2024

NATURAL RESOURCES COMMITTEE

NEBRASKA LEGISLATURE

LR 469
Interim Study Report

Interim Study to Examine Existing, new, and emerging technologies in the nuclear industry.

ONE HUNDRED-EIGHTH LEGISLATURE

SECOND SESSION

NATURAL RESOURCES COMMITTEE MEMBERS

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LR 469

NATURAL RESOURCES COMMITTEE
OCTOBER 2024

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MEMORANDUM REPORT

TO: NATURAL RESOURCES COMMITTEE MEMBERS
FROM: SEN. BRUCE BOSTELMAN, CHAIRMAN
DATE: December 17, 2024
SUBJECT: LR 469

Introduction

The Natural Resources Committee introduced LR469 in the Second Session of the One Hundred and Eighth Legislature 2024.[1] An informational hearing on the Resolution was held on October 17, 2024 at the Southeast Community College So. 68th Street campus. The following report will present the history of nuclear energy in Nebraska, as well as the new and emerging technologies introduced and discussed by industry experts who were invited to testify at the October 17, 2024 informational hearing. As expanding technological opportunities in both energy generation and medicine appear significant in the coming years, and as the need for increased energy is expected to grow, the committee felt it was important to receive information on the new nuclear technologies.

There are a number of new designs being proposed and in the process of licensing. The informational hearing, along with this report, is intended to broaden the understanding of different technologies being developed.

Background History of Nuclear energy in Nebraska [2]

The Atomic Energy Act (AEA) of 1954 ended complete government control and promoted the expansion of the idea and use of nuclear fission and power to peaceful civilian uses in the areas of power generation and nuclear medicine.

The results for Nebraska included a partnership between the Atomic Energy Commission (AEC) and Nebraska's Consumers Public Power District (CCPD), later named Nebraska Public Power District (NPPD) to develop and construct Nebraska's first sodium-graphite-modulated nuclear reactor at Hallam, Nebraska.

The Hallam project was part of the Power Demonstration Reactor Program that began in 1959. Its purpose was to advance atomic energy by demonstrating operation of a design that used sodium as a liquid metal coolant. The reactor was co-located with a coal-fired plant, which was constructed by CPPD. There were plans to construct a second generator after the nuclear reactor was fully operational. Construction began in 1959 and was completed in November 1961. The

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[1] Appendix 1: LR469, as introduced.

[2] Appendix 2: History of Nuclear in Nebraska, Legislative Research Office (LRO)RESOURCES, October 2024; Additional History of Nuclear in Nebraska, R. Herchenbach.

Hallam plant operated between 1962 and 1964 and was decommissioned by 1969 due largely to technical challenges.
The construction of a smaller reactor used for medical research was installed in Omaha under the United States Department of Veterans' Affairs Medical Center in 1959 at a cost of $154,000. Security concerns led to its shutdown in 2001 and it was dismantled in 2016.

NPPD and OPPD constructed larger reactors in Nebraska beginning in the late 1960s. Cooper Nuclear Station, owned by NPPD, was located near Brownsville, Nebraska, and Fort Calhoun Nuclear Station near Fort Calhoun, Nebraska, was owned by OPPD.

In 2010, The Nuclear Regulatory Commission (NRC) extended the licensed operation of the Cooper facility until 2034 and, in February 2024 the NPPD Board of Directors approved the process to request another renewal of the facilities license until 2054. Spent fuel discharged from the reactor is stored in water pools as part of a short-term cooling period. After they are "cooled" the fuel assemblies are then stored in above ground dry casks.

In 1968, construction of the Fort Calhoun reactor began adjacent to the Missouri River. Around 700 people were employed at the plant, with operation costs around $200 million per year. OPPD made the decision in Spring 2016 to permanently shut down the Fort Calhoun Station. With the shutdown they then proceeded into a phase which is called decommissioning. Federal regulations require a commercial nuclear plant to establish a decommissioning fund sufficient for all closure activities. In 2016, OPPD began the process of decommissioning the Fort Calhoun power plant. The decommissioning activities themselves have employed almost 300 people. The expected decommissioning completion for Fort Calhoun is 2026, at which time, it is anticipated that fifty employees will remain for security and maintenance purposes.

There were plans to construct a federal waste storage facility, the Yucca Mountain Nuclear Waste Repository in Southwest Nevada. Temporary on-site spent fuel storage at facilities like Fort Calhoun became somewhat more indefinite when the Yucca Mountain project was abandoned.
High-level radioactive waste and spent nuclear fuel, 944 bundles of it, will be stored at the Fort Calhoun site in concrete containers with five-foot thick walls. Waste storage is expected to cost OPPD ratepayers as much as $6 million per year until a new storage plan emerges. The utility has currently budgeted for 50 years of on-site storage.

Currently, Cooper Nuclear Station is the only nuclear power plant operating in the state. The station has a generating capacity of 835 megawatts, which can provide enough energy for 385,000 homes at its peak. The reactor is what is known as a boiling water reactor. The facility received an operating license in 1974 and the NRC has approved and renewed licensing until 2034. In February, 2024, the NPPD Board of Directors voted to seek a further license renewal from the NRC to continue operating Cooper Nuclear Station until 2054.

What is the anticipated need for new energy sources in Nebraska moving forward?[3]

The Nebraska Power Association Load and Capability Annual Report for 2023 was released by Nebraska Public Power in September 2024. The report is required to be submitted for review to the Nebraska Power Review Board. In 2023, the report illustrated that a statewide capacity deficit based on the state's minimum load obligation will occur in 2027. The calculation was adjusted in the 2024 report and has not been received as of the date of this report.

Nebraska utilities' goals are to support the achievement of resource adequacy by ensuring sufficient capacity to meet the needs of all end-use customers in their service territory. Utilizing Existing, Committed, and Planned resources applied to the current cumulative SPP summer resource adequacy requirement, a statewide capacity deficit would occur starting in 2035. The statewide deficit based on the state's resource adequacy requirement in last year's report will occur in 2027 but was calculated using only Existing and Committed resources.
As manufacturing and other industries grow in Nebraska, the need for more reliable energy resources will be required.

More recently, artificial intelligence (AI) and cryptocurrency mining advances have significantly increased the anticipated need of more and more energy needs in the state.
The AI revolution is expected to require increasing amounts of energy for the most advanced models to run and nuclear power is thought by those in the industry to provide the answer to the new and increasing energy demand.[4]

What Nuclear technology currently exists in Nebraska?[5] [6]

As the movement away from fossil fuels and towards clean, carbon-free sources of energy has grown, lawmakers and power utilities in Nebraska have participated in learning and providing

[3] Appendix 3: The Annual Nebraska Power Association Load and Capability report reflects an annual update inclusive of the collective resource planning efforts of Nebraska Public Power District (NPPD), Omaha Public Power District (OPPD), Lincoln Electric System (LES), Municipal Energy Agency of Nebraska (MEAN), Hastings Utilities, City of Grand Island Utilities, City of Fremont Utilities, City of Beatrice, Falls City Utilities, City of Neligh, Nebraska City Utilities, Northeast Nebraska Public Power District (NNPPD), City of Scribner, South Sioux City, City of Superior, Tri-State Genera on & Transmission, City of Valentine, City of Wakefield, Village of Walthill, and City of Wayne. This includes solving for near-term load growth while also providing a foundation for future resource needs.

[4] Appendix 4: Article: The Small Modular Reactor Revolution is Arriving Soon." Robert G. Ecclees, Real Clear Energy, Oct. 1, 2024

[5] Appendix 5. Nebraska Advanced Nuclear Forum Report, Oct. 21, 2021; 2023 Advanced Nuclear Forum Report. https://advancednuclearcoalition.org/resources/; Nebraska Advanced Nuclear Forum Report 2023.

[6]Appendix 6: Articles: "Utilities Must Reinvent Themselves to Harness the AI-Driven Data Center Boom: Balancing growth, reliability, affordability, and sustainability is the sector's biggest challenge in decades." Meaghan Rouch, Aaron Denman, Peter Hanbury, Paul Renno, and Ellyn Gray, Bain & Company, October 10, 2024.

more information about nuclear technology being developed in Nebraska. The Advanced Nuclear Forums, presented in 2021and 2023 by the Advanced Nuclear Coalition, presented attendees with information on the future of nuclear power in Nebraska. Topics included microreactors, expandable and less expensive small modular reactors, an examination of reactor fuels, and safety surrounding nuclear technology. At the time of that forum, nuclear energy was powering an estimated 19.7% of the United States, as compared to 18.6% as of October 2024.

Nebraska utilities' goals are to support the achievement of resource adequacy by ensuring sufficient capacity to meet the needs of all end-use customers in their service territories. SPP requires LREs to maintain adequate capacity to meet its resource adequacy requirement for the summer season. SPP will also be enforcing the winter requirement starting presumably in the winter year 2024/25, Generation season.

Nuclear technologies still require some study of the viability of this energy resource to be utilized as a clean-energy, carbon free source to meet the growing demand for energy, in the United States, and in Nebraska. The legislature has explored the needs and availability of nuclear generation as a resource for the anticipated growth of energy in the state.

As part of funding provided by the American Rescue Plan Act of 2021 (ARPA), Nebraska legislators, through LB1100 which was introduced by Senator Bruce Bostelman, allocated $1 million to the Nebraska Department of Economic Development to conduct a feasibility study assessing siting options for new advanced nuclear reactors in Nebraska. In January 2023, the Nebraska Department of Economic Development (DED) awarded $863,000 to NPPD to undertake the 2021 feasibility study. NPPD released the Phase 1 of the SMR Siting Technical Screening Study Report in August 2024.[7]

What new and emerging technology exists and is on the horizon?

