Nuclear Energy Overview

Presentation to the Midwestern Governors Association

John Kotek
Senior VP, Policy & Public Affairs

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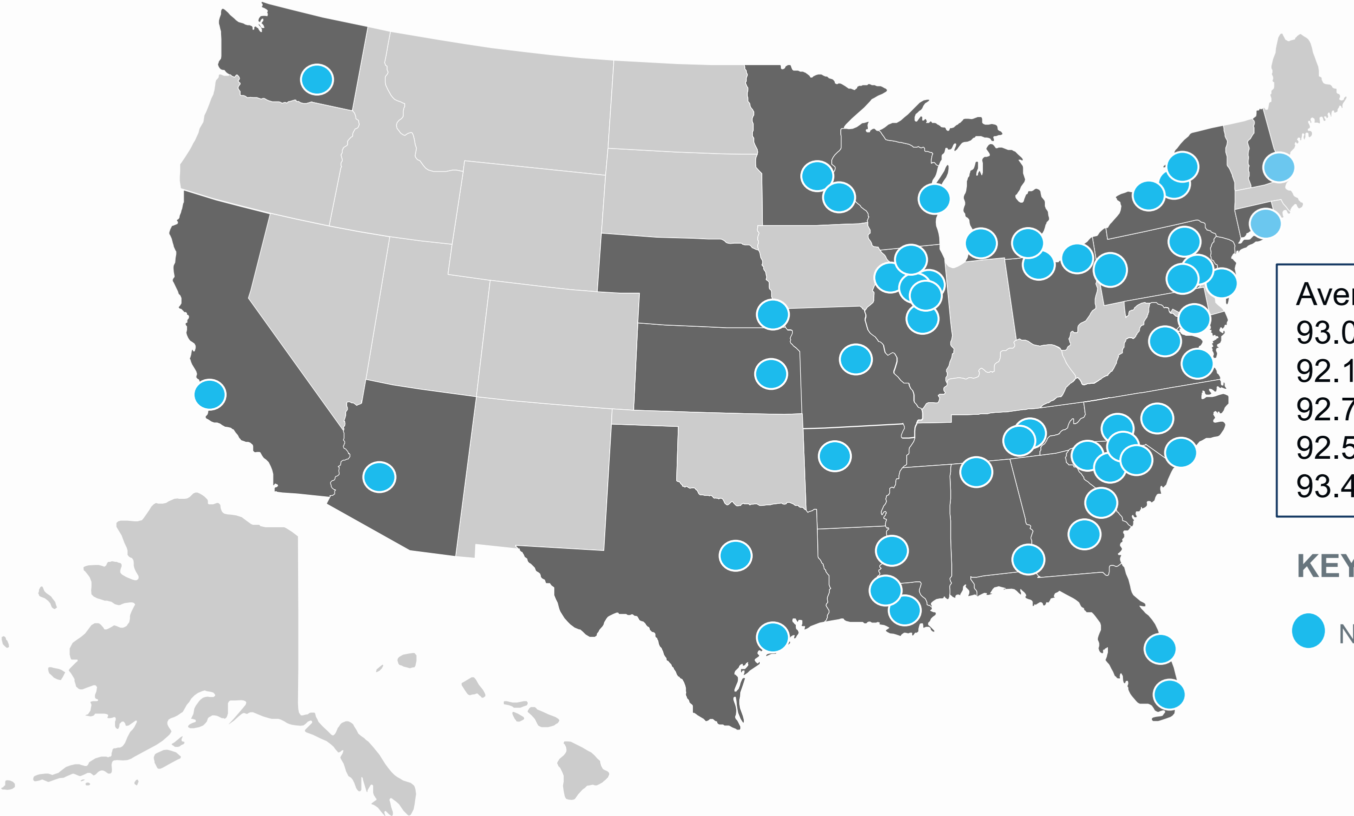
NEI NUCLEAR ENERGY INSTITUTE

About NEI

- Washington, D.C., policy and membership organization
- A unified industry voice before U.S. government, international organizations and venues
- A forum to resolve technical and business issues for the commercial industry
- A source of accurate and timely information to members, policymakers, the news media and the public
- 370+ members from more than a dozen countries

94 reactors at 53 plant sites across the country



Average Capacity Factor:
93.0% in 2023
92.1% in 2022
92.7% in 2021
92.5% in 2020
93.4% in 2019

