Overview of X-Energy's 200 MW_{th} Xe-100 Reactor

NUPIC Vendor Conference

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Xe-100 Technology

- On April 1, 2021, X-energy, Energy Northwest, and the Grant County Public Utility District signed a memorandum of understanding establishing the mutual partnership to support the development and commercial demonstration of the country's first advanced reactor.

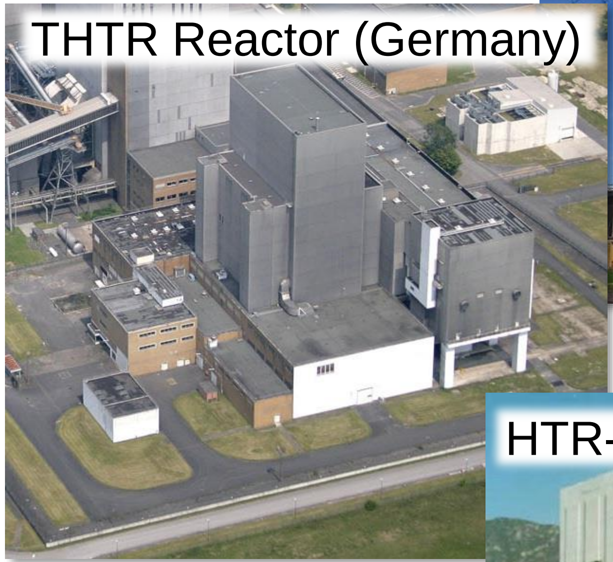
- The TRi-energy partnership provides the framework for the team's deployment of 4 Xe-100s under the DOE's ARDP.

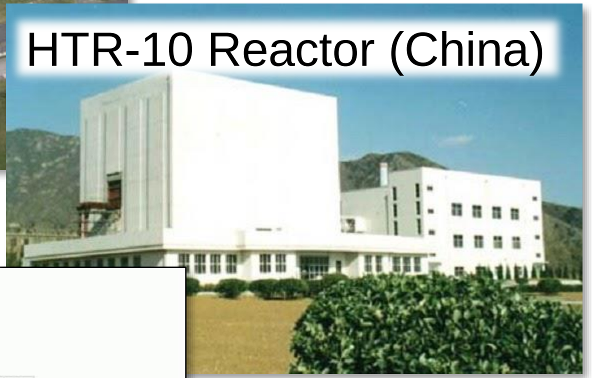
- The TRi-energy will also enable Energy Northwest and Grant County to meet the State of Washington's clean energy goals established under the Clean Energy Transformation Act to deliver 100% carbon-free electricity by 2045.

Advanced Reactor Design

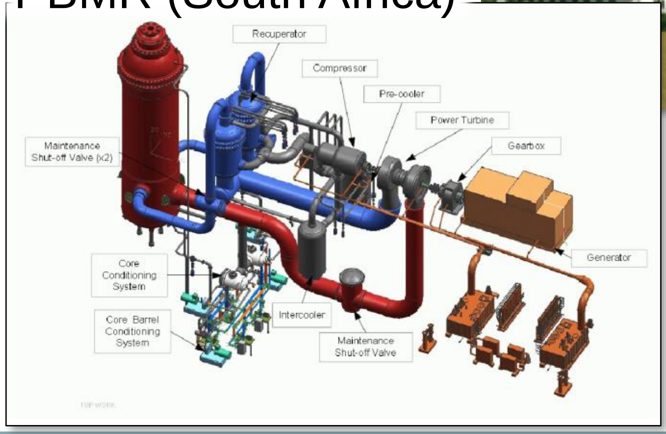
Xe-100 Technology

- The HTGR is a most mature GEN IV advanced reactor technology, both in terms of Reactor and Fuel
- X-energy did not start from scratch – We benefit from a rich history of design development, testing and operation of Pebble Bed Reactors across the globe
- R&D requirements were identified in 2015 and were fully funded through to July 2021 by DOE ARC program (currently 80% complete)
- The Xe-100 design is a cutting-edge design evolution that can be deployed in the next 5-6 years while providing a cost competitive, low risk, carbon free, versatile energy source



