Advanced Technologies

Low-Level Radioactive Waste Forum Spring 2024 Meeting

April 3, 2024

NUCLEAR ENERGY INSTITUTE

Topics

- Advanced reactor technologies
  - Light-water SMRs
  - Non-water cooled
  - Micro-reactors
- Key enabling technologies
  - Advanced manufacturing
  - Coolant
  - Fuel
- New uses and applications
  - Remote locations
  - Mobile uses
  - Heat, Hydrogen, Desalination
- Non-power technologies
  - Space
  - Medical
- Fusion

https://www.nei.org/resources/fact-sheets/nuclear-energy-just-the-facts

Current State of Advanced Nuclear

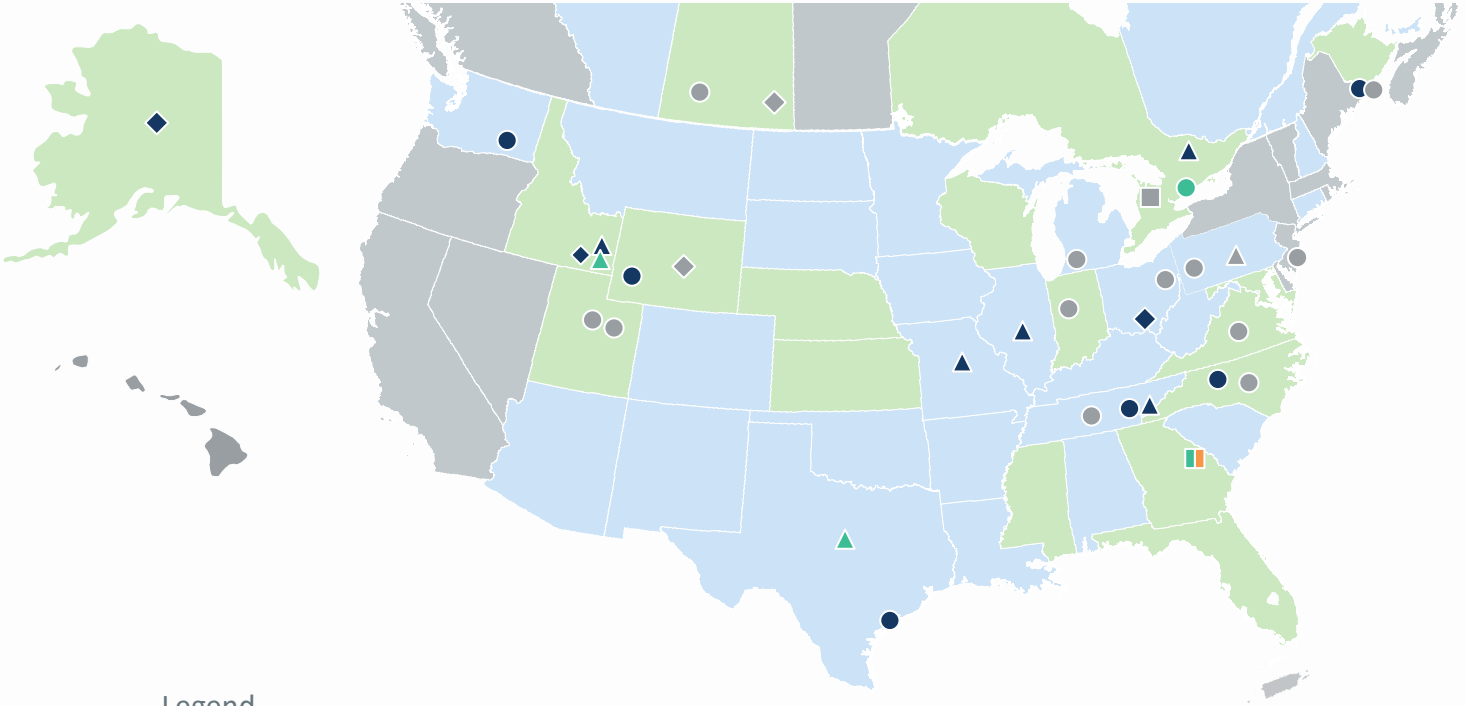
- Over 60 new technologies being actively developed by private sector
- DOE funding 12 different designs, >$5B over 7 years
  - 3 Demonstration Plants
  - 9 Technology Development
- U.S. utilities evaluating nuclear in integrated resource plans (IRPs)
- Growing interest in conversion of coal power sites to nuclear
- Continued strong support in Congress

Technology Developers – NEI Members

Advanced Nuclear Deployment Plans

State support and projects that may be in operation by early 2030s

Updated 12/19/2023



Legend

State Actions – Substantive Incentives

State Actions – Supportive and Exploring

Considered project

Planned project

Under construction

Operating

Large (1,000 MWe)

Small (<300 MWe)

Micro-reactor (<50 MWe)

University / Research / Test

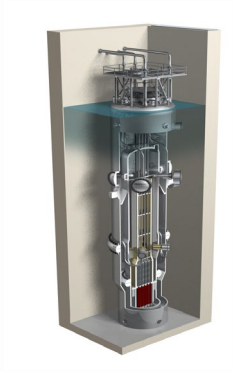
Types of Advanced Reactors

Range of sizes and features to meet diverse market needs

Micro-reactors <50MWe

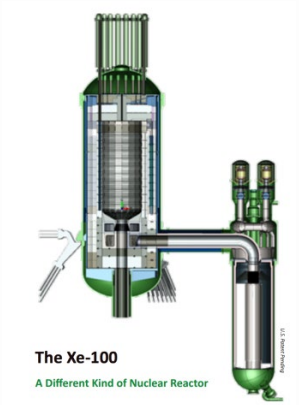
Westinghouse eVinci™ (shown)
Approximately a dozen in development

