Fuel Strategy for the eVinci Microreactor

Dr. Kallie Metzger, eVinci Fuel Director

13 March 2024

Westinghouse

Westinghouse: a Deep History of Innovation

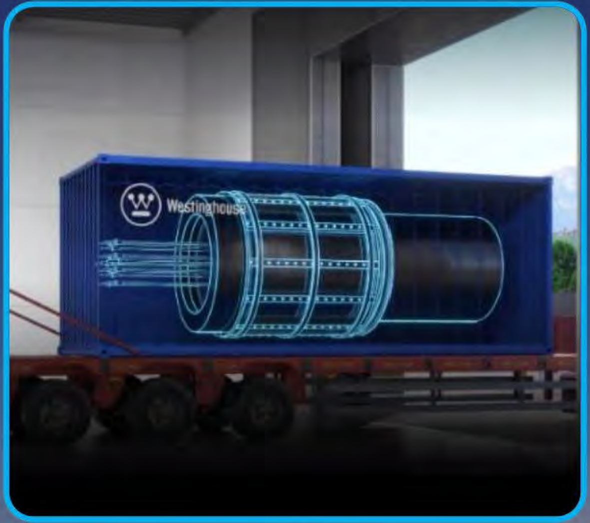
Established nuclear solutions provider

- Founded by George Westinghouse in 1886
- USS Nautilus (commissioned 1954)
- World's first commercial pressurized water reactor
- (PWR) in 1957 in Shippingport, Pennsylvania, U.S.
- Responsible for some of the world's greatest advances and innovations in energy technology
- Key partner in solving the global energy challenge
- 1st and only U.S.–based company to bring GEN III+ Nuclear Power technology to commercialization
- 10,000 employees, 21 countries, 3 fuel fabrication facilities

Innovative Solutions Portfolio

Meeting customers' flexible energy demands by shaping today's and tomorrow's energy landscape

eVinci™ Microreactor
5 MWe

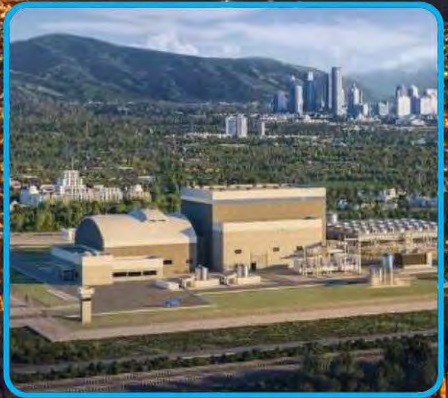


Westinghouse Space Reactors
10 kWe to 2 MWe

AP1000® PWR
~1200 MWe

AP300™ SMR
300 MWe

Lead Fast Reactor
450 MWe



eVinci Technology Overview

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eVinci Microreactor Capability

Nuclear battery designed for safe and reliable electricity and heat generation

Technical Capabilities

- 15 MWt reactor with 8+ year refuel cycle
- Effective cogeneration nuclear battery
- Transportable for ease of installation and elimination of spent fuel storage on site
- Cost-competitive plant lifecycle
- Minimal onsite personnel
- Proven technology, manufacturing, and regulatory readiness
- High speed load-following capability
- Versatile and flexible open-air Brayton power conversion
- No onsite cooling water required

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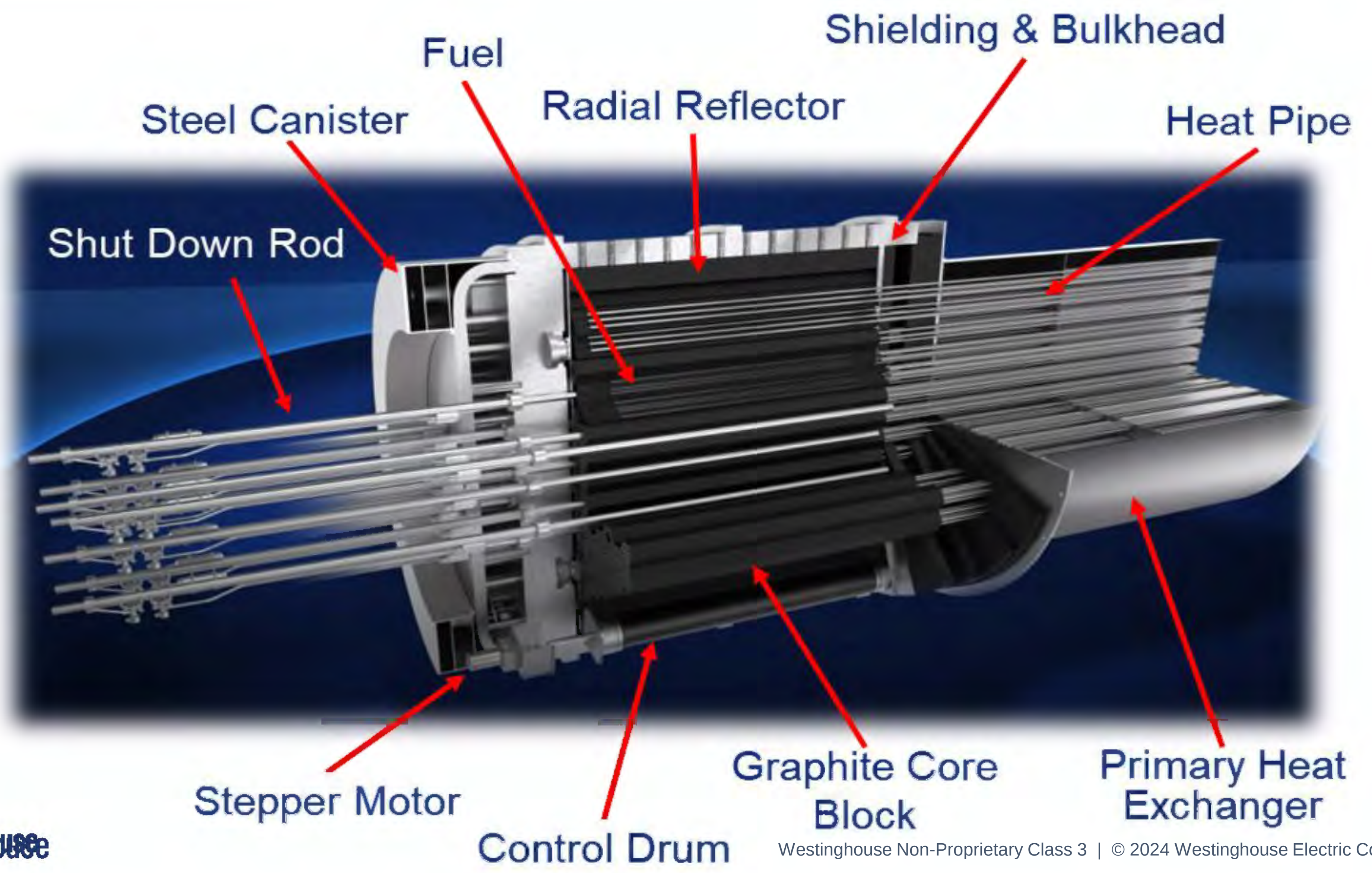
Minimal Components for Simplicity, Safety and Reliability



eVinci Microreactor – Developed from Decades of Research

Safety through passive heat pipe technology and a solid-state, very low-pressure design