In 2024, the Natural Resources Committee introduced LR469 and set an October 17, 2024 informational hearing with invited testifiers to further explore, expanding and emerging technologies and when it might be expected to be available for various uses.

1. Nuclear Energy Institute (NEI)[8] Katie Austgen, of Nuclear Energy Institute. (NEI) testified. NEI is a Washington D.C. based policy and membership organization that provides a voice for over 340 members before the U.S. government and international organizations, agencies, and venues.

More and more utilities and communities are setting reduced- and net-zero de-carbonization goals. There are only a few options for clean firm power. Advances in nuclear energy generation provide a clean and reliable means of achieving lower and zero carbon goals. Across the United States, 476.5 million carbon emission reductions per year in metric tons are achieved through the use of nuclear power. As of the date of the informational hearing, there were 94 reactors at 53 plant sites across the U.S. Nuclear power produces 47.8% of clean generation throughout the

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[7] Appendix 7: "SMR Siting Technical Screening Study: Phase 1, 1898 & Co., submitted by Nebraska Public Power District August 2024.

[8] Appendix 8: NEI Presentation Slides; copy on file in Natural Resources Committee office.

U.S., compared to 26.2% wind, 14.8% Hydro, 10.2% solar, and 1% geothermal. Nuclear power operates with greater than a 90% capacity of reliability 24/7, 365 days a year .[9] In Nebraska, the Cooper Nuclear Plant houses the sole nuclear reactor currently operating in the state. Cooper Nuclear Plant has operated from 2021 to 2023 at a median capacity factor of 90.69% as documented in the same journal noted above.

A survey of NEI's U.S. utility members on nuclear power potential found that greater than 90% of the fleet expects to operate their reactors for at least 80 years and see potential for doubling electricity produced through nuclear reactor generation by 2050. NEI estimates those opportunities could translate to roughly 300 small modular reactor scale plants.

NEI presented materials describing the types of advanced reactors in development in the United States and across the world. They come in a range of sizes and features to meet diverse market needs. Austgen introduced:

A. Microreactors, which she described as small, generally producing less than 15 megawatts of electricity, citing potential use for remote and off-grid applications, such as the mining industry, or in a district energy setting for a hospital or a university campus providing its own electricity and heat. It is anticipated that Microreactors will be demonstrated yet in the 2020s, with some demonstration construction currently in process in Idaho. A map also provided in NEI materials shows the locations of current development.

B. Light-water small modular reactors use the same technology that is used by todays-reactors utilizing cooling water. These can be produced in a modular fashion, in a factory or similar setting and delivered to a site and installed rather than constructed from the ground up. Typically, a 300–350-megawatt electric range is about a third of the size of one of our current nuclear facilities. These SMRs are expected to provide electricity to the grid by the early 2030s.

C. Grid-scale Small modular reactors not using water cooling, but having the capability to produce more heat and be as large as 1,000-megawats. These come in three different types and can provide additional diversity for market needs.

D. Liquid metal reactors (See TerraPower below)'-

E. Molten salt reactors are cooled with a mixture of molten salt and sometimes a liquid fuel. These are poised to provide electricity to the grid and process heat to industrial customers by the early 2030s.

Info on Advanced Reactors

The Energy Act of 2020 (Division Z of P.L. 116-260) defines an "advanced nuclear reactor" as a fission reactor "with significant improvements compared to reactors operating on the date of enactment" or a reactor using nuclear fusion. Such reactors include LWR designs that are far smaller than existing reactors, as well as concepts that would use different moderators, coolants, and types of fuel. Many of these advanced designs are considered to be small modular reactors (SMRs), defined by the International Atomic Energy Agency (IAEA) as reactors with electric

[9] Appendix 9: "U.S. nuclear capacity factors: Ideal for data centers?", Susan Gallier, American Nuclear Society Journal, Nuclear News, May 2024.

generating capacity of 300 megawatts (MW) and below. IAEA classifies reactors with 10 megawatts or less as microreactors. - https://crsreports.congress.gov/product/pdf/R/R45706

Next-generation reactors are designed with safety as a top priority. Small modular reactors (SMRs) have built-in systems that improve even further upon the strong safety performance of current reactors. Many advanced reactors can be built below ground, providing physical security and even less vulnerability to extreme weather events. Advanced nuclear reactors also consume fuel more efficiently, producing less byproduct in smaller volumes and forms that make disposal easier. Some designs can also run on reprocessed fuel. - NEI Advanced Reactors 101

- https://www.rff.org/publications/explainers/advanced-nuclear-reactors-101/

Table 1. Advanced Nuclear Reactors: The Basics

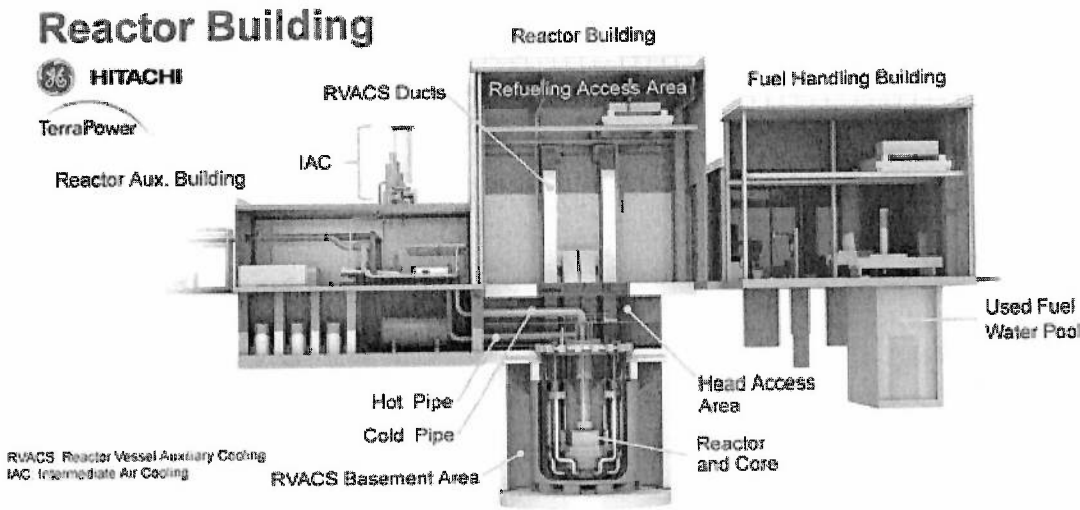
Type	Thermal vs. Fast	Materials	Capacity	Sample Cost Predictions
Small Modular Reactors (SMRs)	Either	Coolant and moderator vary	Less than 300 MW	$1-$3 billion (NuScale)
Molten Salt Reactors (MSRs)	Either	Coolant is generally molten fluoride salt; moderator varies.	Varies: <300 MW for SMR; Terrestrial Energy MSRs **range** up to 600 MWe	Less than $1 billion total and about $50 per megawatt-hour (**Terrestrial Energy**)
Sodium-Coole d Fast Reactors (SFRs)	Fast	Coolant is generally liquid sodium; no moderator is used.	Varies: As a small modular reactor, 50-300 MW; can range **up to 1,500 MW**	**Overnight** capital cost **estimated** at $1633/kW for 1500MW plant
Lead-Cooled Fast Reactors (LFRs)	Fast	Coolant is molten lead or lead-bismuth eutectic alloy; no moderator used.	Examples range from a **25-MW** micro-reactor to the **450-MW** Westinghouse Lead Fast Reactor	Overnight construction cost **estimated** at ~$200,000 per kW for ELECTRA model, with high uncertainty.

Gas-Cooled Fast Reactors (GFRs)	Fast	Coolant is generally helium gas; no moderator is used.	Examples range from **0.5 MW** to **2,400 MWth thermal power capacity**	$3,800 per kW for General Atomics' **500-MW** Energy Multiplier Module
Supercritical Water-Cooled Reactors (SCWRs)	Either	Coolant is supercritical water; moderator is generally water.	Varies, including ranges between **300 MW and 1,700 MW**	For a **submarine powered by SWCRs:** $2.71 billion in capital cost, plus $50 million annual operating cost
High Temperature Gas Reactors (HTGRs)	Thermal	Coolant is generally helium gas; moderator is generally graphite.	**Often designed as SMRs** with capacities under 300 MW	**200-MW first-of-a-kind HTGR** (2015$): ~$4 billion capital investment; $76 million per year for operation, maintenance, and fuel
Micro-Reactor s	Either	Coolant and moderator vary	2-50 MW	Varies depending on type of reactor
Fusion Reactors	N/A	Coolants may include water and helium; moderator may be water.	ITER Theoretical Example: 500 MW	For ITER, estimates range between $22-65 billion

2. TerraPower Reactors.[10] Chris Blessing testified on behalf of TerraPower. Blessing serves as TerraPower's director of strategic development. TerraPower was founded in 2006 by Bill Gates. The goal of TerraPower is to try to solve issues related to sanitation, disease, and energy poverty. The company has also focused on load following/Integrated Energy (Thermal Storage) to be stored when renewables are producing power and discharge when they are not. TerraPower currently has three basic product groups being developed.

(1) Natrium is an advanced sodium fast reactor that uses metal fuel and, currently, TerraPower is developing a demonstration project in Kemmerer, Wyoming. TerraPower's 345 MW Natrium Reactor in Wyoming, will be replacing a coal fired plant. https://www.terrapower.com/terrapower-submits-cpa-nrc/;https://www.terrapower.com/natrium/

[10] Appendix 10: TerraPower Presentation slides, available in the Natural Resources Committee office.



(2) Molten Chloride Fast Reactor, which uses liquid fuel and provides opportunities for integrated energy storage systems, such as energy island thermal storage. The technology is in the lab in its earlier stages of technology readiness. The company has found that this technology has the ability and flexibility to be useful in load-balance for the future grid, even if it's a renewable-based grid.

