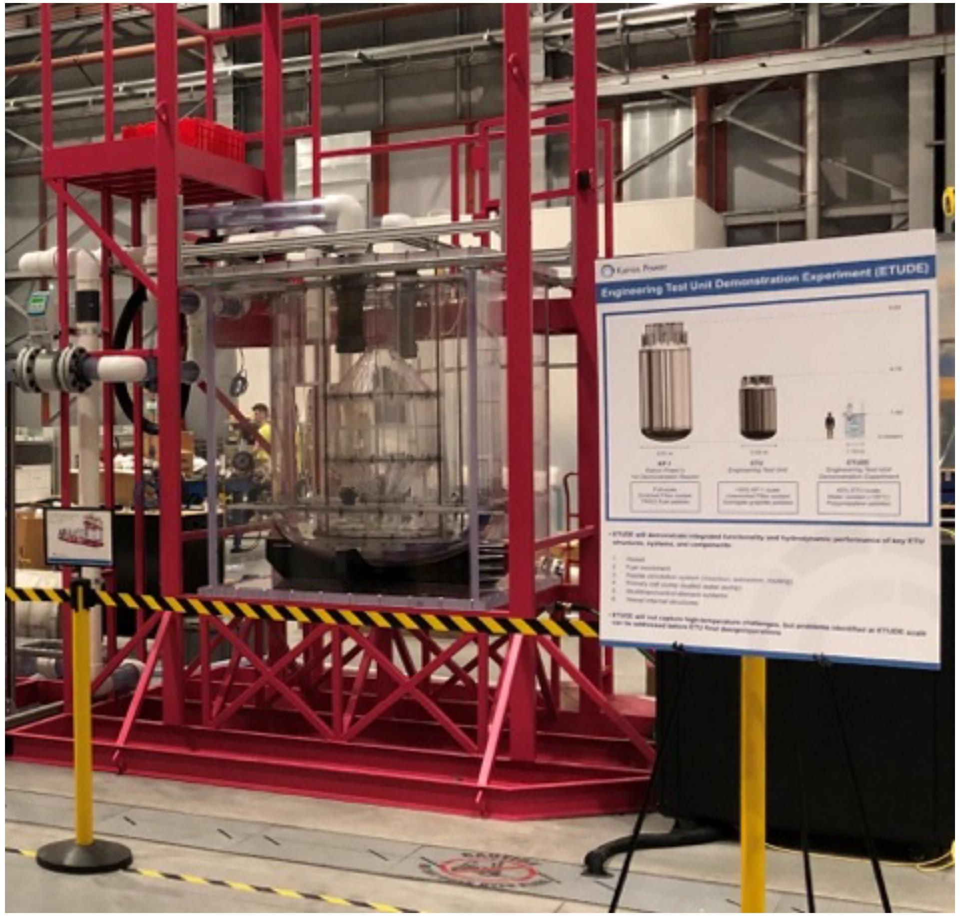
| Reaction | Uncertainty, pcm |
|---|---|
| $^{235}$U nu | 373 |
| $^{12}$C elastic | 263 |
| $^{238}$U capture | 257 |
| $^{7}$Li capture | 197 |
| $^{235}$U capture | 171 |
| $^{19}$F elastic | 143 |
| $^{235}$U fission | 120 |

D Shen and et al. "ZERO-POWER CRITICALITY BENCHMARK EVALUATION OF THE MOLTEN SALT REACTOR EXPERIMENT"

# Conclusion

- Nuclear data needs for FHRs are not unique, well known and widely used isotopes
- Liquid Flibe TSLs:
  - Zhifeng Li, et al "On the improvements in neutronics analysis of the unit cell for the pebble-bed fluoride-salt-cooled high-temperature reactor" – showing 100-500pcm change in k-eff
- Uncertainties can be bounded for important figures of merit for safety
- Hermes will be used to validate computational tools and predicted uncertainties

# Questions?


Kairos Power
Engineering Test Unit Demonstration Experiment (ETUDE)