EISPC
EASTERN INTERCONNECTION STATES' PLANNING COUNCIL

Assessment of the Nuclear Power Industry – Final Report

June 2013

Navigant Consulting, Inc.
For EISPC and NARUC
Funded by the U.S. Department of Energy

Assessment of the Nuclear Power Industry

Study 5: Assessment of the Location of New Nuclear and Uprating Existing Nuclear
Whitepaper 5: Consideration of other Incentives/Disincentives for Development of Nuclear Power

prepared for

Eastern Interconnection States' Planning Council
and
National Association of Regulatory Utility Commissioners

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The information and studies discussed in this report are intended to provide general information to policy-makers and stakeholders but are not a specific plan of action and are not intended to be used in any State electric facility approval or planning processes. The work of the Eastern Interconnection States' Planning Council or the Stakeholder Steering Committee does not bind any State agency or Regulator in any State proceeding.

Acknowledgements

This material is based upon work supported by the Department of Energy, National Energy Technology Laboratory, under Award Number **DE-OE0000316.**

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Navigant would like to thank NARUC and EISPC for the funding and support. In addition, Navigant and EISPC gratefully acknowledge the generous and timely assistance of the Energy Zones Working Group:

Argonne National Laboratory
Vladimir Koritarov
James Kuiper
Donna Brunner

Forward

The National Association of Regulatory Utility Commissioners (NARUC) is a non-profit organization dedicated to representing the state public service commissions who regulate the utilities that provide essential services such as energy, telecommunications, water, and transportation. NARUC's mission is to serve the public interest by improving the quality and effectiveness of public utility regulation. Its members include all 50 U.S. States, the District of Columbia, the City of New Orleans, Puerto Rico, and the Virgin Islands.

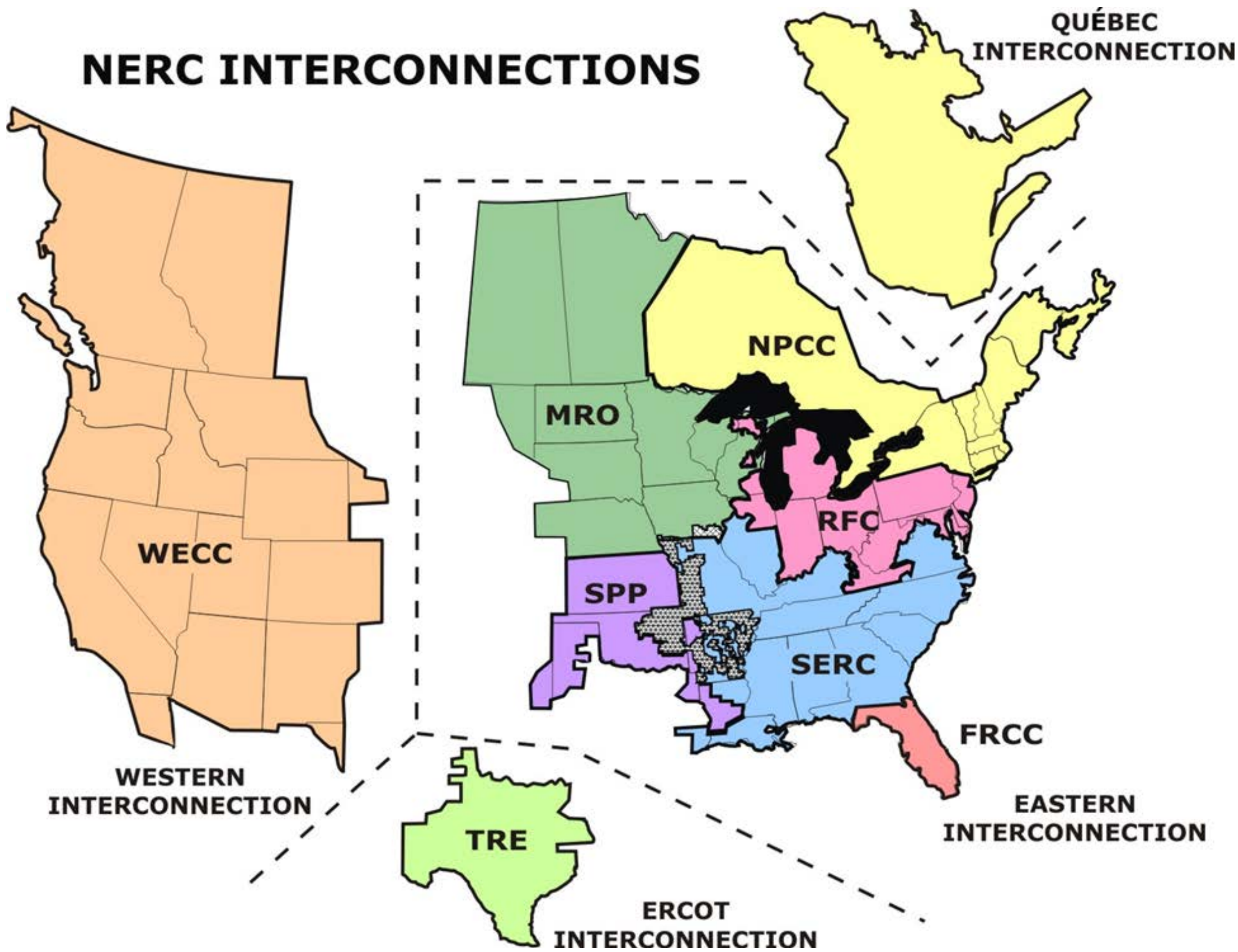
NARUC serves as the umbrella organization for the Eastern Interconnection States' Planning Council (EISPC), a collaboration of the 39 eastern states[1], the City of New Orleans, and the District of Columbia, to support the coordinated involvement of member entities for region-wide planning efforts. This endeavor to institute a more coherent and comprehensive approach to planning for long-term electric power needs is supported by funding from the United States Department of Energy (DOE) pursuant to a provision of the American Recovery and Reinvestment Act (ARRA).

All members of EISPC are served by the Eastern Interconnection. The six North American Electric Reliability Corporation (NERC) regional reliability entities that comprise that territory are:

- Florida Reliability Coordination Council (FRCC)
- Midwest Reliability Organization (MRO)
- Northeast Power Coordinating Council (NPCC)
- ReliabilityFirst Corporation (RFC)
- SERC Reliability Corporation
- Southwest Power Pool (CPP)

[1] Alabama, Arkansas, Connecticut, Delaware, Florida, Georgia, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Maine, Maryland, Massachusetts, Michigan, Minnesota, Mississippi, Missouri, Montana, Nebraska, New Hampshire, New Jersey, New Mexico, New York, North Carolina, North Dakota, Ohio, Oklahoma, Pennsylvania, Rhode Island, South Carolina, South Dakota, Tennessee, Texas, Vermont, Virginia, West Virginia, and Wisconsin

Map of NERC Interconnections



The purpose of this study is to provide EISPC members with a better understanding of the history of the commercial nuclear power industry and the forces that are shaping it today. The whitepaper also includes a study of the locations for new nuclear power plants and evaluates the suitability of existing plants for power uprates. The information within this document will also inform future analyses that EISPC members may conduct.

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Basic Nuclear Power Concepts

The language of nuclear power can quickly become a language all its own with numerous acronyms and abbreviations. The authors have attempted to minimize the use of jargon and explain relevant concepts at appropriate points within this document. As various readers will have different levels of familiarity with some of the topics discussed, below is a short list of terms and there is a more complete glossary in the Appendix.

Decay Heat Unlike conventional fueled power plants, nuclear reactors continue to generate up to 7% of their power level immediately after shutdown due to energy produced by fission byproducts within the reactor. This energy requires the continuous circulation of coolant to prevent possible damage to fuel rods and is the basis for emergency core cooling systems and their support equipment. Spent nuclear fuel remains in pools of water for up to five years to allow this heat source to dissipate.

Moderator The purpose of the moderator is to slow down high energy neutrons created during the fission process in order to increase the probability of fission within a thermal reactor. Water is the most common moderator used in modern U.S. reactors. Other moderators used in reactors include heavy water (deuterium) and graphite.

Coolant The fission process raises the temperature of the fuel rods used in the reactor. Coolant transfers the heat from the fuel rods to an intermediate heat exchanger or turbine depending on the design of the power plant. Modern U.S. reactors use water as the coolant. Other reactors use heavy water (deuterium), liquid sodium, or helium.

Reactor Names The basic nomenclature of nuclear reactors includes several important terms. The first part of the description is the type of coolant used to remove heat from the reactor core. Typical coolants are:

Light water – This is regular water (H_2O). All operating power reactors in the U.S. employ light water as a coolant.

Heavy water – This is water in which the hydrogen atom contains a proton and a neutron and is called Deuterium (D_2O). Operating power reactors in Canada employ heavy water as a coolant.

Gas – Carbon dioxide or an inert gas such as helium may be used as a coolant.

Liquid metal – Liquid metal may be sodium, a combination of sodium and potassium, lead and bismuth or some other metal(s). Metal-cooled reactors may be a "loop" or "pool" design.

Molten salt - In a Molten Salt Reactor (MSR), the fuel is dissolved in a fluoride salt or other salt coolant.

The second descriptor refers to the neutron moderator being used to slow down the neutrons. The presence of a moderator indicates that it is a thermal (slow) neutron reactor. Typical moderators include:

Light Water (most widely used moderator)

Heavy Water (Predominant in Canadian CANDU reactors, allows use of natural un-enriched uranium)

Graphite (United Kingdom, Russia)

If there is only one descriptor, such as light water, it implies that it is both the coolant and the moderator. For example, in the United States, pressurized light water reactors (PWR) and boiling light water reactors (BWR) use light water as both the coolant and the moderator. The basic difference between these two types of reactors is that PWRs have an intermediate heat exchanger between the radioactive primary coolant and the steam turbine. In a boiling water reactor, the primary coolant is heated to boiling by nuclear fission and the steam is sent directly to the steam turbine. Each reactor type is depicted in Section 7.

Should the term "fast" appear in the name of the reactor, it implies that high energy neutrons are used to split uranium and plutonium isotopes that would not normally fission with slow neutrons. Fast reactors do not have moderators, only coolants.

If the term "small" appears in the name of the reactor, it is understood to be less than 300 MWe unless noted otherwise.

Fission

All nuclear reactors generate heat from the energy released by splitting atoms with neutrons. These neutrons have different energy levels. Three isotopes, Uranium-233, Uranium-235, and Plutonium-239, are called fissile material as they are fissionable by neutrons of all energies. However, Uranium- 235 is the only one that occurs naturally and it does so in very small amounts. Thorium-232 and Uranium-238 are abundant naturally, but are fissionable only if split with highly energetic neutrons. However, these materials can be converted to fissile isotopes within a reactor.

Natural uranium ore is 99% U-238 and 1% U-235. The process of increasing the ratio of U-235 to U-238 is called enrichment, which is very energy intensive and requires a highly sophisticated workforce and infrastructure. The enrichment process raises proliferation concerns because highly enriched material can also be used in nuclear weapons as well as reactors.

Design Margin

Design margin refers to the relationship of a nuclear power plant's operating parameters (temperature, pressure, flow) and the maximum allowable engineering design parameters.

Public Safety Modern nuclear power plants use several lines of defense to protect the public from the release of radioactive material. The first is conservative operating practices and strict equipment reliability requirements. The second is a robust fuel design that attempts to minimize release of fission products into the coolant during normal plant operations. The third is the reactor coolant system, which is designed to remove heat from the fuel rods. Should the primary coolant pumps fail, design criteria require multiple secondary safety system activate to remove decay heat. The final barrier is the containment vessel that surrounds the reactor coolant system. Should the coolant system rupture, the containment and its pressure suppression system are designed to prevent the release of radioactive material.

Passive/Active Safety Systems

Passive systems refer to emergency cooling systems that use natural circulation or gravity to fulfill their function. Active systems use pumps or valves and rely on AC or DC power to fulfill their function.

Radiation Unstable materials change into stable materials through the process of radioactive decay. Three types of radiation are of most concern for human health: alpha particles, beta particles, and gamma rays. Each of these forms of energy can interact at the cellular level and cause varying degrees of biological damage. Alpha and beta particles are typically considered only an internal hazard. Therefore, appropriate precautions are taken to prevent ingestion of material that emits them through radioactive decay. Gamma radiation accounts for almost all of the small amounts of radiation nuclear workers receive.

Contamination Radioactive material that is present within or on other material. Contamination can be mitigated by disposing, painting over the contamination, or attempting to clean the material.

Radiation Measurement

There are two basic types of radiation measures. One is the level of radioactive activity, which is related to the number of radioactive decays per second a material undergoes and is measured in Curies or Becquerel. One Becquerel is defined as the activity of a quantity of radioactive material in which one nucleus decays per second. One Curie is defined as 3.7×10^{10} decays per second, or approximately the activity of 1 gram of radium.

The other measure is an approximation of the biological damage the radiation may cause to the human body. The level of damage is related to the specific organ, level of activity the organ is exposed to, type of radiation particle, energy of the radiation particle, and length of exposure. Two basic measures are the rem and Sievert. One Sievert equals 100 rem.

The average annual radiation exposure from natural sources in the United States is about 310 millirem (3.1 millisieverts or mSv). Another 310 millirem is received through commercial, industrial, and medical processes, so the annual average exposure is 620 millirem in the United States.

The NRC requires that its licensees limit maximum radiation exposure to individual members of the public to 100 millirem (1mSv) per year, and limit occupational radiation exposure to adults working with radioactive material to 5,000 millirem (50 mSv) per year.

Executive Summary

This assessment of the nuclear power industry combines the findings of a Locational Study for new and existing nuclear power plants with a Whitepaper analyzing state level policies germane to the continued development of nuclear power. The combined document serves as a primer on the development of nuclear power in the United States, identifies current issues facing the industry, and provides an overview of future nuclear technology.

Existing U.S. nuclear plants have sustained superior operational performance over the last decade. The industry's average capacity factor has hovered near 90% and its costs have stabilized as it has increased efficiencies through consolidation. It offers a sustainable baseload technology that is carbon free and provides local economies with greater economic stimulus than any other fuel source. Although it has taken over 50 years and significant investment, the nuclear industry has been at the forefront of both developing new management techniques and partnerships with labor to support new construction projects and creating new behavioral paradigms that can be applied to other industries. If viewed in the context of baseload power plant longevity, 50 years is little more than one generation in the technology development cycle.

The pace of change is accelerating in electric power markets and the challenge facing U.S. nuclear power stakeholders is whether or not they can adapt fast enough over the next 50 years to remain relevant to future electric market needs. Deregulated electric markets will require future nuclear plant designs to have greater operational flexibility to complement the operating characteristics of intermittent renewable generation sources while sustaining the level of operational excellence the industry has currently achieved. Construction costs and schedules will need to be credible and predictable. Long-term operations for relicensed nuclear plants will advance the body of knowledge with respect to material science, nuclear fuel design, accident analysis, and asset management. Past experience with "backfits" has shown that such advances in knowledge can have significant cost implications for nuclear plant operators. In the two months prior to completing this study, four nuclear power plants have been permanently shut down. Three of the four, San Onofre 2 & 3 in San Diego, California and Crystal River 3 in Florida, were shut down due to the prohibitive cost of repair associated with damage to vital pieces of equipment essential to long term operations. Five new nuclear power plants are currently under construction and will make up for this lost nuclear capacity, but significant additions of new nuclear baseload generation envisioned as little as five years ago are unlikely to be built unless CO_2 emissions fees are enacted.

The unanticipated closure of a nuclear power plant can disrupt a local economy through loss of jobs and the regional power market through loss of generating capacity. Stranded spent nuclear fuel will remain at closed sites for the foreseeable future and remains the single most contentious issue facing all nuclear stakeholders. Licensing of new plants and relicensing of existing plants has been suspended by the NRC until it revises its Waste Confidence Rule in 2014.

