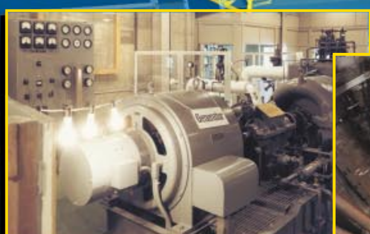
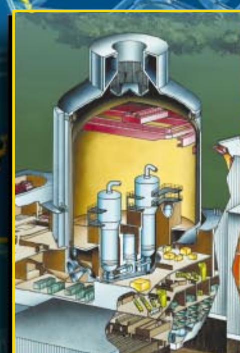
Powering Nuclear Energy Through the Generations



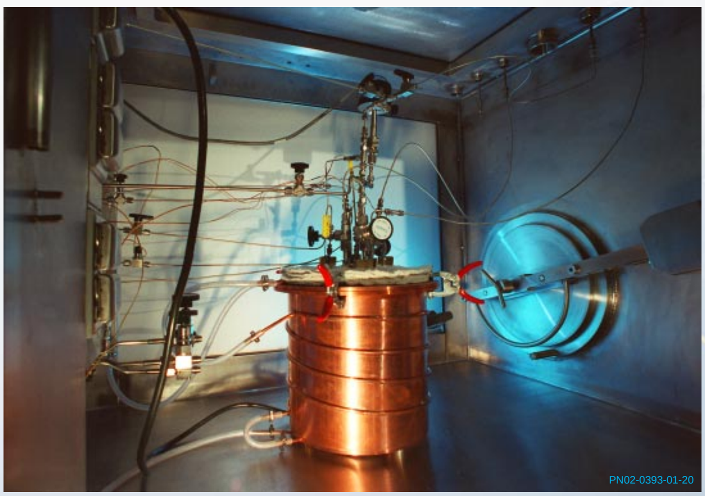


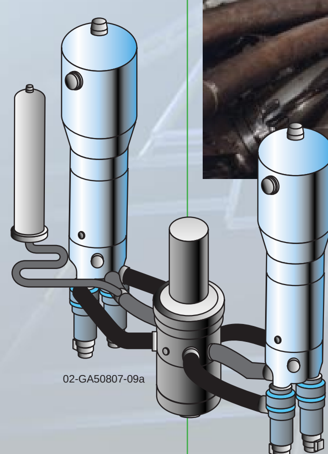
IDAHO NATIONAL ENGINEERING AND ENVIRONMENTAL LABORATORY

INEEL

Home of Science
and Engineering Solutions

Contents





Foreword

To whom much is given, much is required. These famous words, spoken over 40 years ago by President-elect John F. Kennedy, are poignantly appropriate today for the Idaho National Engineering and Environmental Laboratory. That's because in the summer of 2002, the INEEL was given new mission direction from the Secretary of Energy. The secretary said, "INEEL will be the epicenter of our efforts to expand nuclear energy as a reliable, affordable and clean energy source for our nation's energy future." He added, "The coming years ought to prove an exciting time for INEEL. The array of new responsibilities you are being assigned carry the weight of grave expectations, because your labors will be critical to our national security and energy security missions. But they also offer tremendous opportunities … opportunities to break new ground … to tread new pathways."

As the Laboratory assumes the responsibility as the nation's leading center for nuclear energy research and development, Lab leadership is keenly aware of the grand challenge and requirements now facing the INEEL. The INEEL is prepared to rise to this challenge much as the Lab site did more than a half-century ago when Idaho and its reactor testing station were first called upon to help develop and prove nuclear energy's viability for commercial and military applications.

The energy security and, indeed, the national security of America now demand both our collective best efforts to maintain and extend the operating lifetimes of today's nuclear reactors, and exploration and development of the next generation of nuclear power systems.

With that in mind, the INEEL is working hand-in-hand with Argonne National Laboratory, other national laboratories, universities, industry, members of the Generation IV International Forum and others to ensure the world's best and brightest are working together in an atmosphere of cooperation.

In the coming pages of this document, information is shared to demonstrate the INEEL's time-proven commitment to collaboration, its past, present and future willingness to take on the grandest of technological challenges, and its success in putting the best science to work to achieve meaningful advancements and real results across the broad spectrum of nuclear science.

"INEEL will be the epicenter of our efforts to expand nuclear energy as a reliable, affordable and clean energy source for our nation's energy future."

***Spencer Abraham**—U.S. Secretary of Energy*

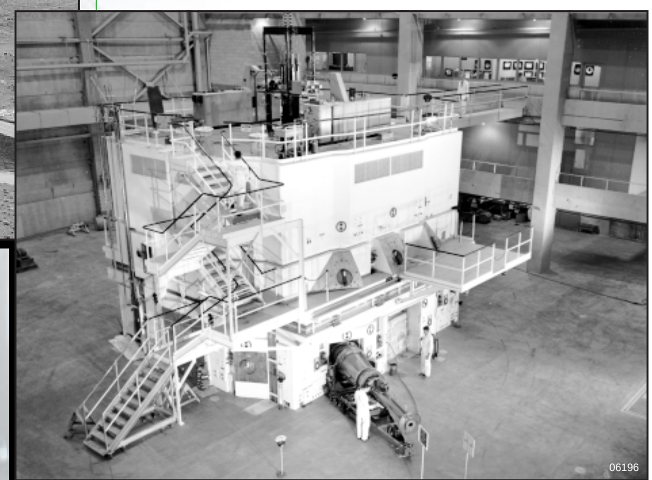
Historical Contributions

The site now known as the Idaho National Engineering and Environmental Laboratory has long played a key role in the development of the nation's nuclear energy capability. Beginning in the late 1940s when the newly created Atomic Energy Commission went looking for a remote site where it could conduct its proposed reactor experiments, Idaho quickly emerged as strongest of nearly two dozen potential locations. On land originally set aside as the Naval Proving Grounds and used to test fire relined big guns during World War II, the fledgling AEC established the pioneering National Reactor Testing Station – the forerunner of today's INEEL – in 1949. The nearest major city to the high desert NRTS was Idaho Falls, some 29 miles to the east.