Light-water SMRs <300MWe



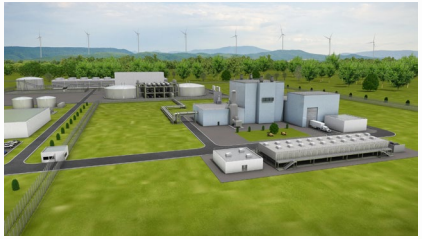
NuScale (shown)
GEH X-300
Holtec SMR-160
Westinghouse AP300

High Temp Gas Reactors



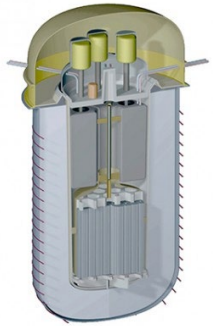
X-energy (shown)
Several in development

Liquid Metal Reactors



TerraPower Natrium™ (shown)
Several in development

Molten Salt Reactors



Terrestrial (shown)
Several in development

Non-Water Cooled
Most <300MWe, some as large as 1,000 MWe

Learn more about innovative technologies with the Nuclear Innovation Alliance.

Cost/Value Proposition

SIMPLER

- Inherent Safety
- Less Equipment
- Smaller Facility
- Regulatory Efficiency

READILY AVAILABLE EQUIPMENT

- Off-the-shelf Equipment
- Proven Performance

FACTORY-BUILT

- 60-80% of Equipment
- U.S. Supply Chain Growth

FASTER CONSTRUCTION

- Smaller Structures
- Assembly vs. Construction
- Modern Construction Methods

IMPROVED PERFORMANCE

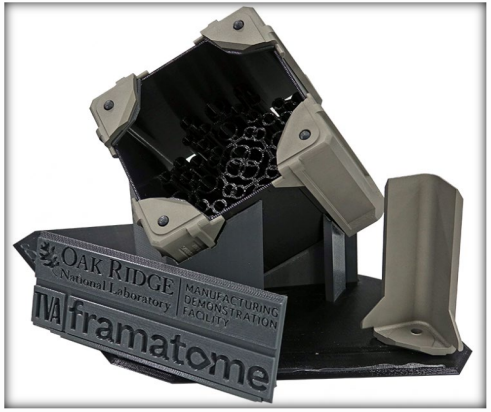
- Higher Thermal Efficiency
- Design and Construction Best Practices
- Operational Excellence

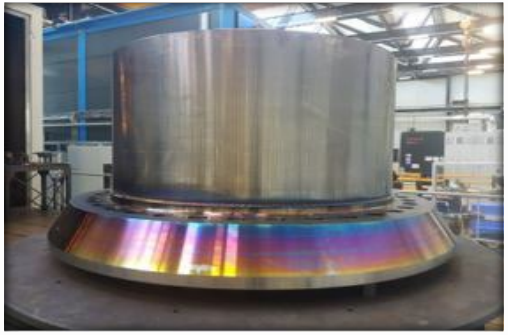
Key Enabling Tech – Adv Manufacturing

- Laser Powder Bed Fusion
- Powder Metallurgy – Hot Isostatic Pressing (PM-HIP)
- Electron Beam Welding (EBW)
- Cold Spray
- Directed Energy Deposition (DED)
- And many others…

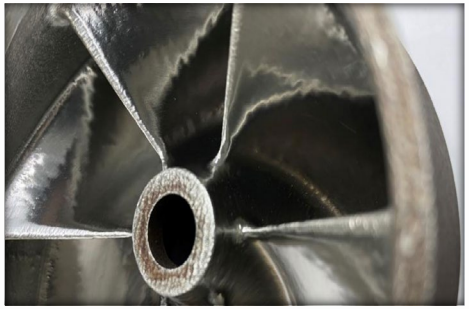
Courtesy: Westinghouse

Courtesy: ORNL

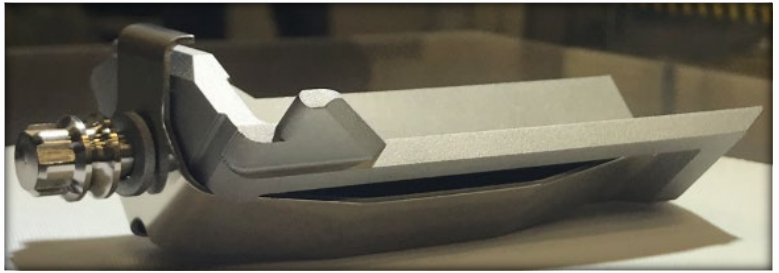




Courtesy: EPRI

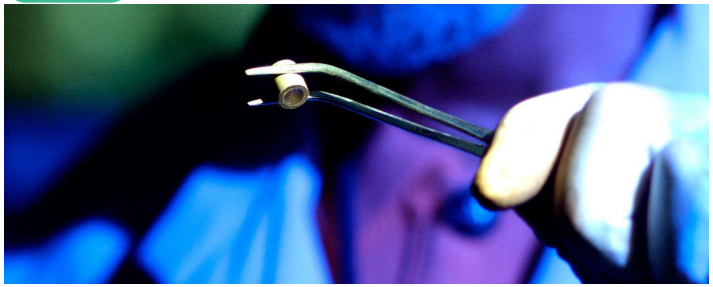


Courtesy: Kairos



Courtesy: Framatome

Technology – Fuel Choice



- Ceramic UO_2 pellets stacked in rods
- 17x17 PWR Fuel Assembly
- Relative size of BWR and PWR fuel assemblies