Section 1 of this report provides an overview of nuclear power development. While reading this section, it is useful to note that nuclear power was the Federal government's first attempt to commercialize a technology. Along the path to commercialization, nuclear power generation encountered many of the challenges faced today by energy storage, Smart Grid, and renewable energy technologies. These include the need for government funding for demonstration projects, policy changes to promote widespread use, and a tolerance for the uncertainties associated with R&D type investments. When the government first promoted nuclear power to industry, nuclear power did not provide a solution to a problem the electric utility industry was trying to solve. It held promise to be a disruptive technology, but its capital intensive nature and unknown operational requirements caused most utilities to adopt a "wait and see" attitude.

To overcome this skepticism, the Atomic Energy Commission (AEC) built reactors around the country as part of its Power Reactor Demonstration Program and President Eisenhower's Atoms for Peace initiative. The goal was to have the experience gained through these efforts provide the foundation for a domestic and international commercial atomic power industry. Eventually, firms such as General Electric, Bechtel, and Westinghouse subsidized the construction of early nuclear power plants. Their patience was rewarded in the latter half of the 1960s when orders for new plants rapidly increased.

The construction of the new plants became problematic because the AEC regulators and manufacturing companies lacked the capacity to respond to the market demand. Delays increased and costs became uncertain. Against a backdrop of international and national atomic weapon tests, public perceptions of atomic power began to change. By the mid-1970s, reactor orders started to be cancelled because of local opposition and changes in economic outlook due to the 1973 Oil Crisis and subsequent recession.

The AEC never successfully transitioned from power reactor promoter to commercial power industry regulator and was abolished in 1974 after contentious public hearings on reactor safety standards. Tasked solely with enforcement responsibilities, the newly created Nuclear Regulatory Commission (NRC) increased regulatory oversight of the industry. However, the staff of the former AEC became that of the NRC, so a change in organizational attitudes did not occur instantaneously.

The 1979 accident at Three Mile Island brought radical change to the nuclear utility industry and the NRC. Nuclear plant staff doubled or tripled in size to keep up with the wave of new regulatory requirements imposed by the NRC and self-imposed on the industry by the Institute for Nuclear Power Operations (INPO). Operational costs for existing plants increased dramatically and delays increased for plants under construction. Industry operational performance began to improve in the latter half of the 1980s, but by then, nuclear power had higher average operational costs than coal-fired generation.

Rapidly escalating costs for electric service pushed the industry toward electric market deregulation. In 1995, electric market deregulation and a change in NRC regulatory philosophy spurred on significant efforts to find efficiencies and improve operational performance. Industry consolidation began as corporations sought efficiencies through economies of scale, and efforts to merge utilities continue today.

Having proven that it can safely and efficiently operate nuclear power plants, the industry now faces the greater challenge of economic competition from a resurgent natural gas industry and increased penetration of wind energy. Extremely low operating costs have traditionally insulated nuclear power plants from being concerned with power market margins. However, increasing penetration of wind, which is eligible for production tax credits that enable negative market prices during some hours, and the competitive nature of natural gas-fired power plants have lowered the price of power. This has resulted in the shutdown of Dominion's Wisconsin-based Kewaunee nuclear power plant. Nuclear power plants in deregulated markets will be challenged to maintain operational excellence and identify cost-saving efficiencies under present power market conditions. An analysis of potential nuclear power plant uprate candidate plants and an explanation of Navigant's coal plant retirement estimates is found in Section 2.

Section 3. contains a discussion on nuclear power plant operating and construction costs and provides a historical comparison of construction costs for all U.S. nuclear power plants. Review of nuclear plant construction cost data shows that the industry has never been able to reap construction cost economies of scale by building larger power plants. Small modular reactors may provide a solution to this problem if modules can be consistently manufactured at reasonable cost. This section also reviews the operating cost differences between dual unit and single unit nuclear plants in order to examine why single-unit plants may be more financially vulnerable in deregulated markets.

Section 4. traces the evolution of Federal regulation within the AEC and NRC and presents the various incentives and disincentives affecting new nuclear construction found in each state. Navigant reviewed legislative impediments and inducements for new nuclear power construction, ratemaking polices, market structure, and renewable portfolio standards to rank individual states by incentives. Review of that analysis concludes that a nuclear renaissance may be a regional phenomenon confined to the southeastern United States.

The accidents at Windscale, Three Mile Island, Chernobyl, and Fukushima are reviewed to give some perspective regarding the challenges operators, local authorities, and national leaders face during abnormal conditions. Japan's decision to raise permissible radiation exposure limits will result in international study to see whether or not long-term exposure to low level radiation will be statistically proven to affect public health. The long-term implications of such research will determine whether or not radiation protection standards are tightened or relaxed worldwide.

Navigant reviewed the issues surrounding the long-term storage of spent nuclear fuel in light of the Department of Energy's recent decisions to proceed with consent-based siting of spent fuel and high-level radioactive waste repositories. This is perhaps the most complex problem the industry faces, and its resolution is out of the hands of the industry's regulator (NRC). Highlights of the problem include:

- Federal government is in default on a contractual obligation to dispose of spent fuel from nuclear utilities and estimates its financial penalties at $20 billion through 2020.
- Expenditures of the approximately $32 billion in the dedicated utility-funded Nuclear Waste Fund are now limited to discretionary appropriations and are cut off from use for their intended purpose.
- Ten states have enacted moratoriums against new power plant construction until a SNF repository is operational.
- Even if the decision to abandon Yucca Mountain were reversed, the legislated capacity of Yucca Mountain is inadequate to handle today's waste until a second geological repository is opened or current legislation is modified.
- Reactor relicensing activity dependent on interim fuel storage has been halted until the NRC revises its Waste Confidence Rule.
- Railroads cannot currently support shipment of spent nuclear fuel.

The report discusses the current status of U.S. design certification efforts as well as the construction status of new plants. Additionally, an overview of next generation nuclear plants and future generation nuclear technologies is provided with an emphasis on NRC-certified designs or those undergoing certification. Many of the reactors built in the early years of nuclear power development would be classified as small modular reactors (SMRs) today. It is interesting to note that some of the proposed "advanced" future generation plants use the same basic type of reactors that were successfully tested nearly 50 years ago.

To supplement information in this assessment, there is a database containing individual unit information such as ownership, location, size, historic capacity factors, age, and other information.

1. BACKGROUND

Nuclear electric power generation was the first of many technologies that have since used the partnership among contractor-managed national laboratories, Federal agencies, and industry in an attempt to develop and commercialize new energy-related technology. Along the path to commercialization, nuclear power generation encountered many of the challenges faced today by energy storage, Smart Grid, and renewable energy technologies. These include the need for government funding for demonstration projects, policy changes to promote widespread use, and a tolerance for the uncertainties associated with R&D type investments. This section provides an overview of the attempts by industry and government to develop a commercial nuclear power industry within the United States and for export abroad. As with many new technologies, a lack of knowledge and experience led to oversimplification of the technical and policy challenges obstructing the path to successful commercialization.

1.1 Early Years – (1946-1957)

The Manhattan Project built an impressive array of research, development, enrichment, and production facilities to support the development of the atomic bomb and began the academic-industry-Federal partnership. In 1946, the "U.S. Congress declared that atomic energy should be employed not only in the Nation's defense, but also to promote world peace, improve the public welfare, and strengthen free competition in private enterprise"[2]. As a result, the newly created U.S. Atomic Energy Commission (AEC) inherited Manhattan Project facilities and was granted sweeping powers to perform its dual missions of national defense and promoting peaceful uses of atomic power. Its employees were exempt from the Civil Service system and all research findings and technical information remained under the sole control of the Commission. The constraints on the free flow of information and government ownership of uranium effectively stifled private industry developmental activities.

The Soviet Union's successful test of a nuclear weapon and the onset of the Korean War in 1950 caused the AEC to focus on quickly expanding U.S. nuclear weapons capability and production facilities. During this period, the AEC and the Department of Defense also focused on non-explosive uses of atomic power. Plans and testing were conducted for nuclear power rockets[3], an atomic-powered airplane, and small power reactors for remote military applications. It was also during this period that the U.S. Navy started to focus on developing a nuclear-powered aircraft carrier and a nuclear-powered submarine. This was an era of great expectations, high confidence, and little knowledge of the long-term effects of radiation or the engineering challenges that would arise. The emphasis on national defense permeated the thinking of the time, and it was believed that dual use reactors that could produce both plutonium and electric power would form the basis of a private nuclear power industry.

To explore this option, in 1951, the AEC began the Industrial Participation Program to involve manufacturing firms and utilities in estimating the technical and economic feasibility of various dual-purpose reactors that would use natural uranium for fuel. Four study groups responded to the initial

[2] A History of the Atomic Energy Commission DOE Alice L Buck July 1983
[3] Project Rover-http://www.lanl.gov/science/NSS/issue1_2011/story4a.shtml

announcement: (1) Dow Chemical and Detroit Edison, (2) Commonwealth Edison and Public Service Company of Northern Illinois, (3) Bechtel Corporation and Pacific Gas and Electric (PG&E), and (4) Monsanto Chemical and Union Electric Company of Missouri.[4] The participants made a number of important observations:

- Dual-purpose reactors had an inherent design contradiction. A reactor designed for efficient power production would be less efficient at plutonium production and vice versa because of the difference in required neutron energy spectrum.
- Siting criteria needed to be changed so power reactors could be closer to population centers and electrical grid infrastructure.[5,6]
- Government funding would be required to encourage the electric utility industry to consider nuclear power as a generation source because of the magnitude of the required capital expenditures.
- Industry required greater access to information and technical knowledge before it would consider the use of nuclear power.

In December 1953, newly elected President Eisenhower proposed his Atoms for Peace initiative to promote peaceful uses of nuclear power around the world. To accomplish this goal, the Atomic Energy Act of 1954 was passed allowing the sharing of technical information with foreign governments and private industry. One of the aims of the legislation was to develop an export market for nuclear reactors and allow private industry to conduct its own R&D.[7] Concurrently, the AEC planned to build five experimental power reactors within five years to test various designs and show the world the feasibility of generating electrical power with nuclear energy. These five experimental power reactors included:

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[4] Nuclear Reactors For Generating Electricity: U.S. Development From 1946 To 1963 Rand--2116, 1977 p20

[5] To determine acceptable reactor locations, the AEC's Reactor Safeguards Committee used an exclusion formula that took into account size, rate of plutonium production, and associated risk. If this formula were used to evaluate potential sites for the 100-300 megawatt electric (MWe) plants considered in the feasibility studies, the cost of purchasing enough land would have been prohibitive for any private corporation or utility. Nuclear Reactors For Generating Electricity: U.S. Development From 1946 To 1963 Rand-2116, 1977 p23

[6] The idea of a "containment" was first introduced in 1949 for GE Knolls Laboratory breeder reactor in West Milton N.Y Hewlett and Duncan, Nuclear Navy" p. 176.

[7] Nuclear Reactors For Generating Electricity: U.S. Development From 1946 To 1963 Rand-2116, 1977 p34,p37

Table 1. Experimental Reactor Program Participants

Participating Utility	Project Name	Reactor Type	Manufacturer	Size (MWt)	Location	Years of Operation	Decom Completed
Duquesne	Shippingport	Pressurized Light Water Reactor (PWR)	Westinghouse	230	Shippingport, PA	1957-1982	1990
Southern California Edison	Sodium Reactor Experiment	Sodium-Cooled Graphite Moderated	Atomics International (North American Aviation)	20	Santa Susana Field Laboratory Simi Valley, CA	1957-1964	
	Experimental Boiling Water Reactor	Boiling Light Water Reactor (BWR)	Argonne National Laboratory	60	Argonne National Lab, Chicago IL	1956-1967	1996
	Experimental Breeder Reactor -2	Sodium-Cooled Fast Reactor	Argonne National Laboratory	62.5	National Test Site- ID	1964-1994	
PPL	HRE-2	Homogeneous Reactor	Oak Ridge National Laboratory	5	Oak Ridge National Laboratory	1957-1961	

1.1.1 Shippingport

The decision to build a pressurized light water reactor (PWR) at Shippingport, Pennsylvania for the sole purpose of producing electrical power was the result of a number of policy pressures and technological innovations that occurred in 1953. In that year, the National Security Council thought the early development of nuclear power was a prerequisite for maintaining the United States' lead in the atomic field.[8] The U.S. Atoms for Peace program was founded on the principle of worldwide adoption of peaceful uses for atomic power and there was political pressure to develop a demonstration project. Additionally, being the first nation to successfully produce electricity with nuclear power was a matter of national prestige.[9] Thus, in the spring of 1953, President Eisenhower accepted a National Security Council recommendation to drop the Navy's nuclear powered aircraft carrier and the Air Force's atomic airplane from that year's defense budget, and he left open the opportunity to turn the carrier reactor into a civilian power plant.[10] By this time, a great deal of highly successful developmental work had already gone into the PWR that was designed for use in the first nuclear-powered submarine, USS Nautilus, and specifications had been developed for an aircraft carrier reactor. In March 1953, the USS Nautilus land prototype reactor, S1W, achieved criticality for the first time and performed brilliantly in a 100-hour test run.[11] Admiral Rickover's naval reactors program had achieved a reputation for successful reactor development.

[8] Development And Commercialization Of The Light Water Reactor, 1946-1976, R-2180, 1977 p7
[9] Shippingport became the first nuclear reactor to be built solely to produce commercial electrical power on December 18, 1957. Britain's dual use reactor Calder Hall produced commercial power on 27 August 1956. The Soviet Union' experimental Obninsk Nuclear Power Plant produced 5 MWe on June 26, 1954 , the North Amercian Aviation Sodium Experiment Reactor supplied power to Moorpark, CA on July 12, 1957. In 1955, the BORAX-III test reactor powered Arco, Idaho. Vallecitos Nuclear Center started producing electric power in October 1957
[10] Rickover: Controversy and Genius 1982 Polmar & Allen p 603.
[11] http://en.wikipedia.org/wiki/S1W_reactor

Detroit Edison, one of the original study groups in the Industrial Participation Program, and its chairman, Walker L. Cisler, favored the breeder reactor design and formed a coalition of companies to begin the nuclear reactor industry in the United States.[12] Breeder reactors produce more fuel than they consume through the conversation of uranium to plutonium. In December 1951, Experimental Breeder Reactor–I, developed by Argonne National Laboratory, illuminated a string of four 200-watt light bulbs, which meant, if successfully scaled up, utilities would be able create their own fuel. Successful development of this concept would free utilities from fossil fuels forever and lower the cost of new fuel to reprocessing charges. While the utility industry and its allies in the AEC favored this approach to developing an initial full-scale nuclear power plant, there were two drawbacks. The first was the requirement to closely control plutonium due to proliferation and waste disposal concerns and the second was that it was not foreseen that a full-scale breeder reactor would be ready in less than five years.

Given its maturity of design and successful track record in testing, the PWR was selected as the basis for the first civilian nuclear power plant. Westinghouse had the most experience building PWR reactors due to its close association with the U.S. Navy's nuclear propulsion program and was chosen as the principal contractor with the U.S. Navy's Naval Reactors Branch designated as the project manager. Prior to that decision, concerns had been raised about having a branch of the military put in charge of a civilian construction project, which conflicted with the AEC's mission to promote "free completion in private enterprise".[13] And, it should be recalled that at the time, the government had never attempted to commercialize any technology, and it was generally assumed that it would provide limited support to demonstrate feasibility and then those utilities would adopt the new power source. However, these concerns yielded to the nation's need for a successful demonstration of peaceful use of the atom before another country could claim that honor.[14]

The AEC had chosen three possible sites for the project; Oak Ridge, Tennessee; Paducah, Kentucky; and Portsmouth, Ohio. Industry response was tepid following the announcement of the civilian nuclear power plant project, and utilities found none of these sites attractive. Nevertheless, eventually the Duquesne Light Company of Pittsburgh proposed to provide $5 million towards reactor development and provide the site at Shippingport.[15]

The specific terms of this contract foreshadowed those of some other AEC developmental reactors. For Duquesne, the AEC would build and own the reactor as a R&D project while the utility would buy steam for the electric generation plant and operate the entire site.