Almost immediately upon announcement of its testing station siting decision, the AEC began construction. In 1950, work got under way on Experimental Breeder Reactor-I. EBR-I shortly thereafter achieved a historic milestone when on Dec.

EBR-I achieved a historic milestone when on Dec. 20, 1951, it produced usable amounts of electricity from nuclear power for the first time.

The Materials Testing Reactor (1952-1970) was the second reactor built at the NRTS, and it was used to test materials' performance in intense radiation environments.



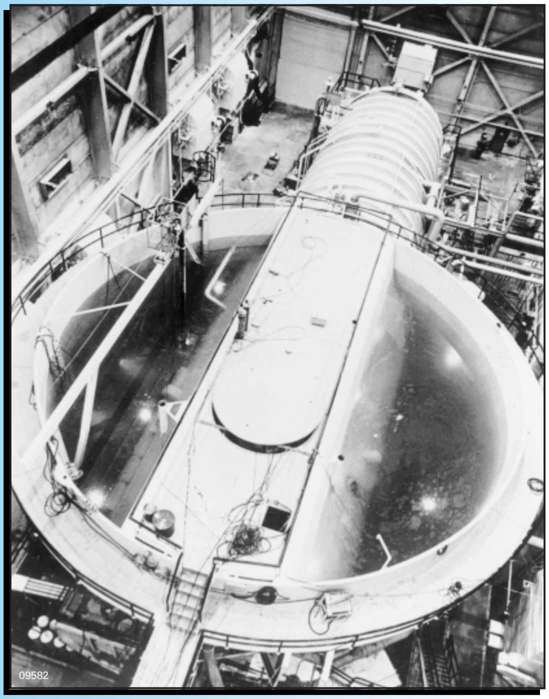
Alphabetical Listing of Idaho Reactors* (From *Proving the Principle* http://www.inel.gov/proving-the-principle/appendices.pdf)

1. Advanced Reactivity Measurement Facility No. 1 .... (10/60 – 1974)
2. Advanced Reactivity Measurement Facility No. 2 .... (12/62 – 1968)
3. Advanced Test Reactor .... (7/67 – present)
4. Advanced Test Reactor Critical Facility .... (5/64 – present)
5. Argonne Fast Source Reactor .... (10/59 – late 1970s)
6. Boiling Water Reactor Experiment No. 1 .... (1953 – 7/54)
7. Boiling Water Reactor Experiment No. 2 .... (10/54 – 3/55)
8. Boiling Water Reactor Experiment No. 3 .... (6/55 – 1956)
9. Boiling Water Reactor Experiment No. 4 .... (12/56 – 6/58)
10. Boiling Water Reactor Experiment No. 5 .... (2/62 – 9/64)
11. Cavity Reactor Critical Experiment .... (5/67 – early 1970s)
12. Coupled Fast Reactivity Measurement Facility .... (1968 – 1991)
13. Critical Experiment Tank .... (1958 – 1962)
14. Engineering Test Reactor .... (9/57 – 12/81)
15. Engineering Test Reactor Critical Facility .... (5/57 – 1982)
16. Experimental Beryllium Oxide Reactor .... (never operated)
17. Experimental Breeder Reactor No. I .... (8/51 – 12/63)
18. Experimental Breeder Reactor No. II .... (9/61 – 9/94)
19. Experimental Organic Cooled Reactor .... (never operated)
20. Fast Spectrum Refractory Metals Reactor .... (3/62 – 1968)
21. Gas Cooled Reactor Experiment .... (2/60 – 4/61)
22. Heat Transfer Experiment No. 1 .... (11/55 – 1956)
23. Heat Transfer Experiment No. 2 .... (7/57 – 3/61)
24. Heat Transfer Experiment No. 3 .... (1958 – 12/60)

*Includes reactors built/operated by Argonne National Laboratory-West

20, 1951, it produced usable amounts of electricity from nuclear power for the first time. In 1953, it demonstrated the principle of "breeding" – that a reactor can produce more fuel than it consumes.

The Materials Testing Reactor (1952-1970) was the second reactor built at the NRTS, and it was used to test materials' performance in intense radiation environments. Every reactor designed in the United States has been influenced by the knowledge gained from the MTR.



Other major projects undertaken during these early days included development of the submarine thermal reactor, the prototype power plant for the nation's first nuclear submarine, the USS Nautilus, and construction of the Idaho Chemical Processing Plant, used to recover uranium from spent reactor fuel.

The U.S. nuclear Navy "docked" in eastern Idaho's high desert in 1950. For 45 years, it operated a training facility for thousands of its personnel who went on to command and operate nuclear submarines and surface ships.