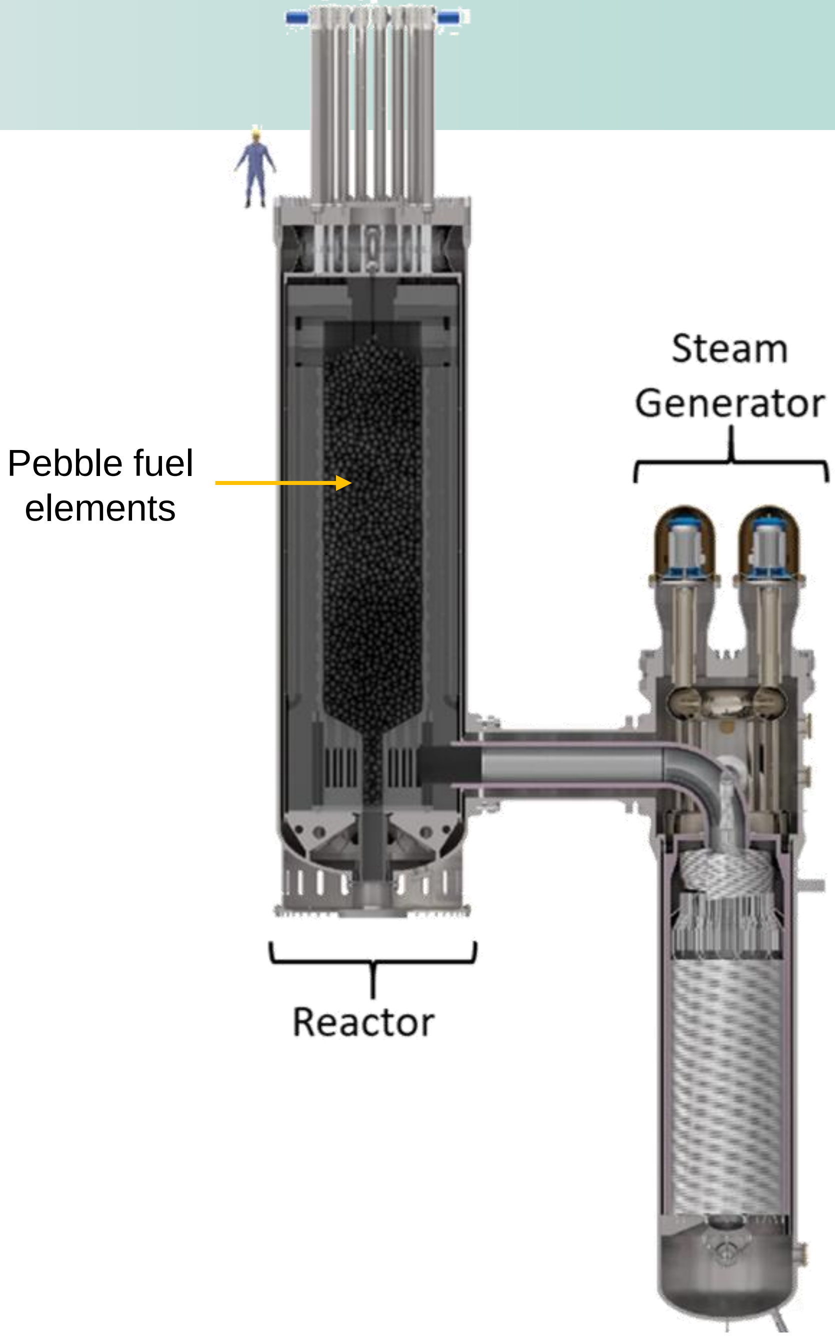


PBMR (South Africa)