Ground was broken on September 6, 1954 by an automated bulldozer activated by President Eisenhower waving a neutron wand.[16] As a national priority, the Shippingport project was completed on time three

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[12] Rickover: Controversy and Genius 1982 Polmar & Allen p 605
[13] Rickover: Controversy and Genius 1982 Polmar & Allen p 606.
[14] Ibid p 606.
[15] Ibid p 609.
[16] Rickover: Controversy and Genius 1982 Polmar & Allen p 609.

years later in December 1957.[17] During the last five years of its life, Shippingport operated as light water breeder reactor with a thorium and U^{-233} based core, and on October 1, 1982 after operating successfully for 25 years, it was shut down.

1.1.2 Power Reactor Demonstration Program

In January 1955, the AEC announced the first round of the Power Reactor Demonstration Program (PRDP), which had the purpose of generating R&D information and involving commercial firms and utilities in the construction of nuclear power plants. It also wanted to demonstrate nuclear power in the most cost effective manner possible. Initially the AEC provided R&D funds, waived fuel charges, and provided other technical support; however, when smaller utilities such as Duquesne became involved, it paid for the reactors and retained ownership or sold its interest for a nominal fee after a successful five-year warranty run. From 1954 through November 1962, the AEC estimated it spent $1.275 billion and that industry had invested $500 million in civilian reactor development.[18]

The first round of the PRDP required that proposers be "willing to assume the risk of construction, ownership, and operation of reactors designed to demonstrate the practical value of such facilities for industrial or commercial purposes."[19] Price-Anderson liability protection did not exist at that time, so owners assumed liability without a government backstop. First round terms limited the AEC to waving fuel lease charges for seven years, performing mutually beneficial R&D research at a national laboratory free of charge, and entering into a fixed price R&D contract with the owner in exchange for access to technical information and for the right to share that information with the rest of the nuclear industry.[20] This later clause may have influenced Commonwealth Edison-General Electric's team to withdraw from the PRDP in order to retain proprietary rights to information developed during the construction and operation of Dresden 1.

Four projects came to fruition in the first round of the PRDP. The Yankee Atomic plant, built by a consortium of New England utilities, was a successful adaptation of the Shippingport PWR reactor design, but on a larger scale.

As previously mentioned, in December 1951, Experimental Breeder Reactor-1, (EBR-1) was the first reactor to generate a small amount of electrical power. EBR-1, which used sodium-potassium (NaK) coolant, was built by Argonne Laboratory to test the fast breeder reactor concept. Although it suffered partial fuel meltdown in 1955, it was repaired and continued to successfully test the breeder reactor concept until it was shut down in 1964. Detroit Edison and Power Reactor Development Company built the Enrico Fermi (Fermi 1) power plant as the first attempt to increase the size of this technology and exploit the fast breeder concept. The benefit would be the elimination of fossil-fueled power plants and the ability for a utility to generate its own fuel.

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[17] Ibid p 615. On his own authority, Rickover got Duquesne to agree that a representative of Naval Reactors could observe operations throughout plant life and shutdown the reactor at any time if they thought it unsafe. Shippingport was never licensed by the NRC.

[18] Civilian Nuclear Power a Report to the President 1962 p.8 Atomic Energy Commission

[19] Nuclear Reactors For Generating Electricity: U.S. Development From 1946 To 1963 Rand--2116, 1977 p 39

[20] Ibid p 40

Table 2. First Round PRDP Projects

Participating Utility	Project Name	Reactor Type	Manufacturer	Size (MWe)	Location	Years of Operation	Decom Complete
Yankee Atomic	Yankee (Rowe)	Pressurized Light Water Reactor (PWR)	Westinghouse	185	Rowe, MA	1960-1992	2007
Detroit Edison	Enrico Fermi fast breeder reactor	Fast Breeder Reactor (NA-K)	Combustion Engineering	94	Lagoona Beach, MI	1963-1972	December 1975
Consumers Power Nebraska	Hallam	Sodium Graphite	General Atomic	75	Hallam, NE	1962-1964	1969
Commonwea lth Edison	Dresden 1	Boiling Water Reactor	General Electric	200	Dresden, IL	1960-1978	

The permitting process for Fermi was the first to highlight the inherent tension in the dual AEC missions to promote peaceful uses of atomic power and ensure its safety. The licensing and permitting process for early nuclear power plants was not a public process subject to challenges. The Advisory Committee for Reactor Safeguards (ACRS) provided an independent technical safety evaluation of proposed power plants and made a recommendation to the AEC Commissioners. AEC Commissioners made the final decisions on construction permits and operating licenses. In 1956, after reviewing the Fermi design, the ACRS concluded that, "there is insufficient information available at this time to give assurance that the PRDC reactor can be operated at this site without public hazard."[21] The reluctance of the AEC to share this information with Congress and the State of Michigan and its subsequent approval of a conditional construction permit generated enough controversy to create the Price-Anderson Act in 1957. While noted for creating a liability cap for the nascent atomic power industry, the Price-Anderson Act also created the ACRS as a statutory body, required ACRS reports on licensing cases be made public, and required public hearings on all reactor applications. [22]

Fermi 1's initial criticality occurred in August 1963 and the plant operated at reduced power level for two and half years; however, the technological leap from small test reactor to 94 MWe power reactor proved too great, and in 1966, it suffered a fuel meltdown.[23] It returned to service in 1970, but was permanently shut down in 1972.

Chicago-based Commonwealth Edison participated in the Industrial Participation Program and subsequently became the nation's largest nuclear utility. Its Dresden 1 was initially part of the Power Reactor Development Program, but subsequently withdrew and became the world's first privately financed nuclear power station. General Electric, Bechtel, and a consortium of other firms provided financial assistance as part of the project, and free of government assistance, any technical information and data developed through the project remained proprietary to the consortium. GE contracted to build

[21] http://www.nrc.gov/about-nrc/short-history.html#aec
[22] http://www.nrc.gov/about-nrc/short-history.html#aec
[23] http://www.nrc.gov/info-finder/decommissioning/power-reactor/enrico-fermi-atomic-power-plant-unit-1.html

Dresden 1 for $45 million and expended an additional $20-40 million as R&D expenses.[24] Dresden 1 was also the world's first commercial scale boiling water reactor (BWR). Argonne National Laboratory had developed the BWR concept and conducted some dramatic experiments through the BORAX testing program at the National Reactor Testing Station in Idaho. The tests were very successful in proving BWR stability and in 1956, General Electric and Pacific Gas and Electric quickly built the world's first privately-funded prototype BWR in Pleasanton, California. The 5 MWe Vallectios plant served as a testing platform for core components and a training center for Dresden 1 plant operators.[25] As a first generation nuclear power plant, Dresden 1 operated for 18 years and had lifetime capacity factor of approximately 50%[26].

Consumers Power of Nebraska (predecessor of Nebraska Public Power District) was a small public utility that could not meet the PRDP first round requirements for assuming the financial risk to build the power plant. However, PRDP second round, declared nine months after the first round announcement, development efforts would be targeted at small municipal utilities with the AEC owning the reactor. The government eventually contracted with Consumers Power to build a sodium-cooled graphite moderated power (SGR) plant and required Consumers to finance only 25% of the project.[27] The Hallam plant was attractive to the AEC because in 1955, sodium graphite reactors were viewed as a very promising technology. Hallam would be the first attempt to scale up SGR technology.

The Hallam reactor was unsuccessful because of a design flaw and shut down in 1964 after 18 months of operation. The AEC decommissioned the site in 1969 and the DOE monitors it as part of its legacy management program. 1964 was also the last year for power reactor operations at the Sodium Reactor Experiment.[28] There have been no sodium-cooled graphite moderated power reactors built in the United States since then.

Second Round

The difference between the first and second PRDP rounds was the AEC's offer to finance and to retain ownership of the reactor portion of the plant. Small public utilities were excluded from the first round because they could not meet the 90% financing requirement. In response to pressure from rural electric utilities, Congress eventually required the AEC to pay directly for the small reactors and retain ownership.[29] Second round plants were limited in size to less than 40 MWe. Seven proposals were received by the AEC and two were accepted.

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[24] Electric Utility Decision Making and the Nuclear Option 1977 Rand-2148 p.52 ;NYT 3Nov1957 Atomic Industry at Awkward Age

[25] http://en.wikipedia.org/wiki/Vallecitos_Nuclear_Center
[26] NCI calculation based on Dresden Post-shutdown Decommissioning Activities Report, Jun 1998 Exelon letter to NRC
[27] Development And Commercialization Of The Light Water Reactor, 1946-1976, R-2180, 1977 p 12
[28] Sodium Reactor Experiment Decommissioning Final Report-ESG-DOE-13403
[29] NYT September 19 1957

Table 3. Second Round PRDP Participants

Participating Utility	Project Name	Reactor Type	Manufacturer	Size (MWe)	Location	Years of Operation	Decom Complete
Rural Cooperative Power Assn.	Elk River	EBWR	American Machine and Foundry later Allis-Chalmers	22	Elk River, MN	1964-1968	1974
City of Piqua Ohio	Piqua	Organic cooled and moderated	Atomic International	12.5	Piqua, OH	1963-1966	1969[30]

Elk River, MN

The Elk River experimental BWR incorporated an intermediate heat exchanger to prevent radioactive steam from entering the turbine building. A coal-fired superheater would operate in parallel to provide additional steam to the turbine. The reactor plant was to operate in a natural circulation mode, which eliminated the need for reactor coolant pumps. The original designer was replaced early on by Allis-Chalmers, which had done some work in the Manhattan Project facilities and had two additional reactor projects. In 1965, four years after the original target date, commercial operations commenced. Three years later, in January 1968, hairline cracks in the pressure vessel were found and the plant was shut down.[31] The Rural Cooperative Power Association refused to exercise its option to purchase the reactor and the AEC ended the project. The reactor was dismantled and the site has since produced power as a fossil-fueled and waste burning power plant.[32]

Piqua, OH

The organically cooled and moderated reactor demonstration project in Piqua, Ohio was the first attempt to create a power reactor of this design. In 1957, the Organic Moderated Reactor Experiment (OMRE) at the National Reactor Testing Station in Idaho had proved the concept. Organic (Hydrocarbons) liquids were attractive because they could be handled in a manner similar to water, had better corrosion properties, and eliminated the need for large pressure vessels.[33] Atomics International built and operated both the OMRE and the Piqua reactors. By early 1963, the AEC had reevaluated its organic reactor development program and concluded that the prospects of improving organic reactor performance to a level competitive with light water reactors was not sufficient to warrant further support of the concept.[34] The Piqua project continued; however, decomposition of the coolant caused fouling of the reactor's heat transfer surfaces and prevented the insertion of all control rods. The Piqua reactor that had first gone critical in June 1963 was permanently shut down in January 1966. The City of Piqua refused to exercise its option to purchase the reactor, and the DOE manages the site as part of its legacy management program.

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[30] SEC Petition Evaluation Report Petition SEC-00126 April 27, 2009

[31] http://atomicpowerreview.blogspot.com/search/label/%22elk%20river%22

[32] http://en.wikipedia.org/wiki/Elk_River_Station

[33] Nuclear Reactor Engineering, Glasstone and Sesonske, 1967, 13.41

[34] Nuclear Reactors For Generating Electricity: U.S. Development From 1946 To 1963 Rand--2116, 1977 p. 65

Neither of the PRDP second round reactors was technically successful. The AEC had failed to differentiate between demonstration projects of proven technologies and pure R&D projects. The AEC's plan to enter into fixed price contracts with second round vendors was unsuccessful because vendors did not want to assume financial risk for first-of-a-kind projects. The AEC bore the responsibility for cost overruns on these two reactors.

Rand Corporation's whitepaper on AEC reactor development programs noted that "Project failure seems to have stemmed from treating immature reactor designs as if they were ready for near-commercial demonstration coupled with involving small, publicly owned utilities as if they were the appropriate participants in what were essentially R&D projects"[35].

Third Round

Two years after the initial announcement of the PRDP program, the AEC announced a third round in January 1957. Terms required that construction of all projects be completed by June 30, 1962, and that all project R&D activities requiring AEC funding be of a finite scope. Projects were to be of "proven" designs and could include light water, heavy water, and homogeneous reactors.

Table 4. Third Round PRDP Participants

Participating Utility	Project Name	Reactor Type	Manufacturer	Size (MWe)	Location	Years of Operation	Decom Complete
Carolinas-Virginia Nuclear Power Associates (CVNPA)	Carolinas-Virginia Tube Reactor (CVTR)	HWMTR	Westinghouse	17	Parr, SC	1963-1967	2009 Greenfield
Consumers Power	Big Rock Point	BWR	General Electric	70	Charlevoix, Michigan	1962-1997	1999
Northern States Power	Pathfinder	Superheated BWR	Allis-Chalmers	60	Sioux Falls, South Dakota,	August 1966-September 1967	1992. See NRC website
Philadelphia Electric	Peach Bottom	HTGR	Gulf General Atomic	40	Peach Bottom, PA	1966-1974	
Southern California Edison	San Onofre	PWR	Westinghouse	430	San Clemente, CA	1967-1992	

Carolina Virginia Tube Reactor

The CVTR was the only heavy water moderated and cooled reactor built in the U.S. for civilian nuclear power prototype purposes. The plant was sized at 17 MWe and operated successfully for five years before being shut down. By then in the U.S., light water reactor technology had developed to the point of commercialization and heavy water technology development had lagged. After shutdown and

[35] Ibid. p. 66

defueling, the site was used to test containment vessel behavior during accident scenarios. The CVTR containment design is the forerunner of modern reactor containments. Heavy water reactors are attractive to some countries because they do not require enriched uranium fuel or large pressure vessels. Heavy water civilian power reactors were not fully developed in the United States because the Manhattan Project infrastructure provided enrichment capabilities and had developed the capability to produce large forgings. Canada is an example of a country that has developed its nuclear program without enrichment facilities or forging capability, but leveraged its large stocks of heavy water.

Big Rock Point

Consumers Power financed the original construction and operation of the Big Rock Point power plant. The plant was originally designed to produce 50 MWe and the AEC funded R&D research post-construction to raise power output to 75 MWe. The R&D program took precedence over power generation for four and a half years, but is credited with enhancing General Electric's design capabilities for other BWRs.[36]

Pathfinder

The Pathfinder project is perhaps the least successful of all the AEC demonstration reactors. Built by Allis-Chalmers, Pathfinder attempted to introduce the concept of employing nuclear superheated steam to increase the pressure and temperature of steam used in the turbine. The technical challenges proved intractable and the plant succeeded in only operating at full power for 30 minutes. In 1968, Northern States Power converted the plant to run on gas and oil.[37]

Peach Bottom I

Philadelphia Electric Company led a consortium of 50 utilities to build a pilot high temperature gas-cooled power plant. The reactor was moderated with graphite, cooled with helium, and had thorium mixed with enriched uranium fuel. Advantages expected from this new design were improved nuclear fuel performance, high temperature, and high pressure steam conditions that promised more economical power generation and fuel use.

Even after a fuel element failure in the initial core, the plant operated successfully for eight years as a prototype for HTGR technology. Its lifetime gross capacity factor was 74%.[38] Factors leading to the plant shutdown on October 31, 1974 include the size and operating costs of the plant compared to those of other plants and the increased investment required to meet new NRC safety regulations. Peach Bottom accomplished its goal of demonstrating the feasibility of commercial scale HTGR technology and became the prototype for Colorado's Fort St. Vrain power plant.