The five Boiling Water Reactor Experiment (BORAX) facilities (1953-1963) were designed to pioneer work in boiling water reactors. BORAX-III provided enough nuclear power to light the city of Arco, Idaho, briefly on July 17, 1955.

Through the 1950s and 1960s, more than 40 other, mostly first-of-their-kind reactors were designed, built and operated at the testing station.

With the success of its reactor operations, the Site's future was promising. On Aug. 14, 1974, the NRTS was renamed the Idaho National Engineering Laboratory to reflect its growing potential for conducting research, engineering and experiments in nuclear and non-nuclear projects of national importance. In January 1997, the Site became the Idaho National Engineering and Environmental Laboratory to more fully acknowledge its expansive environmental management responsibilities.

The INEEL developed the submarine thermal reactor, the prototype power plant for the nation's first nuclear submarine, the USS Nautilus.

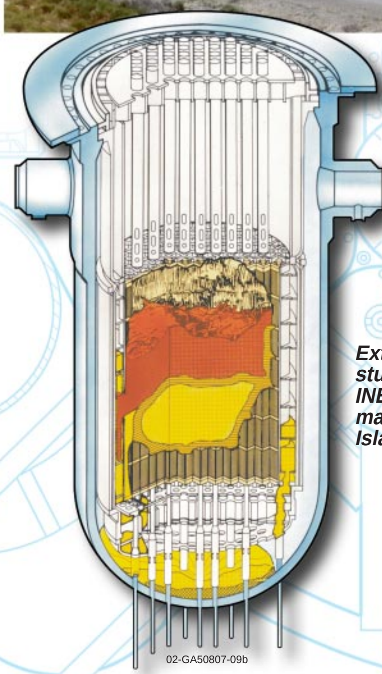
Every reactor designed in the United States has been influenced by the knowledge gained from the MTR.

25. High Temperature Marine Propulsion Reactor .... (1962 – 1964)
26. Hot Critical Experiment .... (1958 – 3/61)
27. Large Ship Reactor A .... (10/58 – 1/94)
28. Large Ship Reactor B .... (7/59 – 1987)
29. Lost of Fluid Test Facility .... (1973 – 7/85)
30. Materials Testing Reactor .... (3/52 – 4/70)
31. Mobile Low-Power Reactor No. 1 .... (3/61 – 5/64)
32. Natural Circulation Reactor .... (9/65 – 5/95)
33. Neutron Radiography Facility .... (continuing)
34. Nuclear Effects Reactor .... (8/68 – 6/70)
35. Organic Moderated Reactor Experiment .... (9/57 – 4/63)
36. Power Burst Facility .... (9/72 – 1985)
37. Reactivity Measurement Facility .... (2/54 – 4/62)
38. Shield Test Pool Facility .... (early 1960s)
39. Special Power Excursion Reactor Test No. I .... (6/55 – 1964)
40. Special Power Excursion Reactor Test No. II .... (3/60 – 10/64)
41. Special Power Excursion Reactor Test No. III .... (12/58 – 6/68)
42. Special Power Excursion Reactor Test No. IV .... (7/62 – 8/70)
43. Spherical Cavity Reactor Critical Experiment .... (11/72 – 1973)
44. Stationary Low-Power Reactor .... (8/58 – 1/61)
45. Submarine Thermal Reactor .... (3/53 – 10/89)
46. Systems for Nuclear Auxiliary Power (SNAP) 10A Transient No. 1 .... (early 1960s)
47. Systems for Nuclear Auxiliary Power (SNAP) 10A Transient No. 3 .... (4/64 – 4/64)
48. Systems for Nuclear Auxiliary Power (SNAP) 10A Transient No. 2 .... (1965 – 1/66)
49. Thermal Reactor Idaho Test Station .... (last operated in 1964)
50. Transient Reactor Test Facility .... (2/59 – 4/94)
51. Zero Power Physics Reactor .... (4/69 – 4/92)
52. Zero Power Reactor No. 3 .... (10/55 – 11/70)

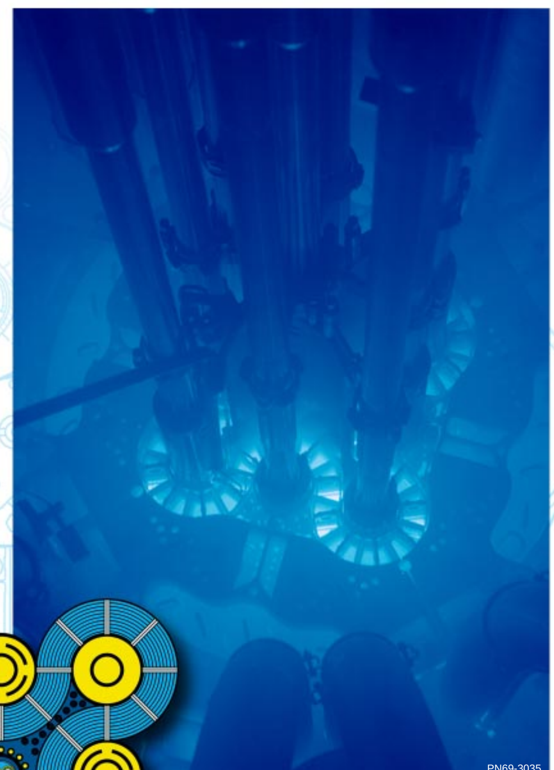
The early 1970s was an era of unprecedented nuclear safety research at the INEEL, much of it performed for the Nuclear Regulatory Commission. Major operating facilities at the time devoted to the effort were the Loss-of-Fluid-Test (LOFT) facility, Semiscale, the Power Burst Facility and the Advanced Test Reactor. LOFT was a scale-model version of a commercial pressurized water power plant built chiefly to explore the effects of loss-of-coolant accidents (LOCAs). Thirty-eight nuclear power tests were conducted on various accident scenarios, including the real accident at Three Mile Island. The INEEL played a key role in examining fuel, instrument nozzle, and vessel samples from the TMI-2 reactor. Examination results provided key insights to the international community about the potential for vessel failure during this accident.

