Briefing: Advanced Microreactor Safety

April 8, 2022

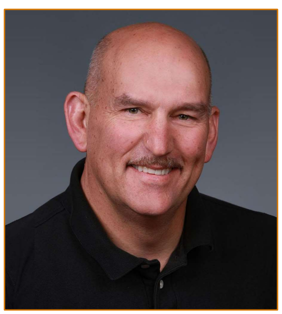
Bruce McDowell
Senior Advisor
Dr. Mark Nutt
Nuclear Energy Sector Manager

PNNL is operated by Battelle for the U.S. Department of Energy

PNNL-SA-171900

PNNL is DOE’s **most diverse national laboratory**

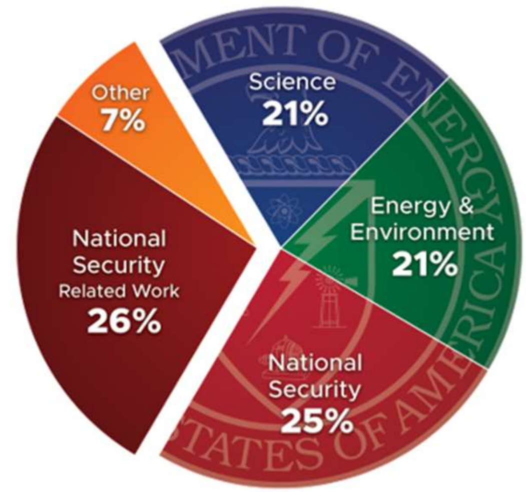
Mark Nutt, Deputy National Technical Director of the Integrated Waste Management program for DOE/NE, Pacific Northwest National Laboratory



Bruce McDowell, Senior Advisor, Energy and Environment Directorate, Pacific Northwest National Laboratory

$1.24B Funding

5,300 Staff



Pacific Northwest NATIONAL LABORATORY

Bottom Line Up Front: Nuclear Power is Safe

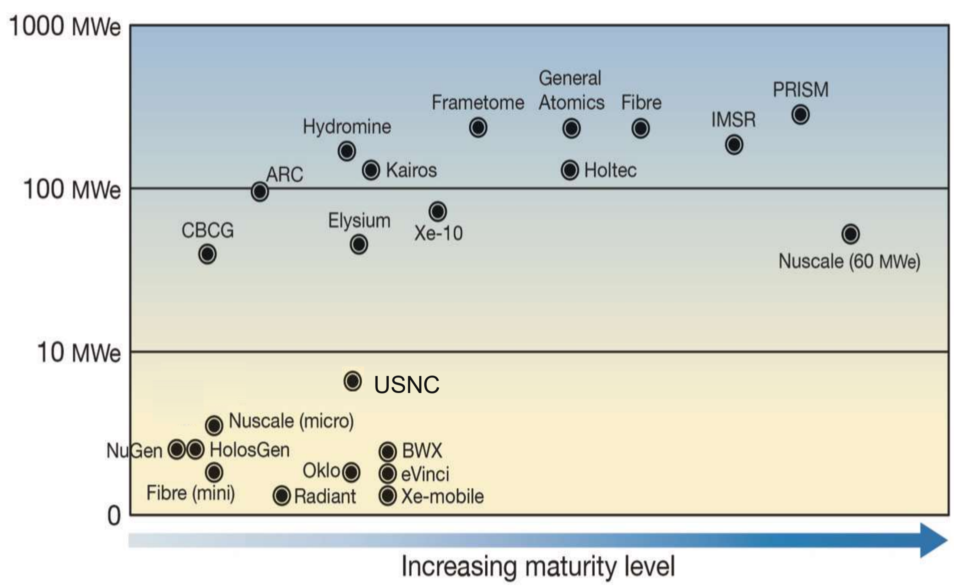
The potential hazard of nuclear's high energy density has always been known and has always been factored into the design of nuclear power plants.

