Enclosure 2
Presentation Slides for the November 30, 2023
KP-FHR Core Design and Analysis Methodology Pre-Submittal Meeting
(Non-Proprietary)

(Note that the enclosed information is preliminary and pre-decisional and is subject to change during detailed planning and project execution. It is provided for planning and familiarization purposes in support of pre-application discussions with the NRC Staff.)

KP-FHR Core Design and Analysis Methodology Pre-Application Meeting

PUBLIC SESSION

NOVEMBER 30, 2023

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*.

Agenda

- General Topical Report Outline
  - Highlight sections with major changes from KP-TR-018

- Methodology Re-Introduction
  - DEM
  - Neutronics
  - Thermal Hydraulics

- Modeling Boundary

- Data Flow

- Modeling, Tools, and Applications
  - Discrete Element Methods (DEM)
  - Neutronics
  - Thermal Hydraulics (TH)

- Request for Review

- Timeline

Topical Report General Outline

- Section 1: Introduction

- Section 2: KP-FHR Core Design Features
  - Reactor Core General Features
  - Reactor Core Design
  - Operational Regimes

- Section 3: Core Modeling
  - Core Modeling Paradigm and Boundaries
  - DEM Modeling
  - Neutronics Modeling
  - Thermal Hydraulic Modeling*
  - Calculational Outputs

- Section 4: Modeling Tools
  - Data Flow
  - STAR-CCM+
  - Serpent 2
  - Wrapper Codes
  - Other Core Modeling Tools

- Section 5: V&V and Uncertainty Analysis*
  - DEM Validation Methodology*
  - Serpent 2 Code-to-Code Validation*
  - Neutronic Uncertainty Analysis*
  - Nuclear Reliability Factors*
  - Thermal Hydraulics V&V and Uncertainty Quantification*
  - Reduction of Uncertainties*

- Section 6: Applications
  - Input to Safety Analysis
  - Inputs to Nuclear Design
  - Thermal Hydraulics Applications*
  - Core Composition*
  - Core Follow*
  - Startup Physics Testing*

- Section 7: Summary
  - Limitations of the Methodology*
  - Conclusions

- Appendix: Sample Calculation

*Content has changes or additions made relative to KP-TR-017

Methodology Re-Introduction

- Report will describe methodology for core design and analysis for normal steady state operation.

- Applicable to a KP-FHR.

- Methodology for core analysis and design aligns with the physical behavior of the core by using three major modeling paradigms:
  - Discrete element methods (DEM)
  - Neutronics
  - Thermal hydraulics (TH)

- Modeling tools are consistent with what was provided in Technical Report KP-TR-017.

Modeling Boundary
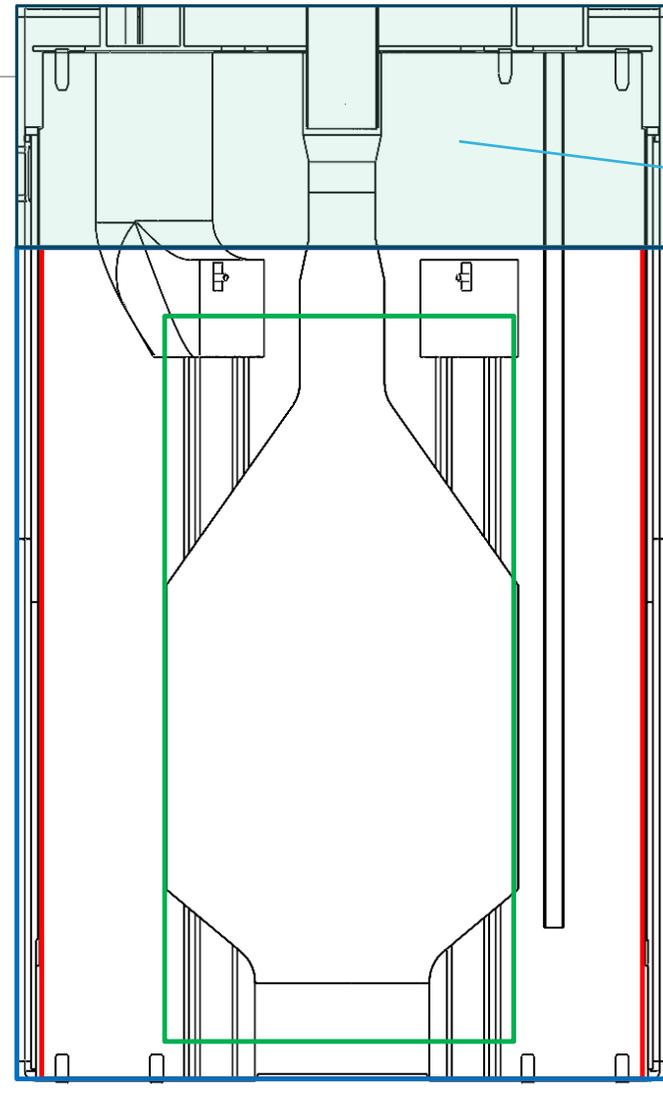
DEM
- Core shape
- Reflector material
- Pebbles
- Coolant flow