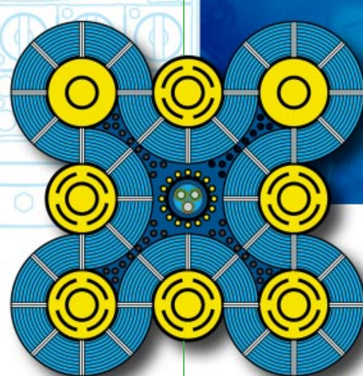
The Advanced Test Reactor is one of three operable reactors now at the INEEL and is the world's largest test reactor. With its unique design and capability to produce extremely high neutron flux, ATR performs studies on the effects of intense radiation on reactor materials, especially fuels. It is able to duplicate the effects of years of radiation in weeks or months. The unique four-leaf-clover core design provides nine main test spaces. Additional smaller test spaces allow even more experiments to be conducted independently. The Advanced Test Reactor is also used for production of important isotopes used in medicine, research and industry.

The Loss-of-Fluid-Test (LOFT) facility was one of several INEEL facilities used to support nuclear safety research in the 1970s and early 1980s.



Extensive loss-of-coolant accident studies were conducted at the INEEL, including scenario and material analyses of the Three Mile Island reactor core (left).





The Advanced Test Reactor's unique four-leaf-clover core design provides nine main test spaces at 250 MWTH. It is the world's largest test reactor.

Current Activities

The INEEL maintains a full spectrum of research, development and testing efforts in areas as diverse as nuclear power systems, low-energy nuclear physics, system safety analysis and neutron capture therapy.

Nuclear Engineering Design and Research

INEEL efforts in this key area support programs and projects for the advancement of future generation nuclear power and nonpower systems, encompassing the conceptualization, design and engineering of nuclear systems, and the development of analysis tools and data to support these activities. Capabilities include fusion reactor safety, Generation IV research, advanced reactor design and analysis, safety experiments and thermal-fluid experiments. DOE-Idaho and the INEEL are managing three DOE nuclear university programs – the Nuclear Engineering Education and Research (NEER) program, the University Reactor Instrumentation (URI) program, and the University Fuel Assistance program.

Nuclear and Radiological Sciences

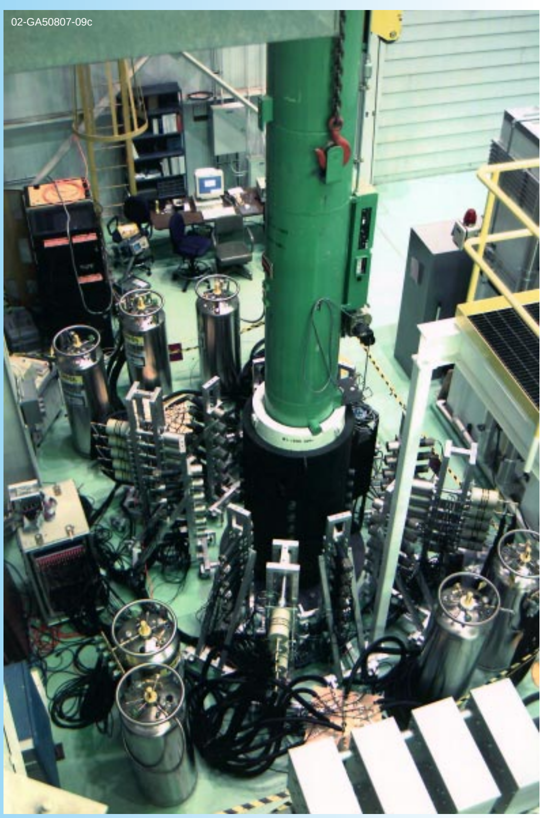
INEEL scientists and engineers are conducting research and supporting technology development in the areas of fundamental low-energy nuclear physics, medical applications of radiological science, development and qualification of basic data for nuclear criticality safety assurance, as well as development and application of advanced radiation detection systems for various applications including nondestructive assay, subsurface science and national security applications. In addition, the INEEL is maintaining a comprehensive radiochemistry capability to support INEEL site operations, and for various research applications in the areas of fundamental nuclear physics, environmental remediation and nuclear waste dispositioning.

Nuclear Systems Safety Analysis

Advancing the state of the art in nuclear reactor safety through the development and application of advanced analytical tools is a priority activity at the INEEL. Research and development areas include the thermal hydraulic system safety codes, such as RELAP5-3D;

Advancing the state of the art in nuclear reactor safety...is a priority activity at the INEEL.

The INEEL has evaluated the Multi-Detector Analysis System as a tool for characterization of spent fuel and remote-handled transuranic waste.