- The nuclear energy industry is one of the most heavily regulated commercial enterprises. The Nuclear Regulatory Commission (NRC) has principal responsibility for government oversight. The NRC's mission is to protect public health and safety by ensuring that plants comply with the terms of their licenses as well as all the technical and administrative requirements imposed by the agency.
- The NRC assigns at least two NRC resident inspectors to every US nuclear energy plant, where the inspectors conduct more than 2,000 hours of baseline inspections each year.
- The industry also conducts peer reviews of plant operation through the Institute of Nuclear Power Operations (INPO). An INPO team and industry peers conduct on-site, two-week inspections at each plant once every two years.
- Major studies all conclude that nuclear is an exceptionally safe way to produce electricity on an industrial scale. Nuclear has the lowest number of direct fatalities of any major energy source per kWh of energy produced—over 100 times less than hydro and liquefied natural gas (OECD 2010).

Source: Health Physics Society, February 2020

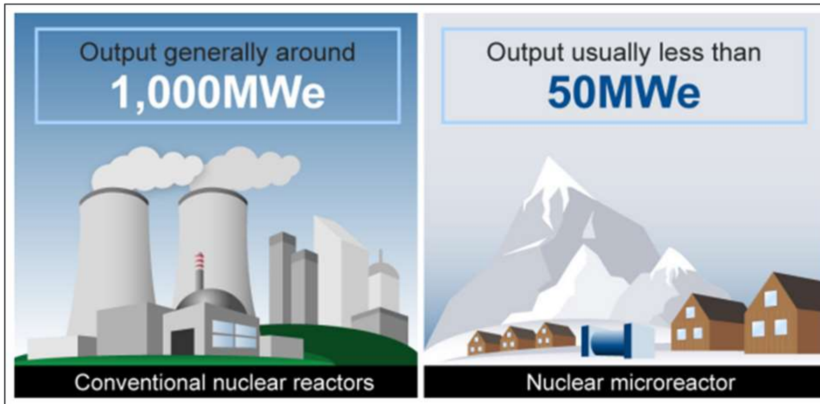
What microreactor design sizes are being considered?

Small Nuclear Reactors
(under development in U.S., <300 MWe)



** Approximate maturity level is subjective based on 2021 publicly available information*

Nuclear microreactors are very small reactors usually generating less than 50 megawatts electric (MWe). They are seen as an alternative to small modular (50-300 MWe) or conventional reactors (often around 1,000 MWe). Source: GAO-20-380SP Nuclear Microreactors



Source: GAO. | GAO-20-380SP

By comparison, microreactors can be produced more quickly, and within weeks, transported and deployed to locations such as isolated military bases or communities affected by natural disasters. They are designed to provide resilient, non-carbon emitting, and independent power in those environments.

What is an “Advanced Nuclear Reactor”?

According to 42 USC § 16271(b)(1) (1) Advanced nuclear reactor The term “advanced nuclear reactor” means (A) a nuclear fission reactor, including a prototype plant (as defined in sections 50.2 and 52.1 of title 10, Code of Federal Regulations (or successor regulations)), with significant improvements compared to reactors operating on December 27, 2020 , including improvements such as:

(i) additional inherent safety features
(ii) lower waste yields
(iii) improved fuel and material performance
(iv) increased tolerance to loss of fuel cooling
(v) enhanced reliability or improved resilience
(vi) increased proliferation resistance
(vii) increased thermal efficiency
(viii) reduced consumption of cooling water and other environmental impacts
(ix) the ability to integrate into electric applications and nonelectric applications
(x) modular sizes to allow for deployment that corresponds with the demand for electricity or process heat
(xi) operational flexibility to respond to changes in demand for electricity or process heat and to complement integration with intermittent renewable energy or energy storage;

What is an “Advanced Nuclear Reactor”?

According to 42 USC § 16271(b)(1) (1) Advanced nuclear reactor The term “advanced nuclear reactor” means (A) a nuclear fission reactor, including a prototype plant (as defined in sections 50.2 and 52.1 of title 10, Code of Federal Regulations (or successor regulations)), with significant improvements compared to reactors operating on December 27, 2020 , including improvements such as:

(i) additional inherent safety features
(ii) lower waste yields
(iii) improved fuel and material performance
(iv) increased tolerance to loss of fuel cooling
(v) enhanced reliability or improved resilience
(vi) increased proliferation resistance
(vii) increased thermal efficiency
(viii) reduced consumption of cooling water and other environmental impacts
(ix) the ability to integrate into electric applications and nonelectric applications
(x) modular sizes to allow for deployment that corresponds with the demand for electricity or process heat
(xi) operational flexibility to respond to changes in demand for electricity or process heat and to complement integration with intermittent renewable energy or energy storage;

What are "Passively Safe" and "Inherent Safety" Designs"?