Neutronics
- Core
  - Pebble distribution
- Flibe
- Reflector
  - Temperature distribution
- Reactivity Control and Shutdown System
  - Neutron absorber
  - Cladding
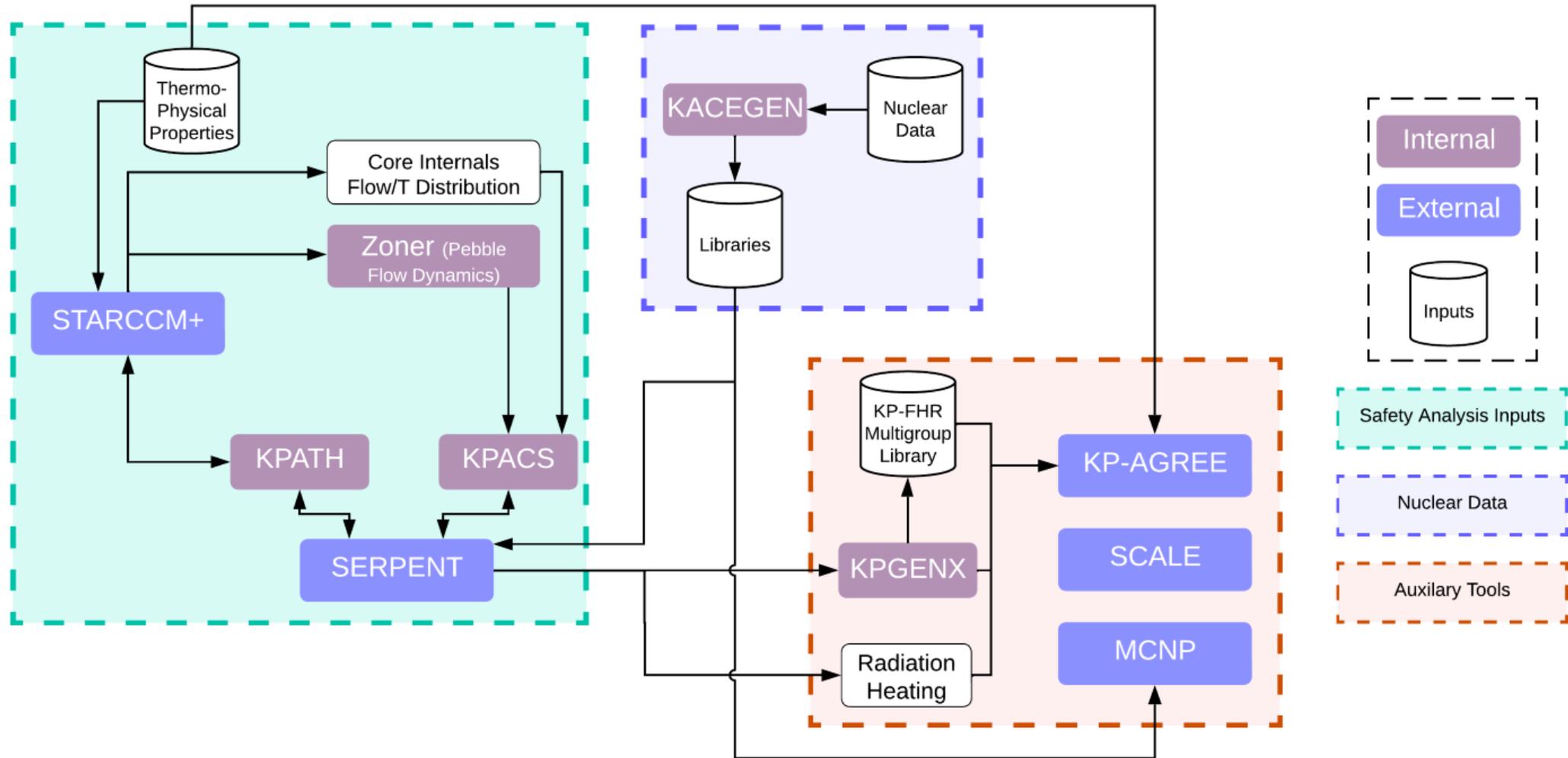- Core Barrel
- Downcomer
- Reactor Vessel