KEY

Nuclear power plant site

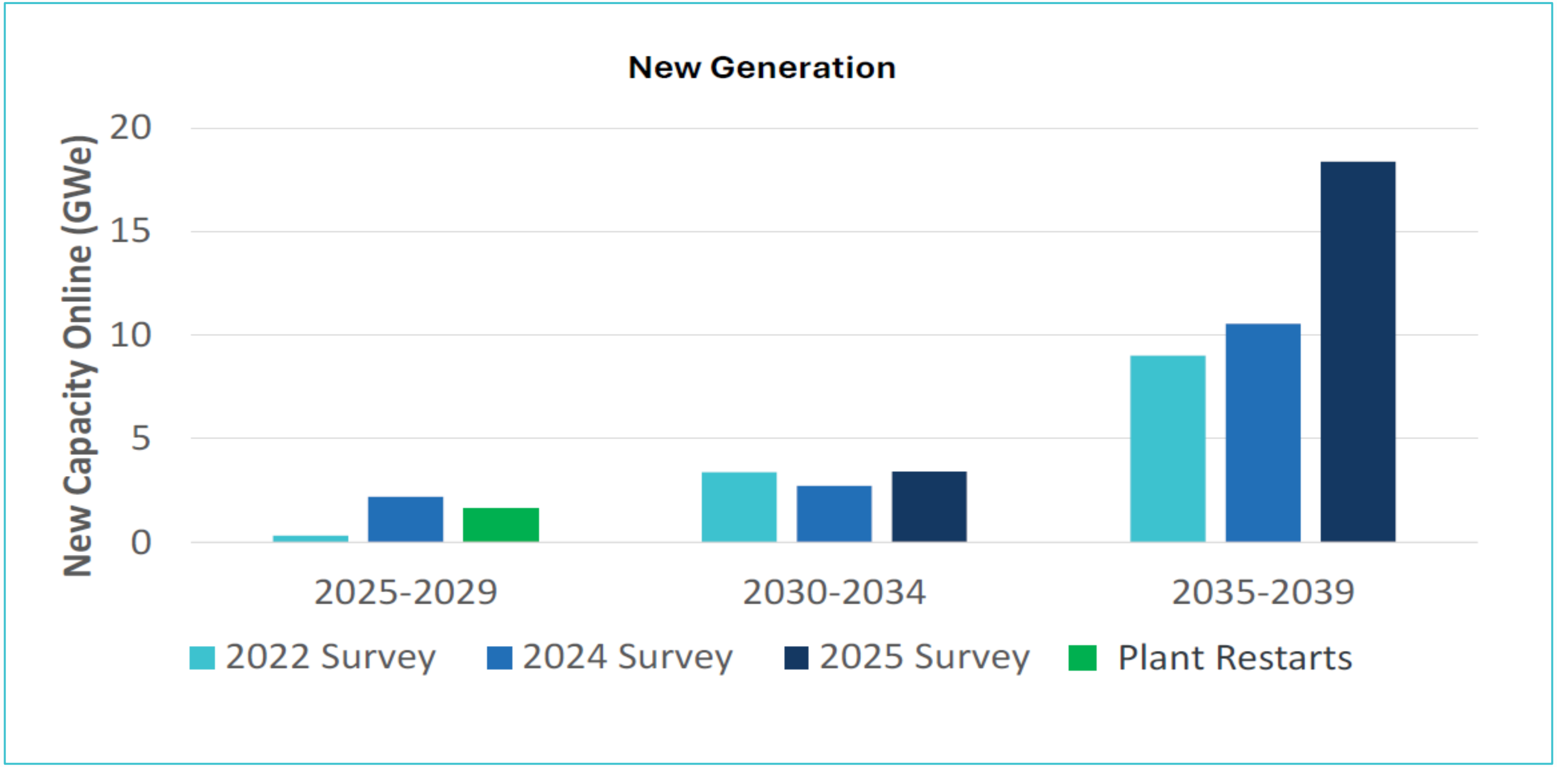
Updated: May 2023

System Benefits of Advanced Reactors

Long term price stability	• Low fuel and operating costs
Reliable dispatchable generation	• 24/7, 365 days per year, years between refueling (Capacity factors >92%)
Efficient use of transmission	• Land utilization <0.1 acre/TWh (Wind =1,125 acre/TWh; Solar 144 acre/TWh)
Environmentally friendly	• Zero-carbon emissions, one of lowest total carbon footprints • Many SMRs are being designed with ability for dry air cooling
Integration with renewables and storage	• Paired with heat storage and able to quickly change power
Black-start and operate independent from the grid	• Resilience for mission critical activities • Protect against natural phenomena, cyber threats and EMP

Source: SMR Start, *SMRs in Integrated Resource Planning*

Interest in New Reactors is Increasing



Source: NEI, The Future of Nuclear Power, 2025 Update

Types of Advanced Reactors

Range of sizes and features to meet diverse market needs

Water Cooled

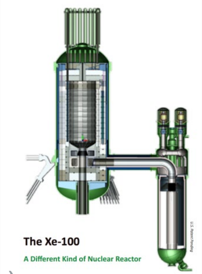
Non-Water Cooled

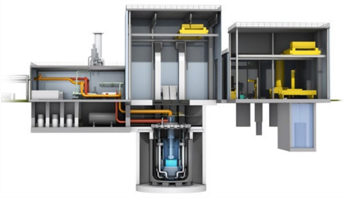
Either

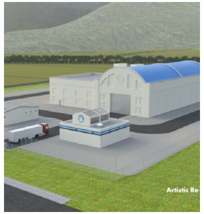
High Temp Gas Reactors

Liquid Metal Reactors

Molten Salt Reactors







Westinghouse AP1000® (shown)
GE ABWR
GE ESBWR

GEH BWRX-300 (shown)
NuScale
Holtec SMR-300
Westinghouse AP300

X-energy (shown)
General Atomics

TerraPower Natrium™ (shown)
ARC Clean Energy

Kairos Hermes (shown)
Terrestrial
Natura Resources

Aalo (shown)
Oklo
Radiant
Westinghouse eVinci
(Many others)