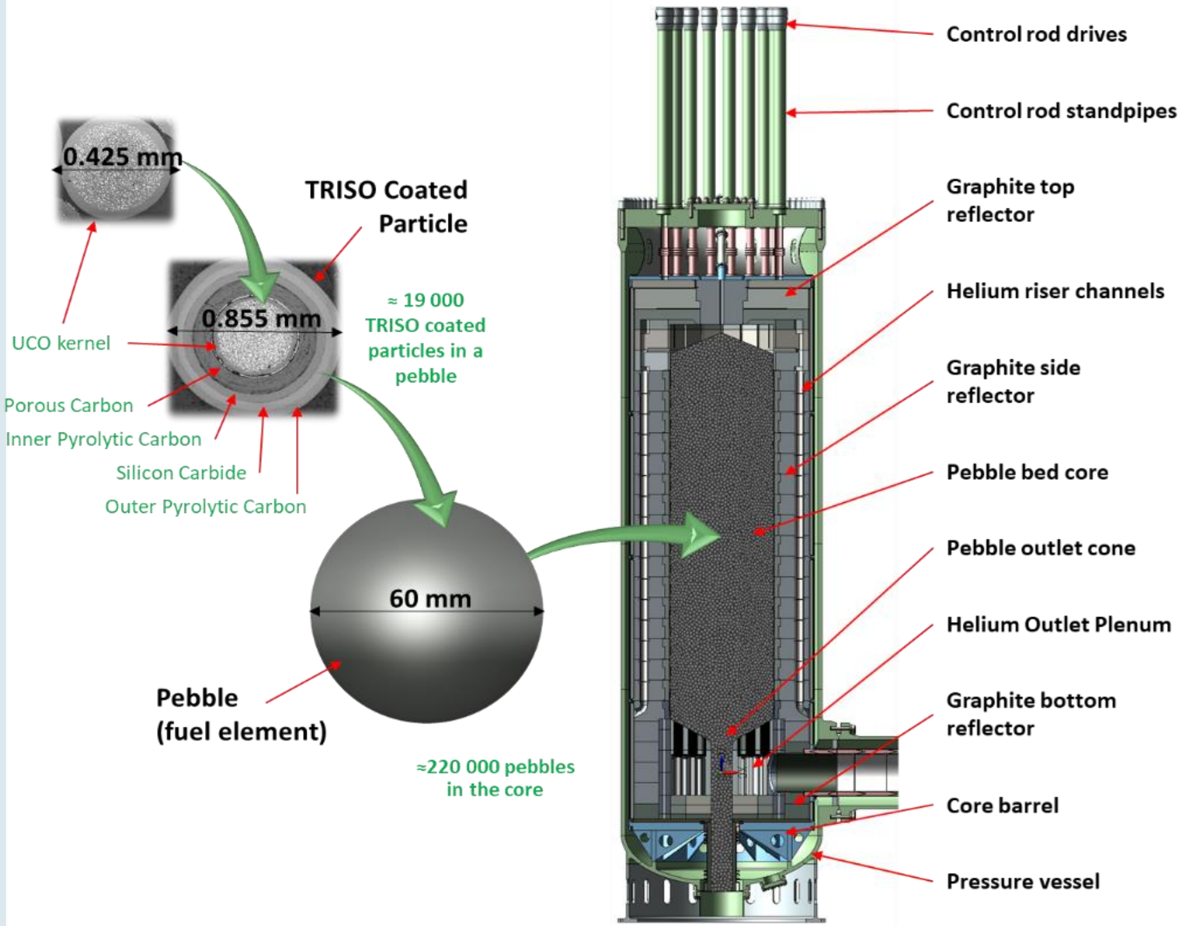
The Xe-100 Design Solution

- Proven High Temperature Pebble Bed Reactor – Derived from +50 years of design and development – Significantly reducing costs enabling competitive deployment
- Proven fuel technology (US DOE Advanced Gas Reactor irradiation program)
- Versatile Nuclear Steam Supply System (NSSS) deployable for electricity generation and/or process heat applications
- Conservative design not requiring new material development and or code cases (saving 15 – 20 years)
- Steam pressure and temperature designed to provide steam to multiple Commercially Off The Shelf Steam Turbine / Generator sets (typically those used in Combined Cycle Power Plants)