Thermal-hydraulics
- Core
- Porosity
- Temperature distribution
  - Fuel, Moderator, coolant, reflector

Neutronics can extend to inform fluence distribution, cross section tallying, etc.

Data Flow

DEM Modeling, Tools and Application

- DEM methodology is used to model the pebble statistical average behavior in the core: residence time profile, packing fraction, and pebble locations.
  - Considers drag, buoyancy, pebble-to-pebble and pebble-to-wall contact forces.

- DEM modeling results provides statistical basis (i.e., time histories of velocity, position, and residence time) for use in core neutronic and thermal-hydraulic calculations.

- STAR-CCM+ is an analytical tool used to perform DEM modeling of the pebble bed and provide input to neutronics code KPACS (fuel cycle analysis).

Neutronics Modeling, Tools and Application

- Monte Carlo method is used to model neutronic behavior in the core, reflector, reactivity control and shutdown system, core barrel, downcomer and vessel

  ◦ Figures of merit include criticality, kinetics parameters, rod worth, reactivity coefficients, power distributions, flux distribution

- Serpent 2 is the primary tool for neutronics modeling and is used for best-estimate calculations of neutronics figures of merit

- Applications of Serpent 2 results include inputs into:
  ◦ Definition of activated sources for shielding
  ◦ Reactor startup calculations

TH Modeling, Tools and Application

- The thermal hydraulics modeling provides best estimate prediction of flow and temperature distribution across core and reflector regions
  - Core is modeled using local thermal non-equilibrium (LTNE) porous media (PM)
  - Reflector blocks, channels and gaps are explicitly modeled
    - Core coolant bypass is explicitly modeled
    - Core momentum and energy are coupled with reflector region

TH Modeling, Tools and Application (continued)

- The primary tool STAR-CCM+ uses input (energy deposition distribution) from Serpent 2 to calculate material temperatures (i.e., reflector, fuel, moderator and coolant.)

- Two-way coupling between STAR-CCM+ and Serpent 2 steady-state provides thermal hydraulic feedbacks for criticality calculations, power shape and power peaking calculations.

- Applications of thermal hydraulic and neutronics models provide:
  - reflector and core temperature distribution
  - reflector fluence distribution

Request for Review

- Kairos Power requests NRC review and approval of the methods described in the topical report for use in core design and analysis. Core design and analysis methods will provide a means to satisfy, in part, PDCs as noted below:
  - PDC 4: Methods of analysis are acceptable means to calculate environmental conditions for the analysis of the reactor vessel and internals
  - PDC 10: Methods of analysis are an acceptable means to calculate the core material temperatures, power distributions, kinetics parameters, reactivity coefficients, rod worth, fuel performance, and vessel and internals fluence/dpa for a KP-FHR core design to ensure the designed KP-FHR core does not exceed SARRDLs during normal operation.
  - PDC 11: Methods of analysis are an acceptable means to calculate the reactivity coefficients to demonstrate the net effect of prompt inherent nuclear feedback characteristics tend to compensate for rapid increases in reactivity.
  - PDC 12: Methods of analysis are an acceptable means to demonstrate the nuclear stability of the KP-FHR.
  - PDC 16: Methods of analysis are acceptable means of determining inputs to the fuel performance to ensure functional containment design conditions are not exceeded
  - PDC 26: Methods of analysis are an acceptable means to calculate the shutdown margin of the KP-FHR core.
  - PDC 31: Methods of analysis are an acceptable means for calculating inputs to the analysis of the reactor coolant boundary
  - PDC 35: Methods of analysis are an acceptable means to calculate environmental conditions for analysis of the reactor vessel internals that support maintaining integrity of decay heat removal.

Timeline

- Topical Report Walk-through   Late January 2024

- Submittal of Topical Report   End of 1Q 2024