Background and development to date

- **1980s** to **2000 –** heat pipe reactors developed for space due to simplicity, small size & passive cooling
- **2000** to **2015** – national laboratory led materials and reactor design development research
- **2015** – Westinghouse began development of heat pipe & microreactor concepts
- **2018** – U.S. national laboratory led demonstration of 5kW heat pipe reactor (KRUSTY)
- **2020** – completed construction of eVinci test facility & manufactured first sodium heat pipe
- **2021** – electrical demonstration of heat pipe core assembly at operating temperature
- **2022** – material compatibility testing & conceptual design completed; technical white papers & first topical reports delivered to U.S. NRC; produced first heat pipe for Nuclear Test Reactor (NTR)

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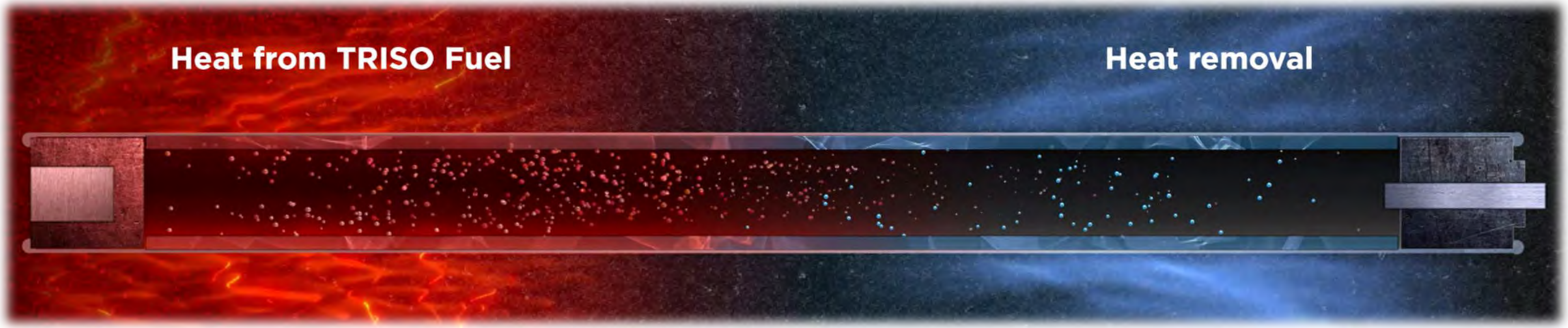
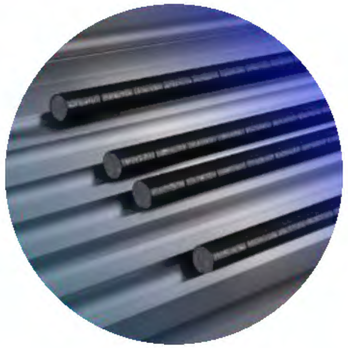
Heat Pipes Enable the Nuclear Battery Model

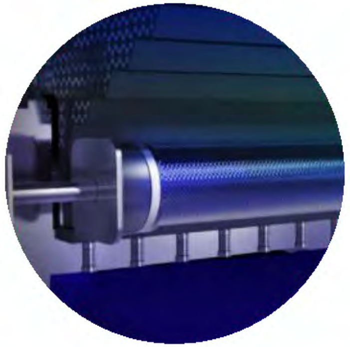
Very Low Pressure ● Passive ● Isothermal ● Self-Regulating