(3) Nuclear Related Medicine[11] Actinium-225, designed for use in Cancer-fighting treatments, recently started delivery for testing in human trials.
- On October 1, 2024 TerraPower announced it was producing Actinium-225 at a commercial scale. This isotope is being used in multiple drug developer's radiopharmaceuticals in clinical trials.
- Actinium-225 is used as a starting material for targeted cancer treatments.
- Specifically, being looked at to be used to treat prostate, colon, breast and neuroendocrine cancers, melanoma and lymphoma

3. Westinghouse Clean Energy Solutions[12]

John Battaglini testified on behalf of Westinghouse. Westinghouse Electric Company LLC is a nuclear power company formed in 1999 from the original Westinghouse Electric Corporation. Westinghouse has delivered nuclear plants for a number of years and offers nuclear products and services to utilities internationally. The company's Generation III design is the AP 1000, a modern pressurized water reactor providing modular construction intended to lower construction time and cost.

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[11] Appendix 11: Nuclear Medicine: Article: "Nuclear Innovation to Advance New Cancer Treatments", TerraPower; Orano Nuclear Medicine; "Westinghouse Advances Key Radioisotope Technology to Fight Cancer." Westinghouse Electric Co., June 23, 2023.
https://info.westinghousenuclear.com/news/Westinghouse-advances-key-radioisotype-technology-to-fight-cancer

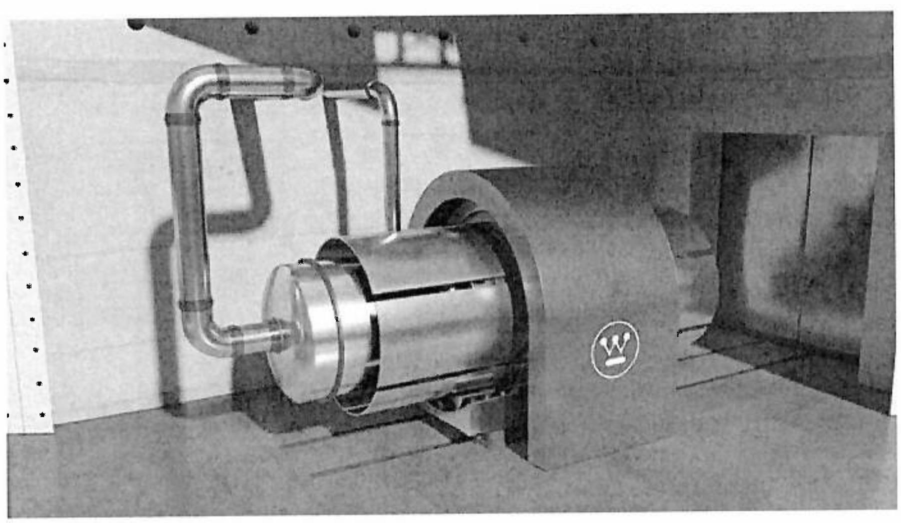
[12] Westinghouse slide presentation, available in the Natural Resources Committee office.

In June 2023, Westinghouse announced it had successfully demonstrated an approach to produce Actinium-225 radioisotopes in its commercial nuclear reactors

- Westinghouse also has contracts to produce other isotopes such as Cobalt-60 and Lutetium-177 in their commercial reactors
    - Cobalt-60 is used in medical procedures where gamma rays from the cobalt-60 are used to treat cancer
    - Lutetium-177 is an isotope used to treat neuroendocrine tumors and prostate cancer and is administered intravenously

Westinghouse Reactors

- eVinci Microreactor by Westinghouse
    - https://www.westinghousenuclear.com/energy-systems/evinci-microreactor
    - Expected to produce 5MW
    - Can operate for at least 8 years before refueling
    - Fully factory assembled and transportable in shipping containers
    - Footprint of less than 2 acres
    - Ability to load-follow and load-shed within milliseconds. (Can ramp up/down production within milliseconds)
- AP300 SMR by Westinghouse
    - Based on the technology used in the larger AP1000 reactors of which, 6 units are operational and 4 are under construction (2 AP1000 units are in the US)

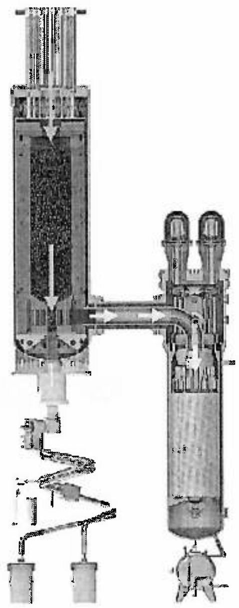


X-energy Reactors

- X-Energy Xe-100
    - Each Reactor is expected to generate approximately 80MWe while the standard Xe-100 "four pack" plant generates approximately 320MWe
    - can also be designed to incorporate passive cooling through natural conduction, thermal radiation and convection in the case of a loss of helium coolant—meaning

it doesn't have to rely on large local water sources, pumps, or safety systems to prevent fuel damage

  - First plant, with four reactors, to be built at the DOW Chemical facility in Seadrift, TX.



Other Reactor News

- BWXT Project Pele for DoD Strategic Capabilities Office (SCO)
  - https://www.cto.mil/pele_eis/
  - Project Pele is a high temperature gas cooled transportable microreactor.
  - Prototype expected to be operational and tested at Idaho National Labs by 2025

The United States Army recently (May 2024) announced it will soon release a request for information to inform a deployment program for advanced reactors to power multiple Army sites throughout the United States

- https://www.newcivilengineer.com/latest/white-house-plans-amrs-to-power-multiple-army-bases-in-the-united-states-31-05-2024/

The Department of the Navy (DON), which comprises the United States Navy and the United States Marine Corps, issued a request for information (October 7th, 2024) from interested developers, utilities, consortia, or similar private or public parties regarding interest in developing non-excess, under-utilized DON lands for the purpose of constructing commercial scale, grid facing clean energy generation to achieve full base energy resilience.

- https://sam.gov/opp/9e96e24253db41e28d9352532a7902eb/view

The United States Air Force released a Request for Information (RFI) for the Air Force (AF) Strategic Real Estate Opportunities at Joint Base San Antonio (JBSA) (Notice ID: FA8903-25-R-1002) on October 24th, 2024 with the purpose of conducting a market survey to solicit interest for potential development, re-development, or lease of underutilized real estate and facilities located on JBSA.

- Project Details for this specific opportunity state that…" *DAF invites any interested U.S. domestic entities, including federal, state, and local governmental entities, private sector entities, or economic development organizations to propose solutions for the Energy Resiliency Opportunity. Responses should explore potential for advanced, or enhanced, resilient carbon pollution-free energy capabilities at JBSA to provide continuous reliable power regardless of weather conditions or other types of power disruptions; this may include innovative, emerging, or advanced technology solutions with long lead times including green hydrogen, geothermal,* ***new nuclear*** *and potentially technologies not yet identified. Further DAF encourages pairing microgrids with long lead time technologies such as* ***new nuclear*** *to increase the resilience of the base and surrounding communities.*

What about Nuclear Used Fuel

History of Reprocessing/Recycling Nuclear Used Fuel

In 1977 reprocessing of spent nuclear fuel was banned in the United States due to proliferation concerns. The ban was lifted during the Reagan Administration but due to economic conditions, e.g., the low cost of uranium, it failed to take off. The Nuclear Waste Policy Act of 1982 (with amendments) requires the Department of Energy to take back commercial used fuel and to create a spent fuel repository (which has yet to be built/operational) https://world-nuclear.org/information-library/nuclear-fuel-cycle/fuel-recycling/processing-of-used-nuclear-fuel

There are currently 7 nations that have or are developing reprocessing facilities: France, Russia, China, Israel, India, Pakistan, and Japan.

Reprocessing is the practice of extracting fissile materials from spent or used fuel for recycling and to reduce the volume of high-level radioactive materials. Reprocessing also reduces the level of radioactivity of the materials and after about 100 years, that level falls more rapidly than used fuel itself.

- Most of the plutonium recovered from used fuel is currently recycled into mixed oxide (MOX) fuel
- MOX fuel is nuclear fuel that contains more than one oxide of fissile material (usually containing Pu and U)

New reprocessing technologies are being developed to be deployed in conjunction with fast neutron reactors which can burn uranium and plutonium without the need for them to be separated.

4. Orano's Work in Reprocessing Nuclear Used Fuel. **Orano Group**.[13] Sven Bader spoke on behalf of Orano, about the backend of reactors, that is about the spent fuel that follows reactor use. Orano is involved in the backend of the Nuclear Fuel Cycle Capability;

[13] Appendix 13: Orano Presentation Slides, available in the Natural Resources Committee office.