San Onofre I (SONGS)

[36] Nuclear Reactors For Generating Electricity: U.S. Development From 1946 To 1963 Rand--2116, 1977 p.70

[37] http://en.wikipedia.org/wiki/Pathfinder_Nuclear_Generating_Station

[38] Peach Bottom Decommissioning Report p.1-1

At 430 MWe, the San Onofre PWR was the second largest nuclear power plant developed as part of the PRDP. The unit operated successfully from January 1968 to November 1992. Although it had 15 years left on its operating license at the time it was shut down, the investments required to bring the plant up to modern safety standards were too great to continue operations. San Onofre continued the trend of reliable PWR operations and demonstrated incremental performance improvements in Westinghouse's PWR design. It had a lifetime capacity factor of approximately 58%[39]. SONGS 1 was unique in that it benefited from R&D support by participating in the AEC demonstration program (~15% total cost)[40], had a fixed price contract with Westinghouse (estimated subsidy ~19% total cost)[41] , and was on land leased from United States Marine Corps Base Camp Pendleton.[42]

Modified Third Round

The final stage of the Power Reactor Development Program was a modified third round announced in August 1962 that extended project submittal deadlines to mid-1964. The goal was to support the construction of large baseload electrical generating facilities to demonstrate reliable sources of electric power. Proposals were invited for all nuclear plants using light water-cooled and moderated reactors of at least 400 MWe that did not use nuclear superheat.[43] The AEC would provide up to 10% of the total project cost in R&D activities and utilities were responsible for remaining costs including building and operating the plant for a period of five years after initial criticality. Two proposals were received and one plant was built under the terms of the modified third round of the PRDP.

Table 5. Final PRDP Selection

Participating Utility	Project Name	Reactor Type	Manufacturer	Size (MWe)	Location	Years of Operation	Decom Complete
Connecticut Yankee Atomic Power Co	Connecticut Yankee	PWR	Westinghouse	575	Haddam Neck, CT	1967-1996	2007

Connecticut Yankee

Similar to the successful Yankee Rowe plant, a consortium of utilities built the first four-loop Westinghouse PWR in Haddam Neck, Connecticut. Connecticut Yankee (CY) was the largest (575 MWe) and last power plant built under the AEC Power Reactor Demonstration Program. Similar to the San Onofre plant, CY benefited from R&D support by participating in the AEC demonstration program (~15% total cost)[44] and a fixed price contract with Westinghouse (estimated subsidy 30% total cost)[45].

[39] NCI Calculation based on SCE SONGS 1 decommissioning website data
[40] Development and Commercialization of LWR 1946-1976, 1977 Rand 2180- p14
[41] Turnkey project data p193 Table 3, Land Economics, Vol. 56, No. 2, May 1980
[42] NYT story 8 Dec 1962
[43] Nuclear Reactors For Generating Electricity: U.S. Development From 1946 To 1963 Rand--2116, 1977 p. 73
[44] Development and Commercialization of LWR 1946-1976, 1977 Rand 2180 p14

Connecticut Yankee operated successfully for 28 years and had a lifetime capacity factor of approximately 70%.

Malibu Beach-First Opposition

The Los Angeles Department of Water and Power (LADWP) proposed a plant similar to Connecticut Yankee near Malibu Beach, California. The AEC executed a contract for the Malibu project contingent upon obtaining an appropriately zoned site. Foreshadowing future permitting struggles, strong public opposition to the project developed in 1965 on the grounds of local earthquake hazards. The delays forced the AEC to terminate the agreement in 1970 because LADWP had been not been able to secure a site for the project.

Unsolicited Proposals

The AEC also supported the development of reactors outside the formal PRDP. Two notable projects were the 16 MWe Boiling Nuclear Superheater Power Station (BONUS) project in Puerto Rico and the Dairyland Power 50 MWe LaCrosse BWR. Contract terms for both projects were similar to second round PRDP terms in that the AEC owned the reactor.

Table 6. Unsolicited Reactors

Participating Utility	Project Name	Reactor Type	Manufacturer	Size (MWe)	Location	Years of Operation	Decom Complete
Puerto Rico Water Resources Authority	BONUS	Superheated BWR	Chicago Bridge and Iron/ Comb Engineering	16.5	Punta Higuera, Puerto Rico	1964-1968	1970/2000
Dairyland Power	Lacrosse BWR	LACBWR	Allis-Chalmers	50	Genoa, WI	1970-1987	

As early as 1956, Congress was pressing the AEC to move faster with its reactor development programs.[46] A project in Puerto Rico was attractive because it would demonstrate U.S. commitment to Atoms for Peace, show the potential for an export market for reactor technology, and serve as a training center for Latin American scientists. Thus, BONUS, which predated the Pathfinder reactor, was developed with the goal of building a prototype nuclear power plant to investigate the technical and economic feasibility of the integral boiling-superheating concept. The higher temperature and pressure of superheated steam would improve the performance of the steam turbine. The reactor operated from April 1964 to June 1968 and shut down due to technical difficulties involving cost prohibitive repairs. DOE's legacy management program continues to oversee the site.[47]

[45] Turnkey Table 3, Land Economics, Vol. 56, No. 2, May 1980
[46] NYT 23 Sept 1956, Where We Stand on Atomic Power
[47] DOE Legacy Management BONUS Fact Sheet; http://www.lm.doe.gov/bonus/Sites.aspx

Figure 1. BONUS Site Today

In 1961, Dairyland Power Cooperative provided the AEC with an unsolicited proposal to build a 50 MWe BWR. Dairyland would provide the site and operate the reactor for ten years. The AEC contracted with Dairyland and Allis-Chalmers in June 1962, and the plant was scheduled for completion in 1965. However, it was not until 1967 that initial criticality was achieved, and 1970 until commercial operations began. Imposition of Federal and state clean air standards on fossil plants and the 1973 Oil Crisis made nuclear power an attractive choice. Dairyland purchased the nuclear portion of the plant from the AEC in 1973 for one dollar[48]. Though licensed to operate through 2001, Dairyland Power had to plan for an early retirement because of the upgrades required due to the accident at Three Mile Island. The plant was permanently shut down on April 30, 1987.

1.2 First Privately Developed Nuclear Power Plants

The Power Reactor Demonstration Program stopped soliciting proposals for reactor demonstrations after approval of the Connecticut Yankee and San Onofre plants in 1963. As previously mentioned, Dresden 1 withdrew from the PRDP to become the first privately financed nuclear power station. There were two other plants, PG&E's Humboldt Bay and Consolidated Edison's Indian Point plant that were also privately financed and built prior to 1963.

Humboldt Bay

Pacific Gas and Electric's Humboldt Bay Unit 3 was a 65 MWe BWR plant located near Eureka, California that operated commercially from 1963 to 1976. It was the seventh nuclear power plant licensed in the United States and was designed by General Electric.[49] It used natural circulation to move primary coolant and was the first to use a pressure-suppression pool as part of the containment system[50]. The plant shared some plant systems with co-located fossil plants and was built below grade level.[51] In 1976, the plant was shut down for regular maintenance and due to the discovery of several previously unidentified earthquake faults. The potential risk of earthquake damage coupled with the relative small scale of the plant and the cost of seismic modifications ultimately resulted in it being kept inoperative

[48] Slow Boil, Wisconsin Magazine of History, Autumn 2000
[49] http://www.energy.ca.gov/nuclear/california.html
[50] Development And Commercialization Of The Light Water Reactor, 1946-1976, R-2180, 1977 p.92
[51] http://www.pgecurrents.com/2011/08/16/eureka-busy-safe-define-the-day-at-humboldt-bay-power-plants

until its decommissioning in 1985. As a first generation BWR, the plant experienced fuel cladding failures that resulted in contamination of the reactor vessel, spent fuel storage pool, and plant systems with fission products and transuranic nuclides.[52] In 1971, Humboldt Bay and Dresden 1 were identified by the AEC as needing modification to meet new general public radiation exposure limits then being imposed.[53] The plant had an estimated lifetime capacity factor of approximately 69%.[54]

Indian Point

Built by Babcock and Wilcox with Consolidated Edison, Indian Point 1 was a 275 MWe PWR that operated from 1962 to 1974. The first core at the Indian Point power station used a thorium-based fuel that failed to perform as desired. Subsequent cores used conventional enriched uranium. The plant incorporated an oil-fired superheater that accounted for 41% of the total energy output while the nuclear reactor contributed 59%. The superheated steam improved steam turbine performance and overall plant economics. The plant was shut down in 1974 because it lacked an emergency core cooling system that met regulatory requirements, oil costs were increasing, and investments required for modifications were cost prohibitive. Lifetime plant capacity factor is estimated to be approximately 48% over the 12 years of operation.

Power Reactor Demonstration Program Summary

The Power Reactor Demonstration Program attempted to demonstrate different power reactor technologies across 12 projects. Of the 11 demonstration projects that were finally built, five operated for more than five years. In 1962, Yankee Rowe was producing power for 9.5 mills/kWh and compared favorably with the 8 to 10 mills/kWh from other sources in New England.[55] It was the performance of the Yankee Rowe plant, which began commercial operations in 1960 that served as one of the catalysts for the Connecticut Yankee and San Onofre projects. Those last PRDP projects, Connecticut Yankee and San Onofre, began commercial operations in 1967. The new plants were expected produce power at competitive rates in other areas of the country where the cost of conventional power was higher than average.

In 1962, the United States, with its approximately 800 MWe of nuclear capacity, was not the world leader in nuclear generating capacity; rather it was Britain with approximately 900 MWe of nuclear generating capacity.[56] This created some angst among those who thought that the U.S. should be the world's leader in nuclear power development. In his 1962 report to President Kennedy, AEC chairman, Glenn Seaborg, provided a longer perspective.

> Nuclear power seems to be on the threshold of coming into being on a significant scale. It must be realized, however, that the development of a mature nuclear power technology and its utilization on an extensive scale will be a long process. As in any

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[52] Humbodlt Bay Historical Site assessment report p 6-16
[53] NYT Jun 8, 1971
[54] PRISM
[55] NYT 6 October 1962
[56] Ibid

> other technology, progress is brought about not only by research and development but also through experience. Operating units must be used and tested throughout their normal lifetimes. Unlike devices normally used intermittently, such as cars, airplanes and radios, the process cannot be shortened by speeding up the tests. Hence successive generations in the development are even decades long.
>
> There is also the factor of psychology. Before committing a substantial fraction of their installations to nuclear technology, utility executives will want to be convinced, themselves, that nuclear power is economical, reliable and safe. With few exceptions this conviction will require observation of results of actual installations operating for periods that are significant in terms of the normal lifetime of power installations.[57]

The fact that Connecticut Yankee, San Onofre, and Indian Point were the largest plants and were all PWRs did not bode well for General Electric. Dresden 1 was the only BWR operating with greater than 100 MWe capacity and had started commercial operations the same year as Yankee Rowe. GE also had only one order, for Nine Mile Point, in its backlog.[58,59]

1.3 Turnkey Era

To improve its competitive position, in December 1963, General Electric ushered in the "turnkey" era of nuclear power plant construction by contracting to build a 640 MWe plant at Oyster Creek, New Jersey for a fixed price of $66 million. The contract price to the utility was set at a level to allow the production of power at the site that would be cheaper than the fossil plant alternatives[60]. In the "turnkey" contract, GE was responsible for: designing and building the entire plant; obtaining construction permits and operating licenses; and meeting plant operating requirements and specifications. It was GE's hope that it could recoup its investment by using the design across several other plants. Westinghouse responded with its own fixed price contracts, and from 1963 to 1966, both GE and Westinghouse subsidized an estimated $1 billion in nuclear power plant construction. GE sold seven turnkey plants and Westinghouse contracted for at least six turnkey plants.[61]

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[57] Civilian Nuclear Power Report to President p.42
[58] GE was awarded PG&E's Bogeda Bay Project in 1961. But local opposition killed the project. LWR p. 28
[59] Electric Utility Decision Making and the Nuclear Option 1977 Rand-2148 p53. Order placed October 1963 NYT
[60] Ibid
[61] San Onofre and Connecticut Yankee are listed as turnkey plants in various literature sources but were contracted for prior to Oyster Creek. This report retains that convention.

Table 7. Turn Key Plants (Millions)

Plant	Utility Cost	Estimated Contractor Cost	Estimated Subsidy	% Contract Cost Subsidized
General Electric				
Oyster Creek	$ 90	$ 170	$ 80	47%
Dresden 2 & 3	$ 196	$ 413	$ 217	53%
Millstone 1	$ 97	$ 182	$ 85	47%
Quad Cities 1 & 2	$ 200	$ 448	$ 248	55%
Monticello	$ 105	$ 168	$ 63	38%
BWR Totals	$ 688	$ 1,381	$ 693	
Westinghouse				
San Onofre	$ 106	$ 131	$ 25	19%
Ginna	$ 83	$ 161	$ 78	48%
Robinson	$ 78	$ 179	$ 101	56%
Point Beach 1 & 2	$ 145	$ 329	$ 184	56%
Connecticut Yankee	$ 104	$ 149	$ 45	30%
Indian Point 2	$ 177	$ 269	$ 92	34%
PWR Totals	$ 693	$ 1,218	$ 525	

The Oyster Creek announcement did not immediately induce other utilities to follow suit because offering turnkey contracts for entire plants was unconventional within the utility industry at that time. Fourteen months passed before Commonwealth Edison ordered Dresden 2 as a turnkey project in February 1965. Two more turnkey projects, Ginna (W) and Millstone (GE), were ordered in the fall and five non-turnkey plants were announced by the end of 1965[62].

The coal and railroad industries responded to the Oyster Creek announcement by lowering the price of delivered coal. In some cases, they offered discounts for specific plants, and in others they would offer to reduce the price of delivered coal across a utility's generation fleet.[63] The coal industry also petitioned the AEC to declare that light water reactors had "practical value". Under the Atomic Energy Act of 1954, such a finding would end AEC subsidies for reactors and allow antitrust review of reactor license applications.[64]

Many executives in the utility industry were against the turnkey concept because they gave up project management responsibilities to the reactor vendor and had to agree to functional specifications and design features for a new and unfamiliar technology. Executives also thought that they were paying extra for contingency fees that the vendors must have included in the contracts.[65] Some economists have

[62] Electric Utility Decision Making and the Nuclear Option 1977 Rand-2148 p. 54
[63] Ibid p. 55
[64] The TurnKey Era in Nuclear Power, Land Economics, Vol. 56, No. 2, May 1980
p. 193
[65] Ibid. p.194

argued that during that era of passive utility regulation, turnkey contracts reduced the profits of regulated utilities and opposition to them would be consistent with a firm's self-interest.[66]

A threefold jump in orders (21) occurred in 1966 with only six being turnkey plants. Half these turnkey orders were from Commonwealth Edison for Dresden 3 and Quad Cities 1 & 2. Several factors were responsible for this dramatic change in orders. The first was that prices for delivered coal stopped decreasing and emerging air pollution regulations foreshadowed increased coal-fired generation costs. Another factor was the November 1965 Blackout of the Northeast that spurred regional power planning. Regional planning favored larger power plants shared by multiple owners allowing them to increase their own system's reliability and pool both financing and transmission assets. A third factor was that the utilities' forced outage experience with large fossil-fueled plants at that time (> 600 MWe) was the same or worse than that experienced by nuclear power plants.[67]

Table 8 shows the lifetime capacity factor of operating nuclear plants and that of similar size and vintage coal plants in 1975. Many nuclear plants performed much better than their coal counterparts, and it was generally assumed that nuclear plant capacity factors would increase in parallel with plant operating experience.