Passive nuclear safety is a safety feature of a nuclear reactor that does not require operator actions or electronic feedback in order to shut down safely in the event of a particular type of emergency (usually overheating resulting from a loss of coolant or loss of coolant flow).

Inherent nuclear safety systems use certain materials and their properties to provide additional layers of protection.

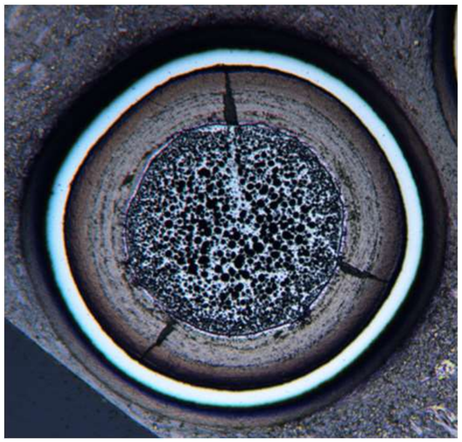
"Certain SMR designs are small enough that natural convection cooling should be sufficient to maintain the core at a safe temperature in the event of a serious accident like a station blackout."

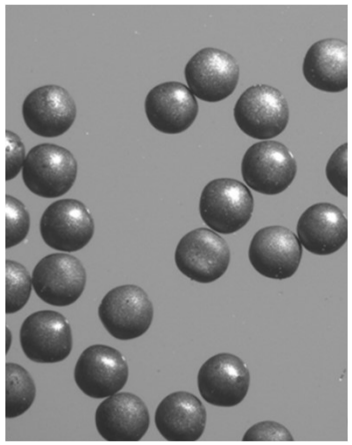
- Union of Concerned Scientists

Idaho National Lab Passive Safety Video

Pacific Northwest
NATIONAL LABORATORY

What is an inherent safety feature?