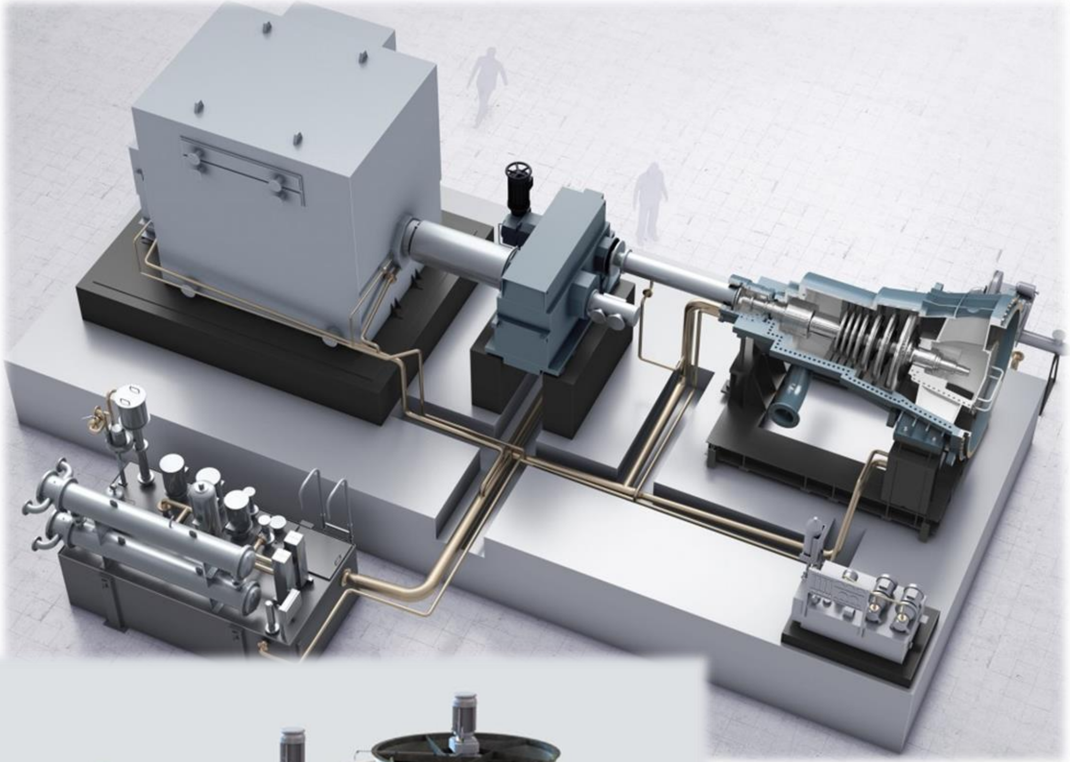
Basic Core Design Parameters

Maximum thermal power rating	200	MW
Effective core volume	41.56	m^3
Core average power density	4.81	MW/m^3
Effective core height	9.18	m
Pebble passes	6	times
Helium inlet / outlet temperature	260 / 750	°C
Helium flow rate (assume 9.6% bypass)	71.1	kg/s
Inlet pressure	6.0	MPa
Side reflector thickness	900	mm
Reactor core barrel thickness	35	mm
Reactor pressure vessel OD	4.78	m
Reactor pressure vessel thickness	95.0	mm
Reactor pressure vessel height	16.4	m
RCSS = RCS + RSS absorber rod banks	9 / 9	rods



Conventional Island – Power Conversion

- 100% Commercial Off The Shelf steam turbine generator set – including condenser and all auxiliary systems
- High turbine thermal efficiency up to 42.3%
- Skid mounted turbine allowing fast swap out/replacement instead of in-situ refurbishment
- Condenser cooling can be done using wet or dry cooling modules
- Rankine cycle cooling uses off the shelf modular dry/wet or hybrid cooling towers



Standard Technology Offering (4-Reactor Plant)

RB: Reactor Building
TB: Turbine Building
AB: Admin Building
HVY: High Voltage Yard
CR: Control Room
EB: Electrical Building
CT: Cooling Towers
HE-SFS: High Energy Spent Fuel Storage
ISFS: Intermediate Spent Fuel Storage
WS: Work Shop
CST: Condensate Storage Tanks
HeST: Helium storage
LW: Liquid waste
ST&IC: Stores and - Inventory Control
RW: Rad. Waste Building

Standard power plant consists of four independent Reactor Modules (Reactor and Steam Generator)

Each reactor module is connected to its own Steam Turbine/Generator

Single shared control room with only three operators

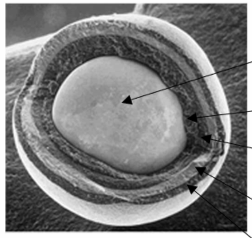
Resource Utilization

TRISO-X Fuel Production

TRISO Coated Particle Fuel is the Key to Safety

- Each TRISO particle forms a miniature containment vessel that retains radionuclides at the source for full spectrum of off-nominal events
- Demonstrated ability to withstand extremely high temperatures for extended periods (1800 °C for 300+ hours) without fuel failure
- High level of maturity due to >$250M investment by DOE in design and qualification and characterization of the TRISO fuel
- World's only active TRISO fuel fabrication facility.

TRISO Coated Particle



History

HTGR	
1954	P Fortescue
1956	R Schulten

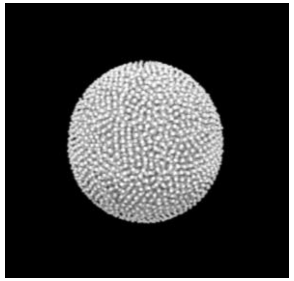
History of coated particles:	
1957	R A U Huddle
1959	W Goeddel
1961	J Oxley, Battelle fluidised bed coating

Manufacturing	
United States	China
United Kingdom	South Africa
Germany	South Korea
Russia	Japan
France	

FUNCTIONS: TRISO COATED PARTICLE

- Fuel Kernel – ρ=10.4 g/cm^3; D=0.350 mm
  - Fission energy source
  - Retain short-lived radionuclides
- Buffer layer (porous carbon) – ρ=1.05 g/cm^3; T=0.100 mm
  - Void volume for fission gases
  - Accommodates fuel kernel swelling
  - Protect PyC and SiC layers from fission product recoil
- Inner Pyrocarbon (iPyC) – ρ=1.85 g/cm^3; T=0.040 mm
  - Diffusion barrier to fission products
  - Provide mechanical substrate for SiC deposition
  - Prevent Cl_2 from reaching kernel during SiC deposition
- Silicon Carbide (SiC) – ρ=3.2 g/cm^3; T=0.035 mm
  - Primary fission product barrier in all anticipated plant conditions
  - Load-bearing layer for TRISO particle
- Outer Pyrocarbon (oPyC) – ρ=1.85 g/cm^3; T=0.040 mm
  - Provide compressive stress on SiC during irradiation
  - Provide bonding layer with matrix graphite
  - Provide fission product barrier