Table 8. Nuclear vs. Coal Operating Experience -1975[68]

Plant	Type	Capacity	Lifetime Capacity Factor Through 1975	Years in Operation	1975 Similar Coal Plant Experience
Three Mile Island 1	PWR	819	77%	1	59%
Point Beach 2	PWR	497	76%	3	65%
Connecticut Yankee	PWR	575	73%	8	63%
H B Robinson 2	PWR	707	71%	4	63%
Point Beach 1	PWR	497	69%	5	66%
San Onofre 1	PWR	450	69%	8	63%
Prairie Island 2	PWR	530	68%	1	63%
Kewaunee	PWR	560	68%	1	63%
Monticello (MN)	BWR	545	66%	4	65%
ANO 1	PWR	850	66%	1	59%
Oconee 3	PWR	886	65%	1	59%
Oyster Creek (NJ)	BWR	650	65%	6	65%
Oconee 2	PWR	886	64%	1	59%
Turkey Point 4	PWR	745	64%	2	63%
Ginna	PWR	490	63%	5	66%
Quad Cities 1	BWR	809	60%	3	63%

[66] Ibid.p.199

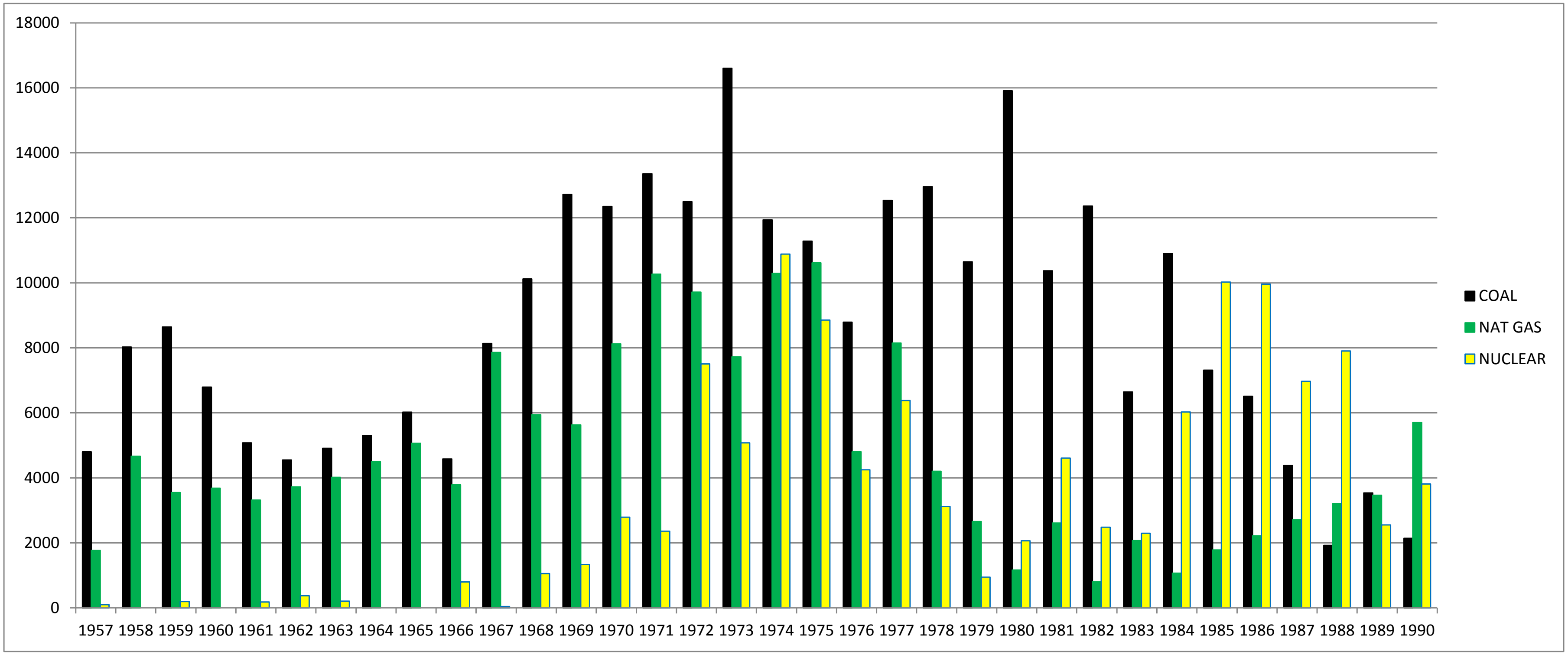
[67] Electric Utility Decision Making and the Nuclear Option 1977 Rand-2148 p.58 EEI data showed better capacity factors for nuclear plants 1965-1974 versus large fossil plants

[68] Power Plant Performance, Charles Komanoff, Council on Economic Priorities, 1976

Plant	Type	Capacity	Lifetime Capacity Factor Through 1975	Years in Operation	1975 Similar Coal Plant Experience
Oconee 1	PWR	886	60%	2	63%
Vermont Yankee	BWR	514	58%	3	65%
Turkey Point 3	PWR	745	58%	3	63%
Quad Cities 2	BWR	809	57%	3	63%
Peach Bottom 3	BWR	1065	57%	1	59%
Cooper	BWR	778	57%	1	59%
Prairie Island 1	PWR	530	55%	2	65%
Nine Mile Point 1	BWR	610	55%	6	65%
Maine Yankee	PWR	790	55%	3	63%
Peach Bottom 2	BWR	1065	55%	1	59%
Indian Point 2	PWR	873	54%	2	63%
Dresden 2	BWR	809	53%	3	63%
Millstone 1	BWR	690	53%	5	65%
Surry 2	PWR	823	53%	2	63%
Zion 2	PWR	1050	53%	1	59%
Fort Calhoun	PWR	457	52%	1	63%
Surry 1	PWR	823	50%	3	63%
Dresden 3	BWR	809	49%	4	63%
Pilgrim 1	BWR	670	49%	3	63%
Zion 1	PWR	1050	46%	2	63%
Palisades	PWR	821	23%	4	63%
Browns Ferry 1	BWR	1098	14%	1	59%

The plants ordered during and immediately after the Turnkey Era were much larger than the earlier plants on which future operating expectations had been based. Plant size increased in the expectation of increased economies of scale and more economical plants, and the wave of industry orders strained the licensing staff at the AEC, which contributed to delays in approvals. Figure 2 shows nuclear's near parity with coal plant generation capacity additions in 1974.

Figure 2. Capacity Additions by Fuel Source and Year



The business environment in which utilities operated began to change in the late 1960s and early 1970s. Government agencies such as the Occupational Safety and Health Administration (OSHA) and Environmental Protection Agency (EPA) were created and emphasized the expanding role of the Federal government in public health and environmental regulations. In 1971, the AEC was ordered by the Federal courts, in accordance with the National Environmental Protection Act, to consider environmental impact as part of the power plant licensing process for the Calvert Cliffs nuclear power station. This stopped all nuclear plant licensing for one year.[69]

As it turned out, two false assumptions were made by both the utility industry and the AEC, one was that the relatively short-lived operating experience of smaller first generation plants was indicative of a "mature" technology and the other was that nuclear power plants could be operated like fossil-fueled plants with a different heat source.

The power industry's nuclear experience began to deviate from its traditional fossil plant experience in that its completed plants were always subject to continuous detailed safety analysis by the AEC, national laboratories, interveners, and the power industry. The Atomic Energy Act of 1954, as amended, states that the terms and conditions of licenses shall be subject to amendment, revision, or modification by reason of amendments to the act and AEC/NRC's rules and regulations.[70] Therefore, the operating licenses continue to be subject to advances or changes in the body of knowledge affecting all aspects of plant operations.

As the body of knowledge related to reactor thermodynamics during potential accident conditions grew, concerns were raised within the AEC over the ability of containment structures to withstand loss of coolant accident pressure transients and of Emergency Core Cooling Systems (ECCS) to perform their designed functions. As the size of the reactors increased, the size of the containments remained the same.[71] The possibility that containment could be breached led greater importance to the proper functioning of the Emergency Core Cooling Systems (ECCS) to ensure accident mitigation. Public hearings were held in early 1972 over the AEC's proposed interim guidance for ECCS, which limited the amount of power operating reactors, could produce. At the start of the hearings, there were 23 operating reactors, 54 under construction, and 49 in the planning stages. Power shortages were being forecast in the Northeast and generation was being built to meet the demand.[72]

The hearings had been forced upon the AEC by scientific opposition to its interim ECCS guidance. The hearings stretched over 18 months, included approximately 140 days of testimony, impaired the reputation of the AEC, and again highlighted the inherent tension in its role to regulate and promote peaceful uses of nuclear energy. The hearings forced the AEC to make minor changes to its ECCS requirements and increased political disenchantment with the AEC. The AEC was abolished within a year of the hearings being completed and regulatory responsibility for civilian nuclear power was given to the newly formed Nuclear Regulatory Commission (NRC).

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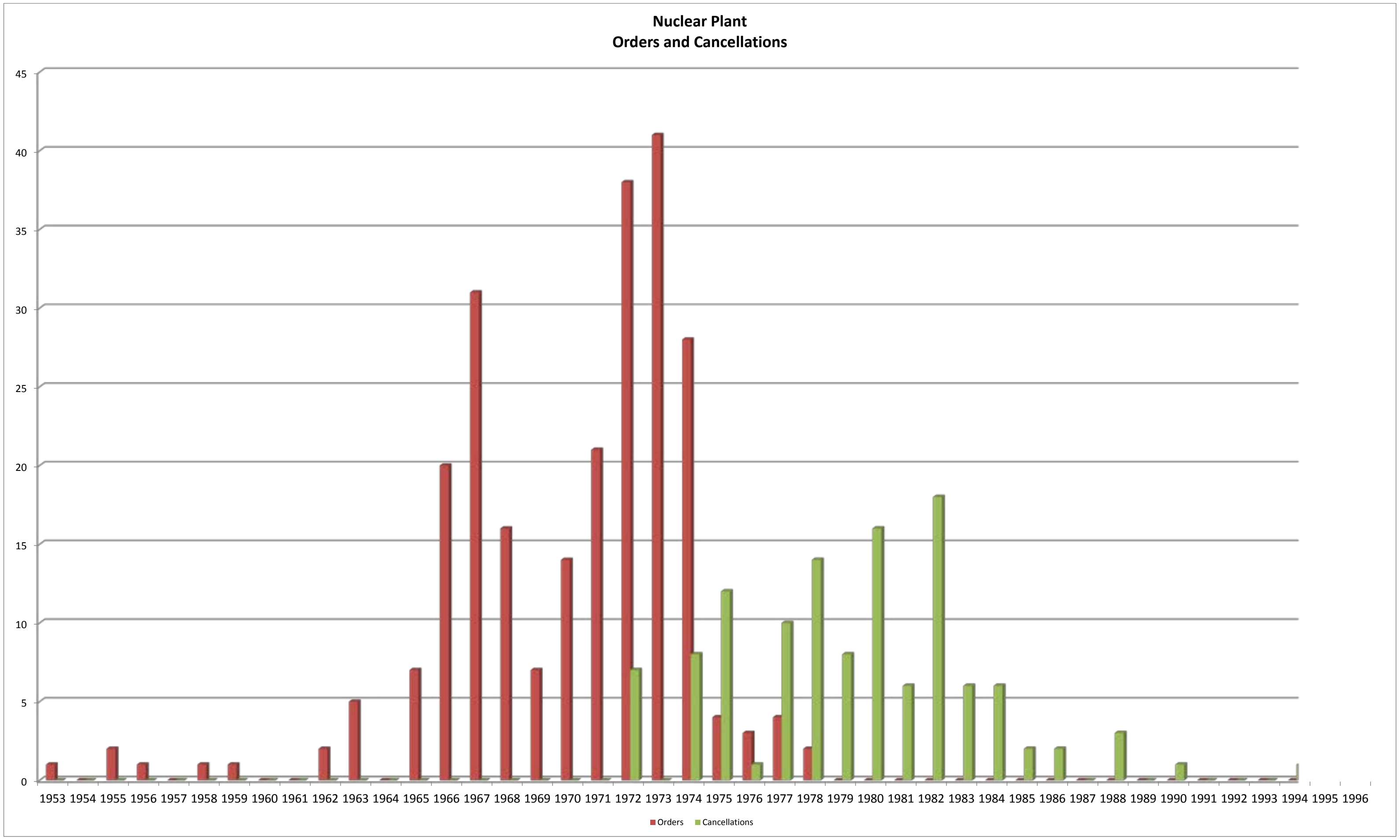
[69] NYT 5 Feb 1973 "AEC Hears critics of Atomic Plants"
[70] GAO RCED 86-27 December 1985 Nuclear Regulation
[71] A Short History of NRC Regulation 1946-1999, www.nrc.gov/about-nrc/short-history.html
[72] NYT 11 Dec 1971" Safety Gear Untried at A-Power Plants"

In 1973, as a result of the ECCS hearings, the AEC imposed additional requirements for systems and components at Indian Point Unit 1. This was the first instance of a "backfit" requirement in the industry and led to Consolidated Edison's decision to shut down the plant instead of investing in uneconomical modifications.

Orders for reactors started to be cancelled in great numbers in 1972, and between 1975 and 1978 more orders were cancelled than placed. Figure 3 shows the order and cancellation history for the U.S. nuclear industry.

Figure 3. Reactor Order and Cancellation History (1953-1996)



During this same period, construction delays and escalating construction costs for nuclear power plants as well as their operating experience made the nuclear option less attractive to many utilities. There were many contributing factors to the construction delays throughout the process. The industrial and regulatory infrastructure that had supported the construction of a few plants per year was now required to support tens of plants a year. The AEC staff was inundated with the number of construction permit and license requests, but did not have increased staff to meet the demand. The queue for pressure vessels alone added almost 18 months to some schedules because of problems at B&W's Mt. Vernon, Indiana manufacturing facility.[73] Nuclear construction costs were escalating faster than fossil plant construction costs and began to impact utility balance sheets. In the five-year period 1970-1975, nuclear construction costs rose from $330/Kw to $1,135/Kw, while fossil generation rose from $220/Kw to $950/Kw.[74]

After the 1973 Oil Crisis, the forecasted demand for electricity and resulting utility revenues was lowered to the point that some utilities questioned the need for a large baseload asset with an ever-expanding construction schedule.[75]

Increased regulatory oversight focused on nuclear plant safety became the mission of the NRC. Within two weeks of the NRC's formation, Congress called for the government to take over nuclear power plant safety inspections, which under the AEC, had traditionally been performed by utility employees.[76] And, within 60 days, all BWRs had to shut down and inspect their ECCS systems. This effort would eventually lead to the creation of the NRC's regional inspector program. The rapid growth of a new Federal agency charged with protecting the public and overseeing reactor safety initially led to inconsistent regulation across the country, and in certain instances further contributed to construction delays.

In March 1975, a candle used to inspect for air leaks inadvertently started a fire in a cable run that caused a major fire at Browns Ferry 1 while it was operating at 100% power. The fire lasted seven hours and caused the NRC to issue fire protection guidelines and increase its focus on "common mode" failures across the nuclear power industry.[77] In some cases, the guidelines required plant equipment modifications and staffing changes to upgrade plant fire response capabilities. The incident increased public concerns about nuclear power and the ability of the government to regulate it.

1.4 Post Three Mile Island Period (1979-1995)

Four years after the fire at Browns Ferry, the reactor accident at Three Mile Island Unit 2 (TMI-2) occurred. TMI-2 had only been in commercial operation for four months at the time of the accident. A detailed review of the accident is found in Section 6. ; however, the NRC response to the accident can be summarized as including:

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[73] Fortune Magazine 1969
[74] NYT 5 Oct 1975, Expenses Soar while Demand Softens
[75] Electric Utility Decision Making and the Nuclear Option 1977 Rand-2148 Page 34
[76] NYT 6 Feb 1975
[77] A Short History of NRC Regulation 1946-1999, www.nrc.gov/about-nrc/short-history.html

- New requirements for operator training, testing and licensing;
- Strict personnel utilization policies similar to the aviation industry;
- Human factors assessments of instrumentation;
- Increased number of resident inspectors at each site;
- Independent analysis of reactor operations data;
- Review of radiation protection programs;
- Upgraded emergency planning requirements and facilities; and
- Increased reactor accident R&D funding.

As equally important as the NRC's response was the nuclear power industry's response to Three Mile Island. The Institute of Nuclear Power Operations (INPO) was formed in 1979 to promote operational excellence in nuclear power operations. Its formation and subsequent success is a testament to the nuclear power industry's recognition that the industry's performance is only as good as that of its weakest member and that nuclear power plants require fundamentally different operating practices than those of conventional power plants. INPO shares best practices among its members and assesses their performance. It also "loans" management personnel to improve operations at those plants requesting assistance. INPO serves as the accreditation authority for member training programs and through this authority can directly impact plant operations.