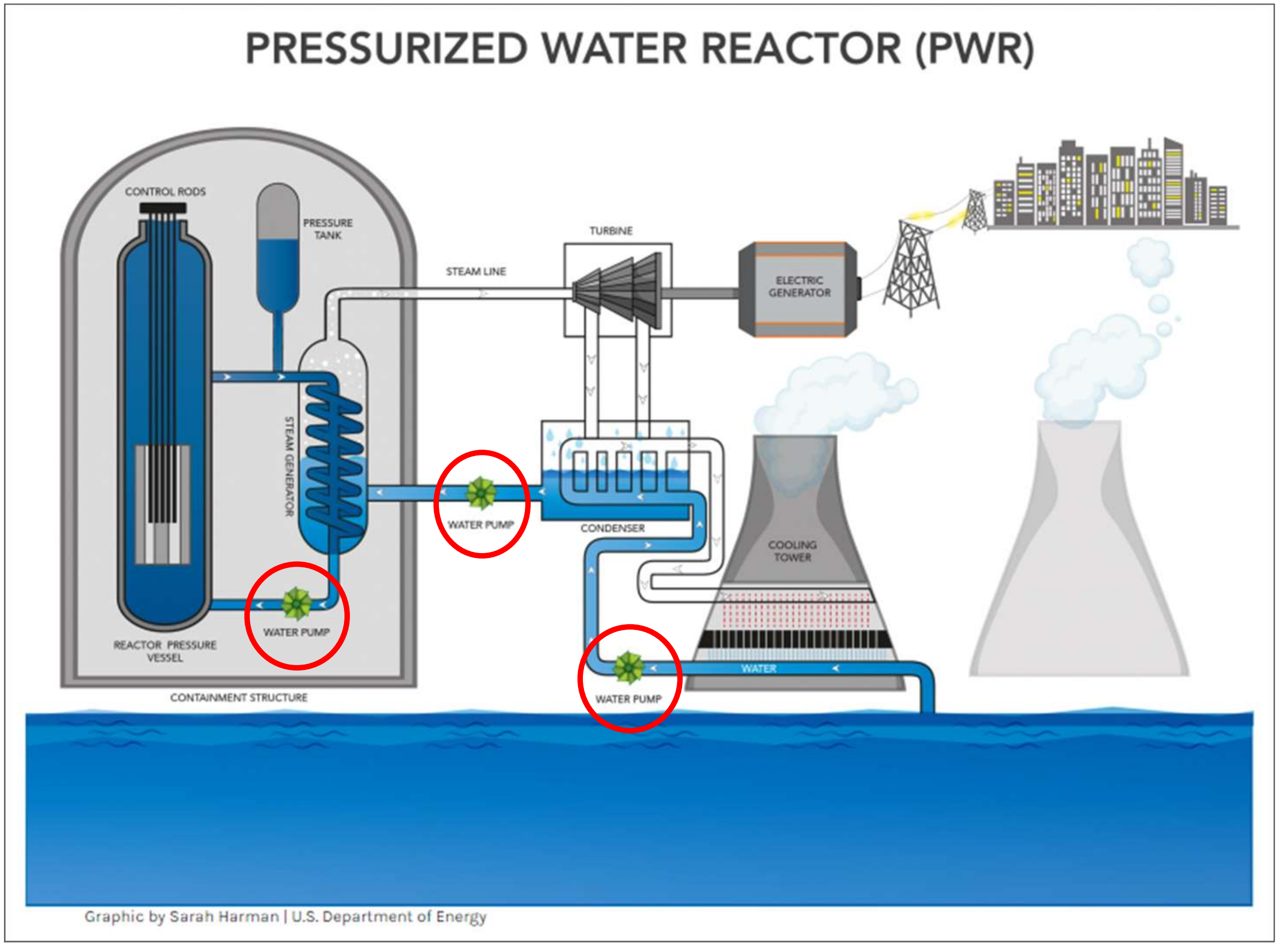
TRISO stands for TRi-structural ISOtropic particle fuel.

- Each TRISO particle is made up of a uranium, carbon and oxygen fuel kernel. The kernel is encapsulated by three layers of carbon- and ceramic-based materials that prevent the release of radioactive fission products.
- The particles are incredibly small (about the size of a poppy seed) and very robust.
- They can be fabricated into cylindrical pellets or billiard ball-sized spheres called “pebbles” for use in either high temperature gas or molten salt-cooled reactors.
- TRISO fuels are structurally more resistant to neutron irradiation, corrosion, oxidation and high temperatures (the factors that most impact fuel performance) than traditional reactor fuels.
- Each particle acts as its own containment system due to its triple-coated layers. This allows them to retain fission products under all reactor conditions.
- TRISO particles can withstand extreme temperatures that are well beyond the threshold of current nuclear fuels.

Source: U.S. Department of Energy

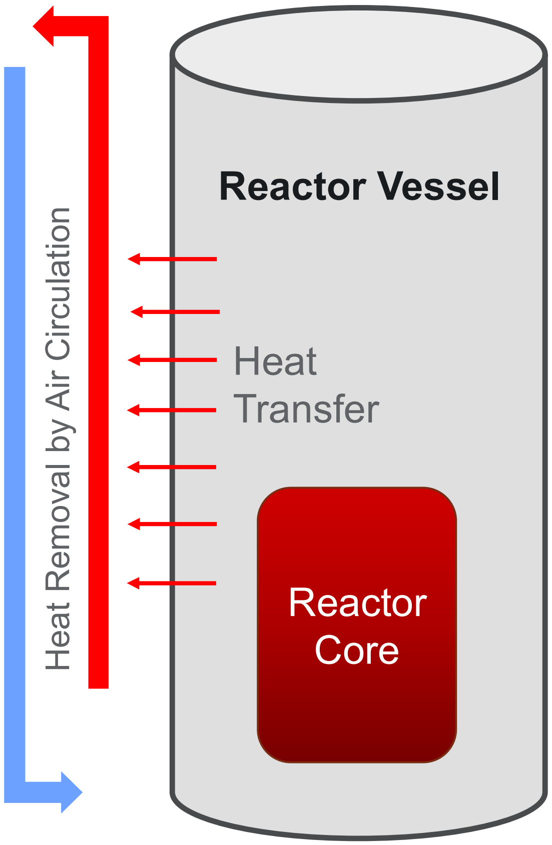
How are “passive” systems different from “active” systems for heat removal

Active Systems in typical large light water reactors require electrical power produced by the plant, provide from the offsite grid, or from emergency generators to operate to cool the plant.