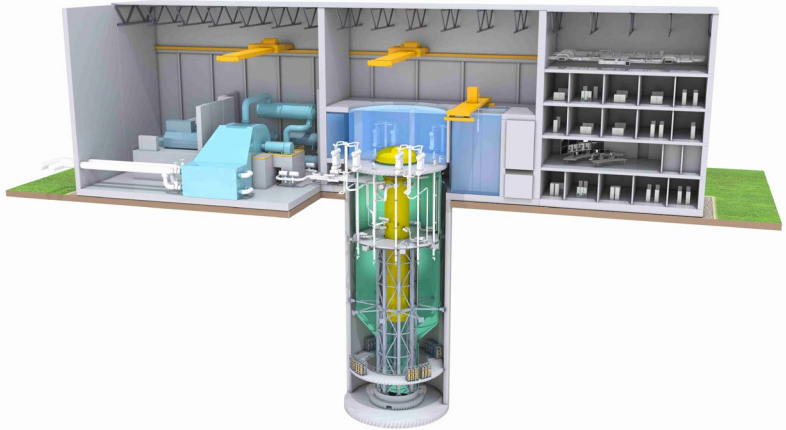
- Light-water SMRs ~1/2 height and/or fewer assemblies, otherwise same

Technology – GEH

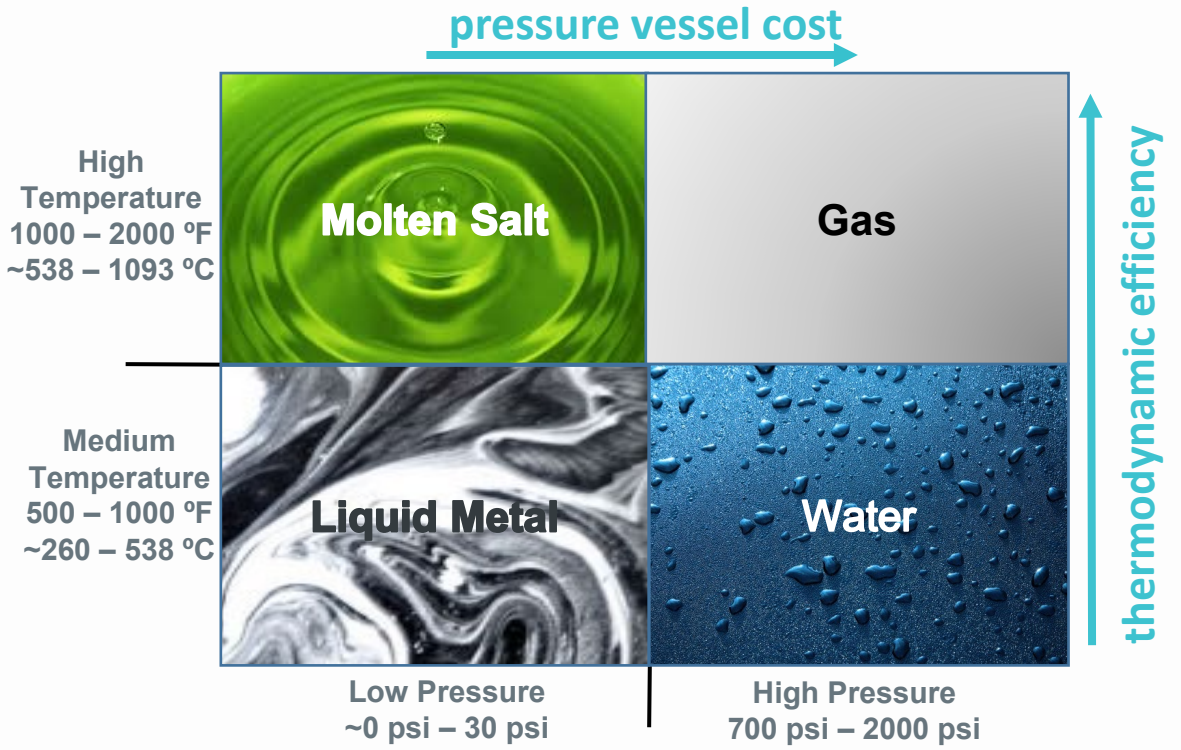
Light-water SMR

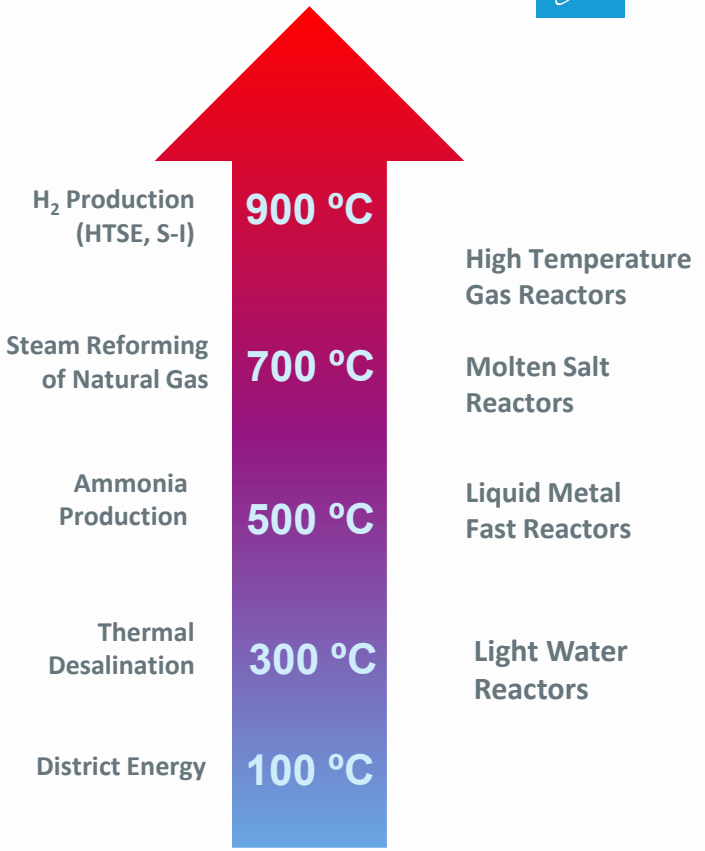
- 300 MWe
- Leverages NRC approved ESBWR
- 7 days of cooling without power or operator actions
- Novel construction techniques
- Existing fuel design
- OPG signed commercial contract
- OPG, TVA, and Synthos Green Energy form Design Centered Working Group