Fuel

Core Block



Control Drum

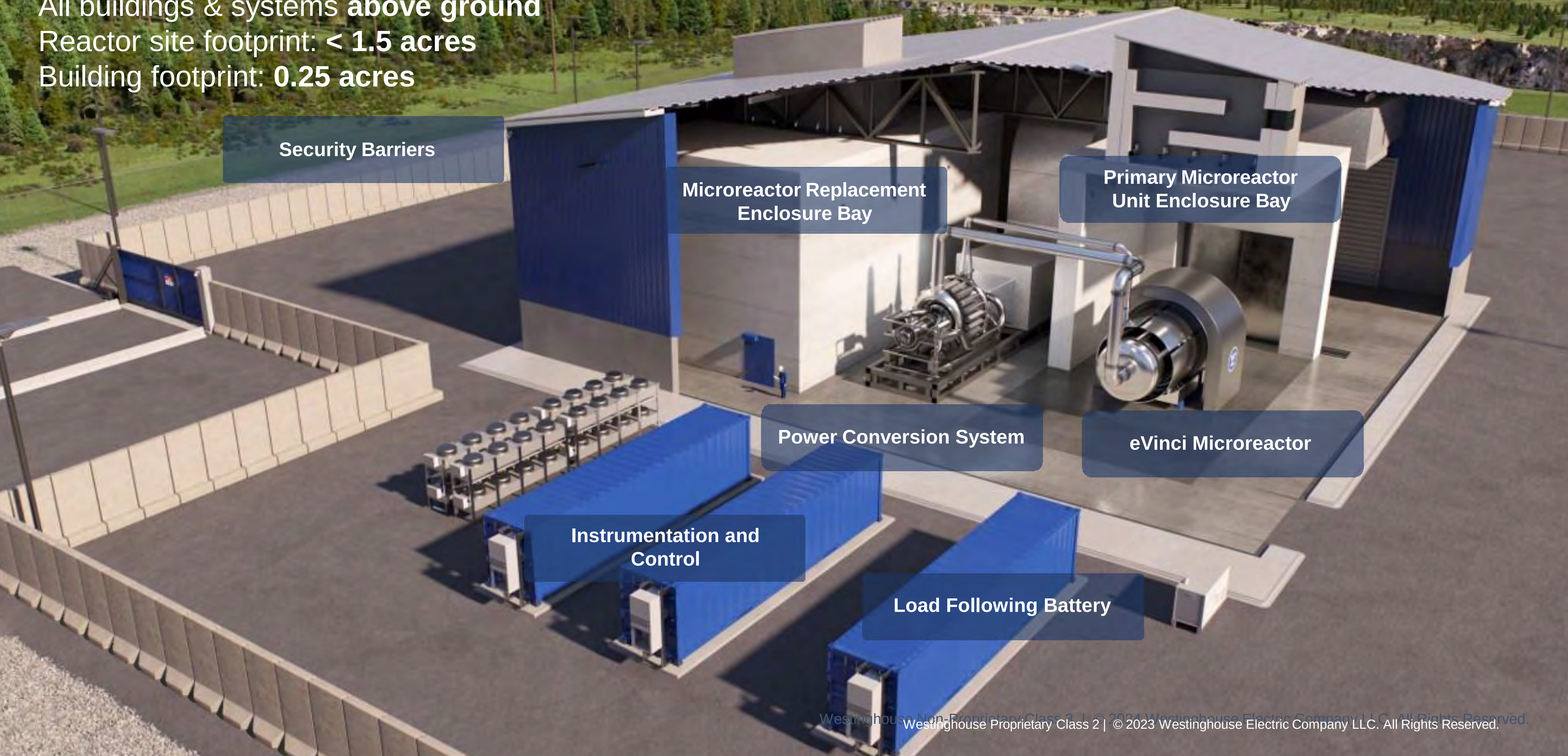
Shutdown Rod

Primary Heat Exchanger

Site Design

In 2023, Westinghouse submitted technical papers to the NRC for eVinci related to Safeguards Information, Physical Security, Reactor Transportation and Cyber Security

All buildings & systems **above ground**
Reactor site footprint: **< 1.5 acres**
Building footprint: **0.25 acres**

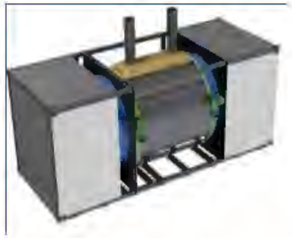


A New Deployment Model Within Current Regulations

1

Test Reactor for Safety Feature Performance Demonstration

Test Reactor – Testing, Data Collection and Analysis



2

Standard Design Certification per 10 CFR Part 52 Subpart B

Opened new eVinci transportation licensing docket for Part 71 efforts

eVinci Micro Reactor Deployment

3

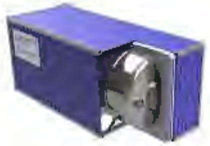
Assemble in Factory

4

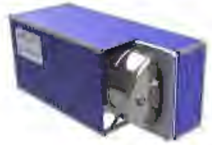
Transport to Site

5

Install and Operate at Site



Primary reactor



Replacement reactor

Remote Monitoring Station

Limited Site Staff w Remote Monitoring

6

Transport Away From Site

Depleted Reactor

7

Refuel/Refurbish

or Decommission

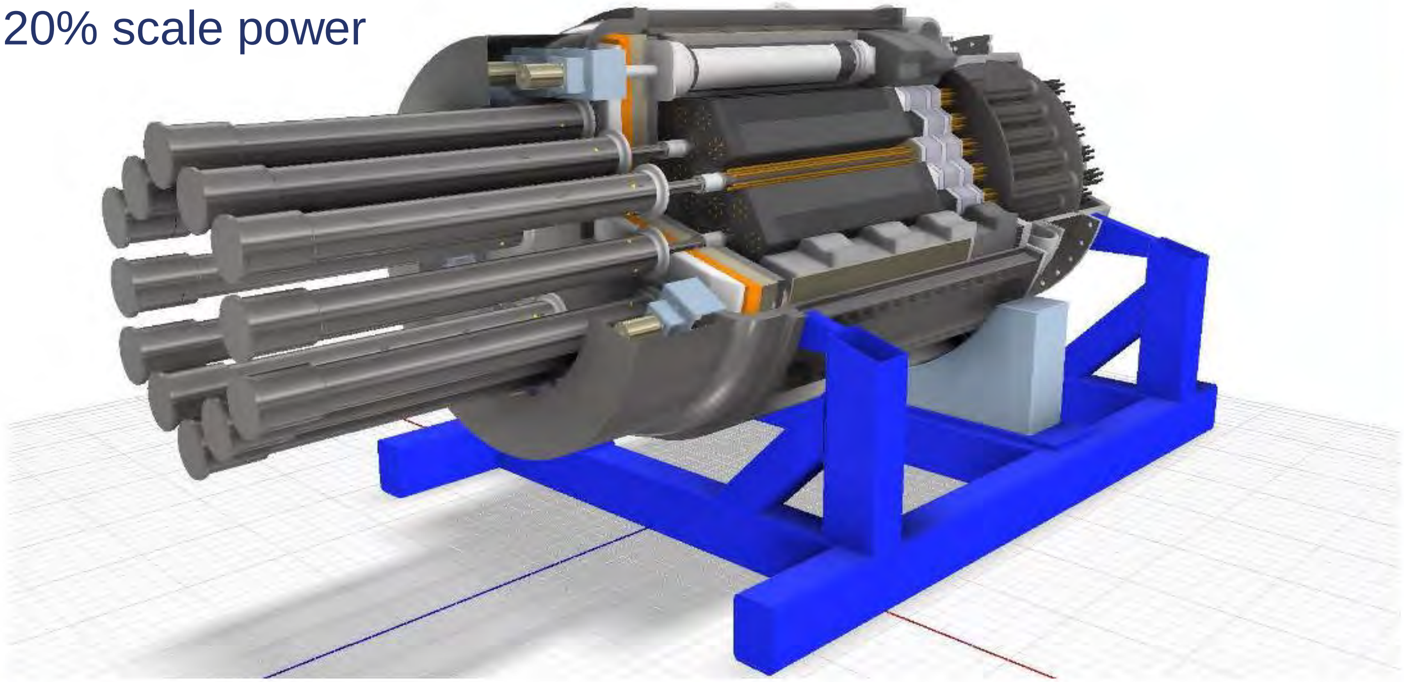
Licensing Progress with US NRC

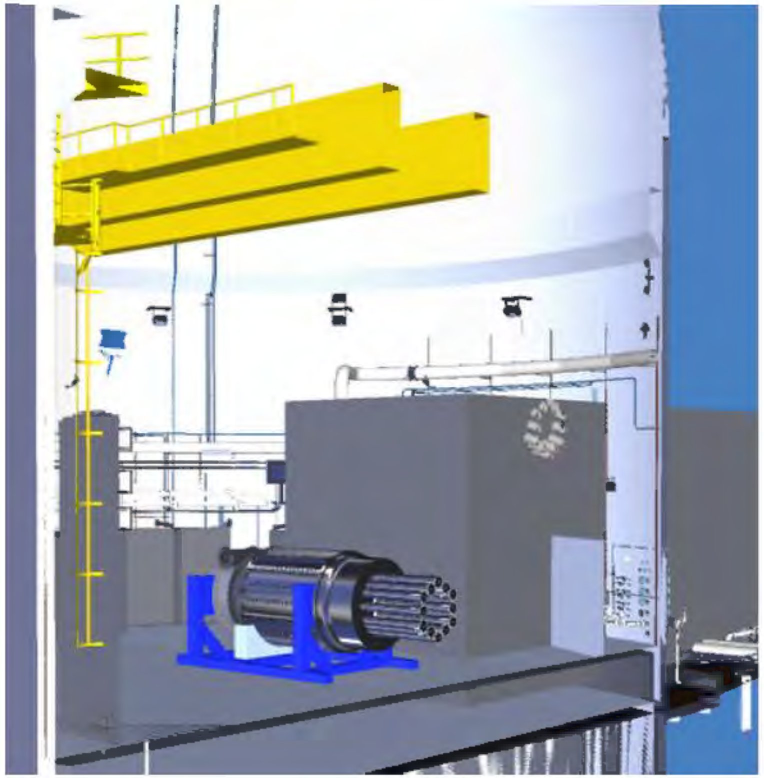
Current Status:
https://www.nrc.gov/reactors/new-reactors/advanced/licensing-activities/pre-application-activities/evinci.html