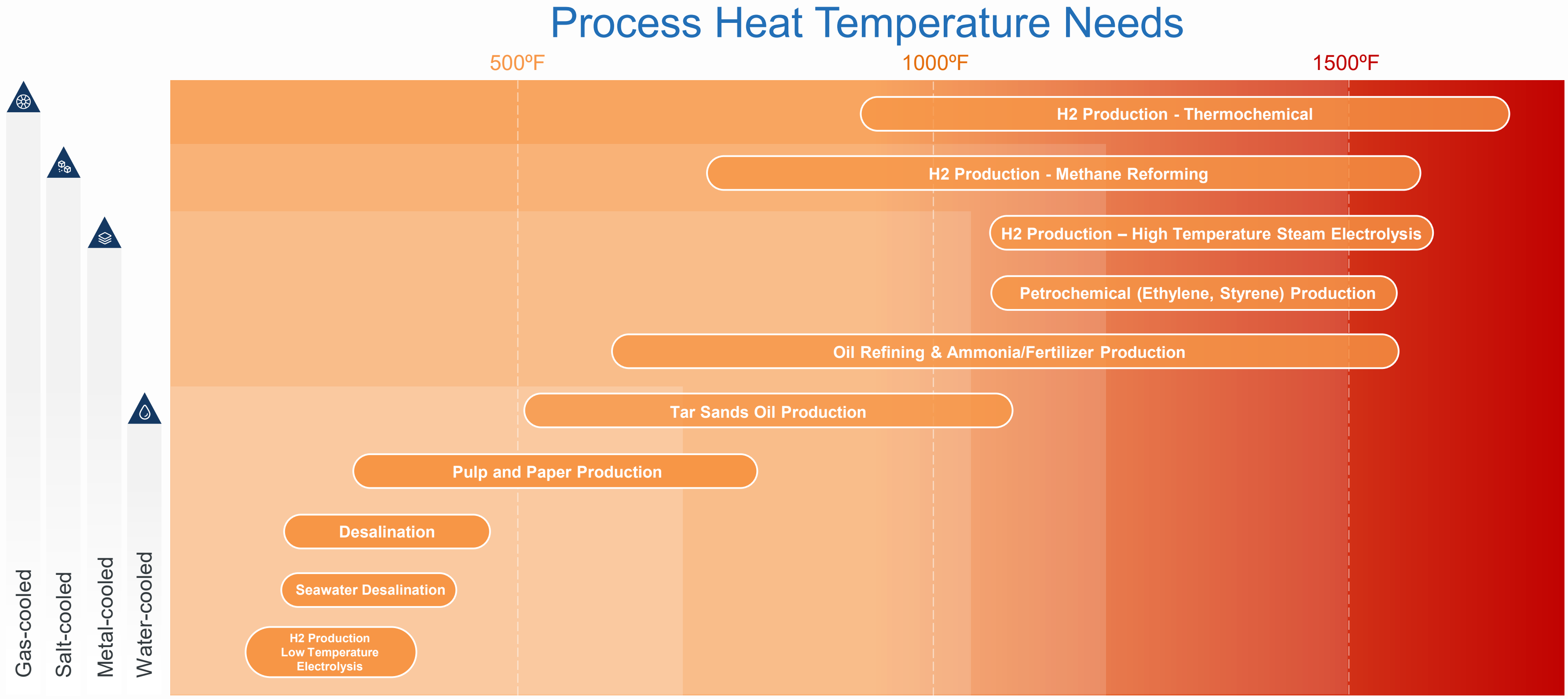
Large

Small Modular Reactors

Micro

Learn more about innovative technologies with the Nuclear Innovation Alliance.

Nuclear Process Heat Capabilities



Bipartisan Leaders Embrace Nuclear Energy

Nuclear Energy Innovation and Modernization Act:
- Directs NRC to modernize regulatory framework

Infrastructure Investment & Jobs Act:
- Operating nuclear plant credit program
- Advanced reactor demonstration funding
- Large-scale H2 demos

CHIPS and Science Act
- Assistance for nuclear RD&D
- University nuclear engineering support

Inflation Reduction Act:
- Tax credits for existing reactors
- Tax credits for all new clean generation
- Tax credits for H2 generation
- Expanded federal loan guarantees

ADVANCE Act
- NRC Modernization
- Extends Price-Anderson Act

2025 Budget Reconciliation
- Retains IRA PTC/ITC for new nuclear

Key Enablers from Executive Orders on Nuclear Energy

National Security (14299), NRC Reform (14300), DOE Testing (14301), and Industrial Base (14302)

Add 300 Gigawatts of U.S. Nuclear Capacity by 2050

- Restarts and power uprates
- 10 large reactors in construction by 2030

1 Speed up Nuclear Reactor Licensing

- NRC licensing less than 18 months
- Faster for DOE/DoD tested designs

2 Lay the Ground-Work for Faster Reactor Testing

- Pilot 3 reactors outside of labs
- Expand DOE testing pathways

3 Deploy U.S. Reactors for AI and Military Bases

- Operate at DoD facilities in 3 years
- AI as critical defense facilities

4 Amp Up Domestic Nuclear Fuel Production

- Maximize domestic fuel production
- Mine, enrich, convert, de-convert

5 Assess Spent Fuel and Recycling

- Recommend a National policy
- Safe, Secure Long Term Fuel Cycle

6 Expand U.S. Nuclear Energy Exports

- Compete for civil nuclear globally
- Pursue new 123 Agreements

7 Bolster the American Nuclear Workforce

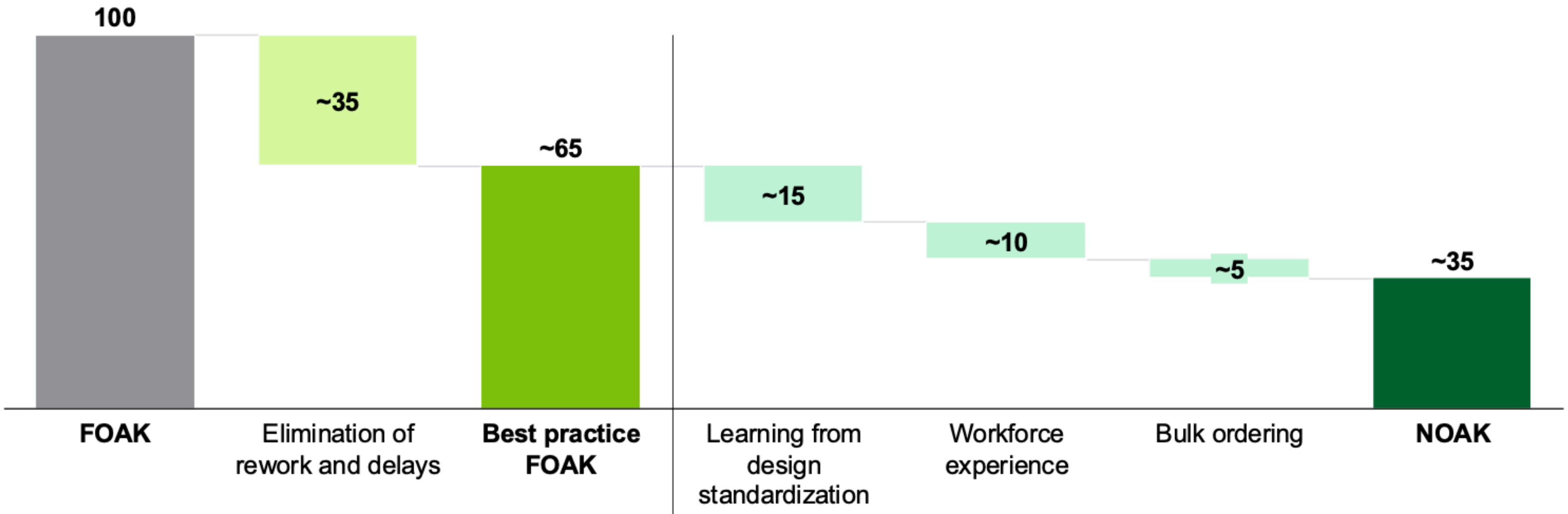
- Increase nuclear apprenticeships
- Prioritize nuclear energy careers

Reference: https://www.energy.gov/ne/articles/9-key-takeaways-president-trumps-executive-orders-nuclear-energy

DOE Liftoff Report

Figure 26: Investment in pre-construction planning and design standardization are essential for reducing costs

Relative impact of FOAK to NOAK cost reduction levers on overnight capital costs, $/kW