Idaho State University's Idaho Accelerator Center supports low-energy nuclear science research by the INEEL, government, industry and academia.

Advanced Fuel Cycle research is a component of the Generation-IV reactor program.

severe accident codes such as SCDAP; ATHENA codes for nonwater applications; and development of a RELAP5 graphical user interface. These state-of-the-art analytical tools are currently being applied to operating reactors, advanced passive systems and Generation IV designs.

Risk, Reliability and Regulatory Support

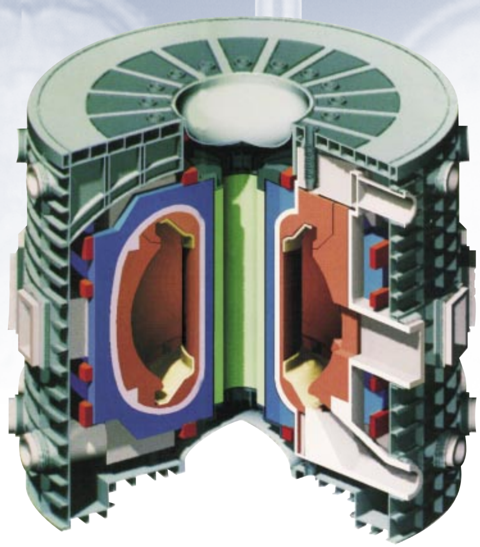
Work in this area at the INEEL involves providing advanced risk and reliability analytical capabilities to support complex engineered facilities and processes, with additional emphasis on nuclear engineering and regulatory analysis support for the U.S. Nuclear Regulatory Commission. Areas of research and applications include probabilistic risk assessment; reliability, availability, maintainability analysis; system safety analysis; nuclear plant operations analysis and technical assistance; statistical analysis; and operational event database development, analysis and maintenance.

The INEEL was designated lead lab for fusion safety by DOE in 1979.

Safety Analysis Resources

Work in the safety analysis arena includes defining facility-specific safe operating envelopes through expert hazard identification, site characterization, accident analysis and radiological analysis. Experienced safety analysts develop facility hazard classifications and safety analysis reports that fulfill DOE requirements. Analysts also assist in developing methods to implement and comply with safety analysis commitments.

The INEEL's Fusion Safety Program leads much of the safety effort for the International Thermonuclear Experimental Reactor.



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Fusion Safety

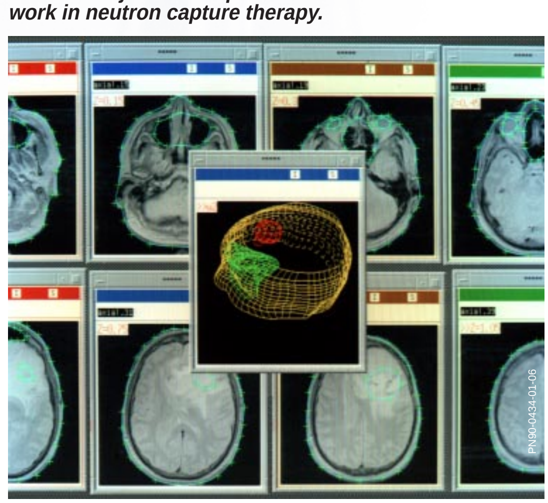
The INEEL was designated lead lab for fusion safety by DOE in 1979. The mission of the Fusion Safety Program is to characterize and assess the safety and environmental issues associated with magnetic and inertial fusion and to assist the fusion community in improving the safety and environmental attributes of their designs.

Neutron Capture Therapy

The INEEL has over 40 years of experience in high-precision gamma spectrometry and spectroscopy as well as computational and experimental neutron physics. The INEEL conducts a multifaceted set of institutional interrelationships focused on the development of the advanced approaches to radiotherapy with Neutron Capture Therapy (NCT) Targeted Radionuclide Therapy, and NCT-enhanced fast neutron therapy as the primary areas of interest. Current partnerships include other national laboratories, universities and private industry.

Molten Salt/Tritium Chemistry studies are among the collaborative experiments under way at the Safety and Tritium Applied Research (STAR) facility.

Development and enhancement of treatment planning software is just one aspect of the INEEL's multi-faceted work in neutron capture therapy.



Future Initiatives

Looking a bit further into the future, and building on its Secretarially defined role as the nation's leading center of nuclear energy research and development, the INEEL will devote significant resources to a trio of national priorities.

Gen IV

The U.S. Department of Energy initiated the Generation IV Nuclear Energy Systems Project (Gen IV) in January 2000. Multiple international representatives participated in this initial discussion and considered the long-term interest of the countries in the application of nuclear energy, the international interest in advanced nuclear technologies and exploring potential multilateral research projects to explore and develop new technologies.

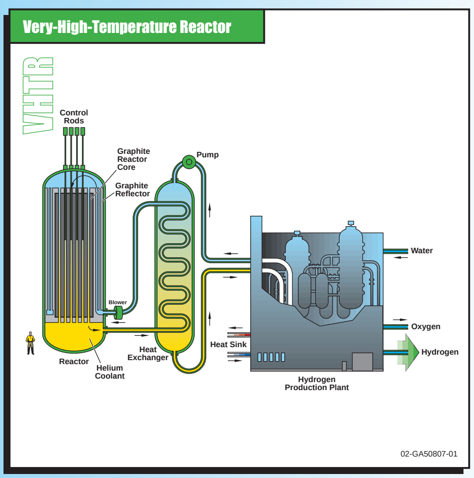
Generation IV nuclear energy systems are future, next-generation technologies that can compete in all markets with the most cost-effective technologies expected to be available over the next three decades. Comparative advantages include reduced capital cost, enhanced nuclear safety, minimized generation of nuclear waste and further reduction of the risk of weapons materials proliferation. Generation IV systems are intended to be responsive to the needs of a broad range of nations and users. The purpose of Gen IV is to develop nuclear energy systems that would be available for worldwide deployment by 2030 or earlier.