#	Topic	Submittal Wave	#	Topic	Submittal Wave	#	Topic	Submittal Wave
1	Facility Level Design Description	Submitted - 1	13	Advanced Logic System®(ALS) v2	Submitted - 3	25	Inservice Inspection Program/Inservice Testing Program	Submitted - 5
2	Principal Design Criteria	Submitted - 1	14	Component Qualification	Submitted- 3	26	Post-Accident Monitoring System	Submitted - 5
3	Safety and Accident Analysis Methodologies	Submitted - 1	15	EPZ Sizing Methodology	Submitted - 3	27	Equipment Qualification	Submitted - 5
4	LMP Implementation	Submitted - 1	16	Physical Security	Submitted - 3	28	PRA Program Strategy	Submitted - 5
5	Regulatory Analysis	Submitted - 2	17	Heat Pipe Design, Qualification, and Testing	Submitted - 3	29	Fire Protection	Submitted - 5
6	Deployment Model	Submitted - 2	18	Nuclear Design	Submitted - 3	30	Cyber Security	Submitted - 5
7	Safeguards Information Plan	Submitted - 2	19	U.S Transportation Strategy	Submitted - 3	31	Radiation Protection and Contamination Methodology	Submitted - 5
8	Test and Analysis Process	Submitted - 2	20	Phenomena Identification and Ranking Table (PIRT)	Submitted - 4			
9	Functional Containment and Mechanistic Source Term	Submitted - 2	21	Integral Effects and Transient Testing	Submitted - 4			
10	Composite Material Qualification and Testing	Submitted - 2	22	Refueling and Decommissioning	Submitted - 4			
11	Fuel Qualification and Testing	Submitted - 3	23	Seismic Methodology	Submitted - 4			
12	Code Qualification	Submitted - 3	24	Operations and Remote Monitoring	Submitted - 4			

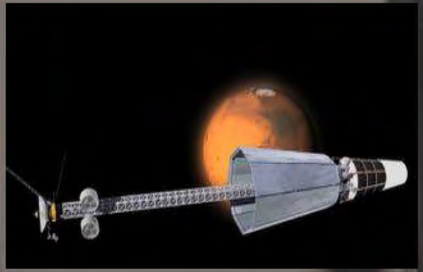
Nuclear Test Reactor

- The U.S. Department of Energy (DOE), through the National Reactor Innovation Center (NRIC) awarded Westinghouse funding for front-end engineering and experiment design (FEEED) process to test microreactor designs in the Demonstration of Microreactor Experiments (DOME) test bed at Idaho National Laboratory
- Reactor system, Reactivity Control systems, heat exchanger, and targeted I&C
  - Prototypical unit cell (e.g. fuel-assembly) dimensions
- 3 MWt – 20% scale power





eVinci Technologies Achievements- Q4 2023



$16.9M awarded from Air Force Research Laboratory's (AFRL) JETSON

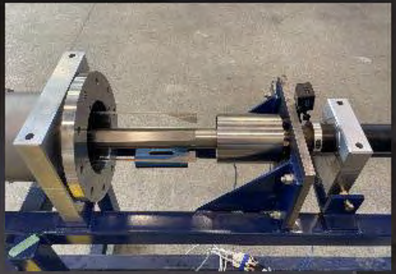
October 2

Selected by Idaho National Labs for FEEED study to plan for deployment of the eVinci Nuclear Test Reactor at INL