Investing in pre-construction planning reduces costly rework and delays: ensuring design completion and constructor proficiency can reduce construction time and cost

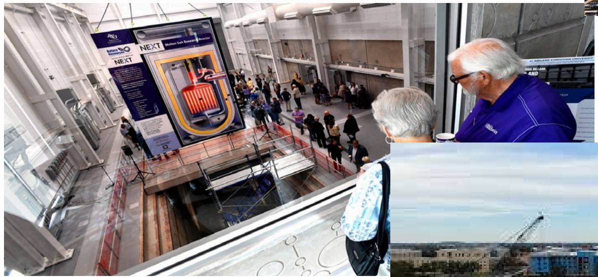
Design standardization maximizes learning: multiple orders of a standardized design increase the ability to realize learning effects between projects

Moving Dirt and Forging Steel

OPG/Darlington GE-H BWR X-300 early site works completed in Ontario

Terrapower Natrium – site preparations underway in Wyoming

Kairos Hermes – first concrete pour in Tennessee



ACU molten salt reactor – reactor building complete in Texas

MARVEL prototype shipped for testing, large components in production for Idaho demonstration

State Options to Support Advanced Reactors

- Reliability Portfolio Standards
- Value-based market/regulatory system
- Tax incentives (e.g., property)
- Advanced cost recovery
- Workforce and infrastructure

State Policy Options: https://www.nei.org/resources/reports-briefs/policy-options-for-states-to-support-new-nuclear

Source NARUC/NASEO: https://pubs.naruc.org/pub/8C96325F-CF7E-90BE-F8B3-B07570F3953B

NEI

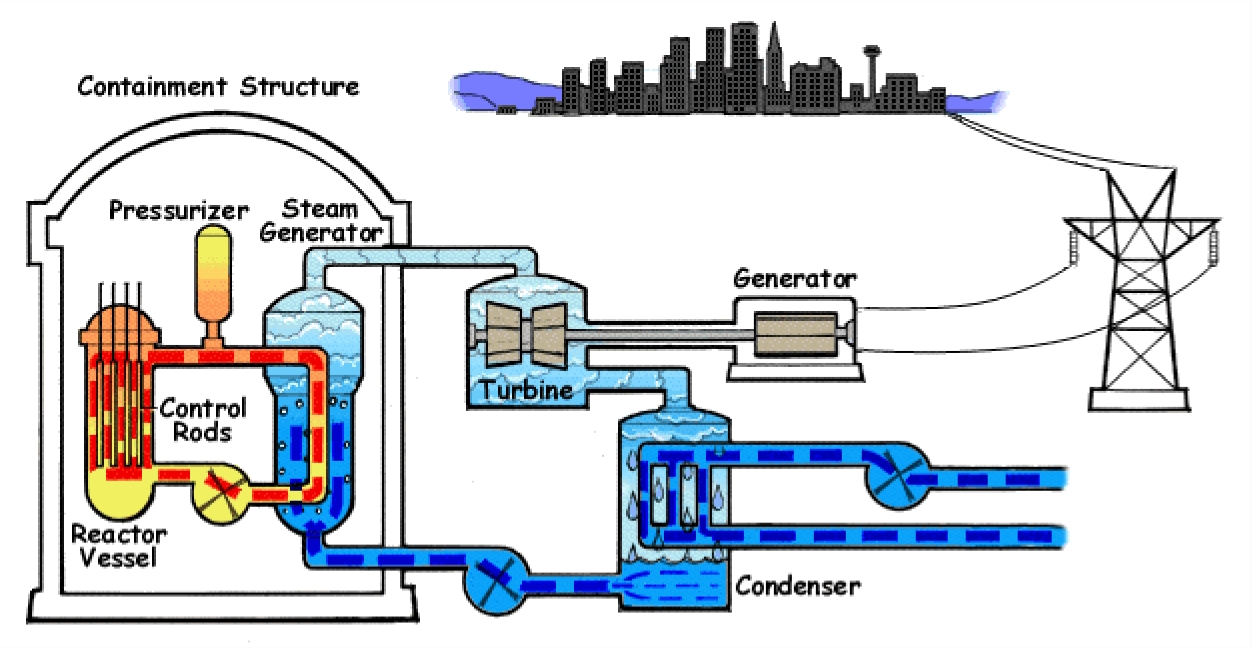
Scan to view state policy options.

QUESTIONS?

By Third Way, GENSLER

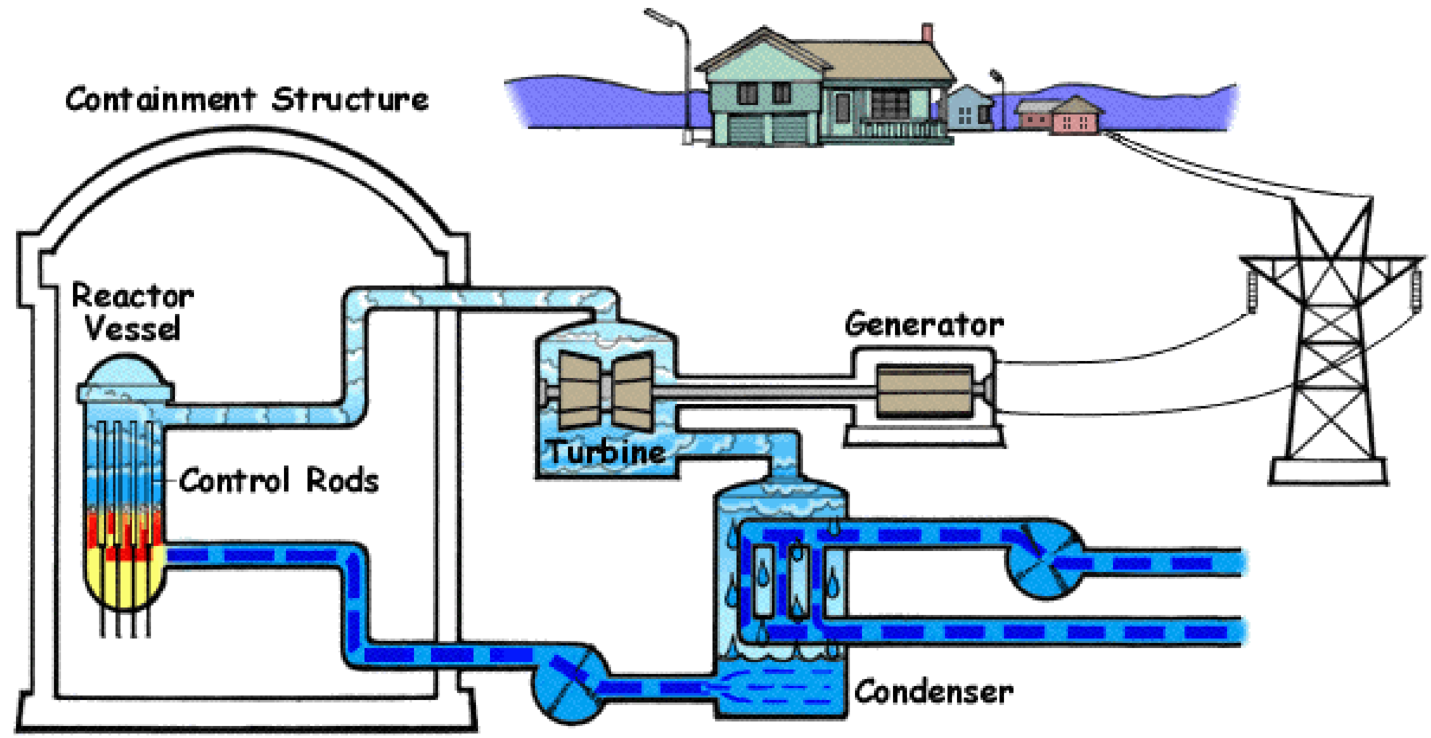
How Does it Work?