GEH's BWRX-300



Key Enabling Tech – Coolant Choice



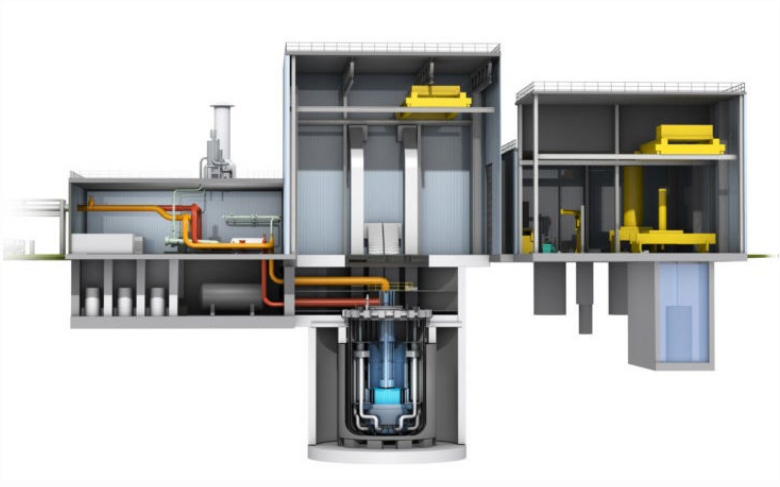


Technology – TerraPower/GEH

Liquid Sodium Fast Reactor (SFR)

- 345 MWe
  - Molten salt thermal storage for peaking to 500 MWe
- Early in NRC interactions
- Requires HALEU – metallic fuel
- Possible higher temperature, non-electricity applications
- Innovative construction methods
- DOE: operational 2027 – 2030
- Location: Kemmerer, Wyoming – retiring coal facility