Over the next 20 years, the median capacity factor for those plants in service for that period increased from 57% to 64%. In 1995 there were 110 nuclear reactors in operation with a median lifetime capacity factor of 66%. Three nuclear power plants, Trojan, Rancho Seco, and Fort St. Vrain, were commissioned and shut down during this period and are not included in the capacity factor calculation shown in Table 9. Additionally, San Onofre 1, Dresden 1, Humboldt Bay and Yankee Rowe retired during this period and are also excluded from the capacity factor calculation.

Table 9. Nuclear Industry Capacity Factors 1975-1995[78]

Plant	Type	Capacity	Lifetime Capacity Factor Through 1975	Total Years in Operation	Capacity Factor 1975-1995	Change
Three Mile Island 1	PWR	819	77%	21	55%	-22%
Point Beach 2	PWR	497	76%	23	84%	9%
Connecticut Yankee 1	PWR	575	73%	28	73%	0%
H B Robinson 2	PWR	707	71%	24	65%	-6%
Point Beach 1	PWR	497	69%	25	79%	10%
Prairie Island 2	PWR	530	68%	21	86%	18%
Kewaunee 1	PWR	560	68%	21	84%	16%
Monticello (MN) 1	BWR	545	66%	24	78%	12%
ANO 1	PWR	850	66%	21	65%	-1%
Oconee 3	PWR	886	65%	21	74%	9%

[78] NCI calculated on EIA data

Plant	Type	Capacity	Lifetime Capacity Factor Through 1975	Total Years in Operation	Capacity Factor 1975-1995	Change
Oyster Creek (NJ) 1	BWR	650	65%	26	57%	-7%
Oconee 2	PWR	886	64%	21	74%	10%
Turkey Point 4	PWR	745	64%	22	63%	0%
Ginna	PWR	490	63%	25	79%	15%
Quad Cities 1	BWR	809	60%	23	66%	6%
Oconee 1	PWR	886	60%	22	74%	14%
Vermont Yankee	BWR	514	58%	23	79%	21%
Turkey Point 3	PWR	745	58%	23	64%	6%
Quad Cities 2	BWR	809	57%	23	63%	6%
Peach Bottom 3	BWR	1065	57%	21	58%	1%
Cooper	BWR	778	57%	21	62%	6%
Prairie Island 1	PWR	530	55%	22	86%	30%
Nine Mile Point 1	BWR	610	55%	26	61%	5%
Maine Yankee	PWR	790	55%	23	72%	17%
Peach Bottom 2	BWR	1065	55%	21	57%	2%
Indian Point 2	PWR	873	54%	22	64%	10%
Dresden 2	BWR	809	53%	23	59%	6%
Millstone 1	BWR	690	53%	25	74%	21%
Surry 2	PWR	823	53%	22	63%	10%
Zion 2	PWR	1050	53%	21	62%	10%
Fort Calhoun	PWR	457	52%	21	71%	19%
Surry 1	PWR	823	50%	23	64%	15%
Dresden 3	BWR	809	49%	24	57%	7%
Pilgrim 1	BWR	670	49%	23	52%	3%
Zion 1	PWR	1050	46%	22	59%	13%
Palisades	PWR	821	23%	24	58%	34%
Browns Ferry 1	BWR	1098	14%	21	53%	39%

In 1982, the General Accounting Office (GAO) estimated the accident at TMI-2 to have cost the industry $14 million per reactor in backfit costs. GAO also estimated that between 1973 and 1982 the nuclear industry spent approximately $5 billion on backfit-related costs for TMI and non-TMI-related backfits.[79] Nuclear plant staffing increased significantly during this period as regulatory and industry imposed requirements grew exponentially. Table 10 shows the industry's average staffing during the period increased by a factor of four.

[79] GAO/RCED-M-27 NRC Backfitting Dec 1985

Table 10. Mean Plant Staffing per Reactor 1975-1995[80]

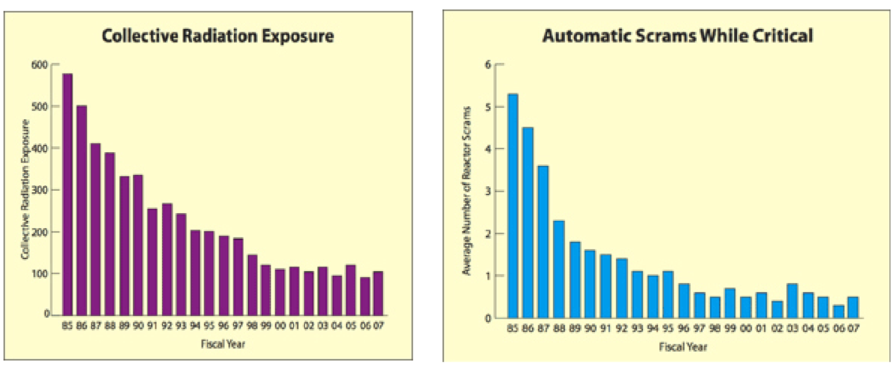
1975-1979	1980-1984	1989-1990	1990-1995
241	426	695	913

As the larger plants were completed through the mid-1990s, it became apparent that the additional costs associated with increased plant size superseded any economies of scale associated with the increase in plant output. Table 11 shows the average cost per kilowatt of construction for all U.S. nuclear plant models normalized to 2012 dollars and broken down by year of commercial operation. Average nuclear construction costs more than tripled during this period, which reflects the costs associated with TMI and increased regulation from the NRC.

Table 11. Average Construction Cost Year of Commercial Operation $2012/Kw[81]

1975-1979	1980-1984	1989-1990	1990-1995
$2,056	$2,809	$5,238	$6,228

Figure 4. Industry Performance Improvement Examples



Performance Improvement 1985-2007

Although costs escalated, operational performance at the plants improved dramatically, as shown in Figure 4. This was due to the increased regulatory scrutiny of the NRC and the self-imposed practices brought on by the Institute of Nuclear Power Operations (INPO).

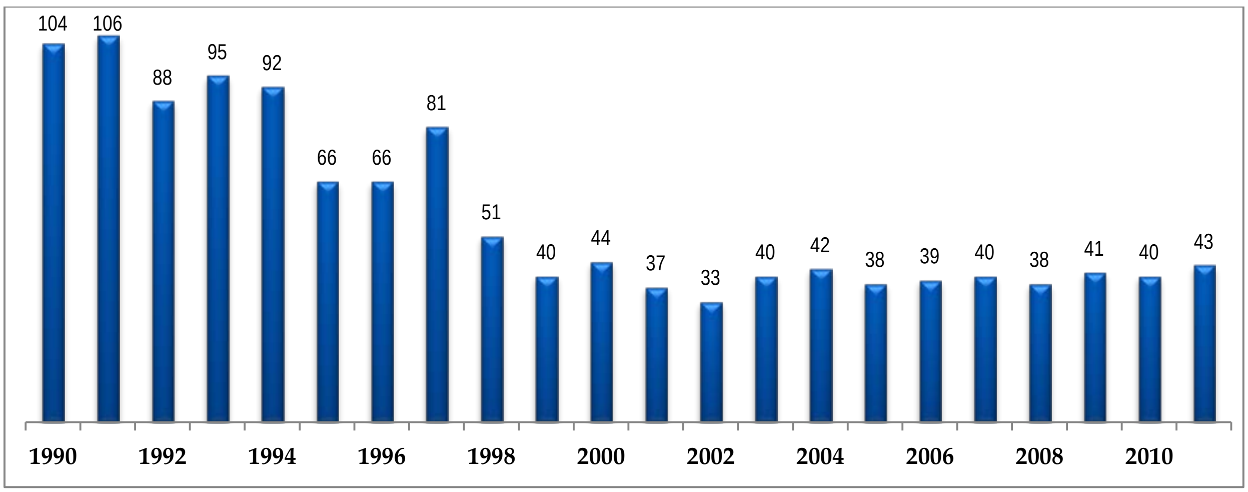
[80] Generic Environmental Impact Statement for License Renewal of Nuclear Plants (NUREG-1437 Vol. 1). NCI data 1990-1995
[81] NCI calculation various data sources

1.5 *Deregulation (1996-Present)*

In 1995, the NRC's inspector general concluded that resident inspectors often lacked a clear understanding and approach for implementing performance-based regulation. The NRC responded by revising inspection guidelines and inspector training programs. The NRC also adopted a policy statement encouraging broad implementation of probabilistic risk assessments in the regulatory process, favoring a risk-informed and performance-based approach to regulation. The change in NRC regulatory policies allowed nuclear power plant operators more flexibility in meeting the challenges of a deregulated electricity market. In preparation for deregulation, utilities revised non-nuclear and nuclear business practices to create efficiencies throughout their organizations. The industry also drove efficiencies through a wave of consolidations that are still continuing. The following figures show the dramatic improvement in nuclear refueling outage days, O&M costs, and capacity factors throughout this period as an example of the magnitude of change the industry was capable of wringing out of its operations. During this period, plant staffing was reduced from a peak of near 900 personnel per reactor to approximately 500 personnel per reactor.[82]

Going forward, the challenge will be to maintain the gains in operational excellence made over the previous years while cutting costs in an increasingly challenging power market.

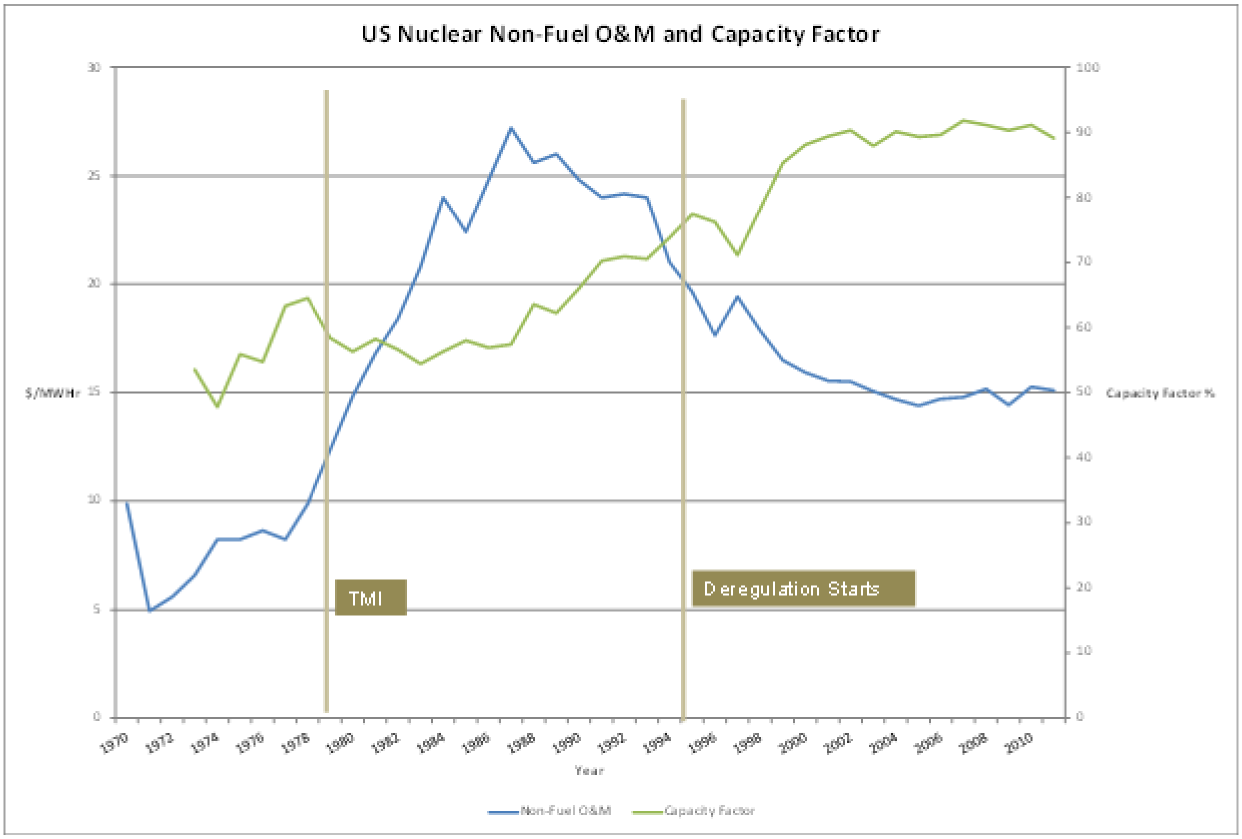
Figure 5. U.S. Nuclear Refueling Outage Days: Average (1990-2011)[83]



[82] NCI Calculation from various nuclear staffing data sources

[83] Source NEI, 2012, 1990-98 EUCG,1999-2011 Ventyx /NRC

Figure 6. Nuclear Non-fuel O&M vs. Capacity Factor



It is important to note that one of the main drivers of deregulation was the high cost of nuclear power plants. Under the traditional regulated model, utilities were requesting rate increases that were driving up the cost of electricity to the point where legislatures had to take action. States restructured their regulatory framework and allowed utilities to exit the rate base after being reimbursed for their “stranded costs”. That is the difference in value between the regulatory value of the asset and the market value of the asset. In return for this arrangement, many utilities agreed to freeze electric rates for a certain period of time. This arrangement forced utilities to become more efficient or perish.

Table 12 shows the dramatic increase in capacity factors since 1975. As a group, this set of plants increased its average capacity by 20% for the period 1996-2011 over that of the previous twenty-year period, 1975-1995. During this period Zion 1 & 2, Maine Yankee, Connecticut Yankee, and Millstone 1 nuclear plants were shut down.