How a Pressurized Water Reactor works…

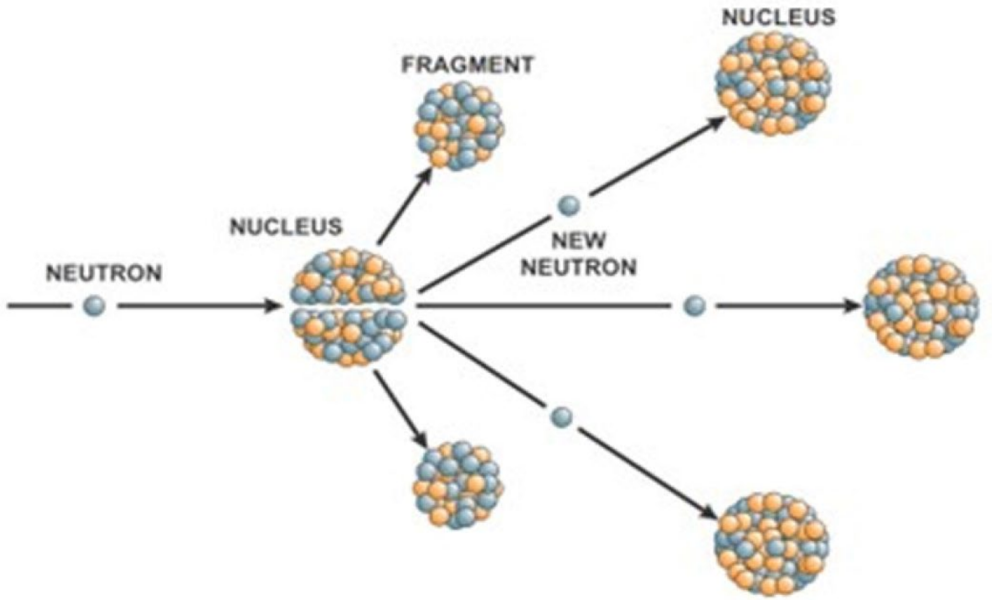


Source: https://www.nrc.gov/reading-rm/basic-ref/students/animated-pwr.html

How a Boiling Light-Water Reactor (BWR) Works

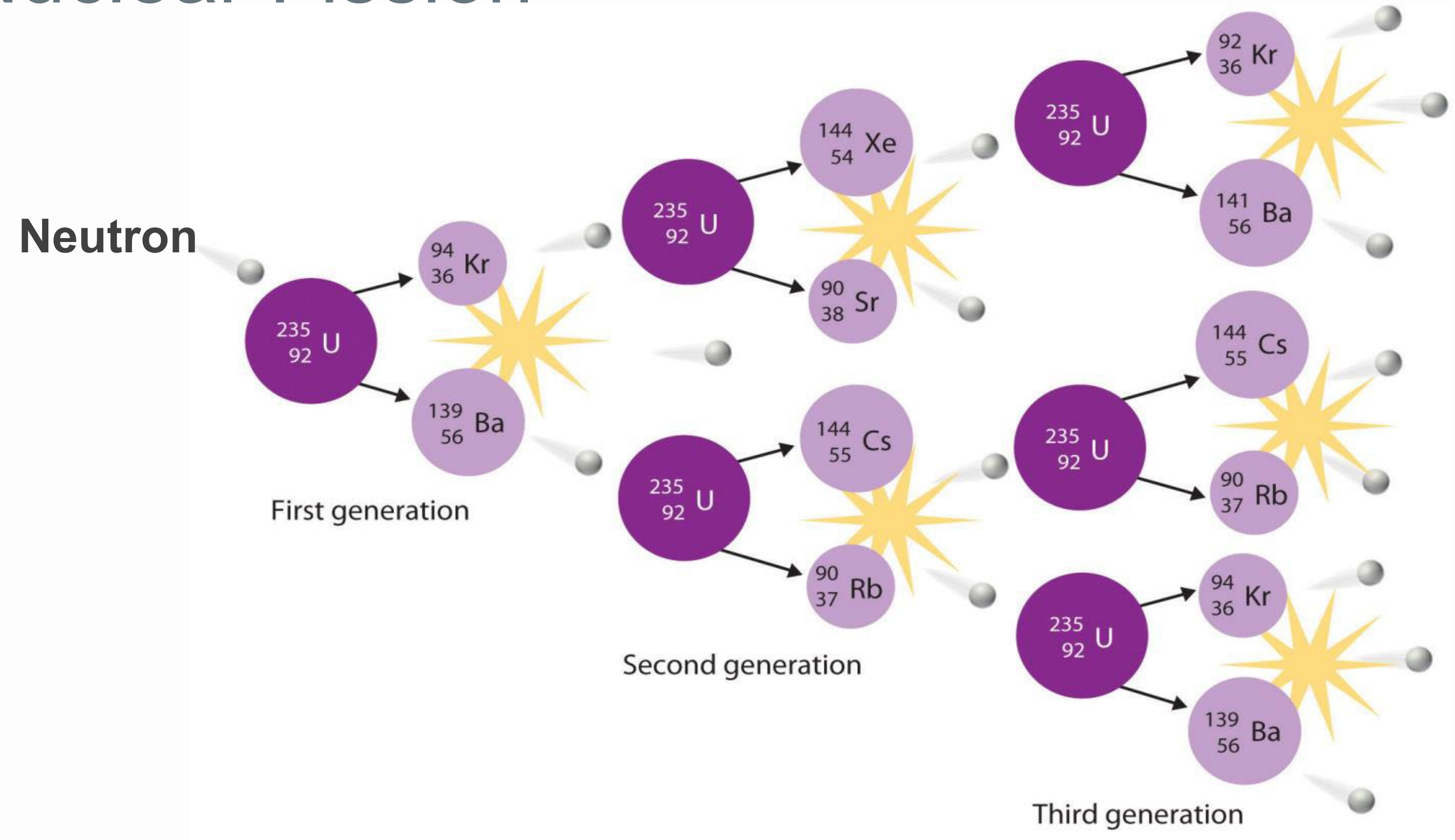


The Fission Process



Source: https://www.energy.gov/science/doe-explainsnuclear-fission

Nuclear Fission



Grid-Scale Designs

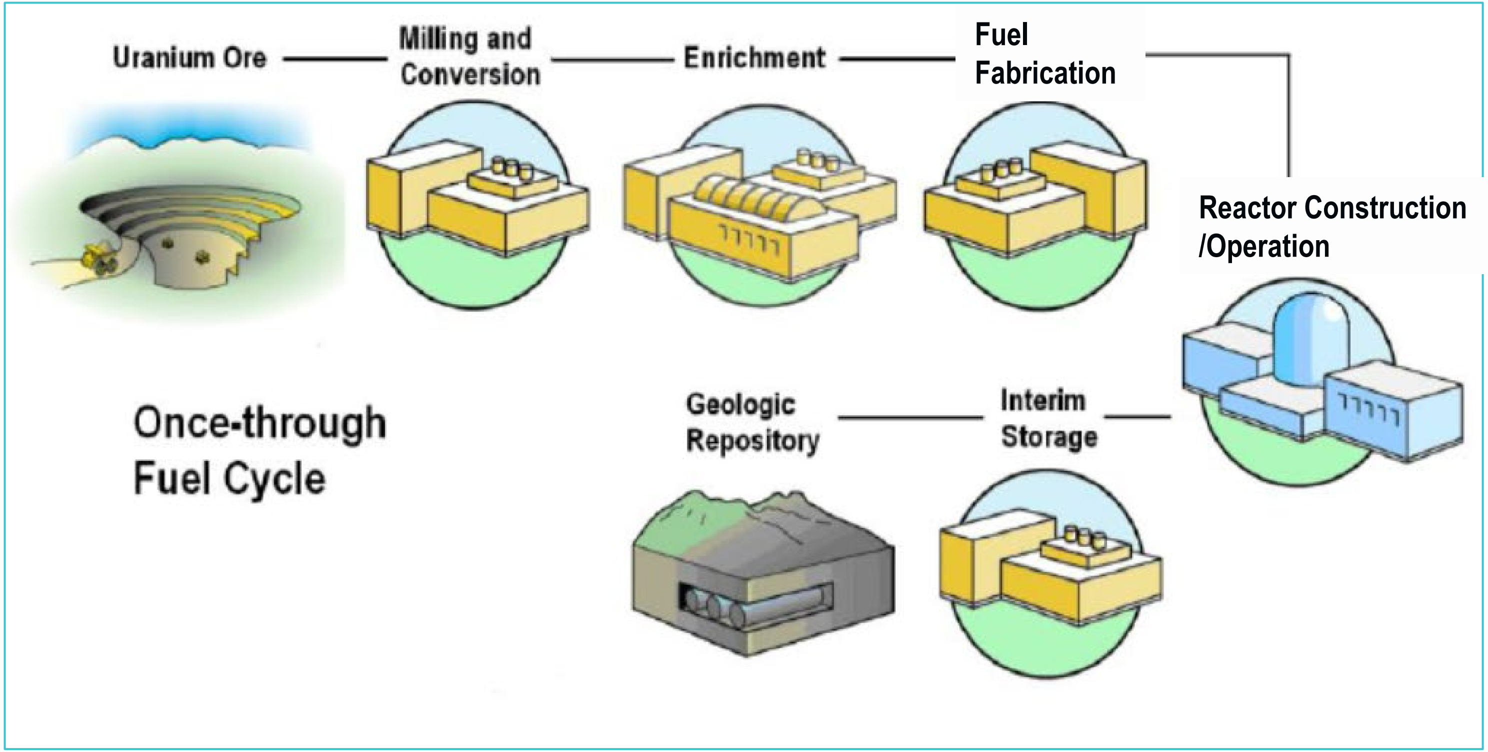
Technology			Description	
Vendor	**Design**	**HQ**	**Power (MWe)**	**Type**
ARC Clean Technologies	ARC-100	U.S.	100	SFR
First America Nuclear	Eagle One	U.S.	240	Lead
GE-Vernova	BWR X300	U.S.	300	LWR
GE/Hitachi/Toshiba	ABWR	U.S./Japan	1,100	LWR
General Atomics	EM2	U.S.	265	HTGR
Holtec	SMR 300	U.S.	300	LWR
Kairos	KP-FHR	U.S.	150	MSR-T
KHNP	AP-1400	ROK	1,400	LWR
Natura Resources	MSR-100	U.S.	100	MSR
Newcleo	LFR-AS-200	France	200	LFR
NuScale	VOYGR-6	U.S.	460	LWR
Rolls Royce	RR-SMR	UK	470	LWR
Reploy Power	SPS	U.S.	300	LWR
TerraPower	Natrium	U.S.	345	SFR
Terrestrial	IMSR	U.S.	392	MSR
Westinghouse	AP300	U.S.	300	LWR
Westinghouse	AP1000	U.S.	1,110	LWR
X-energy	Xe-100	U.S.	320	HTGR