Pacific Northwest
NATIONAL LABORATORY

What is passive heat removal through convection?



Convection is the movement caused within a fluid by the tendency of hotter and therefore less dense material to rise, and colder, denser material to sink under the influence of gravity, which consequently results in transfer of heat.

Passive systems do not require electrical power produced by the plant, provide from the offsite grid, or from emergency generators to operate.

Example microreactor: Westinghouse eVinci reactor design (~5 MWe)

The Westinghouse eVinci micro reactor is a next-generation, small battery for decentralised generation markets and micro grids such as remote communities, remote industrial mines and critical infrastructure. The reactor has heat pipes that remove heat from the core. The heat pipes enable passive core heat extraction.

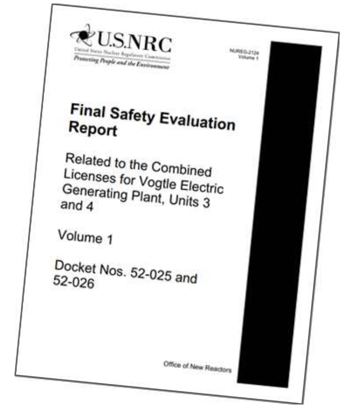
Source: World Nuclear News

What design features does NRC evaluate in their safety review?

Pacific Northwest
NATIONAL LABORATORY

NUREG – 0800: Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants

NUREG – 0800 provides guidance for NRC reactor safety reviews. The result is a Safety Evaluation Report.


U.S.NRC

Final Safety Evaluation Report

Related to the Combined Licenses for Vogtle Electric Generating Plant, Units 3 and 4

Volume 1

Docket Nos. 52-025 and 52-026

Office of New Reactors

The eVinci micro reactor (Image: Westinghouse)

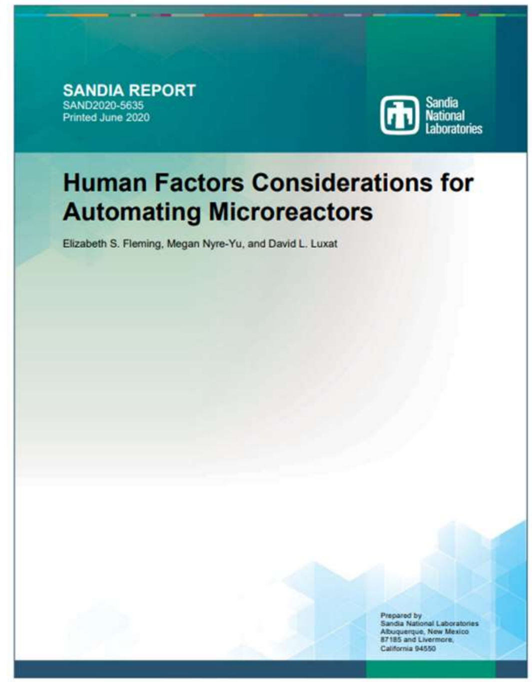
Source: Power Mag July 2019

Pacific Northwest
NATIONAL LABORATORY

What are staffing considerations for microreactors?

What technical skills are required to operate a microreactor and how feasible is it that skilled technicians will be found to work at remote microreactor locations?

- The NRC licenses all individuals who either operate or supervise the operation of the controls of a commercially owned nuclear power reactor or a test/research (i.e., non-power) reactor under 10 CFR Part 55.
- Operators are required to pass a written examination that contains a representative selection of questions on the knowledge, skills, and abilities needed to perform licensed operator duties.
- In general, a smaller plant having inherent and passive safety features with some functions being automated would likely result in a smaller work force as compared to large LWRs.
- The NRC licensing process would end up defining what on-site work force would be required to ensure safety and security.