Table 12. Nuclear Industry Capacity Factors 1996-2011

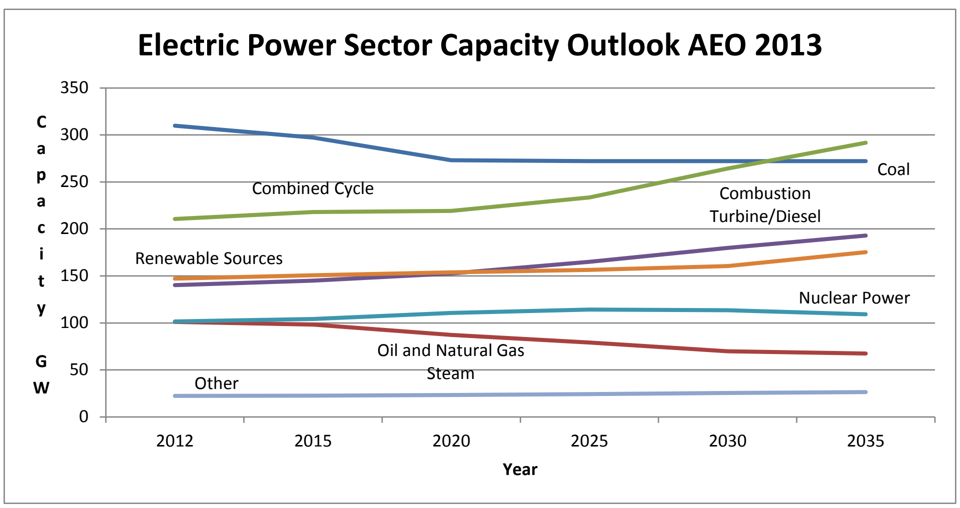
Plant	Type	Capacity	Total Years in Operation	Capacity Factor 1975-1995	Capacity Factor 1996-2011	Change
Three Mile Island 1	PWR	819	37	55%	96%	41%
Point Beach 2	PWR	497	39	84%	80%	-4%
H B Robinson 2	PWR	707	40	65%	94%	29%
Point Beach 1	PWR	497	41	79%	82%	3%
Prairie Island 2	PWR	530	37	86%	91%	5%
Kewaunee	PWR	560	37	84%	84%	0%
Monticello (MN)	BWR	545	40	78%	88%	10%
ANO 1	PWR	850	37	65%	91%	26%
Oconee 3	PWR	886	37	74%	88%	14%
Oyster Creek (NJ)	BWR	650	42	57%	90%	33%
Oconee 2	PWR	886	37	74%	88%	14%
Turkey Point 4	PWR	745	38	63%	91%	28%
Ginna	PWR	490	41	79%	94%	15%
Quad Cities 1	BWR	809	39	66%	84%	18%
Oconee 1	PWR	886	38	74%	84%	10%
Vermont Yankee	BWR	514	39	79%	92%	13%
Turkey Point 3	PWR	745	39	64%	93%	29%
Quad Cities 2	BWR	809	39	63%	86%	23%
Peach Bottom 3	BWR	1065	37	58%	94%	36%
Cooper	BWR	778	37	62%	87%	25%
Prairie Island 1	PWR	530	38	86%	89%	3%
Nine Mile Point 1	BWR	610	42	61%	89%	28%
Peach Bottom 2	BWR	1065	37	57%	94%	37%
Indian Point 2	PWR	873	38	64%	81%	17%
Dresden 2	BWR	809	39	59%	88%	29%
Surry 2	PWR	823	38	63%	91%	28%
Fort Calhoun	PWR	457	37	71%	83%	12%
Surry 1	PWR	823	39	64%	91%	27%
Dresden 3	BWR	809	40	57%	88%	31%
Pilgrim 1	BWR	670	39	52%	91%	39%
Palisades	PWR	821	40	58%	87%	29%
Browns Ferry 1	BWR	1098	37	53%	59%	6%

2. EISPC POWER MARKET OUTLOOK AND LOCATIONAL STUDY

Coal remains the largest energy source of electric generation capacity for the majority of EIA's projection, but its share of total generation capacity declines by 40 GW through 2020. Natural gas is projected to surpass coal as the primary fuel source for electric generation capacity in 2032. Nuclear generating capacity increases from 101 to 114 GW in 2025 per AEO 2013. This is assumed to come through a combination of new construction (5.5 GW), uprates at existing plants (8.0 GW), and retirements (0.6 GW). However, as shown later in this section, nuclear retirements already exceed the AEO2013 ten-year projection. Excluding hydropower, AEO213 forecasts generation from renewable energy to account for 32% of the overall growth in electricity generation from 2011 to 2040.

It is well recognized that the abundance of natural gas and oil being recovered through advanced recovery techniques has dramatically changed the energy outlook for the United States. The U.S. Energy Information Administration (EIA) predicts the United States will be an exporter of natural gas and that 30% of the heavy vehicle fleet will use natural gas as fuel by 2020.[84] EIA's 2013 Annual Energy Outlook predicts installed capacity of natural gas-fired generation to exceed that of coal-fired generation prior to 2035, as shown in Figure 7.

Figure 7. Electric Power Capacity Outlook (Source: EIA AEO 2013)

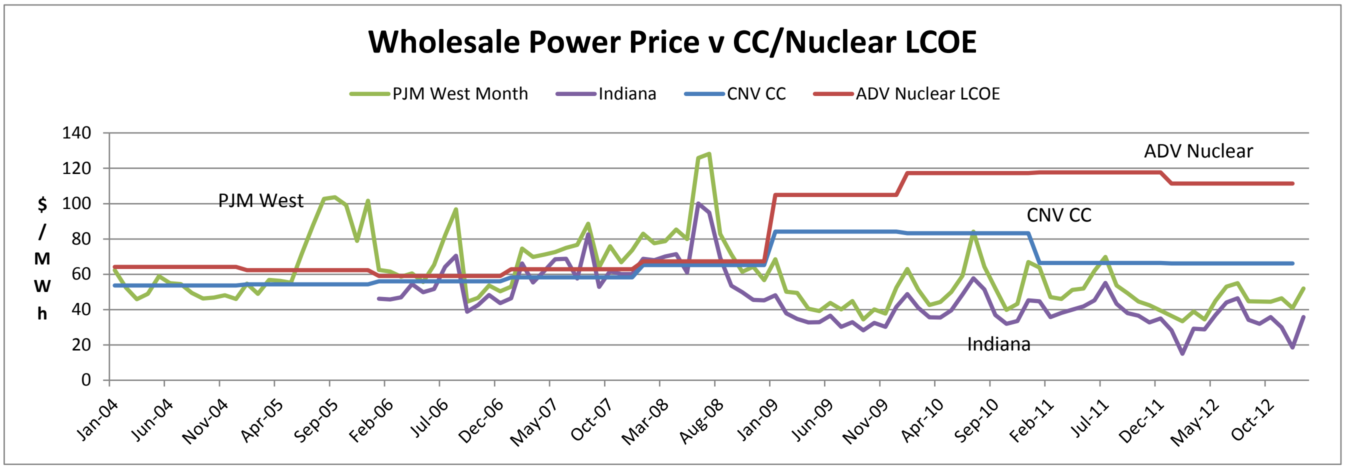


The economics of sustained inexpensive natural gas for power production may force the retirement of more coal-fired power plants than anticipated via environmental regulations or a tax on carbon. Inexpensive natural gas may even force the retirement of additional nuclear generation before license expiration. Natural gas prices were cited by Dominion Resources as a contributing factor in its decision to close its Wisconsin-based Kewaunee Nuclear Power Plant in May 2013. Data in Figure 8 highlights the challenge merchant plant developers face by comparing monthly average weighted wholesale power

[84] US EIA Prospects for U.S. Oil & Natural Gas July 2012 presentation to Aspen Institute Global Energy Forum

prices at the PJM West and MISO-Indiana hubs[85] to levelized cost of energy (LCOE) for new advanced nuclear and conventional combined-cycle generation plants as shown in EIA's Annual Energy Outlook for years 2004-2012.

Figure 8. Wholesale Power vs. New Generation LCOE (Source EIA)



The LCOE reflects the amortization of capital costs plus production costs and the figure shows that the forecast high capital costs for advanced nuclear generation make it uneconomical to pursue in the depicted wholesale power markets. Most nuclear plant production costs are calculated as approximately $20/MWh; however, the production cost for some existing single-unit nuclear plants has been estimated as high as $40/MWh[86]. These marginal economic performers will eventually be forced out of the market if wholesale prices continue to remain at current levels or they are unable to enter into favorable long-term power purchase agreements.

Natural gas prices are not the only factor affecting wholesale power prices, wind energy is also driving prices lower. A combination of market rules and tax credits have allowed wind to keep generating even when there is no demand for the power. In certain instances, this has forced the market price of power below zero. A record low price of negative ($41.08/MWh) was set last October in MISO due to the effects of the production tax credit on wind power.[87] Thus, these market forces do not just apply nuclear plants, they apply to all forms of generation including traditional baseload coal-fired generation; however, coal plants may have more operational flexibility than nuclear power plants in meeting this challenge. Figure 9 attempts to illustrate the current forces in the electric power marketplace that are increasing the need for operational flexibility across all forms of generation.

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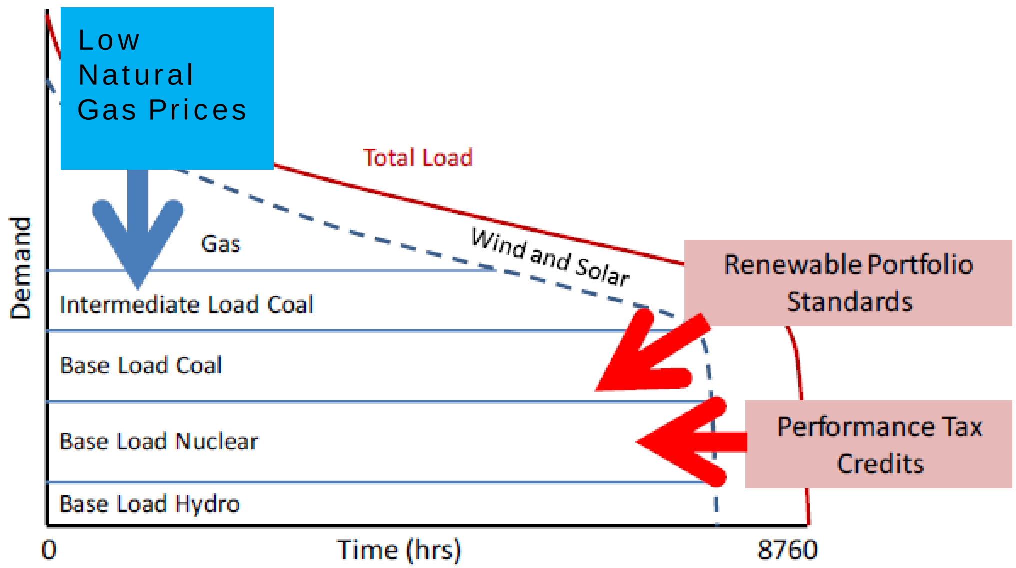
[85] ICE wholesale market data from the EIA website

[86] http://ansnuclearcafe.org/2013/02/21/potential-nuclear-plant-closures /

[87] http://www.sfgate.com/business/bloomberg/article/Nuclear-Industry-Withers-in-U-S-as-Wind-Pummels-4345997.php

Figure 9. Current Power Market Forces

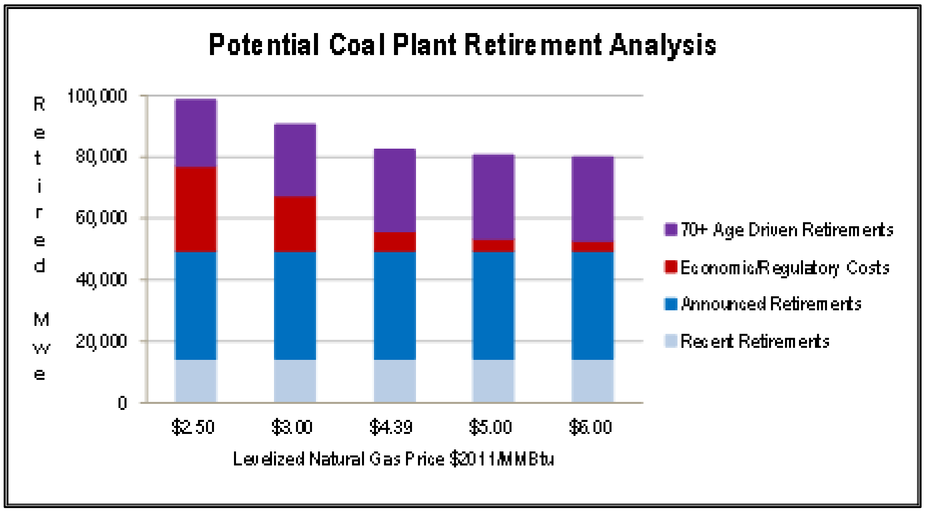


2.1 Coal Plant Retirement Analysis

To model the effects of natural gas prices on coal-fired power plant retirements in an attempt to identify possible opportunities for nuclear power, Navigant Consulting modified its Mercury and Air Toxic Standards (MATS) model[88] to extend the analysis period and forecast economic retirements over the next 20 years. Results indicated capacity retired for economic reasons would add significantly to MATS related and announced retirements if the long-term price of natural gas remained below Navigant's base case price of $4.39/MMBTU. Analysis results are summarized in Figure 10.

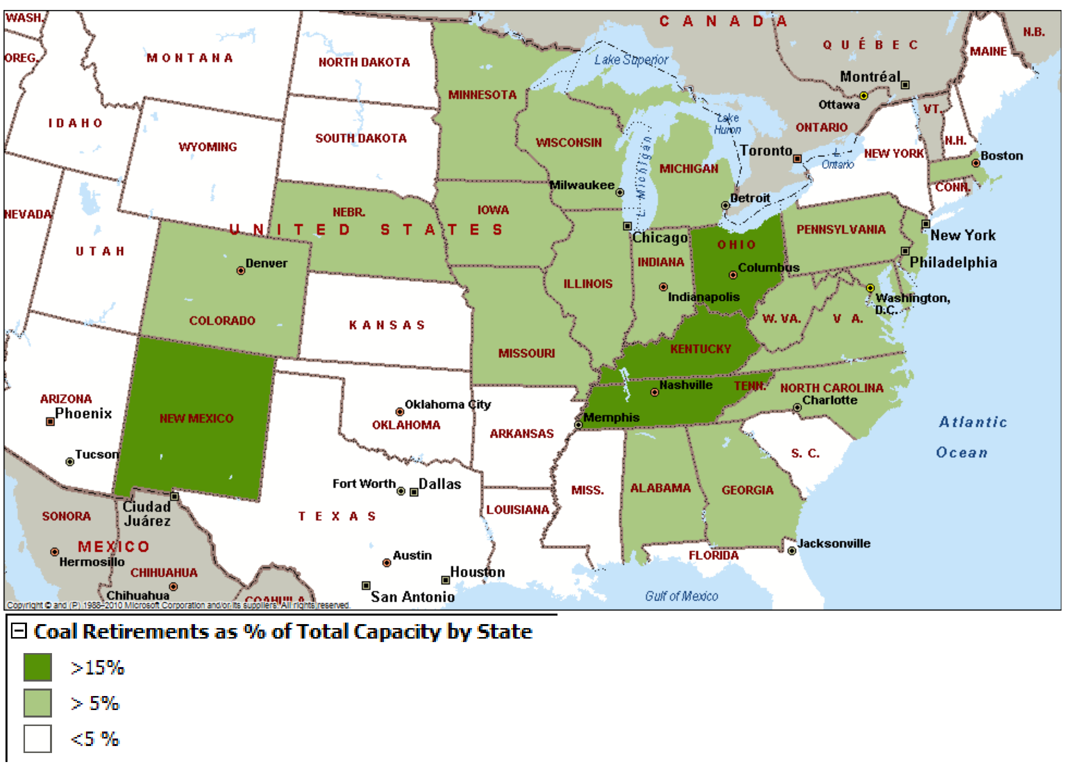
[88] MATS provides a high level conservative estimate of coal plant retirements. Navigant uses other tools for all market modeling engagements.

Figure 10. Twenty-Year Potential Coal Plant Retirement Outlook



Projected coal plant retirements were then mapped to individual state for low price ($2.5), base case ($4.39), and high price ($6) natural gas scenarios in order determine which states would be most affected by generation retirements over a 20-year time horizon.

Figure 11. Base Case Coal Plant Retirement Analyses



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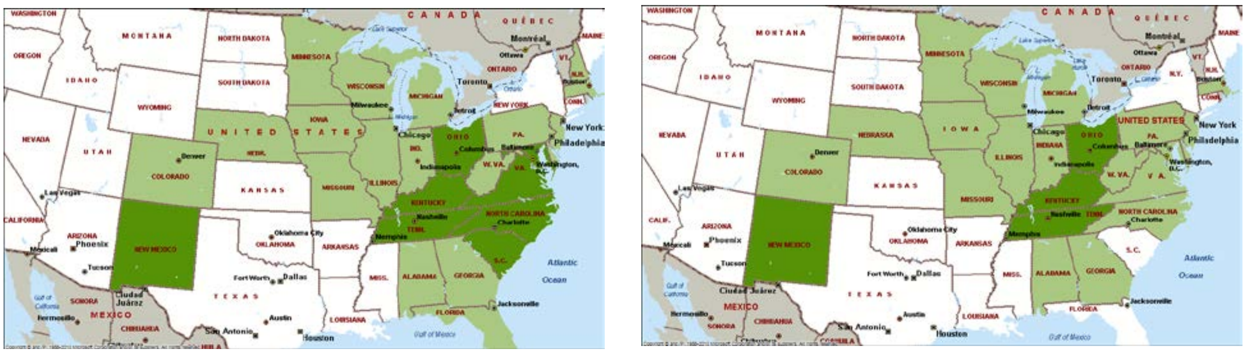
Analysis results mapped projected retirements to each individual state's total generating capacity in order to determine the magnitude of relative impact. Throughout the analysis, it was evident that the Ohio River Valley and southeastern sections of the country will be most impacted by forecasted coal plant retirements.