Micro, Test and Other Reactor Designs

Technology			Description	
Vendor	**Design**	**HQ**	**Power (MWe)**	**Type**
Aalo	Aalo-Pod	U.S.	50	SFR
Antares	R1	U.S.	0.5	HTGR
BWXT	BANR	U.S.	15	HTGR
Deep Fission	DFBR	U.S.	15	LWR
Deployable Energy	Unity	U.S.	1	LWR
General Atomics	GA-FMR	U.S.	50	HTGR
Hadron Energy	MMR	U.S.	10	LWR
LastEnergy	PWR-20	U.S.	20	LWR
NANO	Kronos MMR	U.S.	15	HTGR
Newcleo	LFR-AS-30	France	30	LFR
NuCube Energy	DeccaCell	U.S.	15	Solid State
NuGen	Engine	U.S.	3	HTGR
Oklo	Aurora	U.S.	75	SFR
Radiant Nuclear	Kaleidescope	U.S.	1	HTGR
Steady Energy	LDR-50	Finland	15	LWR
Terra Inovatum	Solo	U.S.	1	HTGR
Valar Atomics	Unknown	U.S.	Unknown	Unknown
Westinghouse	eVinci	U.S.	5	HTGR
X-energy	XENITH	U.S.	7	HTGR
Zeno	RPS	U.S.	0.1	RTG
Zetta Joule	Unknown	U.S.	40	HTGR

The Nuclear Fuel Cycle

The Nuclear Fuel Cycle (today)



Adapted from: Wigeland, R & Dixon, Brent. (2020). Identification, Description, and Characterization of Existing and Alternative Nuclear Energy Systems.

Uranium is Mined and Refined

In situ Uranium mining

"Yellowcake"

Shown: Part of Heathgate Resources' Beverley wellfield (Australia)

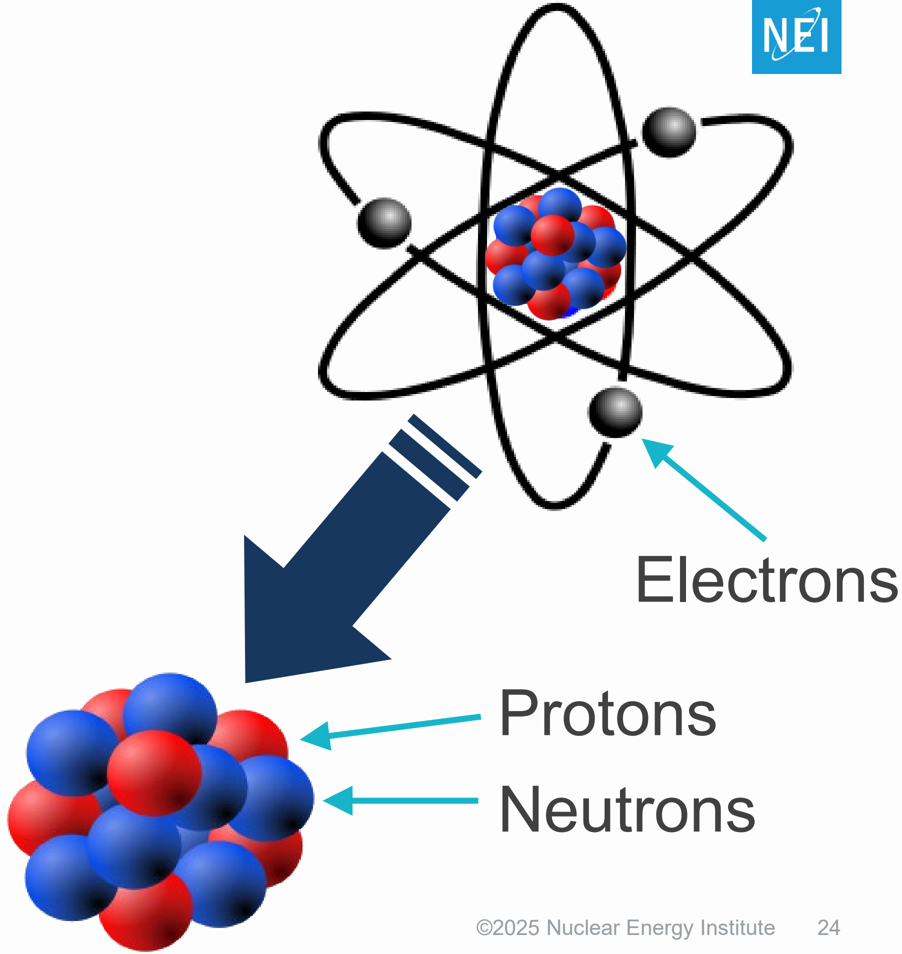
Source: https://world-nuclear.org/information-library/nuclear-fuel-cycle/mining-of-uranium/in-situ-leach-mining-of-uranium.aspx

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



Uranium is Converted to UF_6 gas

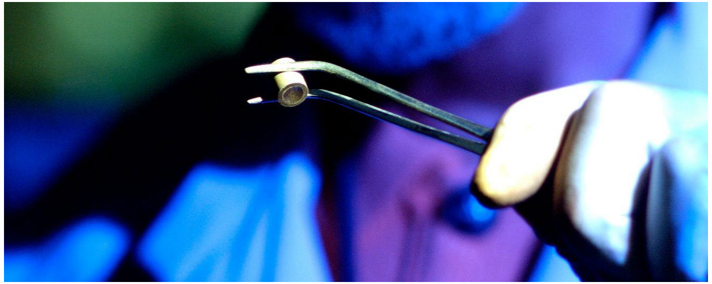
UF_6 Cylinder

Photo Credit: Dean Calma / IAEA
Ania Kaminski, a nuclear safeguards inspector pictured taking a measurement of uranium hexafluoride at the URENCO enrichment plant in the Netherlands.