October 23

Launch of the eVinci Technologies Accelerator at 51 Bridge St. Etna, PA

October 24

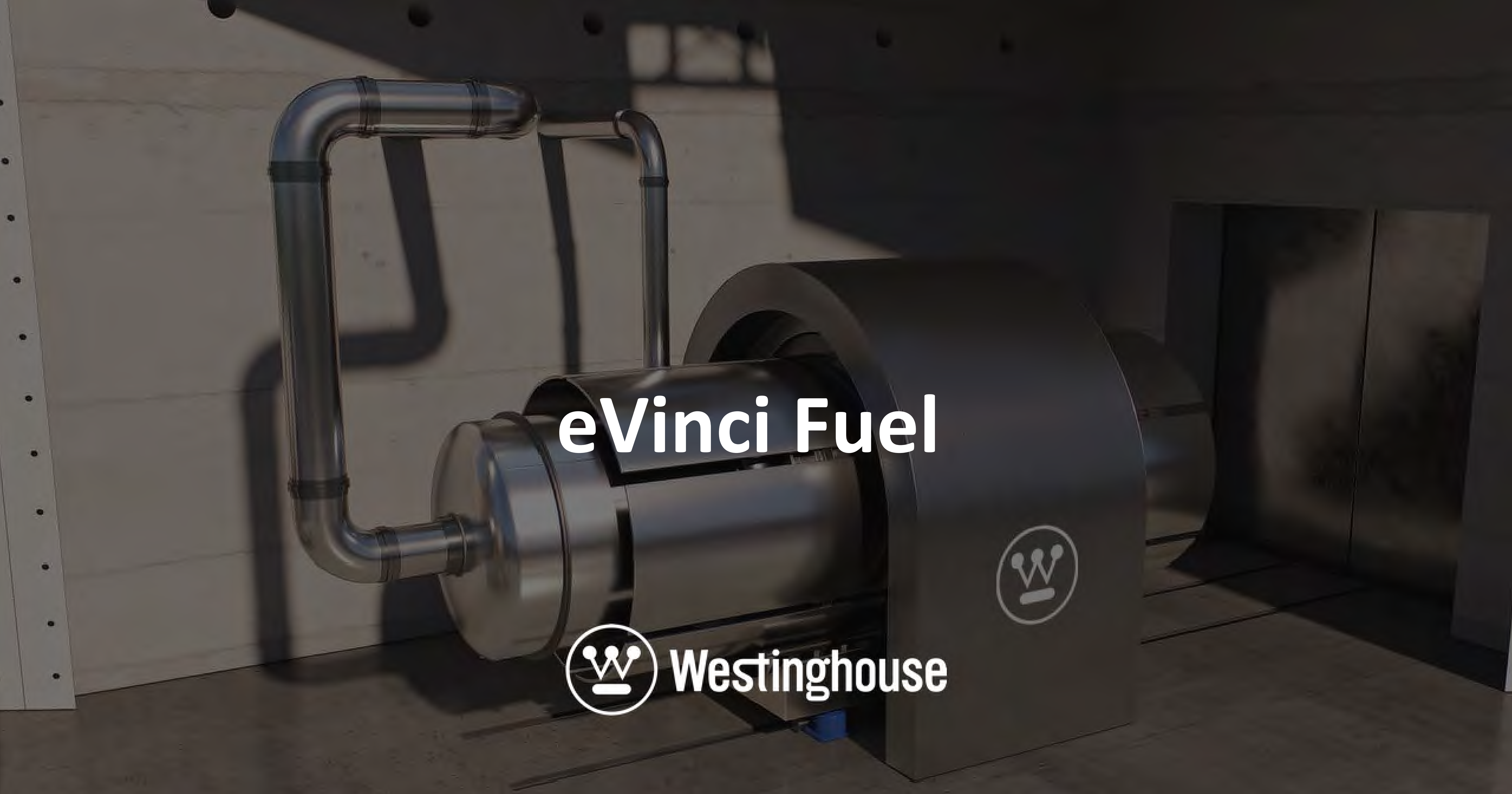


Completed testing of key safety components Control Drums and Shut Down Rods

November 6

First eVinci customer announcement in Saskatchewan with Saskatchewan Research Council

November 27



eVinci Fuel

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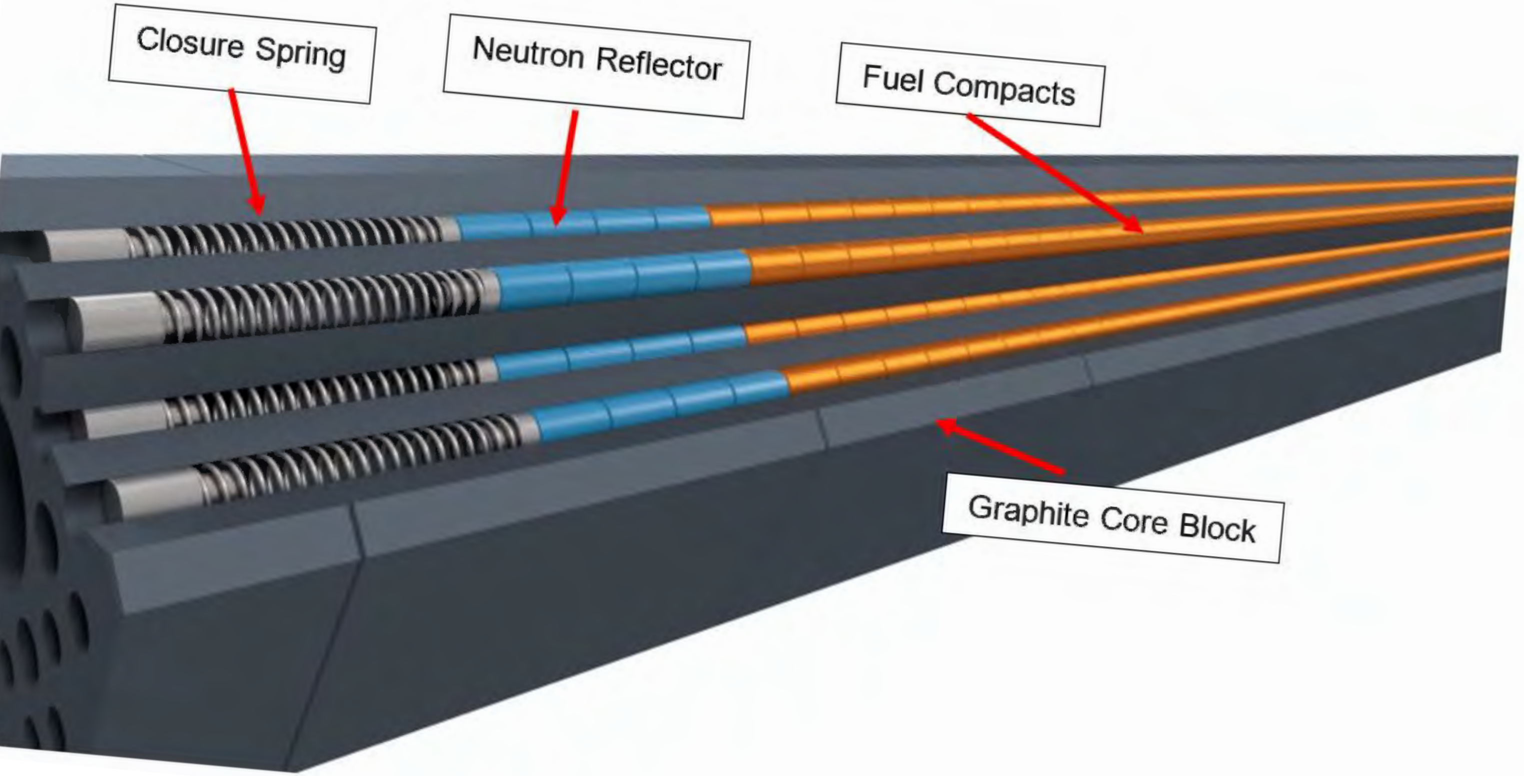
Fuel Channel Design Overview

- Fuel components in the core block’s fuel channel:
  - TRISO fuel compacts
  - Graphite reflector compacts
  - Fuel springs



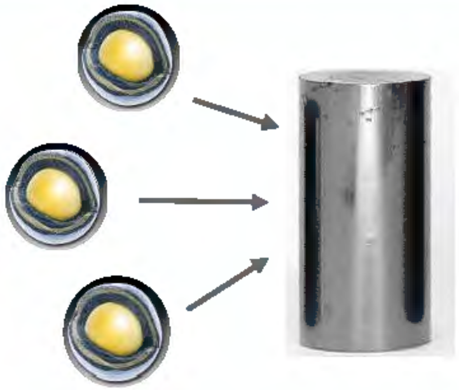
- Same component designs in both demonstration Nuclear Test Reactor (NTR) and commercial eVinci microreactor core designs

eVinci Fuel Design

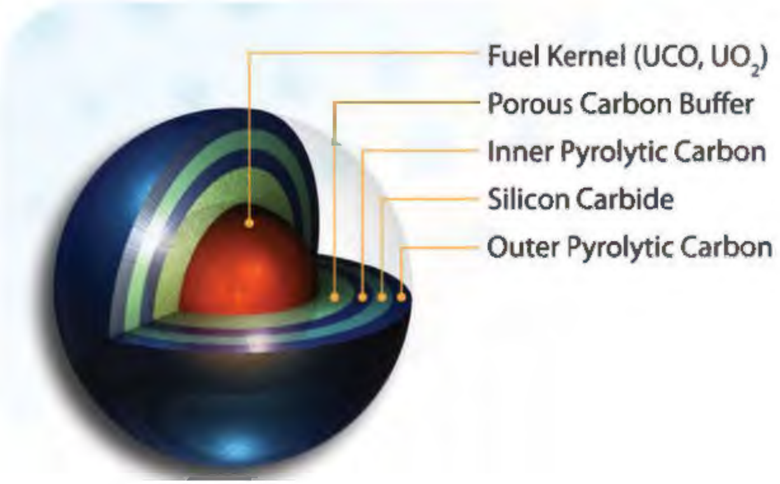
TRISO Fuel

Why TRISO?