TerraPower/GEH's Natrium™



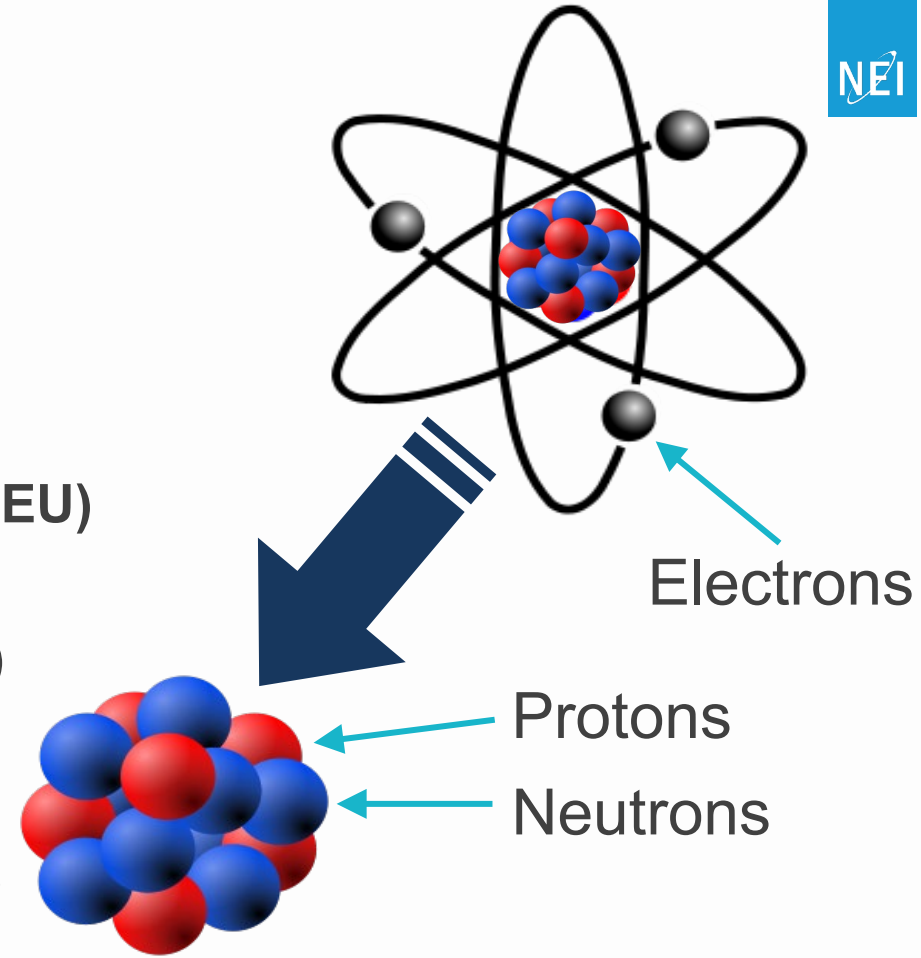
Uranium Isotopes

Natural Uranium (U)

- **0.7% U-235, 99.3% U-238**

Commercial Nuclear Fuel

- **Low Enriched Uranium (LEU)**
- **<5% U-235, >95% U-238**
- **High-Assay LEU (HALEU)**
- **<20% U-235, >80% U-238**



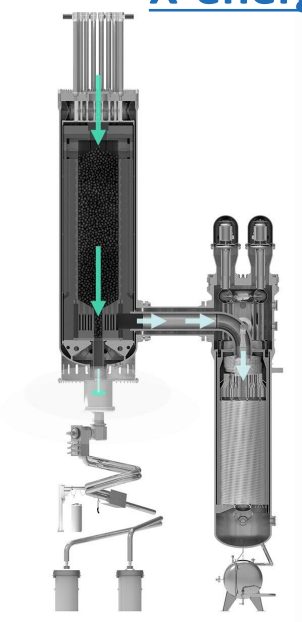
https://www.nei.org/resources/fact-sheets/nuclear-energy-just-the-facts

Technology – X-energy

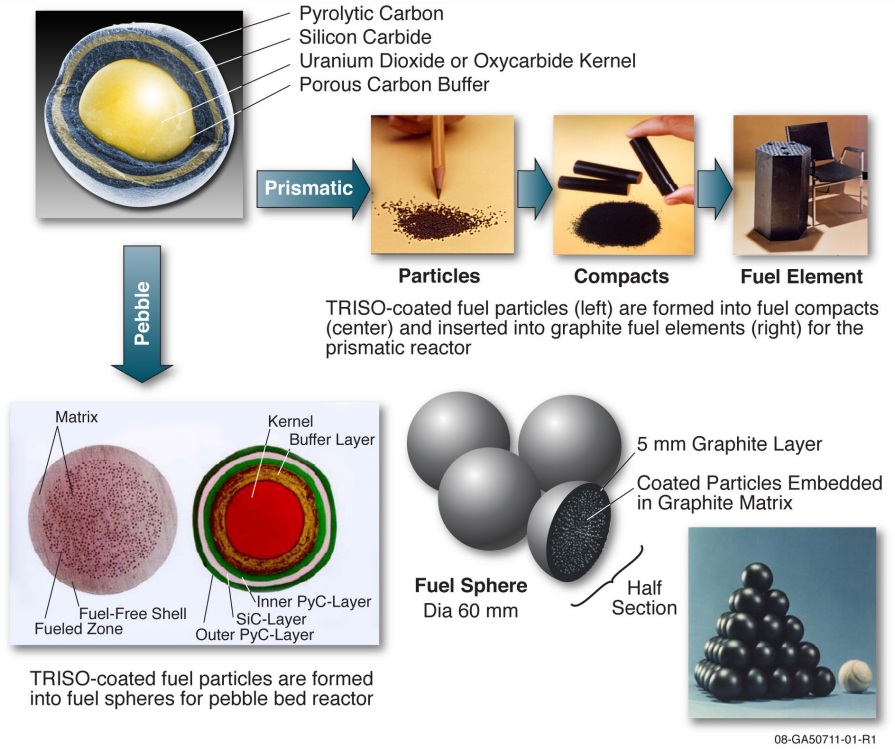
High Temperature Gas Cooled SMR

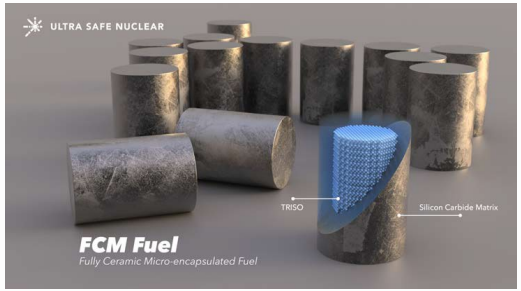
- 320 MWe
  - 4 modules @ 80 MWe each
- Early in NRC interactions
- Requires HALEU for TRISO fuel
- Possible high temperature, non-electricity applications
- DOE: operational 2027 – 2030
- Location: Seadrift, Texas – Dow site