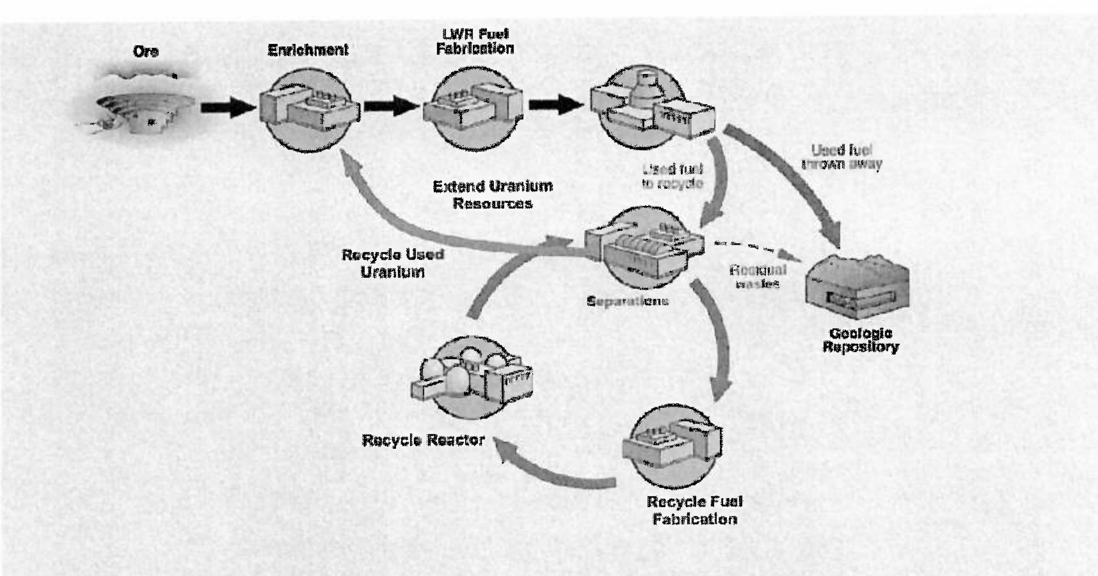
Storage, Recycling, Medical and commercial applications, transportation, Symbiotic Relationship with Advanced Reactors (Fuel fabrication); status of U.S. Department of Energy Related Activities

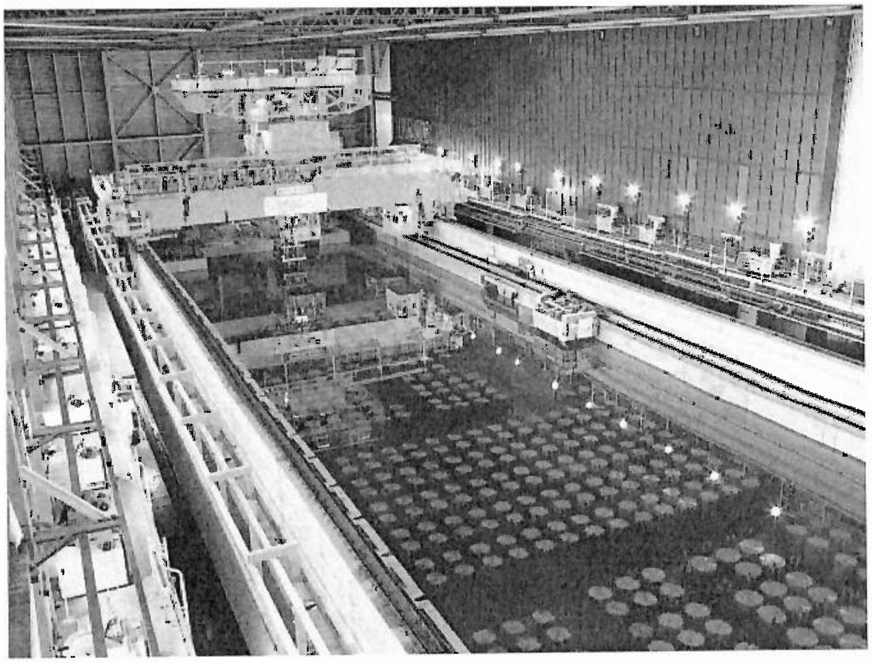
Orano is one of the largest companies which reprocesses and recycles spent nuclear fuel. The steps they take in the reprocessing the fuel is as follows:

- Safe Receipt and Storage- when spent fuel arrives at the facility automated equipment moves the fuel to a concrete walled room with 4-foot-thick walls where the fuel is stored in a cooling pool for 5 to 7 years
- Component separation and recovery of materials- once cooled, the fuel is sheared into small pieces before being immersed in nitric acid which dissolves the material while also separating the recyclable material and other radioactive materials. 96% of the nuclear material is recoverable. Once this is complete the Pu and U are separated and purified before the Pu is remixed with depleted uranium to produce mixed oxide (MOX) fuel and the leftover U is then re-enriched to provide Recycled Uranium Fuel (URE)
- Final Waste Conditioning- after reprocessing and recycling only 4% of nuclear material remains as waste. This waste is heated, mixed with molten glass and then cast in stainless steel containers before being stored onsite while waiting for transfer to deep geological storage. Foreign waste is returned to the country of origin.
- MOX Fuel- The MOX fuel produced is then used to supply nuclear plants in France, Germany, and Japan

In February, 2024, the Orano Group entered into a Memorandum of Understanding with SHINE Technologies in the U.S. to form a pilot plant in the US to recycle used nuclear fuel for light water reactors.
Since 1960, Orano's La Hague facility in France has safely processed over 23,000 tons of spent fuel which is enough to power France's nuclear fleet for 14 years.

- https://www.orano.group/en/nuclear-expertise/from-exploration-to-recycling/world-leader-in-recycling-used-nuclear-fuels





Storage Pool for spent nuclear waste

Safe Storage of Nuclear Materials

In the United States all of the used fuel ever produced since the 1950s would only cover a football field to a height of 10 yards

- Low Level Waste (LLW) is typically sent to a land fill-based disposal immediately following its packaging for long term management
- For High Level Waste (HLW), (non-fuel related) the waste is stored to let the radiation decay and cool
    - This is usually done onsite in cooling ponds or in dry casks

Overall, it is widely agreed upon that deep geological disposal is the best solution for final disposal of most radioactive materials

- There have been studies into a centralized location for safe and environmentally sound solutions to the final management of radioactive material.

Yucca Mountain

- In 1987 Yucca Mountain in the desert of Nevada was designated as the US national repository for spent fuel and high-level waste from nuclear power and military defense programs
- This facility would be around 1,000 feet deep in the rock and waste would be stored in highly corrosion resistant double shelled metal containers
- This project was eventually canceled in 2009 by the Obama administration. However, the NRC rejected the DoE's motion to withdraw the license and in 2013 a federal appeals court ordered the NRC to continue the review of the proposed facility.

- In May 2016, the NRC released its final supplement to the US DoE's environmental impact statement which found that the site would prove safe for one million years; however, the project has been stalled by a lack of funding from congress and local opposition.
    - https://www.nei.org/fundamentals/nuclear-waste gives more NEI Nuclear Waste info

Transportation of Nuclear Waste (Used fuel and materials)

Transportation of nuclear waste is currently regulated by the NRC. Transportation usually occurs between two reactors owned by the same utility in order to share storage space. In over 40 years and thousands of shipments, there has never been a release of waste. When transporting, the waste must be shipped in containers or casks which shield radiation and dissipate heat. Extensive testing has been conducted on the containers and casks to ensure they are safe from potential accidental releases.

Recent Federal Nuclear Policy Updates

In July, with overwhelming bipartisan support, Congress passed S. 870 which contained the ADVANCE Act ("Accelerating Deployment of Versatile, Advanced Nuclear for Clean Energy Act") https://www.congress.gov/118/bills/s870/BILLS-118s870enr.pdf

- Bill contains several initiatives to advance the deployment of advanced nuclear reactors
    - Removes the NRC fee-based cost on pre application
    - Increases staffing at the NRC to process licenses
- Contains language to address licensing roadblocks for all nuclear related technologies including reprocessing/recycling

On May 29, 2024, the White House formed the Nuclear Power Project Management and Delivery working group who will work to identify opportunities to proactively mitigate sources of cost and schedule overrun risk. The working group will also assist the DoD in constructing an advanced reactor to help power Army Bases.

- Group will consist of the following:
    - White House Office of Domestic Climate Policy
    - White House Office of Science and Technology Policy
    - Department of Energy
        - C.F.R part 53 is currently out for 60 days for comment on a new streamlined process for small modular reactor licensing fees and provides that the first entity that successfully completes the proposed process will be reimbursed for certain development fees.

Electric Power Research Institute (EPRI) Advanced Nuclear Roadmap Phase 1

https://publicdownload.epri.com/PublicAttachmentDownload.svc/AttachmentId=83812

- Outlines an achievable path for the deployment of advanced reactors and identifies challenges the industry needs to address such as:

- The ability to separate the scope of nuclear safety and radiation hazards from normal industrial activities. Shifting the industry from focusing on building large one-off plants on-site to factory assembled models
- The need to educate external stakeholders and the public on the perception of nuclear and advanced nuclear technologies and share the accomplishments of nuclear energy and the impacts offered by advanced nuclear
- Recognizing the importance of government support to accelerate commercialization with policies supporting advanced nuclear
- Identified Specific Needs for Advanced Reactors
- Operator Staffing- The need to develop industry standards and guidance on operator staffing and requirements
- Licensing- The need for industry to provide input to the NRC for new rule and guidance that appropriately reflect advanced reactor technology for licensing purposes

Miscellaneous Information

Today there are about 440 nuclear power reactors operating in 32 countries plus Taiwan, with a combined capacity of about 390 GWe. In 2022 these provided 2545 TWh, about 10% of the world's electricity.

Since the first nuclear power plants commenced operations, the IAEA estimates there has been roughly 329,000 tons of nuclear used fuel produced. Of that, roughly 127,000 tons has been reprocessed

Conclusion

Nuclear energy provides a clean, reliable baseload (firm) generation alternative. It can co-exist with, and complement traditional and renewable energy options, and can provide greater reliable energy generation capability, along with economic opportunity and smaller land use requirements than other options. "Small modular reactors provide a cost-effective option, particularly when you assume at least a 60-year lifetime as a long-term generation asset." (Austgen, NEI). Great advances have been made in nuclear used fuel storage and reprocessing, alleviating many previous concerns surrounding the technology. The nuclear industry can provide economic benefits, including job creation, in areas where development is advanced. According to the October 2024 Oxford Economic Report, "Economic Contribution of the US Nuclear Power Industry, the full economic contribution of the nuclear power industry in 2022 for Nebraska was 2,668 employed by the industry, with GDP of $688 million, $70 million in federal taxes, $91 million state and local taxes. Specifically, in Nemaha County, Cooper Nuclear Station employed 1009, with a GDP of $452 million, $34 million in federal taxes, $75 million in state and local taxes.