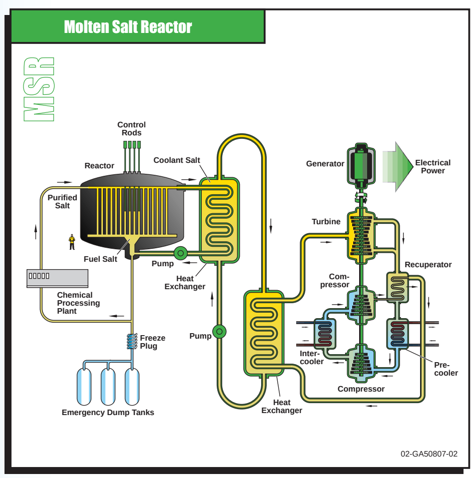
The INEEL and Argonne National Laboratory have facilitated and continue to support DOE-NE's Generation IV International Forum. The Forum is now comprised of 10 countries (Argentina, Brazil, Canada, France, Japan, Korea, South Africa, Switzerland, United Kingdom and the United States.) The final Generation IV systems selected in 2002 are: Gas-cooled fast reactor system, (GFR); molten salt reactor system, (MSR); sodium liquid metal-cooled reactor system (SFR); lead alloy-cooled fast reactor system, (LFR); supercritical water-cooled reactor system, (SCWR) and very high temperature reactor system (VHTR).

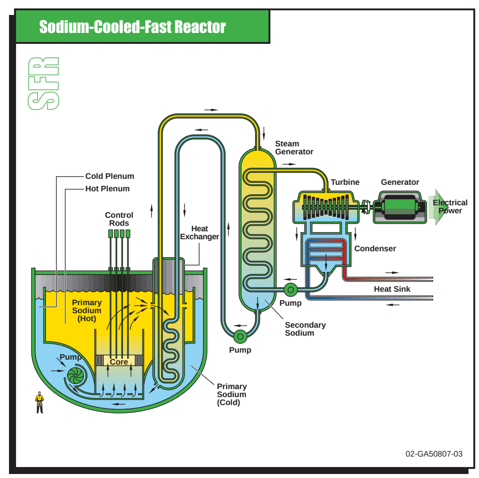
These systems offer significant advances in sustainability, safety and reliability, economics and proliferation resistance and physical protection. The INEEL is integrating long-term research and development for nuclear technology.

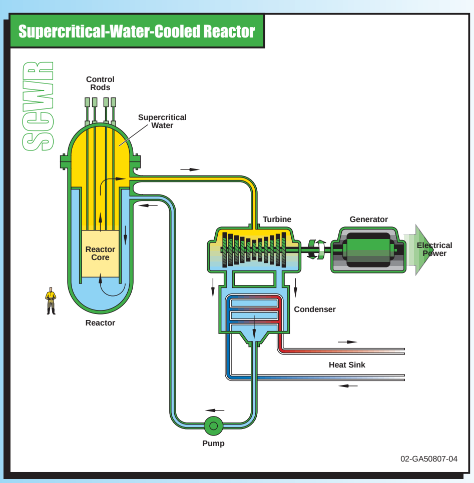
Argentina
Brazil
Canada
France
Japan
South Korea
South Africa
Switzerland
United Kingdom
United States

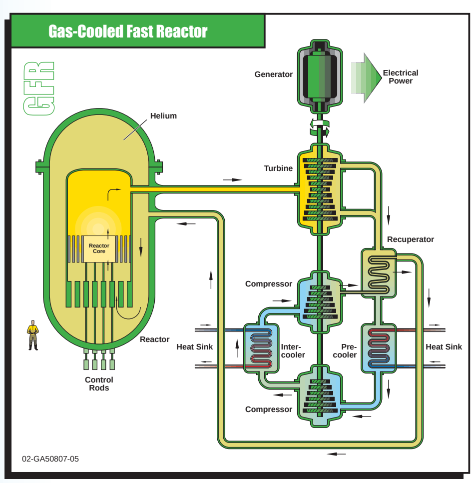
There are six reactor concepts selected for further research by the Generation IV International Forum. The Forum consists of scientists from 10 countries from around the globe.

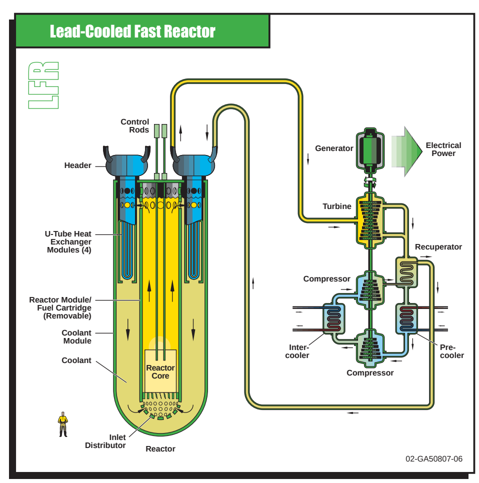












NP 2010

The Department of Energy and the utility industry believe it's critical to deploy new baseload nuclear generating capacity within the decade to help diversify our energy supply and build our energy security. The Nuclear Power 2010 program is a joint government/industry cost-shared program to demonstrate new regulatory processes and to provide certified designs that will lead to the start of construction of new nuclear power plants in the United States within a few years and the beginning of operation in the United States by 2010.