SANDIA REPORT
SAND2020-5635
Printed June 2020

Sandia National Laboratories

Human Factors Considerations for Automating Microreactors

Elizabeth S. Fleming, Megan Nyre-Yu, and David L. Luxat

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico
87185 and Livermore,
California 94550

Source: link

How will Spent Nuclear Fuel be managed?

Multiple agencies and organizations have responsibility for managing spent nuclear fuel:

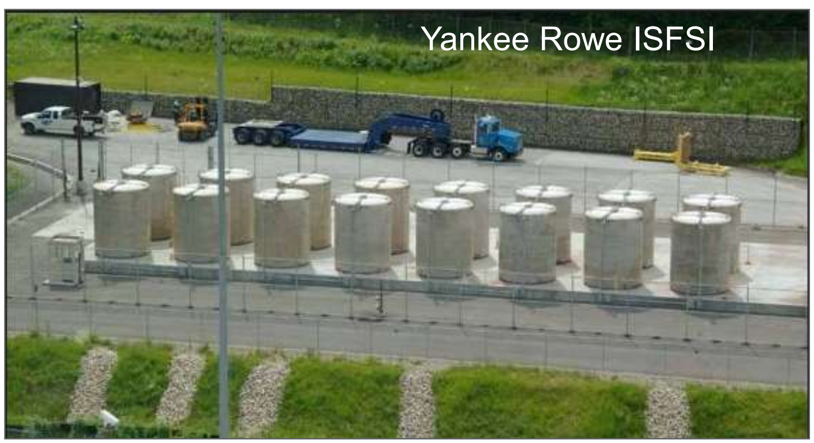
- The Nuclear Waste Policy Act (the Act or the NWPA) of 1982, established a comprehensive federal policy to store and dispose of the nation's SNF and HLW. The NWPA and its amendments directed the Department to develop a system to accept, transport, store, and permanently dispose of SNF and HLW from commercial utilities. The DOE manages and disposes of spent fuel it accepts under the Standard Contract.
- The NRC regulates interim storage, permanent disposal, and certifies SNF transportation casks.
- The Environmental Protection Agency (EPA) sets radiation protection standards
- The Utility/Operator sites, designs, and submits license applications including an environmental report in accordance with requirements established by the U.S Nuclear Regulatory Commission (NRC)
- The NRC prepares an Environmental Impact Statement for the proposed reactor and conducts a review of the license application including any required hearings
- The Utility/Operator constructs and operates reactors in accordance with its NRC license
  - Responsible for the management and storage of all spent fuel until accepted by DOE in accordance with the standard contract

How will Spent Nuclear Fuel be managed?

The NRC has an established regulatory framework for spent fuel storage at 10 CFR 72 and for transportation at 10 CFR 71.

Pending approval of a national repository, there are two general options for managing spent fuel:

1. For the current reactor fleet, Spent Nuclear Fuel is stored in an onsite Independent spent fuel storage installation (ISFSI) under 10 CFR 72 pending U.S. policy decisions on ultimate disposition.
2. For advanced microreactors, the reactor could be returned to the vendor for decommissioning or refueling. This will require a new NRC package approval as there are no currently approved packages for microreactors with SNF.