Committee Recommendations

- The State should create an Advanced Nuclear Authority to coordinate Nebraska's nuclear vision, implement advanced nuclear technologies and oversight of state nuclear incentive programs;
- The Legislature should develop a nuclear energy fund incentivizing one or more SMR projects in Nebraska;
- The State should form a working group that will include UNMC working towards a goal of further developing isotopes that fight cancer;
- The State should aggressively develop the work of the Nuclear/Hydrogen work group in workforce development to include but not limited to scholarships and program development;
- The Nebraska Department of Economic Development should create outreach and development for manufacturing opportunities in advanced nuclear generation and medicine.
- Ensure that our public power districts are including advanced nuclear energy in their Integrated Resource Plans as potential options for future generation.

Links to Other Useful Advanced Nuclear Information

https://www.nrc.gov/reactors/new-reactors/advanced.html

- NRC website for Advanced Nuclear Reactors

https://www.energy.gov/ne/articles/nrc-endorses-new-guidance-advanced-reactor-licensing

- NRC licensing of X-energy design

https://crsreports.congress.gov/product/pdf/R/R45706

- Congressional Research on Advanced Nuclear Reactors

https://www.nei.org/advanced-nuclear-energy/advanced-nuclear-101

- Advanced Nuclear 101- NEI

https://www.energy.gov/ne/advanced-reactor-technologies

- DOE Office of Nuclear Energy- Advanced Reactor Technologies

https://aris.iaea.org/Publications/SMR_booklet_2022.pdf

- International Atomic Energy Agency- List of SMR Reactors/Developments and diagrams of the reactors etc.

https://www.gov.uk/government/publications/advanced-nuclear-technologies/advanced-nuclear-technologies

- UK Government Website on Advanced Reactors

https://www.ans.org/news/article-5634/2024-the-state-of-advanced-reactors/

- American Nuclear Society State of Advanced Reactors
  https://www.eenews.net/articles/white-house-makes-push-for-large-nuclear-reactors/

- White House Advocating for the development of advanced reactors 5-30-2024

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ONE HUNDRED EIGHTH LEGISLATURE

SECOND SESSION

LEGISLATIVE RESOLUTION 469

Introduced by Natural Resources Committee: Bostelman, 23, Chairperson; Brandt, 32; Cavanaugh, J., 9; Fredrickson, 20; Hughes, 24; Jacobson, 42; Moser, 22; Slama, 1.

PURPOSE: The purpose of this resolution is to propose an interim study to examine existing, new, and emerging technologies in the nuclear energy industry.

Many electric utilities are setting carbon reduction goals as well as setting zero net carbon policies. However, the demand for electricity continues to rise as different sectors of the economy move away from traditional fossil fuel resources to reduce emissions. This is most evident in the transportation and agriculture sectors.

Residential, business, and commercial electric utility customers demand a reliable electric energy resource available twenty-four hours per day and three hundred sixty-five days per year. Increased demand for electricity comes while traditional fossil fuel generation resources are being prematurely shut down to meet reduced carbon goals. Loss of baseload resources without comparable replacements puts electric utility consumers at risk. To meet the continuing demand for reliable electricity, zero-carbon baseload generating resources, such as nuclear energy, will be needed to ensure that utilities may meet carbon goals and continue to supply reliable electricity to consumers.

Emerging and new nuclear energy generation technologies and research are changing the way electricity is generated using nuclear energy, making the generation safer and more efficient. The utilization of existing and new advanced nuclear energy technologies also allows spent nuclear energy fuel to be managed as an asset. Education about these technologies is an important part of the process of understanding the role that nuclear energy can play in a low-carbon future.

For purposes of this study, the committee shall hold informational

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hearings inviting key nuclear energy industry companies and support business to provide education and details on existing, new, and emerging technologies in the nuclear energy industry. The committee shall also prepare a report outlining resources that could be used as educational tools about nuclear energy for policy makers, businesses, and members of the public.

NOW, THEREFORE, BE IT RESOLVED BY THE MEMBERS OF THE ONE HUNDRED EIGHTH LEGISLATURE OF NEBRASKA, SECOND SESSION:

1. That the Natural Resources Committee of the Legislature shall be designated to conduct an interim study to carry out the purposes of this resolution.

2. That the committee shall upon the conclusion of its study make a report of its findings, together with its recommendations, to the Legislative Council or Legislature.

2

Nebraska State Legislature

LEGISLATIVE
RESEARCH OFFICE

BENJAMIN THOMPSON
Director of Research

PO Box 94604, State Capitol
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402-471-2221

MEMORANDUM

To: Senator Bruce Bostelman

Cc: Cyndi Lamm, Legal Counsel

From: Mark Marsh, Research Analyst

Date: 10/4/20243

Re: Research Request – Nebraska History with Nuclear Power

A request was received from your office for information regarding the history of nuclear power in Nebraska and of relevant statutes, the mechanism used for power plant funding, dates and costs of construction, operations and decommissioning. The following memo serves to address your questions.

After the power of nuclear fission was revealed at the end of World War II, discussions began about its potential for civilian uses. The Atomic Energy Act of 1946, highlighted and promoted the idea of civilian uses of atomic energy for peaceful purposes consistent with the common defense and security and with the health and safety of the public. Yet, private, commercial utilization was not yet permitted.

That changed with the 1954 Atomic Energy Act (AEA). It broadened the exclusive military focus and ended complete government control, facilitating peaceful applications. The push to develop civilian nuclear applications had grown but was driven, not primarily by anticipation of increased power demand but, by a determination to maintain world technological leadership. The AEA would advance new uses for radiological material including utility-scale generation of electric power as well as medical and research uses.

Developing a civilian program would also require processes to review, declassify and disseminate nuclear technology. A civilian regulatory structure would also be needed to ensure safe utilization of nuclear power and careful control of access to fissile material, a task given to the Atomic Energy Commission (AEC).

Much had been learned in developing an explosive nuclear device. However, the development of a new civilian nuclear power industry would require more technological advancement. Reactor design, demonstration and testing was too risky and expensive to be undertaken by electric utilities alone. The AEC was instrumental in leading these advancements, many times through partnerships with existing power generators.

Hallam Demonstration Reactor

A partnership between the AEC and Consumers Public Power District (CCPD), later renamed Nebraska Public Power District (NPPD), led to construction of a sodium-cooled, graphite modulated, nuclear reactor at Hallam, Nebraska.

The project was part of the Power Demonstration Reactor Program that began in 1959. Its purpose was to advance atomic energy by demonstrating operation of a design that used sodium as a liquid metal coolant. The Hallam reactor was co-located with a coal-fired plant which was constructed by CPPD. Each power source was designed to operate the same turbine generator during the testing phase. There were plans to build a second generator after the nuclear reactor was fully operational.

Construction began in 1959 and was completed in November 1961, and the reactor operated between 1962 and 1964. Technical challenges ultimately led to its decommissioning in 1969 after the AEC abandoned the project and CPPD declined its option to purchase the plant.

The reactor has since been decommissioned. Radioactive fuel and sodium coolant were removed as were most of the above-ground parts of the facility. Other contaminated parts including the reactor vessel, containment structure, fuel storage pit and moderator storage cells, now rest in steel-lined areas encased in several feet of concrete and capped with earth. Continued long-term stewardship, including monitoring of the site, is the responsibility of the Department of Energy Office of Legacy Management.

While most nuclear reactors in operation today are either pressurized or boiling water reactors, a natrium reactor being built in Wyoming through a public private partnership under the U.S. Department of Energy Advanced Reactor Demonstration Program is a beneficiary of demonstration projects like the one in Hallam.

Veteran's Affairs Reactor

Another little-known reactor was housed in the basement of the U.S. Department of Veterans Affairs Medical Center in Omaha. The reactor was used in medical research for studying different physiological processes. The low power reactor was installed in 1959 and cost $154,000. Security concerns lead to its shutdown in 2001 and it was dismantled in 2016.

Commercial Nuclear Power Plants

Two better known reactors were constructed in Nebraska beginning in the late 1960s: the Cooper Nuclear Station near Brownsville Nebraska, owned by Nebraska Public Power District

(NPPD); and the Fort Calhoun Nuclear Station near Fort Calhoun, Nebraska, owned by Omaha Public Power District (OPPD).

Cooper

NPPD's first experience with nuclear power was the short-lived Hallam Nuclear Power Facility. The 767 Mw Cooper facility, on the other hand, continues to produce electricity for Southeast Nebraska as it has since 1974. Permission to begin constructing the facility was given to CPPD (now NPPD), in 1968. Construction of the facility, which sits on 1251 acres, required more than 90,000 cubic yards of concrete and 10,000 tons of steel and cost an estimated $316 million. It was the first facility to use recycled uranium from Soviet Union weapons stockpiles.

In 2010, the Nuclear Regulatory Commission (NRC), extended the license to operate the Cooper facility until 2034. The Board of directors have authorized pursuit of another renewal that, if approved, would provide a license until 2054.

Spent fuel was removed to underground pools until 2006 when pool capacity was reached. After that, above ground dry-cask storage began.

Fort Calhoun

The nuclear power reactor at Fort Calhoun Station was brought online by Omaha Public Power District (OPPD) in 1973. In 1968, construction of the 478 Mw reactor began on a site between Fort Calhoun and Blair, Nebraska, adjacent to the Missouri River. During its operation, around 700 people were employed at the plant. It cost around $200 million per year to operate.

In 2016, after 43 years of operation, OPPD began the process of decommissioning the power plant. Decommissioning activities employ almost 300 people. After the expected 2026 closure of the site, fifty employees will remain for security and maintenance at the 660-acre site. By federal regulation, commercial nuclear plants are required to establish a decommissioning fund sufficient for all closure activities.