- While the eVinci heat pipe reactor is versatile to fuel selection, the design baseline uses TRISO fuel, and the safety case credits the TRISO particle layers as a functional containment barrier
- TRISO fuel is the only high temperature fuel that has regulatory acceptance and extensive qualification basis
- Design goal is to remain within the bounds of the AGR qualification envelope

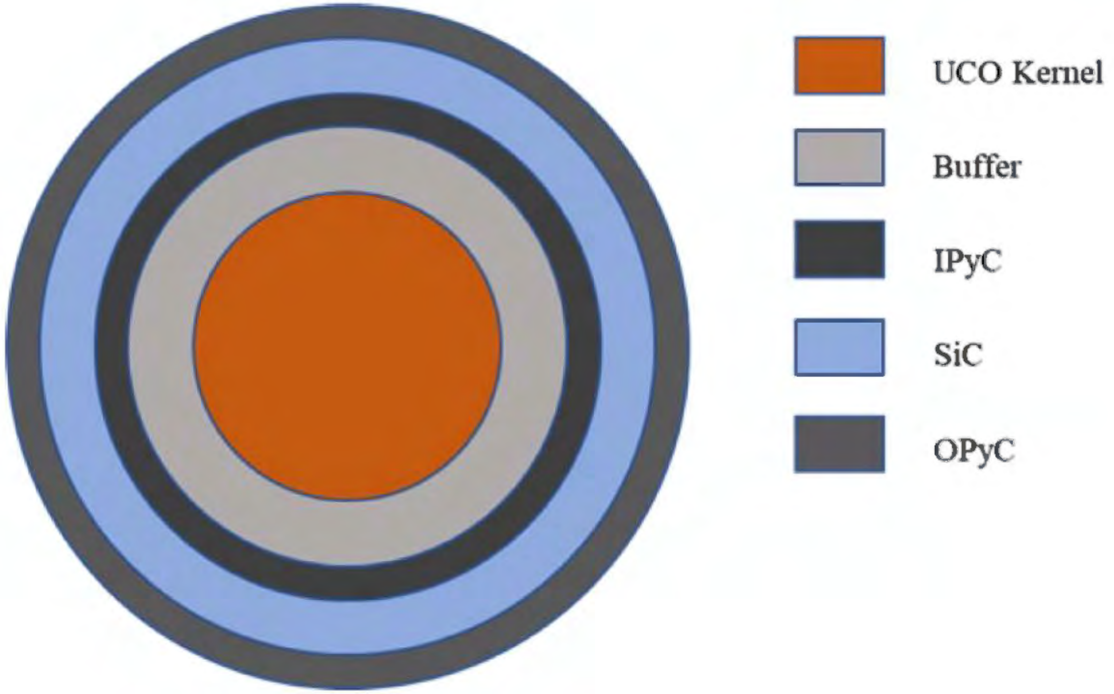


UCO HALEU (<19.75wt% ^{235}U) TRISO coated particles compacted in graphite pellets