Prototype pebble mold



Innovative visualization of particles in pebble

First fuel form pebbles produced at ORNL, Fall 2016

DOE's Dr. Rita Baranwal tours TRISO-X Pilot Lab

Fuel is an integral part of the HTGR safety basis and economics

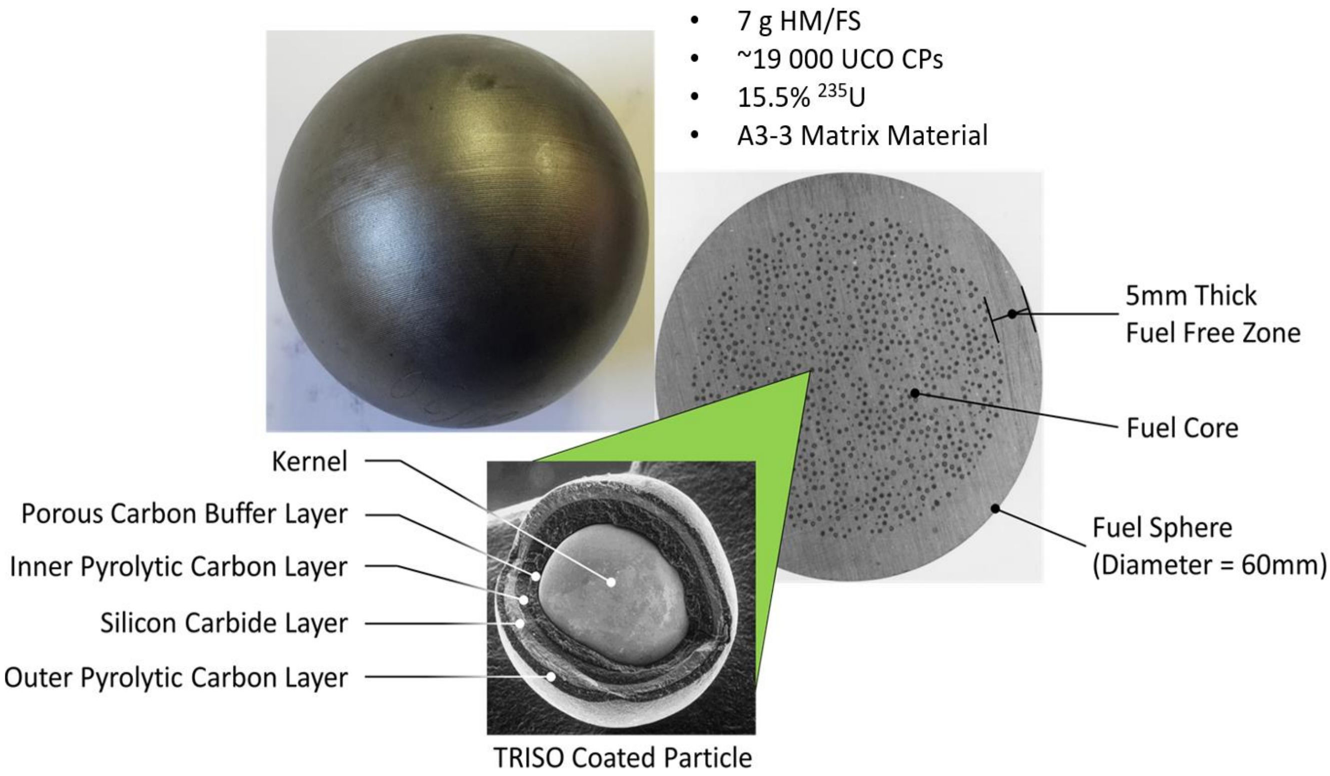
Pebble Fuel Design Data (Equilibrium Core)

- Fuel kernel:

Composition	UCO	
U-235 enrichment	15.5	%
Diameter	0.425	mm
Density	10.4	g/cm^3

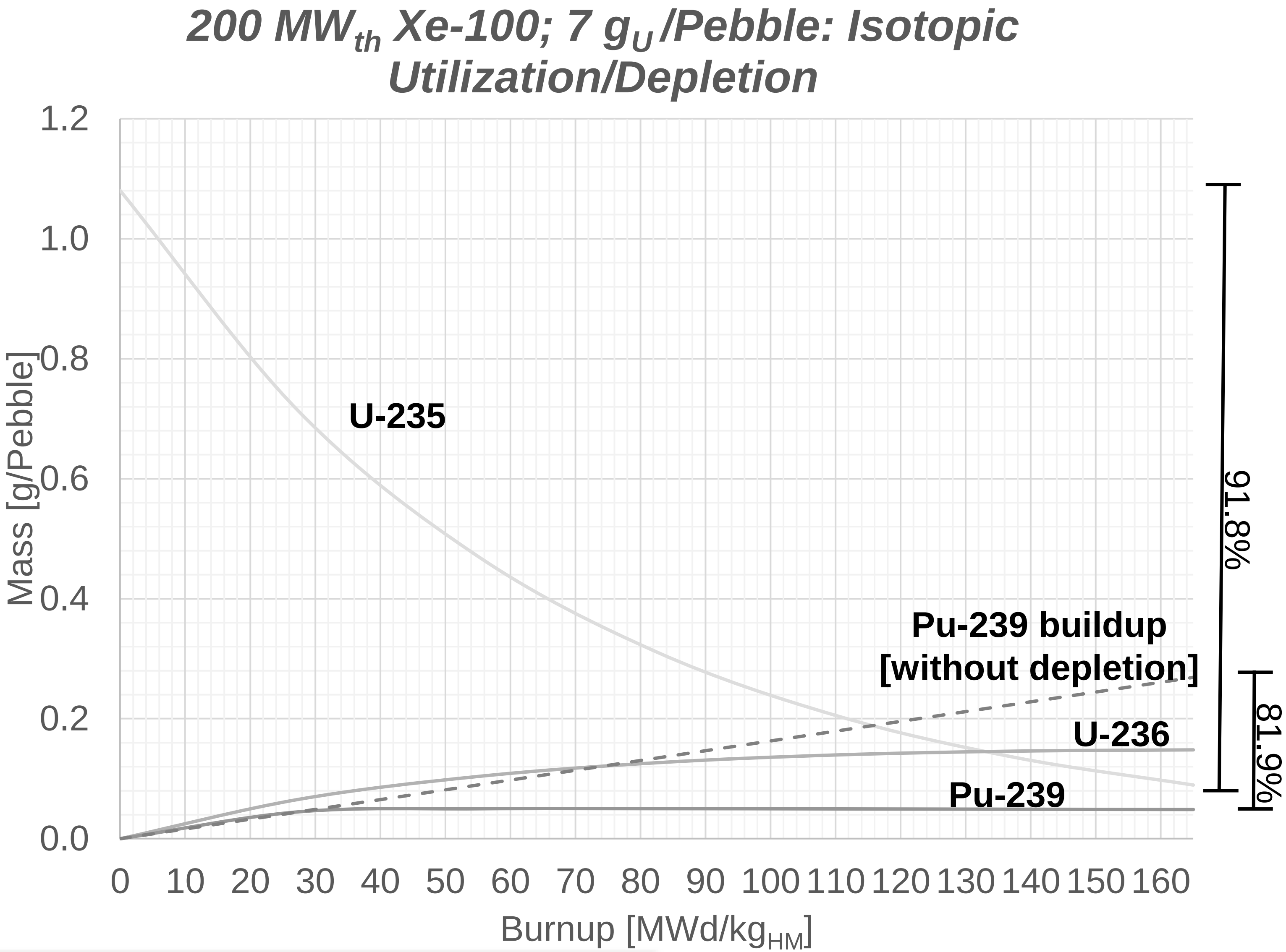
- Coatings:

Coatings:	(mm)	(g/cm^3)
Buffer layer	0.100	≤1.05
Inner dense PyC layer	0.040	1.9
SiC layer	0.035	≥3.20
Outer dense PyC layer	0.040	1.9



Highly In-Situ Utilization of both Fissile & Bred Fissile Materials

- The X-100 achieves exceptional utilization of both the fissile component of the fuel and the bred fissile material
  - The U-235 is depleted by 91.8%
  - An estimation is made of the in-situ utilization of the bred Pu-239 isotope of 81.9%