According to OPPD's 2019 decommissioning report to the NRC, decommissioning cost estimates total $1.2 billion, including: license termination expenses - $832 million; site restoration - $49 million; and spent fuel management - million $331 million. OPPD believed high operating expenses and relatively small power output (Fort Calhoun was the smallest active facility in the U.S. when it was retired) made continued operation uneconomical.

Previously, there were plans to construct a federal waste storage facility, the Yucca Mountain Nuclear Waste Repository in Southwest Nevada. Temporary on-site storage at facilities like Fort Calhoun became somewhat more indefinite when the Yucca Mountain project was abandoned. High-level radioactive waste and spent nuclear fuel, 944 bundles of it, will be stored at the Fort Calhoun site in concrete containers with five-foot thick walls. Waste storage is expected to cost OPPD ratepayers as much as $6 million per year until a new storage plan emerges. The utility has currently budgeted for 50 years of on-site storage.

Funding Fort Calhoun and Cooper

Typically, public power districts fund large-scale large capital projects by issuing revenue bonds. Public power districts in Nebraska derive their authority to borrow and incur debt from N.R.S. § 70-631.

To build the Cooper Nuclear Station, NPPD issued bonds for equipment, materials and all of the construction and engineering services. To achieve certain economies of scale, NPPD partnered with Iowa Power and Light (IPL) and Lincoln Electric System (LES). The partners agreed to purchase a portion of the power produced and to split total project costs. IPL and LES obligations represented fifty percent and twelve- and one-half percent shares of power output and costs.

Nuclear power plants may have been constructed using revenue bonds and purchase agreements but, the AEC's promotion of nuclear power under the Power Reactor Demonstration Program (1955) also provided financial incentives, including research and development technology, fuel-lease waivers, fuel fabrication, and training to cooperating electric utilities. According to a 1979 Comptroller General report, federal support of the civilian nuclear program in its developmental years, 1950 to 1978, cost an estimated $12.1 billion.

Crow Butte

This facility in Northwest Nebraska near the town of Crawford, performed in-situ recovery of uranium. The process is less expensive and particularly effective with low-grade ores because instead of extracting and processing bulky ore material, in-situ recovery injects solutions into the ore body to dissolve and pump out the uranium-enriched solvent which is then purified and concentrated to make yellowcake.

The facility was first developed in 1986 and commercial operation began in 1991. The leased area of the facility covered 3,300 acres. An estimated 1,100 acres of surface area was to be affected over the life of the mine. Its license permitted annual yellowcake production of two million pounds. An application for license renewal was submitted in 1995 and license amendments were requested to expand recovery areas however in 2018, Crow Butte Resources Inc. announced it would cease production at each of its U.S. operations due to low uranium prices.

Advanced Nuclear Reactors

A new initiative to advance nuclear technology was spurred by a program under American Rescue Plan Act of 2021. In response, the Nebraska Legislature allocated $1 million to the Nebraska Department of Economic Development to provide funds to:

> "conduct a feasibility study to assess (1) siting options for new advanced nuclear reactors throughout Nebraska and (2) existing electric generation facilities based on key compatibility assets for such advanced nuclear reactors. The funds will provide for the preconstruction feasibility study as well as applicable planning and design costs to be a key partner in achieving the goals of the EPA's Clean Power Plan (CPP)."

In January 2023, DED awarded a grant of $863,000 to Nebraska Public Power District (NPPD) to undertake the study.

Statutes

Federal

Atomic Energy Act of 1946   42 U.S.C. §2011 et seq.

Atomic Energy Act 1954   42 U.S.C. §§ 2011–2021, 2022-2286i, 2296a-2297h-13

The Energy Reorganization Act 1974   42 U.S.C. §5801 et seq.

> Enacted, in part, to segregate AEC's responsibility to develop nuclear technology from its regulatory responsibilities. As a result, the AEC was split into the Nuclear Regulatory Commission (NRC) and Energy Research and Development Administration.

Nuclear Waste Policy Act of 1982   42 U.S.C. §10101 et seq.

> Established the policy of deep geologic storage of radioactive waste and the evaluation and site selection procedures.

Energy Policy Act of 1992   42 USC §13201 et seq.

> Aimed to diversify and boost renewable energy sources. It began a process of energy industry deregulation and also provided tax incentives for new development and investment in nuclear power.

State

Midwestern Nuclear Compact, Vol. 2A Appendix section   N.R.S. § 1-116
Uranium severance tax   N.R.S. § 57-1202
Nuclear and Hydrogen Development Act   N.R.S. §§ 66-2302 to 66-2308
Power Districts and Corporations, Chapter 70, article 6   N.R.S. §§ 70-601 to 70-682
District; radioactive material and energy; powers; development; contracts   N.R.S. § 70-627.02
Public Power Infrastructure Protection Act   N.R.S. §§ 70-2101 to 70-2105
Radiation Control Act   N.R.S. §§ 71-3501 to 71-3520
Shipment of radioactive materials across the state   N.R.S. §§ 71-3523 to 71-3528
Low-Level Radioactive Waste Disposal Act   N.R.S. §§ 81-1578 to 81-15,116
Uranium mining; department; regulatory duties; prohibited methods   N.R.S. § 81-1531.02

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Reactor Database. World Nuclear Association
The Atomic Energy Commission. Alice Buck. U.S. Department of Energy, Office of Management. Jul 1983.
2019 Annual Decommissioning Funding/Irradiated Fuel Management Status Report. NRC. 2019.
Waste, Families Left Behind As Nuclear Plants Close. National Public Radio. Oct 24, 2016

Appendix

Facility Details			
Facility	**Sheldon Power Station**	**Cooper Nuclear Station**	**Fort Calhoun Nuclear Sta**
Location	Hallam	Brownville	Fort Calh
Site	18 acres	1,251 acres	660 a
Owner	Nebraska Public Power District	Nebraska Public Power District	Omaha Public Power Dis
Operator	Atomic Energy Commission and Nebraska Public Power District	Entergy Nuclear Operations, Inc.	Exelon Generation Company
Reactor Type	Sodium Cooled Graphite Moderated Reactor	Boiling Water Reactor	Pressurized Water Rea
Reactor Vendor, Type	Atomics International	General Electric	Combustion Enginee
Capacity	75 Mw	767 Mw	478
Cooling System		once-through system, Missouri River supply	once-through system, Missouri R su
Spent Fuel Storage		Both, Wet and Dry Cask Storage	Dry Cask Sto
Construction Cost	$57 million	$316 million	$162 mi
Timeline			
Construction Began	1959	1968	1
Construction Completed	1961	1974	1
License Expiration		2034	2
Permanent Shutdown	1964		2
Estimated Closure			2
Fully Decommissioned			2

Additional Information on the Nuclear Energy Industry

Prepared By:

Riley Herchenbach, Legislative Aide for Sen. Bruce Bostelman
Cyndi Lamm, Legal Counsel for the Natural Resources Committee

Info on Advanced Reactors

The Energy Act of 2020 (Division Z of P.L. 116-260) defines an "advanced nuclear reactor" as a fission reactor "with significant improvements compared to reactors operating on the date of enactment" or a reactor using nuclear fusion. Such reactors include LWR designs that are far smaller than existing reactors, as well as concepts that would use different moderators, coolants, and types of fuel. Many of these advanced designs are considered to be small modular reactors (SMRs), defined by the International Atomic Energy Agency (IAEA) as reactors with electric generating capacity of 300 megawatts (MW) and below. IAEA classifies reactors with 10 megawatts or less as microreactors. - https://crsreports.congress.gov/product/pdf/R/R45706

Next-generation reactors are designed with safety as a top priority. Small modular reactors (SMRs) have built-in systems that improve even further upon the strong safety performance of current reactors. Many advanced reactors can be built below ground, providing physical security and even less vulnerability to extreme weather events. Advanced nuclear reactors also consume fuel more efficiently, producing less byproduct in smaller volumes and forms that make disposal easier. Some designs can also run on recycled fuel.- NEI Advanced Reactors 101

- Advanced Reactors 101- Resources for the Future
  - https://www.rff.org/publications/explainers/advanced-nuclear-reactors-101/

Table 1. Advanced Nuclear Reactors: The Basics

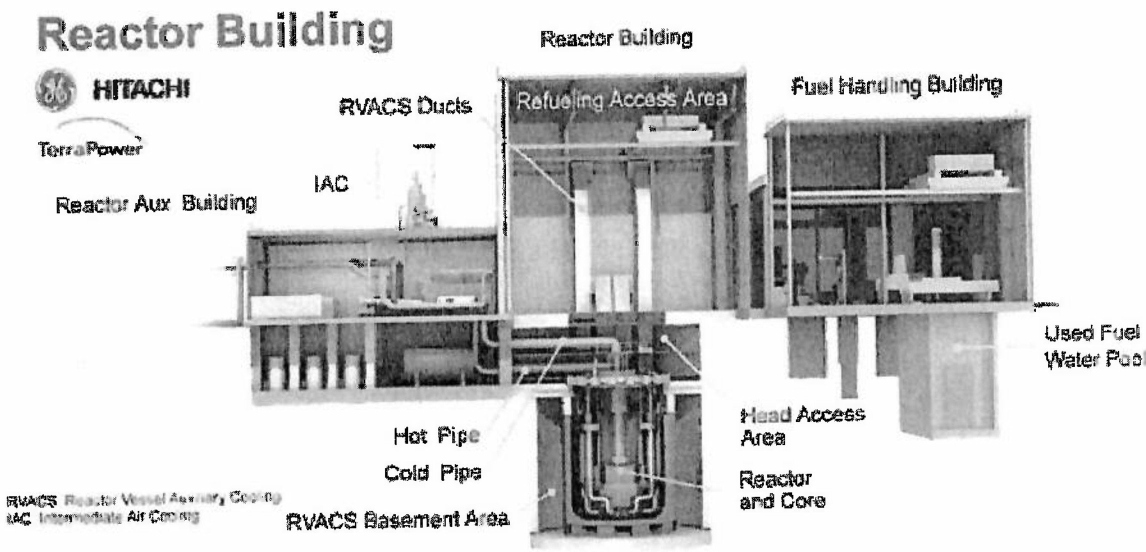
Type	Thermal vs. Fast	Materials	Capacity	Sample Cost Predictions
Small Modular Reactors (SMRs)	Either	Coolant and moderator vary	Less than 300 MW	$1-$3 billion (NuScale)
Molten Salt Reactors (MSRs)	Either	Coolant is generally molten fluoride salt; moderator varies.	Varies: <300 MW for SMR; Terrestrial Energy MSRs range up to 600 MWe	Less than $1 billion total and about $50 per megawatt-hour **(Terrestrial Energy)**