Enrichment Concentrates the Uranium 235 Isotope

Centrifuge Cascade

Light-Water Reactor Fuel Fabrication



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

BWR Fuel

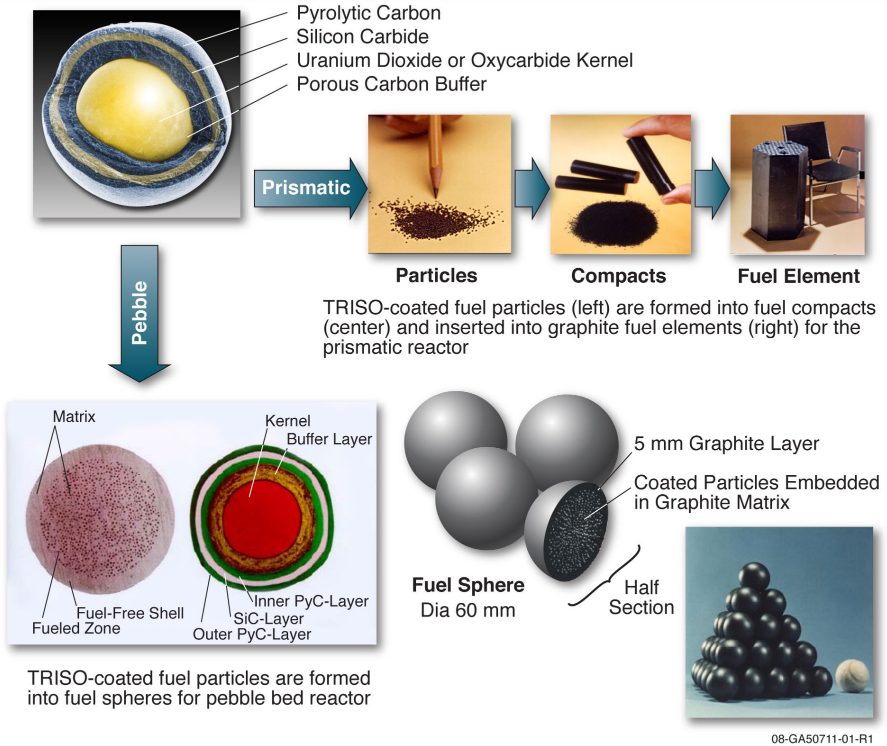
~5.1 inches

PWR Fuel

~8.4 inches

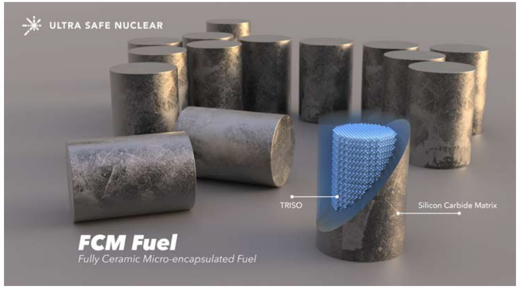
- Light-water SMRs ~1/2 height and/or fewer assemblies, otherwise same

Tri-structural Isotropic (TRISO) Fuel Fab.



TRISO-coated fuel particles (left) are formed into fuel compacts (center) and inserted into graphite fuel elements (right) for the prismatic reactor

TRISO-coated fuel particles are formed into fuel spheres for pebble bed reactor



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

Categories of Radioactive Waste

Low-Level Waste

- Generated during reactor operations, medical procedures, industrial applications, etc.
- Approved for disposal in near-surface engineered commercial disposal facilities
- Licensed facilities in SC, TX, UT, WA

Transuranic Waste

- Generated during nuclear weapons stockpile activities
- Disposed in Waste Isolation Pilot Plant in NM

High-Level Waste

- Includes used/spent nuclear fuel and wastes resulting from nuclear fuel reprocessing
- Stored in pools and in dry containers, generally at sites where it was produced
- Deep geological repository required

Energy Solutions LLW facility, Clive, UT

Waste Isolation Pilot Plant, Carlsbad, NM

Nuclear Safety Regulation

U.S. Nuclear Regulatory Commission (NRC)

Regulates commercial use of nuclear technology

- Nuclear facilities require a license from the NRC – the lead federal agency for nuclear safety and environmental regulation.
- Different facilities (uranium mine, fuel facility, power reactor, research reactor, etc.) require specific licenses

Coordination with States

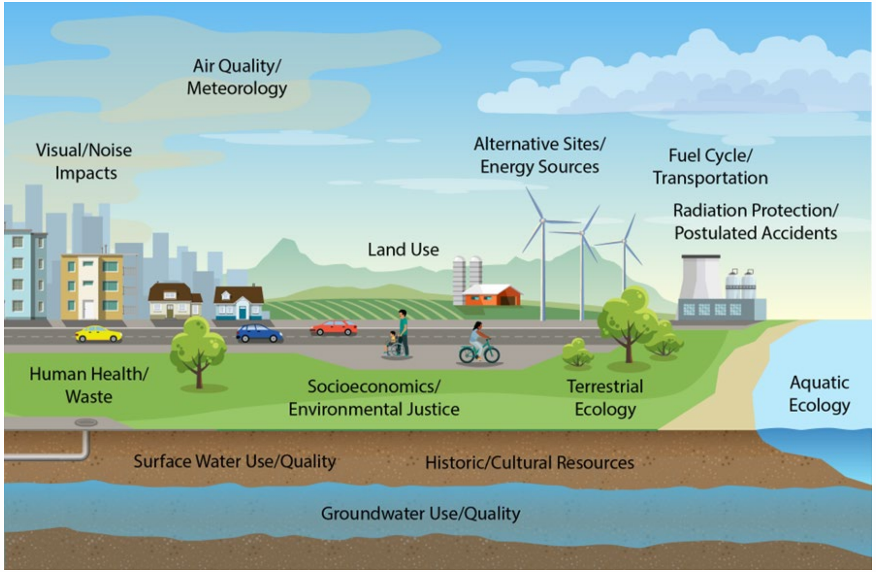
- NRC coordinates with other federal and state regulators for the construction and operation of nuclear facilities.

Scope of Regulation by NRC

Safety Review	Application reviewed for technical safety
Environmental Review	Review per National Environmental Policy Act
Construction Oversight	NRC conducts inspections throughout construction
Reactor Operator Licensing	NRC conducts exams and issues licenses to individuals
Operational Oversight	NRC Resident Inspectors located at current commercial reactors

What NRC Approval Means

- Safety
  - Risks from nuclear plant to public are much lower than other societal risks (less than 0.1%)
- Security
  - Protected against radiological sabotage, theft and diversion
- Emergency Planning
  - Worst case dose at Emergency Planning Zone (EPZ) expected to be less than 1 rem
- Environmental
  - Plant and site meet all NEPA and other Environmental Laws (e.g., Water, Air)



Source: NRC; Typical resource areas analyzed in new reactor NEPA reviews