X-energy's Xe-100



Key Enabling Tech – TRISO Fuel





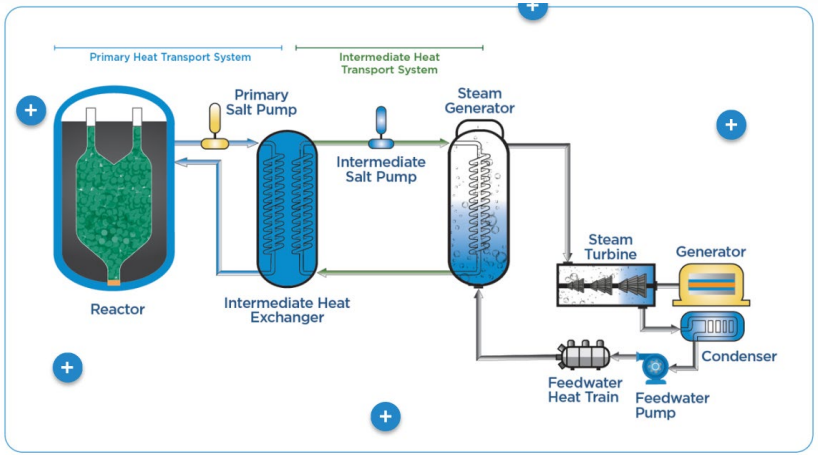
- Provides containment and can withstand temperatures well above accident conditions
- Higher operating temperatures – more efficient
- On-line refueling possible
- Passive decay heat removal

Technology – Kairos Power

Molten Salt Cooled SMR

- 140 MWe (commercial)/35 MWth (test reactor)
- Molten salt cools TRISO fuel pebbles
- Hermes test reactor NRC construction permit issued 2023
- Requires HALEU
- Possible high temperature, non-electricity applications
- Test Reactor Operation: 2026
- Location: Oak Ridge, TN

Kairos Power's KP-FHR



Technology – Terrestrial Energy

Integral Molten Salt SMR

- 390 MWe
  - 2 modules @ 195 MWe each
- Molten salt liquid fuel
- Early in NRC interactions
- Canadian Vendor Design Review Phase 2 complete
- Does not require HALEU
- Possible high temperature, non-electricity applications
- Schedule: TBD

Terrestrial's IMSR®

Versatility – New Market Opportunities

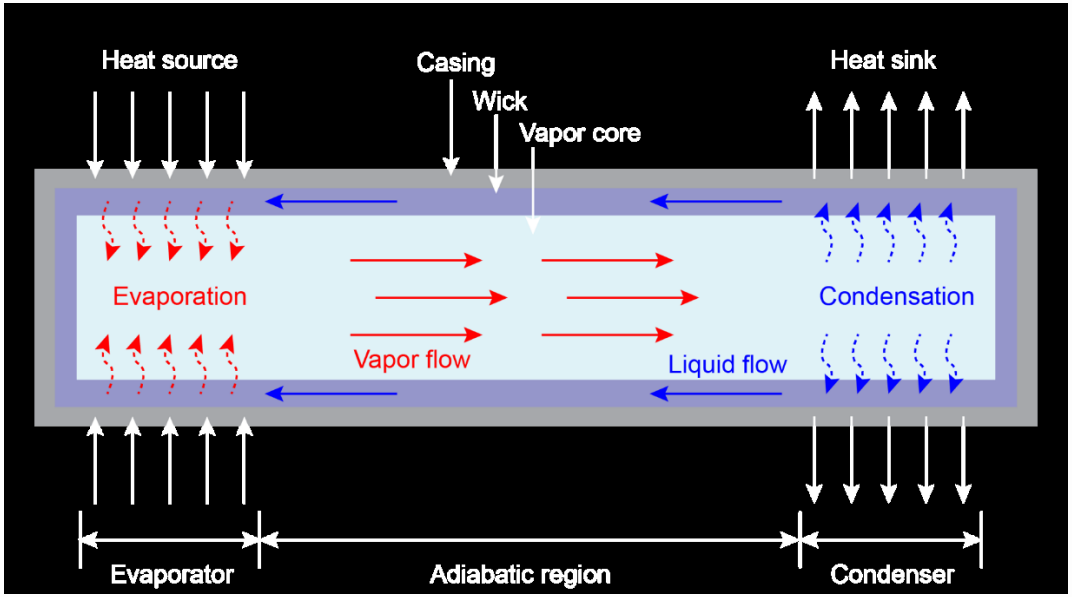
Technology – Oklo

Micro Reactor (SFR)

- 1.5 MWe – “Fission Battery”
- Metal fuel with heat pipes
- NRC license application ~2024
- Requires HALEU – recycling used fuel for first core
- 10-year core
- High temperature applications
- Planned Demonstration: ~2030