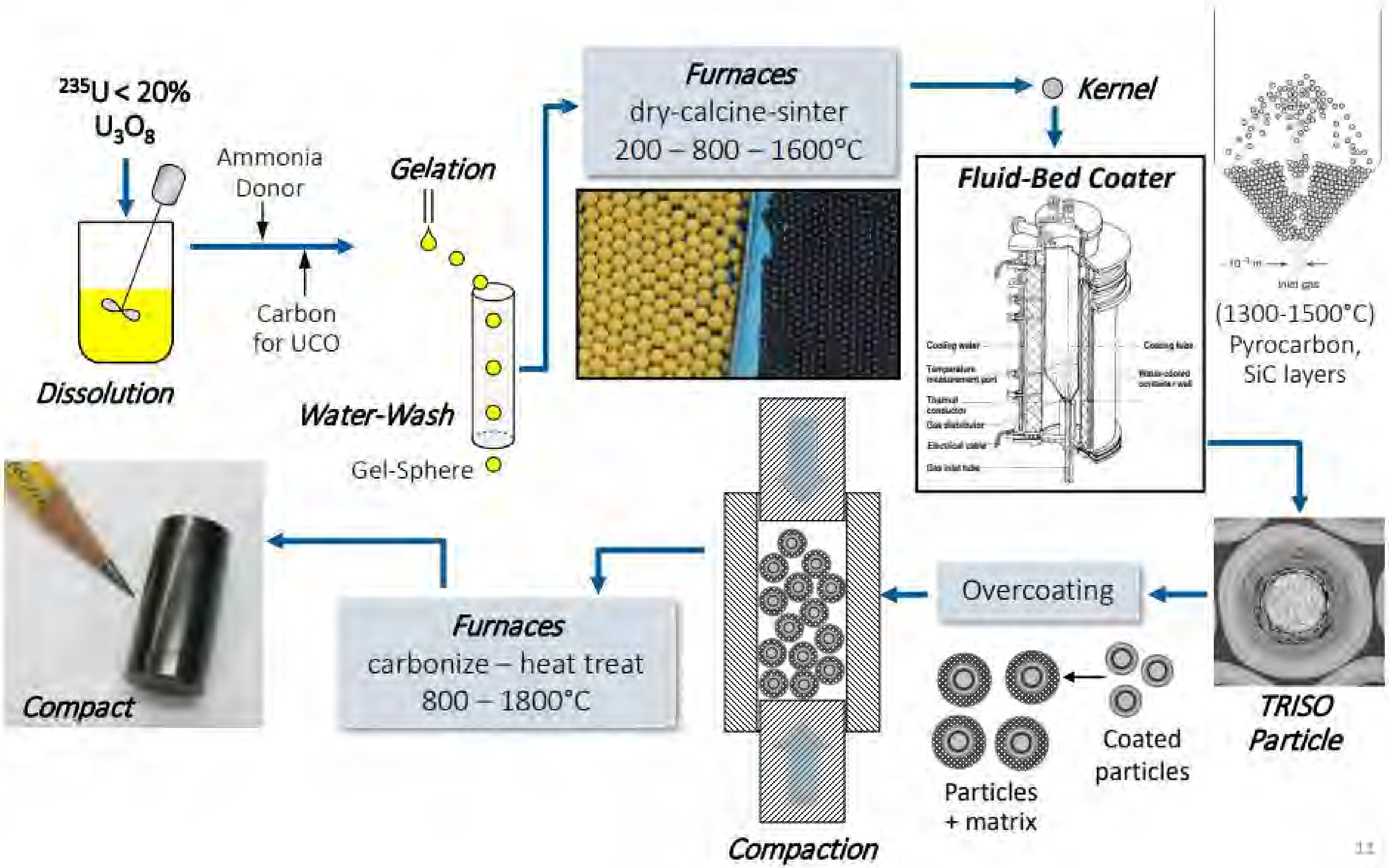
TRISO Particle Fuel Design

- **UCO kernel**: mixed uranium oxide and uranium carbide
  - Primary barrier to fission product (FP) release
  - Addition of carbon → oxygen "getter"
- **Buffer:** low-density pyrolytic carbon
  - Accommodates kernel swelling during irradiation
- **IPyC:** inner pyrolytic carbon
  - Acts as a barrier to prevent CO gas and FPs to reach the SiC layer
- **SiC:** provides structural integrity for TRISO particle
  - Responsible for retention of most FPs
- **OPyC:** outer pyrolytic carbon
  - Protects SiC layer from physical damage during handling and compacting
  - Provides the last barrier in particle for FP retention



Tristuctural Isotropic (TRISO)-coated particle

TRISO Fuel Fabrication



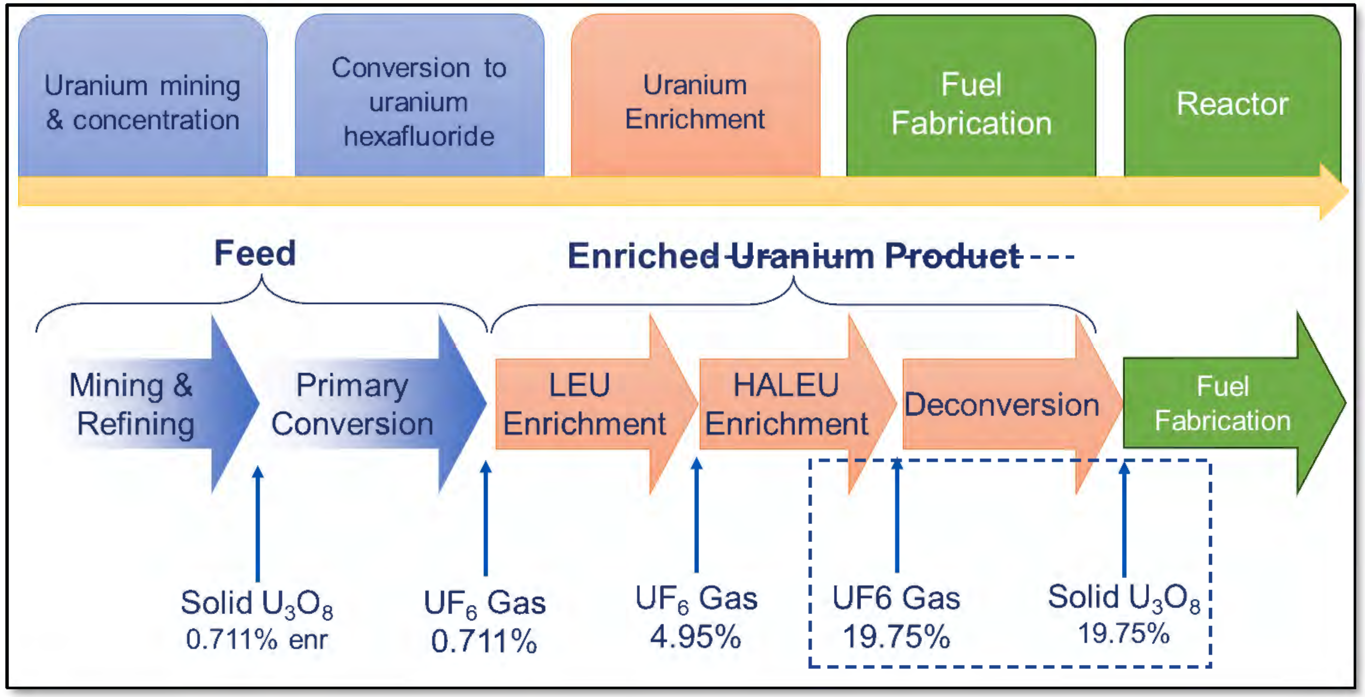
From INL/MIS-19-52869-Revision-0, "TRISO Fuel: Design, Manufacturing, and Performance" (https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_24838.pdf)

HALEU Availability Challenges

defined as Uranium between 5-20% ^{235}U; eVinci uses 19.75%

There is currently no commercial-scale production of HALEU feed for advanced reactor fuel production outside of Russia

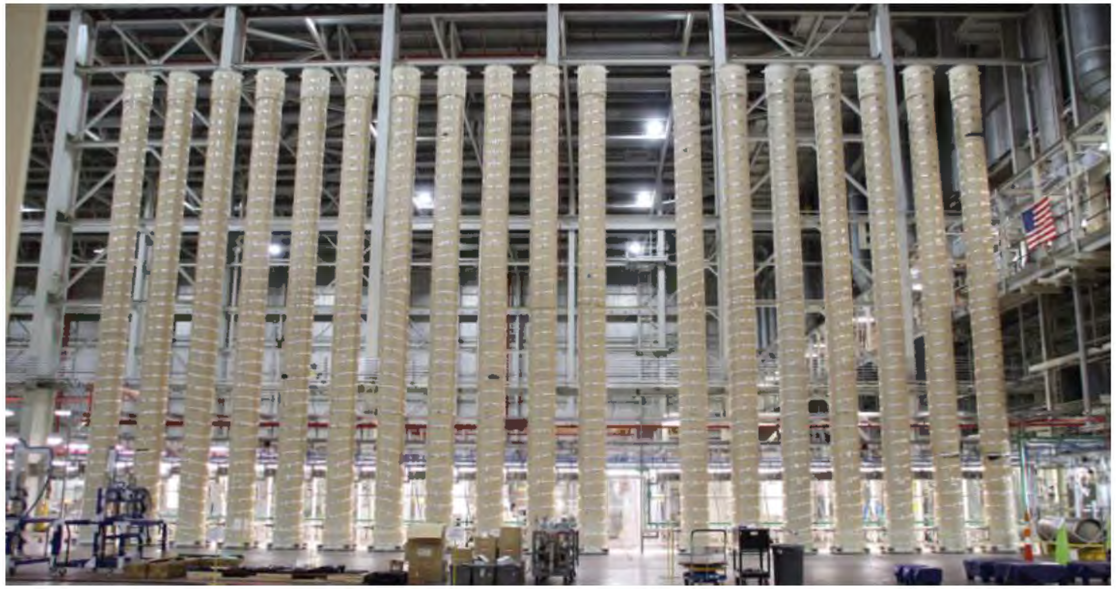
- Two supply chain challenges to address:
  1) UF_6 enrichment to 20%
  2) "Deconversion" to change the UF_6 chemical form post-enrichment to oxide for fabrication
- HALEU will require smaller, purpose-built facilities because of higher enrichment levels