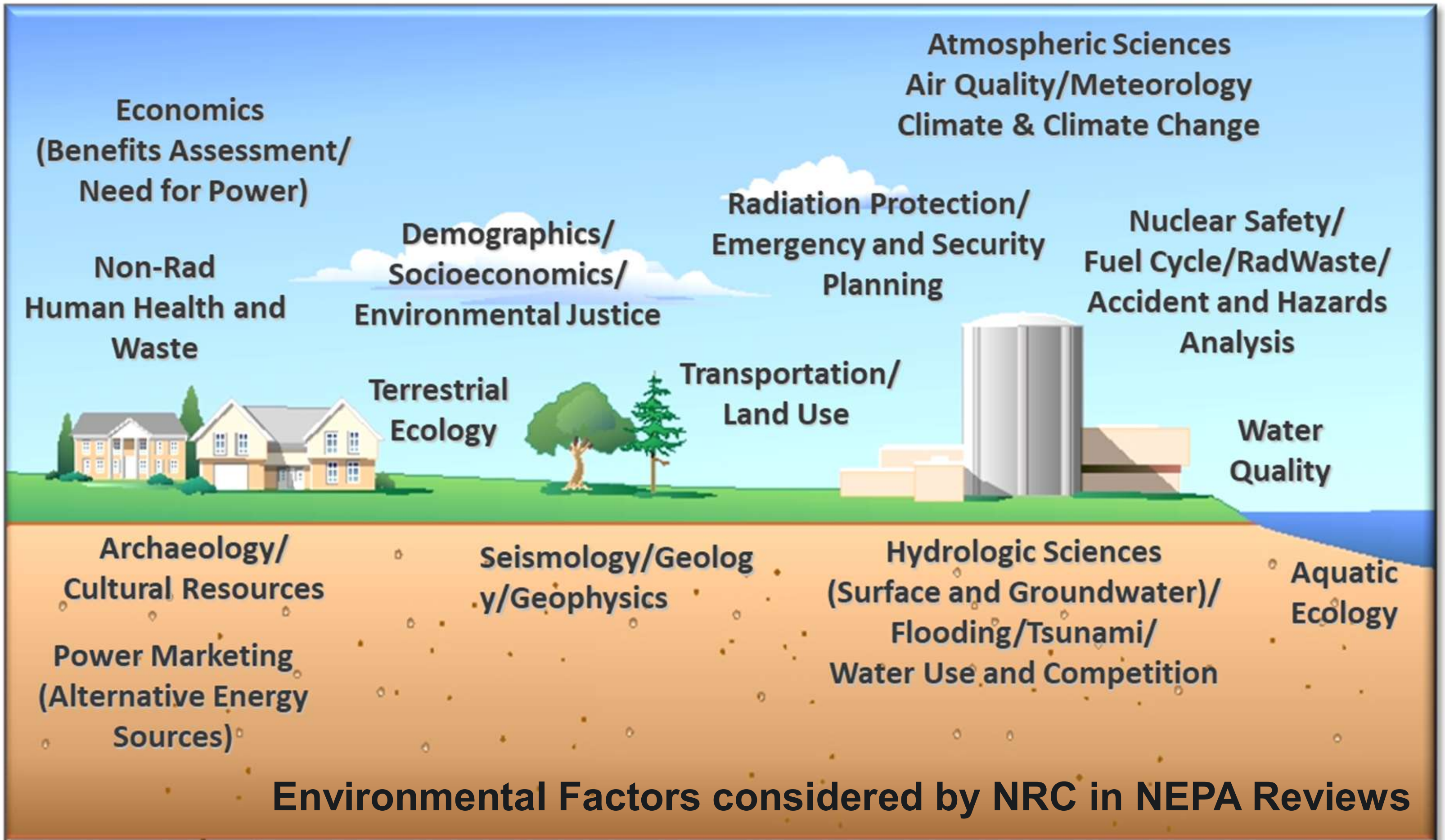
An ISFSI is an NRC-licensed complex designed and constructed for the interim storage of spent nuclear fuel; solid, reactor-related, greater than Class C waste; and other associated radioactive materials.

DOE is considering a national Consolidated Interim Storage Facility for spent nuclear fuel that would be sited using a consent-based siting approach in which communities could volunteer to host the facility

LINK: https://www.energy.gov/ne/consent-based-siting#:~:text=Consent%2Dbased%20siting%20is%20an,(as%20the%20implementing%20organization)