The Nuclear Power 2010 initiative is a joint government/industry program for the construction and operation of new nuclear plants in the United States by 2010.

The Near-Term Deployment Working Group, a group of industry representatives operating under the direction of DOE's Nuclear Energy Research Advisory Committee, issued *A Roadmap to Deploy New Nuclear Power Plants in the United States by 2010* that recommends actions to be taken by industry and DOE, and provides the basis for the activities of the Nuclear Power 2010 program.

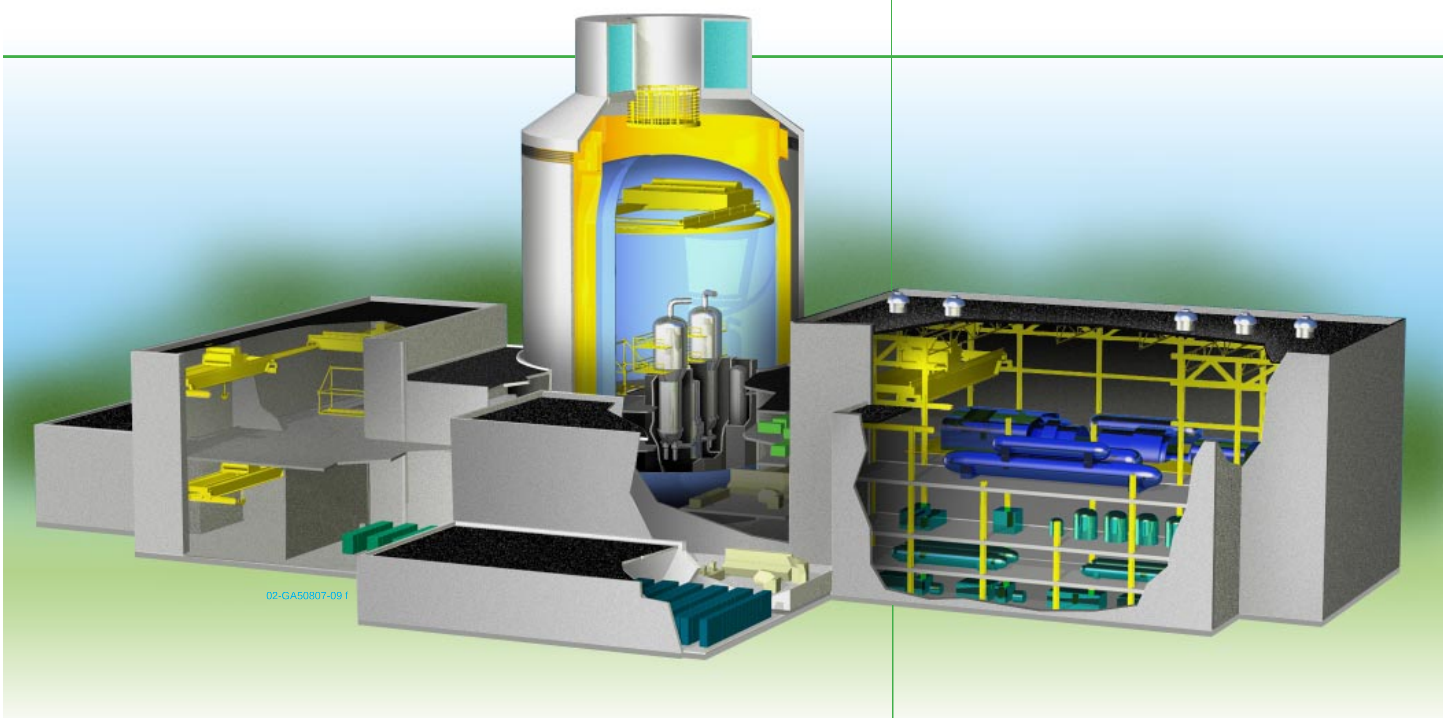
Candidate reactor technologies include both advanced water-cooled and gas-cooled reactor designs. A phased plan of action includes a Regulatory Demonstration phase and a Design Completion phase. The Regulatory Demonstration phase is a parallel effort to demonstrate the previously untested Early Site Permit (ESP) and combined Construction/Operating License (COL) regulatory processes to eliminate licensing uncertainties. DOE initiated this phase by selecting three commercial utilities to develop ESPs for favorable sites that will be forwarded to the Nuclear Regulatory Commission (NRC) for review and approval. The new ESP approach moves the site licensing and safety issues to the front of the process. This makes the licensing process more open to the public and predictable, and reduces risk to the applicant. It also resolves site safety, environmental and emergency preparedness issues, independent of a specific nuclear plant design review.