Sodium-Cooled Fast Reactors (SFRs)	Fast	Coolant is generally liquid sodium; no moderator is used.	Varies: As a small modular reactor, 50-300 MW; can range **up to 1,500 MW**	**Overnight** capital cost **estimated** at $1633/kW for 1500MW plant
Lead-Cooled Fast Reactors (LFRs)	Fast	Coolant is molten lead or lead-bismuth eutectic alloy; no moderator used.	Examples range from a **25-MW** micro-reactor to the **450-MW** Westinghouse Lead Fast Reactor	Overnight construction cost **estimated** at ~$200,000 per kW for ELECTRA model, with high uncertainty.
Gas-Cooled Fast Reactors (GFRs)	Fast	Coolant is generally helium gas; no moderator is used.	Examples range from **0.5 MW** to **2,400 MWth thermal power capacity**	$3,800 per kW for General Atomics's **500-MW** Energy Multiplier Module
Supercritical Water-Cooled Reactors (SCWRs)	Either	Coolant is supercritical water; moderator is generally water.	Varies, including ranges between **300 MW and 1,700 MW**	For a **submarine powered by SWCRs:** $2.71 billion in capital cost, plus $50 million annual operating cost
High Temperature Gas Reactors (HTGRs)	Thermal	Coolant is generally helium gas; moderator is generally graphite.	**Often designed as SMRs** with capacities under 300 MW	**200-MW first-of-a-kind HTGR** (2015$): ~$4 billion capital investment; $76 million per year for operation, maintenance, and fuel
Micro-Reactors	Either	Coolant and moderator vary	2-50 MW	Varies depending on type of reactor
Fusion Reactors	N/A	Coolants may include **water** and **helium**; moderator may be **water**.	**ITER Theoretical Example:** 500 MW	For ITER, estimates range between $22-65 billion

TerraPower Reactors

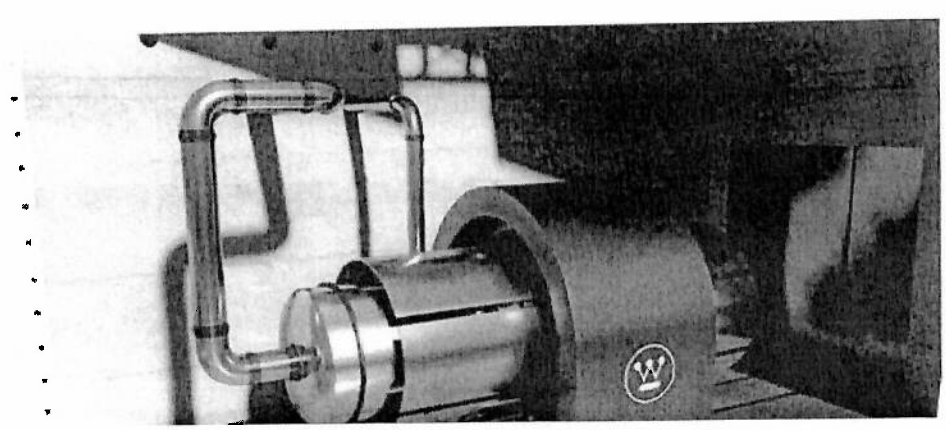
TerraPower is constructing a 345 MW Natrium Reactor in Wyoming, replacing a coal fired plant

- https://www.terrapower.com/terrapower-submits-cpa-nrc/
- https://www.terrapower.com/natrium/
- The Natrium Reactor is a 345 MWe pool type sodium fast reactor using HALEU metal fuel



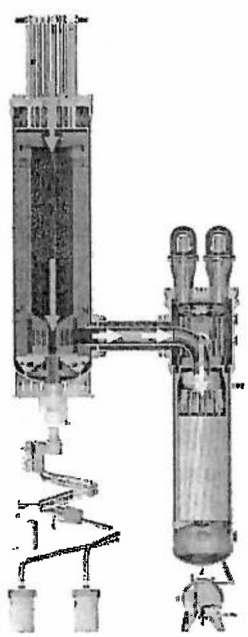
Westinghouse Reactors

- eVinci MicroReactor by Westinghouse
  - https://www.westinghousenuclear.com/energy-systems/evinci-microreactor
  - Expected to produce 5MW
  - Can operate for at least 8 years before refueling
  - Fully factory assembled and transportable in shipping containers
  - Footprint of less than 2 acres
  - Ability to load-follow and load-shed within milliseconds. (Can ramp up/down production within milliseconds)
- AP300 SMR by Westinghouse
  - Based on the technology used in the larger AP1000 reactors of which, 6 units are operational and 4 are under construction



X-energy Reactors

- BWTX Project Pele by X-Energy
    - https://www.cto.mil/pele_eis/
    - Project Pele is a high temperature gas cooled transportable microreactor.
    - Prototype expected to be operational and tested at Idaho National Labs by 2025
- X-Energy Xe-100
    - Each Reactor is expected to generate approximately 80MWe while the standard Xe-100 "fou pack" plant generates approximately 320MWe
    - can also be designed to incorporate passive cooling through natural conduction, thermal radiation and convection in the case of a loss of helium coolant—meaning it doesn't have to rely on large local water sources, pumps, or safety systems to prevent fuel damage
    - First reactor currently being built at the DOW Chemical facility in Seadrift, TX.



Other Reactor News

The United States Army recently (May 2024) announced a it will soon release a request for information to inform a deployment program for advanced reactors to power multiple Army sites throughout the United States

- https://www.newcivilengineer.com/latest/white-house-plans-amrs-to-power-multiple-army-bases-in-the-united-states-31-05-2024/

History of Reprocessing/Recycling Nuclear Waste

In 1977 reprocessing of spent nuclear fuel was banned in the United States due to proliferation concerns. The ban was lifted during the Reagan Administration but due to a lack of subsidies it failed to take off. Commercial nuclear utilities instead opted for a spent fuel repository at Yucca Mountain (which has yet to be built/operational)
https://world-nuclear.org/information-library/nuclear-fuel-cycle/fuel-recycling/processing-of-used-nuclear-fuel

There are currently 7 nations that have or are developing reprocessing facilities: France, Russia, China, Israel, India, Pakistan, and Japan.

Reprocessing is the practice of extracting fissile materials from spent fuel for recycling and to reduce the volume of high-level wastes. Reprocessing also reduces the level of radioactivity of the waste and after about 100 years, that level falls more rapidly than used fuel itself.

- Largely based on converting U-238 to fissile plutonium
- Most of the plutonium recovered from used fuel is currently recycled into mixed oxide (MOX) fuel
- MOX fuel is nuclear fuel that contains more than one oxide of fissile material (usually containing Pu and U)

New reprocessing technologies are being developed to be deployed in conjunction with fast neutron reactors which can burn uranium and plutonium without the need for them to be separated

Orano's Work in Reprocessing Nuclear Waste

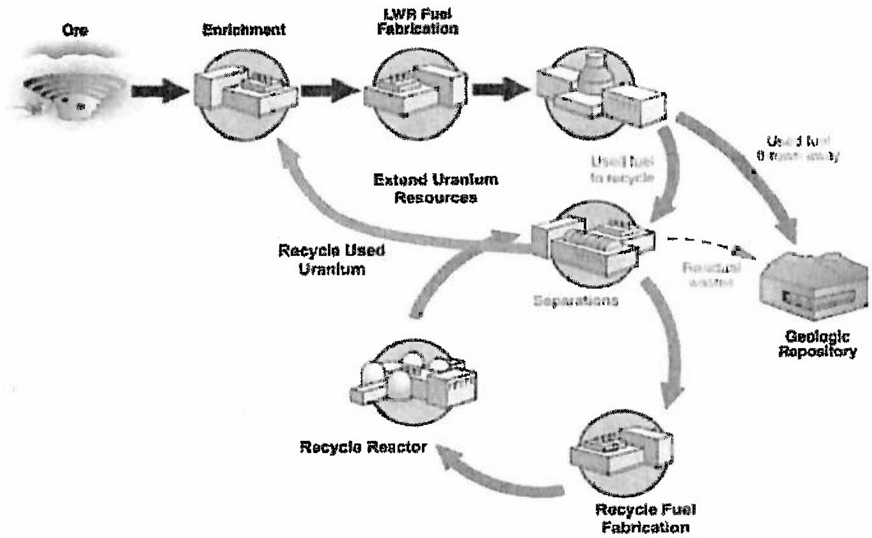
Orano is one of the largest companies which reprocesses and recycles spent nuclear fuel. The steps they take in the reprocessing the fuel is as follows:

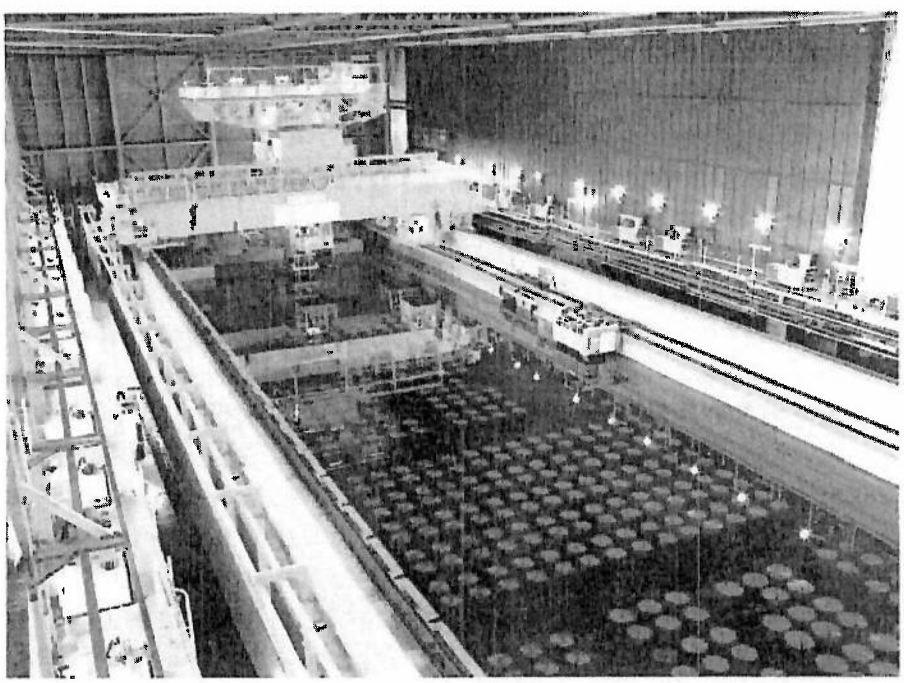
- Safe Receipt and Storage- when spent fuel arrives at the facility automated equipment if moved to a a concrete walled room with 4 foot thick walls where the fuel is stored in cooling pool for 5 to 7 years
- Component separation and recovery of materials- once cooled, the fuel is sheared into small pieces before being immersed in nitric acid which dissolves the material while also separating the recyclable material and waste. 96% of the nuclear material is recoverable. Once this is complete the Pu and U are separated and purified before the Pu is remixed with depleted uranium to produce mixed oxide (MOX) fuel and the leftover U is then re-enriched to provide Recycling Uranium Fuel(URE)
- Final Waste Conditioning- after reprocessing and recycling only 4% of nuclear material remains as waste. This waste is heated, mixed with molten glass and then cast in stainless steel containers before being stored onsite while waiting for transfer to deep geological storage. Foreign waste is returned to the country of origin.
- MOX Fuel- The MOX fuel produced is then used to supply nuclear plants in France, Germany, and Japan

In February, 2024, the Orano Group entered into a Memorandum of Understanding with SHINE Technologies in the U.S. to form a pilot plant in the US to recycle used nuclear fuel for light water reactors

Since 1960, Orano's La Hague facility in France has safely processed over 23,000 tonnes of spent fuel which is enough to power France's nuclear fleet for 14 years.

- https://www.orano.group/en/nuclear-expertise/from-exploration-to-recycling/world-leader-in-recycling-used-nuclear-fuels





Storage Pool for spent nuclear waste

Safe Storage of Nuclear Waste

In the United States all of the used fuel ever produced since the 1950s would only cover a football field to a height of 10 yards

- Low Level waste (LLW) is typically sent to a land based disposal immediately following its packaging for long term management
- For High Level Waste (HLW), the waste is to let the waste decay and cool
    - This is usually done onsite in cooling ponds or in dry casks

Overall it is widely agreed upon that deep geological disposal if the best solution for final disposal of the most radioactive waste

- There have been studies into a centralized location for safe and environmentally sound solutions to the final management of radioactive waste.
    - Most favored solution is the deep geological disposal and has previously been attempted with Yucca Mountain
        - Local opposition ultimately shut this possibility down and the project is on hold

Yucca Mountain

- In 1987 Yucca Mountain in the desert of Nevada was designated as the US national repository for spent fuel and high level waste from nuclear power and military defense programs
- This facility would be around 1,000 feet deep in the rock and waste would be stored in highly corrosion resistant double shelled metal containers
- This project was eventually canceled in 2009 by the Obama administration. However, the NRC rejected the DoEs motion to withdraw the license and in 2013 a federal appeals court ordered the NRC to continue the review of the proposed facility.
- In May 2016, the NRC released its final supplement to the US DoEs environmental impact statement which found that the site would prove safe for one million years however the project has been stalled by a lack of funding from congress and local opposition
- https://www.nei.org/fundamentals/nuclear-waste
    - NEI Nuclear Waste info

Transportation of Nuclear Waste

Transportation of nuclear waste is currently regulated by the NRC. Transportation usually occurs between two reactors owned by the same utility in order to share storage space. In over 40 years and thousands of shipments, there has never been a release of waste. When transporting, the waste must be shipped in containers or casks which shield radiation and dissipate heat. Extensive testing has been conducted on the containers and casks to ensure they are safe from potential accidental releases.

Nuclear Related Medicine

On October 1, 2024 Terrapower announced it was producing Actinium-225 at a commercial scale. This isotope is being used in multiple drug developer's radiopharmaceuticals in clinical trials.

- Actinium-225 is used as a starting material for targeted cancer treatments.
- Specifically being looked at to be used to treat prostate, colon, breast and neuroendocrine cancers, melanoma and lymphoma

In June 2023, Westinghouse announced they had successfully demonstrated an approach to produce Actinium-225 in its commercial nuclear reactors.

- Westinghouse also has contracts to produce other isotopes such as Cobalt-60 and Lutetium-177 in their commercial reactors
    - Cobalt-60 is used in medical procedures where gamma rays from the cobalt-60 are used to treat cancer
    - Lutetium-177 is an isotope used to treat neuroendocrine tumors and prostate cancer and is administered intravenously

Orano is also an industry leader in developing nuclear related medicine. In 2014, Orano opened a facility in Plano, TX to produce the isotope Lead-212 which is a alpha therapy treatment, which is radiotherapy used to target cancer cells.

Recent Federal Nuclear Policy Updates

In July, with overwhelming bipartisan support, Congress passed S. 870 which contained the ADVANCE Act ("Accelerating Deployment of Versatile, Advanced Nuclear for Clean Energy Act") https://www.congress.gov/118/bills/s870/BILLS-118s870enr.pdf

- Bill contains several initiatives to advance the deployment of advanced nuclear reactors
    - Removes the NRC fee based cost on pre application
    - Increases staffing a the NRC to process licenses
- Contains intent language to address licensing roadblocks for all nuclear related technologies including reprocessing/recycling

On May 29, 2024, the White House formed the Nuclear Power Project Management and Delivery working group who will work to identify opportunities to proactively mitigate sources of cost and schedule overrun risk. The working group will also assist the DoD in constructing an advanced reactor to help power Army Bases.

- Group will consist of the following:
    - White House Office of Domestic Climate Policy
    - White House Office of Science and Technology Policy
    - Department of Energy

Electric Power Research Institute (EPRI) Advanced Nuclear Roadmap Phase 1

https://publicdownload.epri.com/PublicAttachmentDownload.svc/AttachmentId=83812

- Outlines an achievable path for the deployment of advanced reactors and identifies challenges the industry needs to address such as:
  - The ability to separate the scope of nuclear safety and radiation hazards from normal industrial activities. Shifting the industry from focusing on building large one off pants on site to factory assembled models
  - The need to educate external stakeholders and the public on the perception of nuclear and advanced nuclear technologies and share the accomplishments of nuclear energy and the impacts offered by advance nuclear
    - Recognizing the importance of government support to accelerate commercialization with policies supporting advanced nuclear
- Identified Specific Needs For Advanced Reactors
  - Operator Staffing- The need to develop industry standards and guidance on operator staffing and requirements
  - Licensing- The need for industry to provide input to the NRC for new rule and guidance that appropriately reflect advanced reactor technology for licensing purposes

Miscellaneous Information

Today there are about 440 nuclear power reactors operating in 32 countries plus Taiwan, with a combined capacity of about 390 GWe. In 2022 these provided 2545 TWh, about 10% of the world's electricity.

Since the first nuclear power plants commenced operations, the IAEA estimates there has been roughly 329,000 tons of nuclear waste produced. Of that, roughly 127,000 tons has been reprocessed

Links to Other Useful Advanced Nuclear Information

https://www.nrc.gov/reactors/new-reactors/advanced.html

- NRC website for Advanced Nuclear Reactors

https://www.energy.gov/ne/articles/nrc-endorses-new-guidance-advanced-reactor-licensing

- NRC licensing of X energy design

https://crsreports.congress.gov/product/pdf/R/R45706

- Congressional Research on Advanced Nuclear Reactors

https://www.nei.org/advanced-nuclear-energy/advanced-nuclear-101

- Advanced Nuclear 101- NEI

https://www.energy.gov/ne/advanced-reactor-technologies

- DOE Office of Nuclear Energy- Advanced Reactor Technologies

https://aris.iaea.org/Publications/SMR_booklet_2022.pdf

- International Atomic Energy Agency- List of SMR Reactors/Developments and diagrams of the reactors etc.

https://www.gov.uk/government/publications/advanced-nuclear-technologies/advanced-nuclear-technologies

- UK Government Website on Advanced Reactors

https://www.ans.org/news/article-5634/2024-the-state-of-advanced-reactors/

- American Nuclear Society State of Advanced Reactors

https://www.eenews.net/articles/white-house-makes-push-for-large-nuclear-reactors/

- White House Advocating for the development of advanced reactors 5-30-2024