Pacific Northwest
NATIONAL LABORATORY

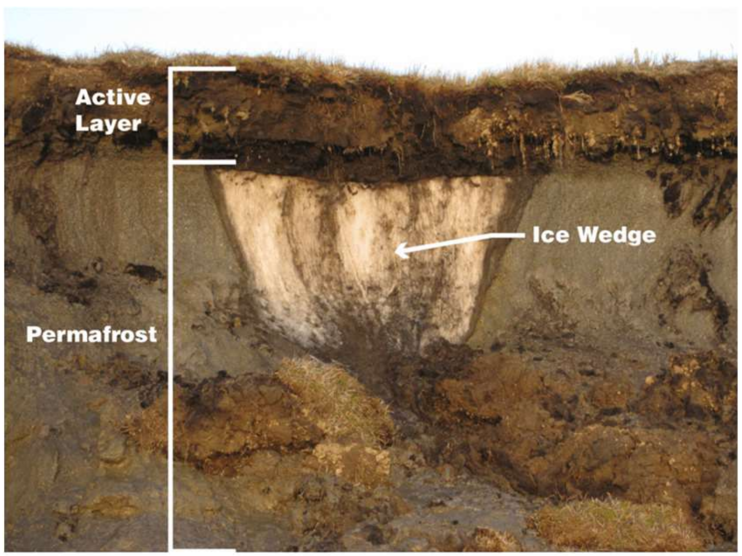
How are environmental impacts different for microreactors?



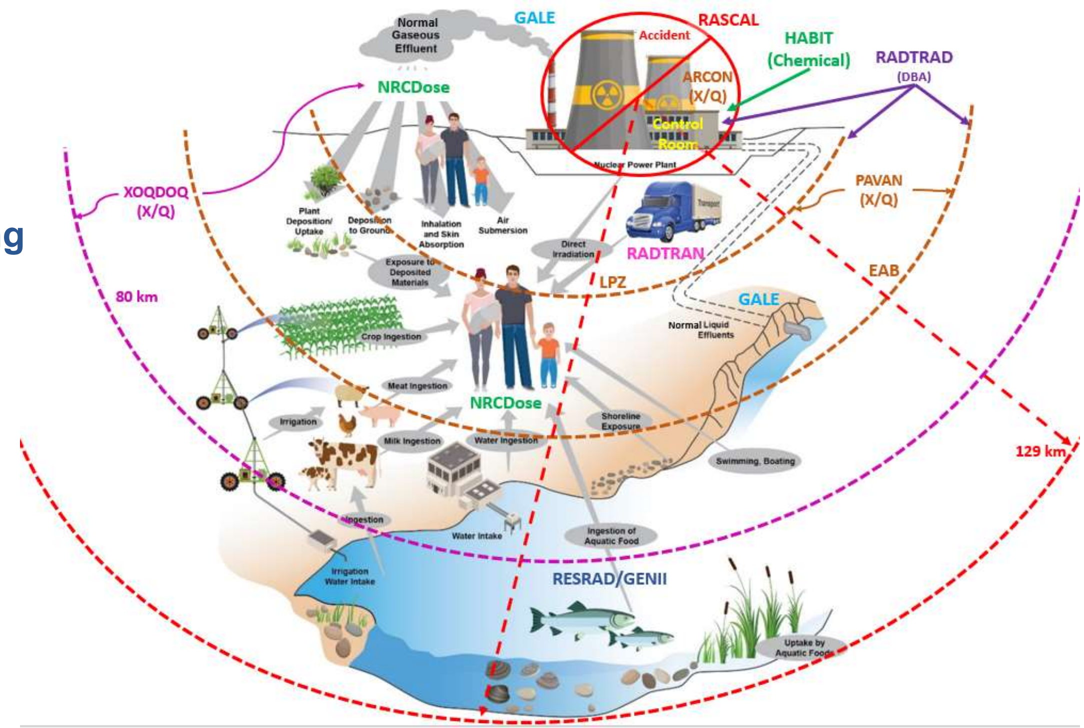
Environmental Factors considered by NRC in NEPA Reviews

What are some of the unique challenges in the Arctic?

NRC conducts geotechnical evaluations for foundation supports for Nuclear Power Plants. These evaluations will have to consider locating plants in permafrost and the potential for permafrost to change over time.



The layers of permafrost. Photo credit: Benjamin Jones, USGS. Public domain (modified)



NRC uses over 10 codes for evaluating potential dose from Nuclear Power Plants during licensing and siting. These are being evaluated for use in artic environments.

Pacific Northwest
NATIONAL LABORATORY

Thank you