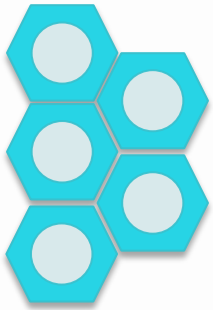
Oklo’s Aurora

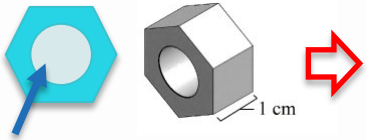
Key Enabling Tech – Heat Pipes



Size of heat pipes

3-D example image



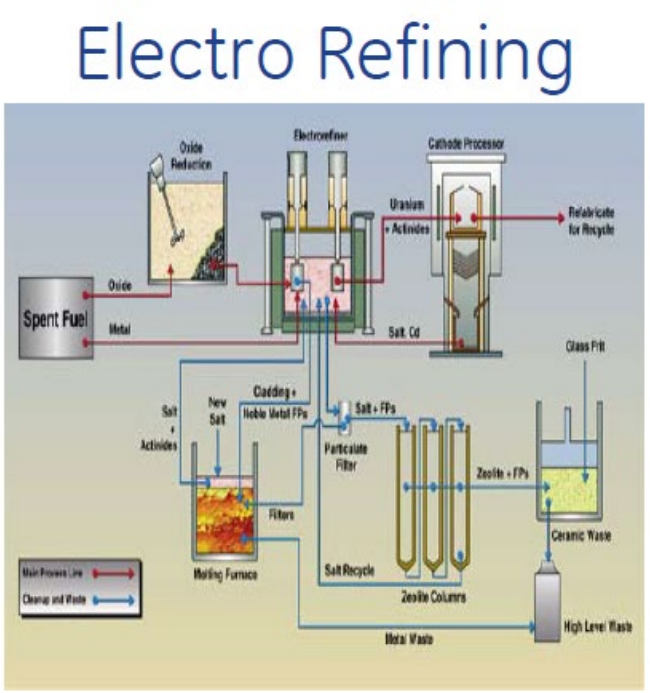


Uranium metal fuel

Hole for heat pipe

Recycling for Advanced Reactors

- Used fuel from existing fleet can be feedstock for some non-LWRs
  - Compliment HALEU supply chain
  - 8/2020 Survey of Advanced Reactor suppliers indicated majority considering recycled feedstock
- Fast Reactors and Molten Salt Reactors (MSR)
  - Potential economic and nuclear efficiencies
- Proliferation resistant
  - Many approaches do not separate plutonium



Source: GEH

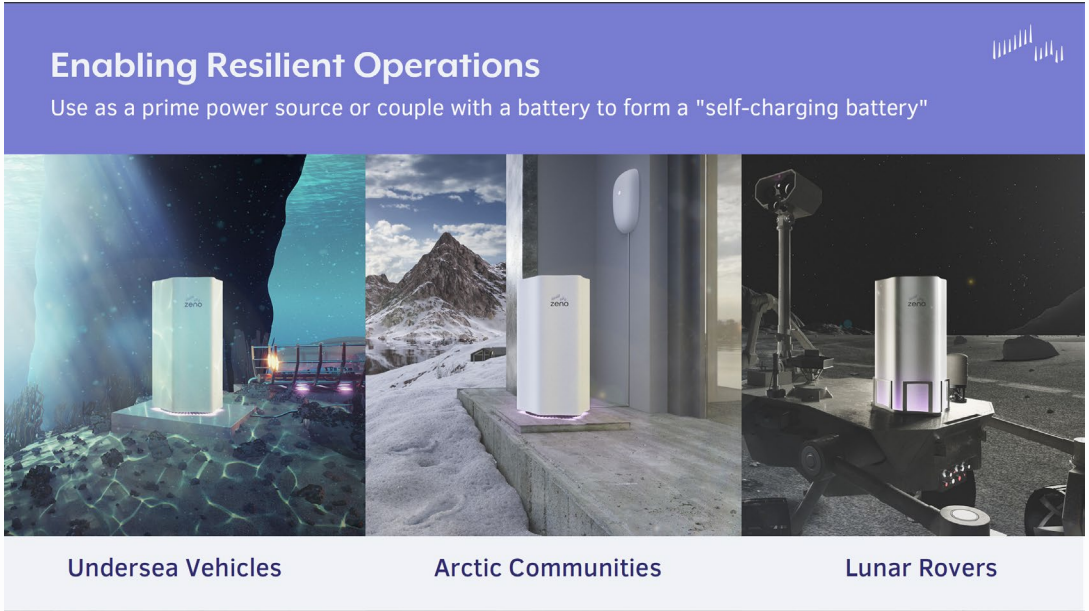
Technology – Radioisotope Power Systems

- Thermoelectric generator
- Watts to kilowatts electric
- Electricity and heat

Other Space Nuclear Power

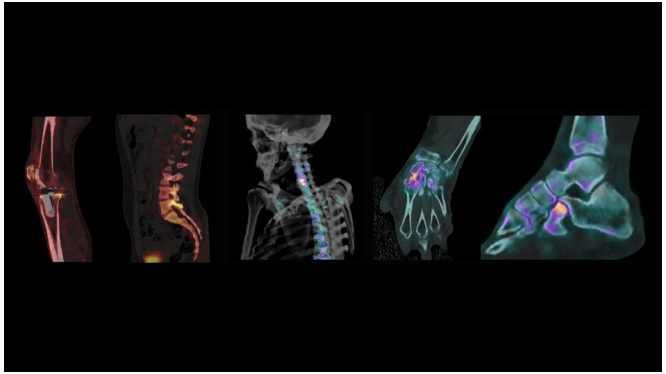
- Radioisotope Thermoelectric Generator (RTG)
- Nuclear Reactor Power System
- Nuclear Thermal Propulsion