Xe-100 achieves high in-situ utilization of bred fissile materials

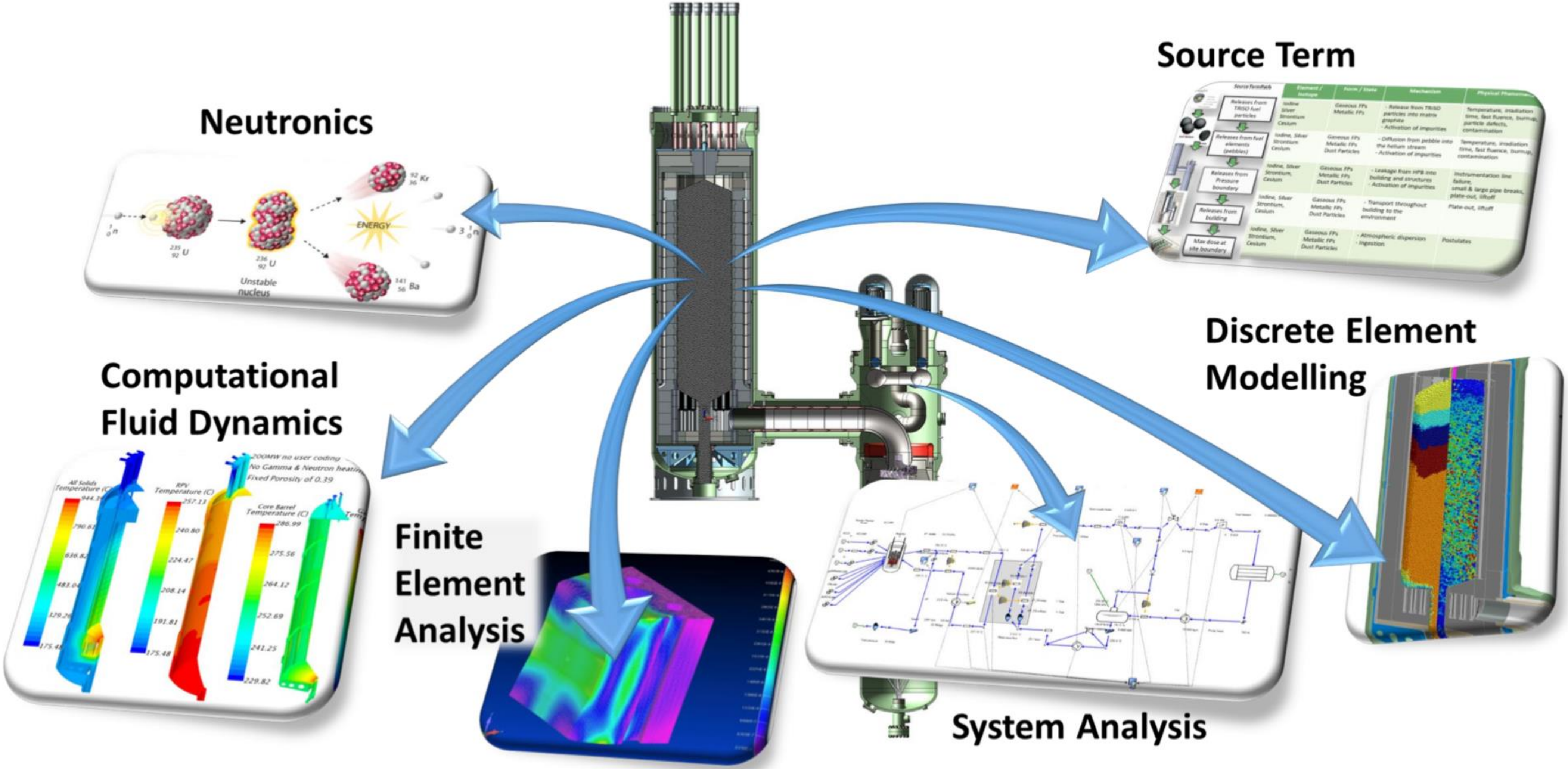
Advanced Fuel Cycle

Fueling/Refueling – Burnup

- The Xe-100 with multi-pass recycling never has to be taken out of service for refueling
- Pebbles that have not yet reached target burnup can be continuously reloaded and recycled during normal reactor operation
- The fuel loading scheme is such that the pebbles remain in the reactor until they reach a target burnup of approximately 168,500 MWd/MgU
- Pebbles with higher burnup are detected by the burnup measurement system (BUMS) and discharged from the internal pebble system and replaced with a fresh pebble
- The pebble dwell period within the reactor core is approximately 1,320 equivalent fuel-power days
- The pebble passes on average 6 times through the reactor during this period
- Fast fission of the uranium-238 present in the fuel makes a minor contribution to power generation (0.5% of total power)
- This results in breeding due to neutron capture where various plutonium isotopes are formed
- In the Xe-100 about 82% of the bred plutonium is consumed in-situ – The bred plutonium is responsible for approximately 35% of total power in the equilibrium core