The Design Completion phase focuses on the first-of-a-kind engineering needed to bring the plants forward for licensing. It involves cooperation with the NRC to identify the technical issues and research required to support licensing, as well as the licensing framework for gas-cooled reactors. In the case of water-cooled reactors such as the AP1000 shown in the figure, it will focus on technical issues relative to the scaling up of the previously certified AP600 design. Once this is complete, DOE will initiate industry cost-shared demonstration projects for the NRC's COL application process. A combined license achieves resolution of the design, site, plant operation and environmental issues before plant construction begins. Ultimately, design certification and new construction methods will allow the plants to be built in under four years.

Advanced Fuel Cycle

The current U.S. plan for the nuclear power fuel cycle involves a once-through cycle with direct disposal of the spent fuel in the Yucca Mountain repository. However, in the LWR fuel cycle, less than five percent of the spent fuel consists of waste material, while 95 percent consists of fissile and fertile uranium and plutonium that could be recycled into new fuel. In addition, a number of the radioactive waste components may be effectively destroyed by also recycling them into new fuel. While good progress is being made toward the preparation and

NP2010 candidates currently under development include the inherently safe AP1000 design shown below, and a variety of other modern plants.



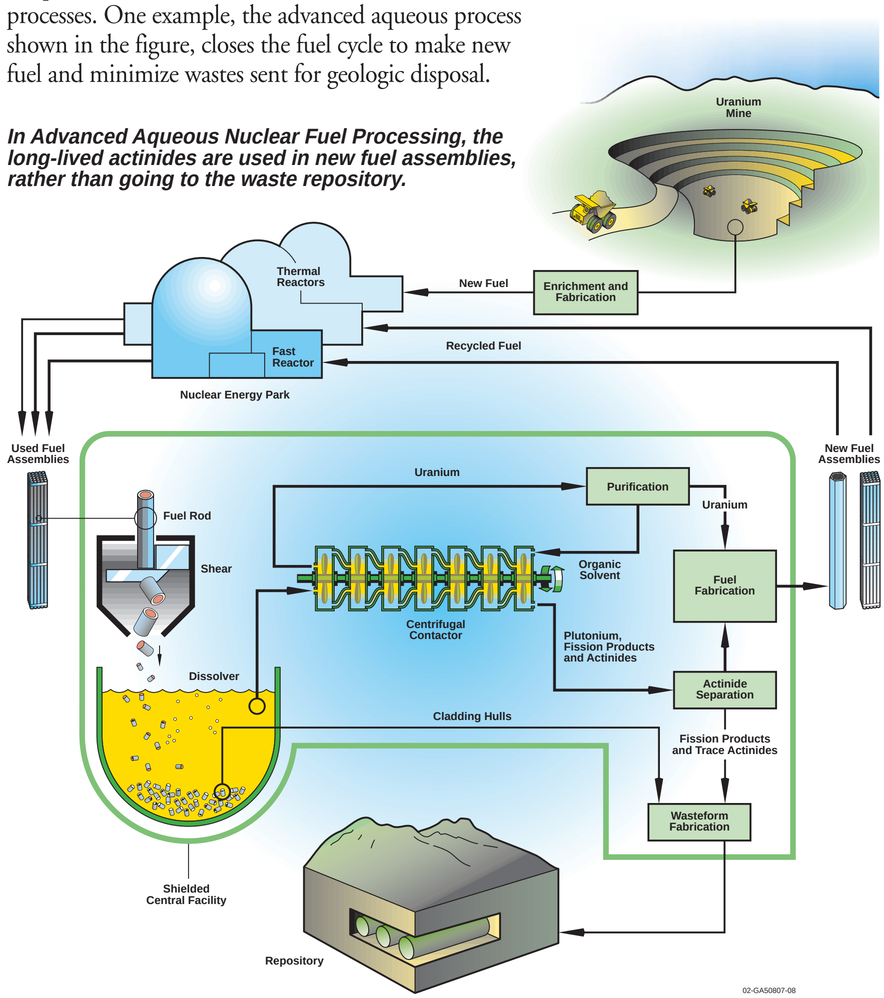
licensing of a geologic repository to support the once-through fuel cycle, the space in the planned repository is limited and would be greatly enhanced by recycling the useful components of discharged fuel and substantially reducing the volume of wastes sent to disposal.

Over the last several years, the DOE, its national laboratories, and university and private industry partners have worked with the international research community to explore the potential of advanced technologies for achieving a dramatic reduction in the volume and toxicity of nuclear waste. This program, known as the Advanced Fuel Cycle Program, has a top priority to develop new technologies that provide timely resolution of issues related to spent nuclear fuel disposition, and that could more effectively make use of the limited space in Yucca Mountain. This would reduce costs and delay or eliminate the need for a second repository.

The technologies being developed in the Advanced Fuel Cycle Program include processes that can safely and effectively separate the useful components of discharged nuclear fuel from the wastes in a manner that preserves the proliferation resistance of the materials and processes. One example, the advanced aqueous process shown in the figure, closes the fuel cycle to make new fuel and minimize wastes sent for geologic disposal.

A small-scale centrifugal contactor is checked out in the laboratory.

In Advanced Aqueous Nuclear Fuel Processing, the long-lived actinides are used in new fuel assemblies, rather than going to the waste repository.



Building on a proud and remarkable past and applying the unique people and physical assets we have today, the INEEL is well positioned to be a key resource for public and private initiatives to advance the safety, efficiency and technical basis of nuclear energy systems today and well into the future. The INEEL is on the job – powering progress in global nuclear energy research.

For more information...

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