Zeno Power Systems



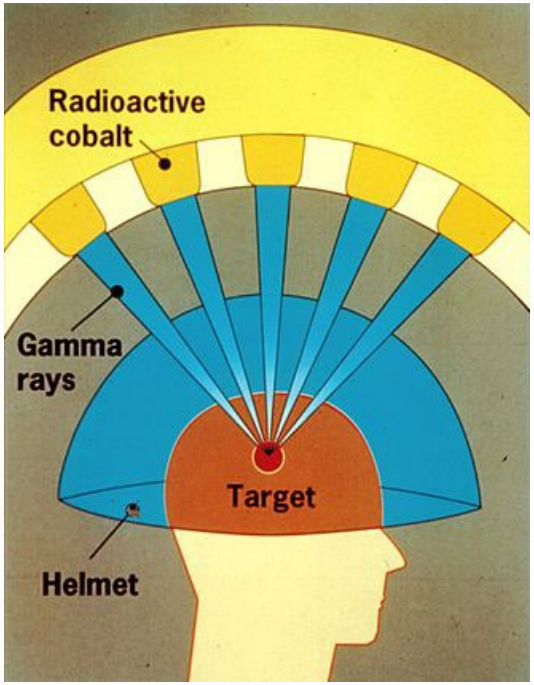
Nuclear Medicine

- Medical Imaging – Tc-99m half-life 6 hrs
- External Beam Radiation Therapy
  - Linear accelerators – x-rays
  - Proton therapy – accelerator
  - Gamma knife – Co-60 half-life 5.3yrs
- Brachytherapy – radioactive implants
- Boron Neutron Capture Therapy



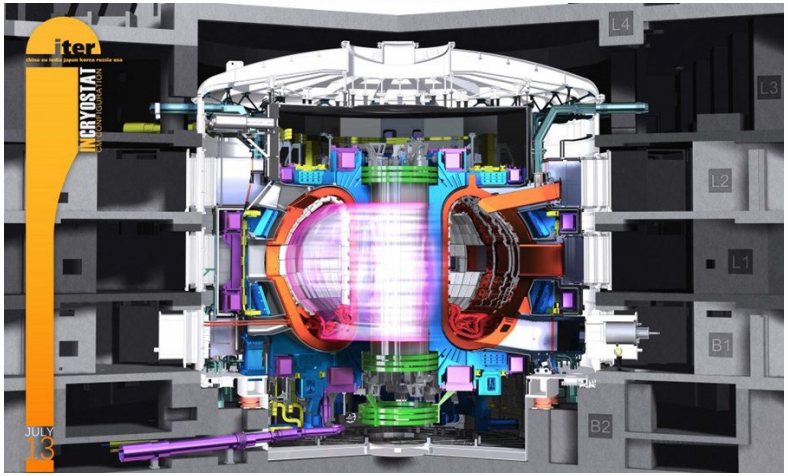
SPECT/CT in orthopedics

Source: www.siemens-healthineers.com



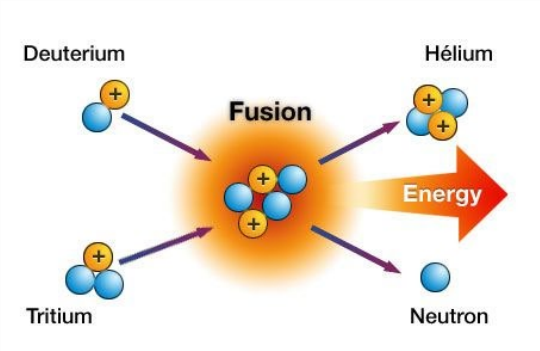
Gamma Knife

Technology – Fusion



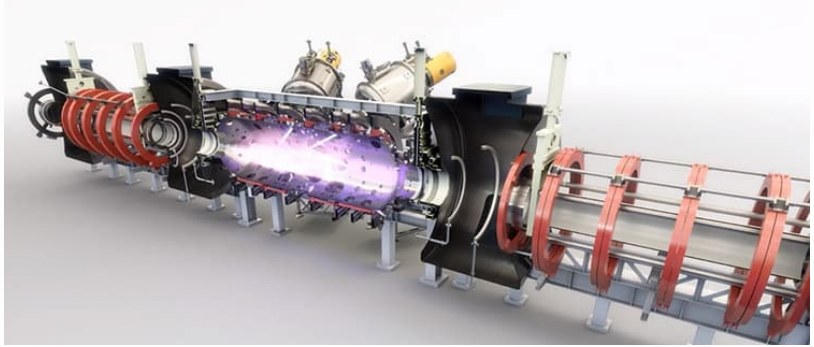
National Programs

- International Thermonuclear Experimental Reactor (ITER)
- Joint European Torus (JET)



Private Development

- >15 Companies
- $2+ Billion invested
- Mostly from wealthy individuals



TAE

Advanced Nuclear Versatility

Spectrum of Sizes and Options

Micro

Small

Large

Variety of Outputs

Electricity

H_2 Hydrogen

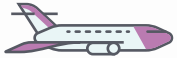
Process Heat

Multitude of Uses

Homes

Vehicles

Businesses



Aviation

Rail

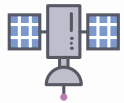
Shipping

Concrete

Steel

Factories

Water



Space

Watch the video: https://www.youtube.com/watch?v=7zN_YLg-roo

QUESTIONS?

By Third Way, GENSLER