Challenging Licensing Issues for Commercialization

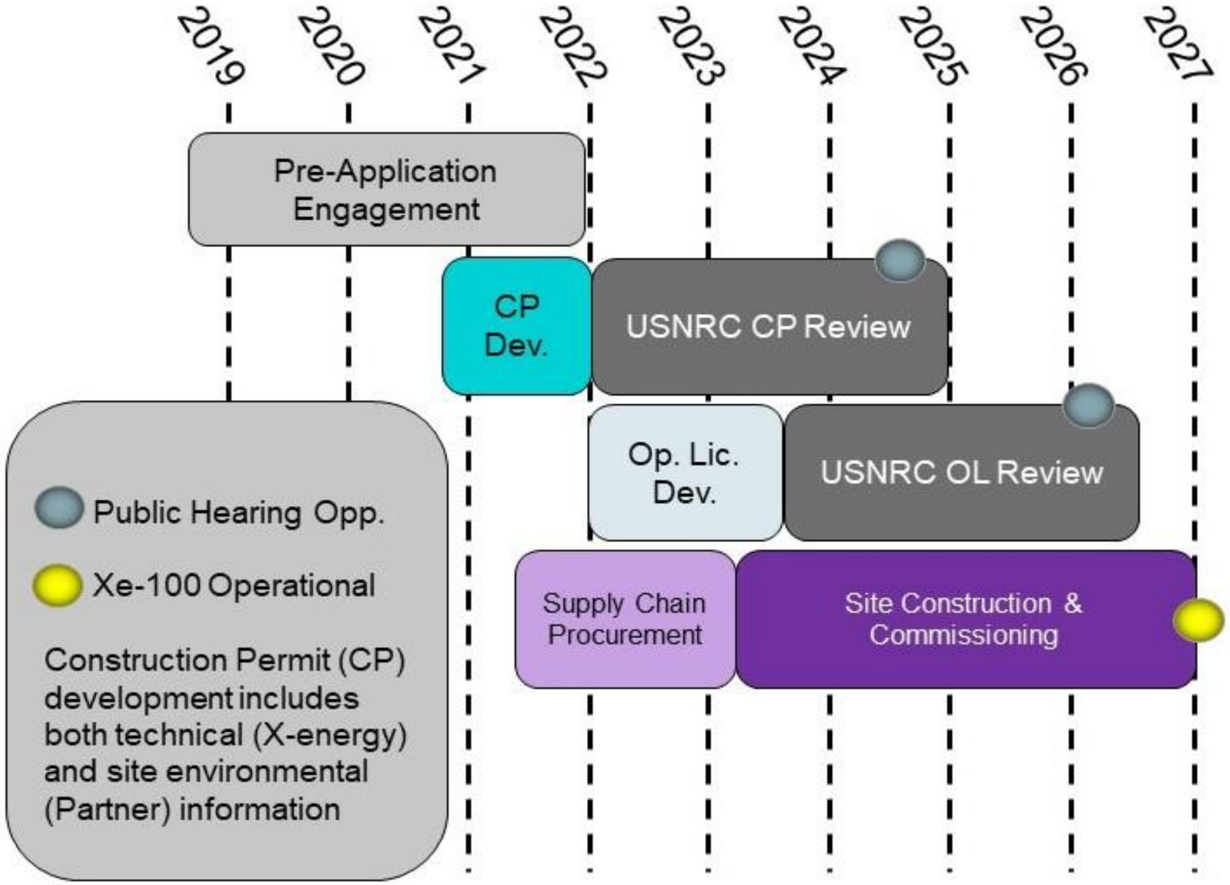
Established modeling and simulation capabilities are applied for design and licensing



We are actively pursuing an aggressive licensing path in the U.S.

- The Xe-100's simple safety case and recent efforts by the USNRC to modernize existing regulations for advanced reactors improve the regulatory environment.
- U.S. regulatory review will most likely follow a 2-part activity (Construction Permit followed by Operating License) for a 1st-of-a-kind unit.
- Subsequent licensees gain review efficiencies through a standardized design process and generic environmental reports in the late 2020's.
- X-energy actively engaged in pre-application activities with the USNRC in 2020/21 to derisk regulatory processes.
- Target application in late 2021/early 2022 depending on the business cases.
- USNRC is adopting less deterministic, more risk-informed licensing posture favorable to X-energy.

"The NRC is the Global Gold Standard [of Regulation]" Doug True, Chief Nuclear Officer, Nuclear Energy Institute



Supply Chain & Staffing Challenges

energy

Construction and Operational Costs

- X-energy has performed a bottom-up costing on as many systems and component of the Xe-100 plant as possible

- Cost estimates are backed by quotes and industry estimates for >95% of the Xe-100 cost items that are derived from the Systems Breakdown Structure

- Focus is provided by multi-level Pareto analyses to help identify the most significant cost areas, as well as for systems and components

- Full-scale requests for proposal were sent to top international manufacturers and suppliers for the identified systems

- Overnight costs and LCOE for the Xe-100 have been estimated for FOAK and NOAK plants:
  - Air-cooled condenser system
  - Wet-cooled condenser system

X-energy: Supply Chain

- Reactor System
  - ✓ Core Internal Graphite Structures
  - ✓ Core Barrel, Reactor Pressure Vessel and Forgings
  - ✓ Reactivity Control & Shutdown System
  - ✓ Pressure Boundary System
  - ✓ Neutron Source
- Nuclear Island Civil Structures
- Steam Generator System
- Spent Fuel Storage System
- Turbine Generator System
- Fuel Handling System
- Nuclear Island Services
- Distributed Control System
- Plant Civil Structures
- Conventional Island Civil Structures
- Helium Circulation System
- Reactor Cavity Cooling System

X-energy: 3 – 5 Year Projected Global Staffing Needs – 480 FTEs

- **Engineering (~380)**
  - Nuclear (75)
  - Mechanical (160)
  - Electrical (15)
  - Chemical (15)
  - Civil (25)
  - Multidiscipline
    - Quality Assurance (30)
    - Licensing (30)
    - Transportation (10)
    - Supply Chain (20)
- **Business (~50)**
  - Marketing, Communications, Business Development (10)
  - Program and Project Managers (30)
  - Contracts Managers (10)
- **Financial (~50)**
  - Accountants (15)
  - Finance (15)
  - Cost Estimators (20)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