Infrastructure needed for HALEU supply chain

Securing HALEU for Early Demonstrations

- The US Government has limited legacy stocks of HALEU they will make available for test reactor demonstrations
  - There is intense industry competition for large quantities of DOE legacy HALEU
  - DOE has also contracted with Centrus to produce and stockpile HALEU UF6
- DOE has communicated they will prioritize near-term HALEU to DOE Advanced Reactor Demonstration Program (ARDP) awardees showing “highest level of maturity in terms of reactor technology and fuel fabrication”



Centrus

Commercial Quantities of HALEU

- Department of Energy established the HALEU Availability Program (HAP)
  - The HAP provides DOE-funded awards to construct and operate 1) enrichment & 2) deconversion facilities in the US
  - HAP will produce 25 MT HALEU/yr for advanced reactor fleet
  - Deconversion RFPs were due Feb 2024, Enrichment RFPs due Mar 2024. Anticipate Deconversion award later this year, Enrichment in early 2025.
  - Over th
  - President signed Water and Energy bill providing $2.7M for HALEU
- Anticipate similar funding in UK through Department of Energy Security and Net Zero (DESNZ)
- DOE also preparing an award opportunity for HALEU transportation package vendors

Integrated Dry Route (IDR) Deconversion

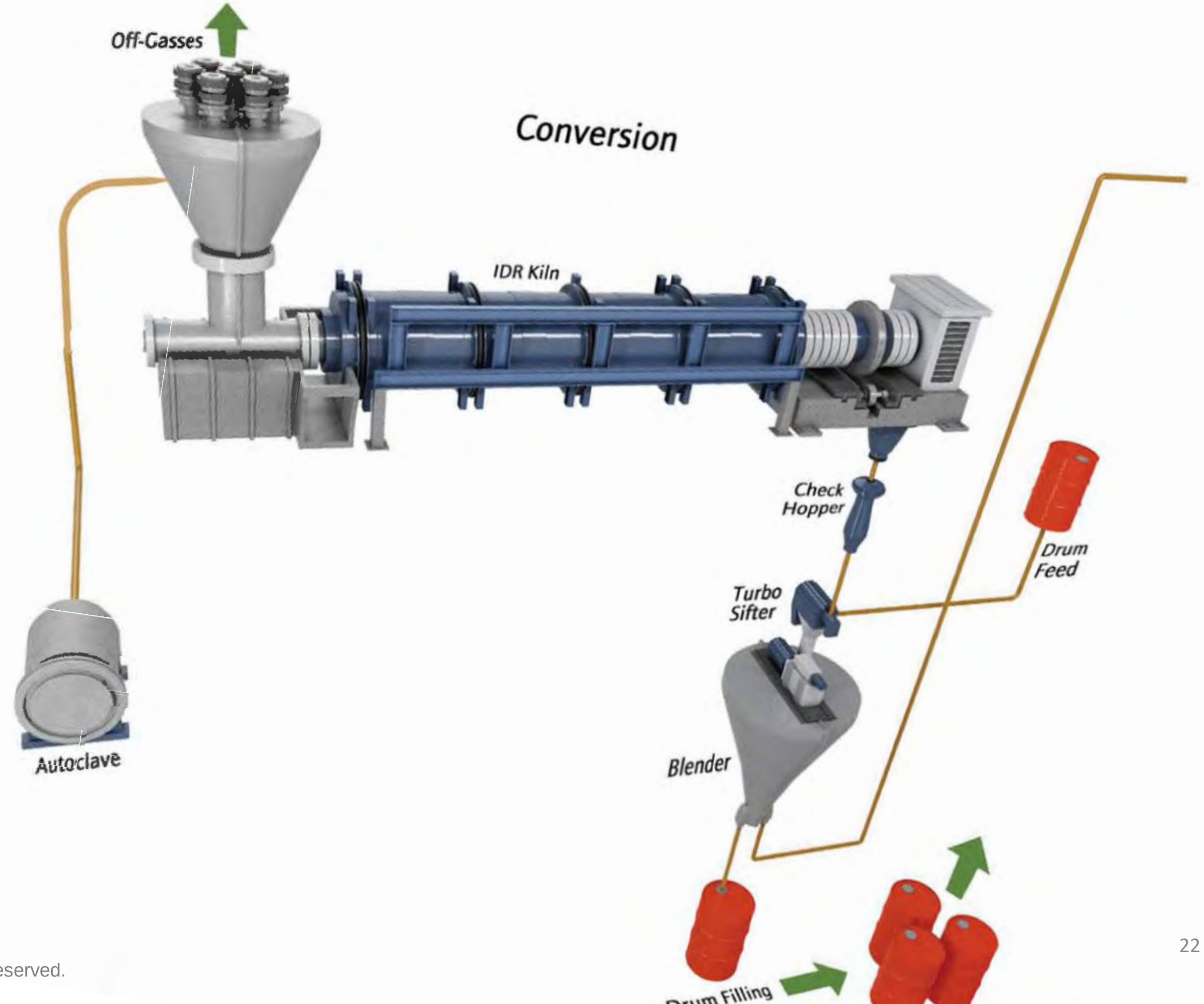
Feed is UF6

Two-stage process:

- UF6 to UO2F2 (flame reactor)
- $UF_6 + 2H_2O \rightarrow UO_2F_2 + 4HF$

Calcine UO2F2 to UO2 powder for UO2 pellet manufacture:

- $UO_2F_2 + H_2 \rightarrow UO_2 + 2HF$



Scaling Deconversion for HALEU

- The Integrated Dry Route conversion process was designed for high-volume LEU UO_2 production
- Existing equipment scales very well to LEU+ with very minor modifications to the kiln and associated systems
- Scaling to HALEU requires smaller scale for criticality safety control, but the basic chemistry works and can also be tweaked to produce U_3O_8 as an intermediate fuel form for e.g. TRISO production:

$$3UO_2F_2 + H_2 + 2H_2O \rightarrow U_3O_8 + 6HF$$

- Westinghouse production of U metal has historically been via the traditional magnesiothermic or calciothermic routes:
  - $UF_4 + 2Ca \rightarrow U + 2CaF_2$
- HALEU U metal can be produced via this route (which also requires UF_6 to UF_4 conversion) or via other routes e.g., electrolytic reduction from oxide

Metal Reduction Reactor Cool-Down Pens at Westinghouse's Springfields facility, circa 1959

Thank You

Questions?

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