Figure 12. Comparisons of Low and High Gas Price Analyses



The top five affected states within the Eastern Interconnection are shown in Table 13.

Table 13. Top Five Coal Plant Retirement States-Base Case

State	Total Generation MWe	Retiring Coal Capacity MWe	Coal Retirements as % of Total State Capacity
TN	22,083	4,757	22%
OH	34,562	6,755	20%
KY	21,132	3,409	16%
NM	8,271	1,310	16%
MI	29,640	3,829	13%

Navigant then attempted to determine if there were any natural gas infrastructure constraints within the affected areas that might afford nuclear generation the opportunity to replace coal-fired generation. Navigant's natural gas experts identified that reliance on historical pipeline flows and capacities would lead to erroneous conclusions because shale gas is rapidly changing both the way infrastructure is used and its directional flows. For example, the Marcellus shale play is reversing historical flows from Texas to the northeastern United States. Navigant then reviewed the average time to construct pipeline projects and gas-fired power plants. The natural gas industry has indicated that it can and has completed major expansions within 36 months of negotiating commercial terms with customers.[89] Recent construction duration estimates for large natural gas-fired power plants range from two to three years after receipt of permits.[90] This compares very favorably to the four to six-year license application process and

[89] TransCanada Response to MISO study 2012 &;
http://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/ngpipeline/develop.html
[90] Consumers Energy to Build New Natural Gas Power Plant, dbBusiness, December 14th, 2012

subsequent five to six-year construction period for a U.S. nuclear plant. These factors led to the conclusion that there are few infrastructure constraints that would tend to favor nuclear power.

After assuming all coal-fired generation would be replaced with natural gas-fired generation, results were examined for fuel source diversification. With the exception of Kentucky and its use of coal, all the states most affected by coal plant retirements will have a more uniform distribution of fuel sources post-retirement, as shown in Table 14. Two of these states, New Mexico and Kentucky, do not have any installed nuclear capacity. New Mexico is has a number of DOE nuclear facilities, but no nuclear power plants and falls mostly outside of the Eastern Interconnection, while Kentucky requires that a spent fuel repository exist prior to consideration of a nuclear plant.

Table 14. Post-Retirement Generation Fuel Source Distribution Top Five States

State	Coal	Natural Gas	Nuclear	Hydro	Petroleum	Pumped Storage	Solar	Wind	Biomass
TN	18%	45%	16%	12%	0%	8%	0%	0%	1%
OH	44%	44%	6%	0%	3%	0%	0%	0%	0%
KY	56%	39%	0%	4%	0%	0%	0%	0%	0%
NM	32%	56%	0%	1%	0%	0%	2%	9%	0%
MI	26%	49%	13%	1%	2%	6%	0%	1%	2%

Post-retirement projections shown in Table 15 indicate ten states within the Eastern Interconnection will continue to rely on natural gas as the predominant fuel source for more than 50% of the state's generation capacity. Each of these states was examined to determine if there were prohibitions on using nuclear power for fuel source diversification.

Table 15. Natural Gas-Dependent States

State	Coal	Natural Gas	Nuclear	Hydro	Petroleum	Other Gases	Pumped Storage	Wind	Biomass
RI	0%	98%	0%	0%	1%	0%	0%	0%	1%
DE	15%	77%	0%	0%	3%	4%	0%	0%	0%
MS	16%	75%	8%	0%	0%	0%	0%	0%	2%
LA	13%	72%	8%	1%	4%	0%	0%	0%	0%
TX	20%	64%	5%	1%	0%	0%	0%	9%	0%
OK	24%	62%	0%	4%	0%	0%	1%	8%	0%
FL	12%	61%	7%	0%	18%	0%	0%	0%	2%
NJ	11%	55%	22%	0%	8%	0%	2%	0%	1%
NY	2%	52%	13%	11%	13%	0%	4%	4%	1%
MA	4%	52%	5%	2%	23%	0%	12%	0%	2%
AL	21%	51%	15%	10%	0%	0%	0%	0%	2%

Three of these states, Rhode Island, Delaware, and Oklahoma, lack nuclear generation capacity. However, Rhode Island requires approval from the state legislature prior to siting a nuclear power plant and its population density is double the Argonne Energy Zone Working Group's planning parameter of 500 inhabitants per square mile for nuclear plant siting. Delaware's population density approaches the Energy Zone parameter limit at 460 inhabitants per square mile.[91] Oklahoma has no restrictions on building nuclear power plants, but the Oklahoma Municipal Power Authority which provides 3% of the state's power, is barred from owning a share of any nuclear power plant.[92]

It should be noted that Small Modular Reactors (SMRs) could also act as onsite replacement power sources for retiring coal plants and utilize the existing transmission infrastructure. The economics of SMRs are discussed later in more detail, but at this juncture it is not anticipated that SMR LCOE would compare favorably with natural gas-fired generation LCOE for the foreseeable future.

The North American Electric Reliability Corporation (NERC) 2012 Long Term Reliability Assessment anticipates that the contribution from nuclear power generation will remain relatively stable over the next ten years and that approximately 10.4 GW of new nuclear capacity will be added through power uprates and plant additions.[93]

The recently announced 2013 closures of Dominion's Kewaunee Nuclear Power Plant in Wisconsin and Duke's Crystal River Unit 3 in Florida may require that forecast to be revised. Crystal River Unit 3 was shut down due to the prohibitive cost of repair for the unit's damage containment structure.[94] Crystal River Unit 3 is a PWR and was shut down in 2009 for refueling and replacement of its steam generators. During the course of the outage, cracks were discovered in the concrete containment walls.[95] Subsequent analysis indicated the cracks could be repaired, but at an uneconomical cost.

Expiration of existing power purchase agreements and the forecast for continued low power prices forced Kewaunee to shut down. Dominion had placed Kewaunee up for sale in April 2011, but was unable to find a buyer and was unable to renegotiate power purchase agreements on favorable terms.[96] The low price of wholesale power shown earlier in Figure 8 makes it difficult for marginal economic performers such as Kewaunee to continue to operate.

In February 2013, UBS noted that merchant nuclear plants would face the same low cost natural gas issues confronting merchant coal plants. UBS identified Exelon's 1,078-MW Clinton plant in Illinois, and New York's 581-MW Ginna and 856-MW Fitzpatrick plants in addition to the 628-MW Vermont Yankee plant as near-term closure candidates. Specifically, they said that they "continue to project negative FCF [free cash flow] for the nuclear business on an un-hedged basis suggesting real retirement risk for units such as Vermont Yankee and Fitzpatrick in '[20]13; we see increased focus on the decomm[issioning]

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[91] Statistical abstract of the United States 2012
[92] Oklahoma Municipal Power Authority: A Historical Review 2002
[93] NERC 2012 Long Term Reliability Assessment p. 65
[94] http://www.duke-energy.com/news/releases/2013020501.asp
[95] http://www.nrc.gov/info-finder/reactor/cr3/concrete-containment-separation.html
[96] http://dom.mediaroom.com/2013-02-19-Midwest-ISO-Concludes-That-Closing-Of-Kewaunee-Power-Station-Will-Not-Affect-Regional-Electric-Reliability

process"[97]. This means that plants not selling power to customers through power purchase agreements are subjected to the daily risks of the wholesale power market and have not been able to reduce, or hedge, their financial risk. UBS is predicting that the above mentioned plants will generate negative cash flows as a result of their high operating costs compared to the market price of power.

2.2 *Uprate Analysis*

Through the licensing process, nuclear power plants are given permission to generate a specific amount of reactor power. As the body of knowledge encompassing reactor thermodynamics and instrumentation has evolved, existing nuclear plants can take advantage of excess "design margin" in their safety analysis calculations and increase the power output of the plant after going through an equipment upgrade and a rigorous NRC licensing modification process. The NRC approves three types of uprates for nuclear power plants:

- Measurement of Uncertainty (MU) provides less than a 2% power increase and is achieved by implementing enhanced techniques for calculating reactor power or improved instrumentation. For example, if the measurement uncertainty in original reactor power measuring devices was 5% and more modern devices have an uncertainty of 4% a power plant operator would be able increase reactor output 1% and still maintain the same operating conservatisms he had with the original equipment.

- Stretch power uprates (S) provide approximately a 7% power increase and are within the design capacity of the plant. The actual value for the percentage increase in power a plant can achieve and stay within the stretch power uprate category is plant-specific and depends on its operating margins.

- Extended power uprates (EPU) require significant modifications to major balance-of-plant equipment such as the high pressure turbines, condensate pumps and motors, main generators, and/or transformers. These have typically provided plants with 12% to 14% increases in thermal power.

One hundred forty-six uprates have been approved since 1977, providing additional generating capacity of 6823 MW[98]. The majority of this generation has come from extended power uprates (47%). Stretch uprates (42%) and margin of uncertainty uprates (11%) account for the remainder. The nuclear subgroup supporting the 2012 EIA Annual Energy Outlook estimated the total uprate potential for the existing fleet of light water reactors (BWRs and PWRs) at 6,000 MWe.[99]

In most cases, uprates cost more than the original construction cost of the plant on a $/kW basis. Exelon estimates its average overnight uprate costs through 2017 at approximately $3000/Kw[100] across various

[97] UBS Investment note Entergy 4 Feb 2013
[98] NRC Website
[99] Power Forecast and Lessons Learned , George Paptzun, GE June 20, 2012
[100] Exelon 8K , September 2012 Overnight costs exclude inflation and escalation

uprates. Xcel estimated extended power uprate total costs for Monticello at $5000/Kw[101] and Florida Power & Light reported a combined 460 MWe increase in generation across its Turkey Point and St. Lucie dual unit plants to cost approximately $6000/Kw.[102]

The ability to perform an uprate is based upon the amount of safety margin that was incorporated during original plant design. A greater percentage of EPUs have been performed for BWRs than PWRs because there is greater excess safety margin in the BWR design. PWR EPUs have averaged a 12.6% increase in thermal power compared to a 14.8% increase in thermal power for BWRs. In addition to increasing the thermal power of the reactor and generating more electrical power, uprates extend plant lifetime and can increase nuclear safety by improving thermal performance and core damage frequency calculations.

All plant designs have benefited from MU and stretch power uprates. The only plants that do not have MU, S, or EPU uprate history in the NRC database are the nation's two oldest BWRs and four Westinghouse four-loop PWRs shown in the following table.

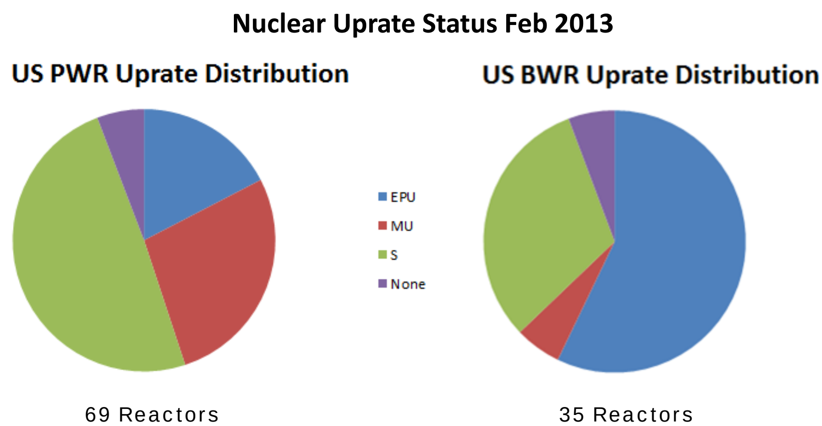
Table 16. Nuclear Plants with No Uprates

Plant Name	State	Type
Oyster Creek	NJ	BWR
Nine Mile Point 1	NY	BWR
ANO-1	AR	PWR
Catawba 1	SC	PWR
Catawba 2	SC	PWR
Diablo Canyon 2	CA	PWR

Market conditions have cancelled or deferred plans for several power uprates. As noted in Figure 13, there has been a 375 MWe decrease in expected uprate applications for the period 2013-2016 since the previous NRC update. Exelon has deferred for approximately two years 600 MWe in uprates across its LaSalle and Limerick plants due to current power market conditions. The NRC recently accepted Exelon's uprate application for approximately 260 MWe for its Peach Bottom plant and Nebraska Public Power District's uprate application for 146 MWe at its Cooper plant. The NRC's application review period averages 18 months, so it will be two to four years before these projects are completed.

[101] Docket No. E002/GR-10-971,Exhibit___(DLK-1),Nuclear Operations, Testimony Mr Dennis Koehl
[102] World Nuclear News; Uprate approved for St Lucie 2, 25 September 2012

Figure 13. Current Power Uprate Forecast



Fiscal Year	Total Power Uprates Expected	Measurement Uncertainty Recapture Power Uprates	Stretch Power Uprates	Extended Power Uprates	Megawatts Thermal	Approximate Megawatts Electric
2013	7	5	0	2	1142	381
2014	0	0	0	0	0	0
2015	0	0	0	0	0	0
2016	2	1	0	1	491	164
2017	0	0	0	0	0	0
TOTAL	**9**	**6**	**0**	**3**	**1633**	**545**
Change in Projection	**-4**	**0**	**0**	**-4**	**-1128**	**-375**

Source :NRC

The only remaining BWRs that could be considered potential candidates for extended power uprates are shown in Table 17. All of these plants are single-unit BWRs with an estimated uprate capacity of 838 MWe. 87% of Perry and 100% of Pilgrim and Fitzpatrick operate as merchant plants. As discussed previously, single-unit nuclear plants have been identified as financially vulnerable, so it is unlikely that any of these three merchant plants would consider an EPU in today's market. This leaves River Bend and Fermi 2 as the remaining candidates with the potential to provide up to 290 MWe within the Eastern Interconnection. Fermi 2 submitted an application for an MU of 1.6% (18 MWe) in February 2013.

Table 17. Potential BWR EPU Candidates

Plant Name	State	Capacity (MWe)	Potential Uprate Capacity (MWe)
Pilgrim	MA	685	95
Fermi 2	MI	1106	154
Fitzpatrick	NY	855	119
Perry	OH	1240	173
River Bend	LA	974	136
Columbia/WNP-2	WA	1131	158
		Total	838

With regards to PWR uprate opportunities, none of the world's 32 large four-loop Westinghouse units has performed an extended power uprate; however, several have performed stretch uprates. There were six Westinghouse two-loop designs in operation prior to the closure of Kewaunee, half of which have completed EPUs. Xcel Energy cancelled EPU plans at its dual unit Minnesota-based Prairie Island plant in November 2012 citing the change in power market conditions. Of the 13 three-loop Westinghouse units that exist, four have completed extended power uprates. The remaining nine units shown in Table 18 are all located in regulated markets within the Eastern Interconnection and could potentially provide approximately 950 MWe through EPUs.

Table 18. Potential Westinghouse Three-Loop EPU Candidates

Plant Name	State	Capacity (MWe)	Potential Uprate Capacity (MWe)
Farley 1 & 2	AL	1734	208
Robinson	SC	724	86
North Anna 1 & 2	VA	1883	226
Shearon Harris	NC	900	108
Surry 1 & 2	VA	1713	205
VC Summer	SC	966	115
		Total	950

Fourteen Combustion Engineering designed units are in operation and four have completed EPUs. Three of the ten remaining units, San Onofre 2 & 3 (CA) and Fort Calhoun (NE) are shut down. In early June 2013, Southern California Edison announced that San Onofre 2 & 3 would be permanently shut down. Fort Calhoun is in the midst of resolving long-term NRC operational concerns. The four remaining units in the Eastern Interconnection operate as merchant plants. It is unlikely that Calvert Cliffs 1 & 2 (MD), Millstone 2(CT), or Palisades (MI) would consider EPUs under current market conditions.

Table 19 summarizes planned and potential nuclear capacity additions and retirements over the next 10 years within the Eastern Interconnection. There are several scenarios that could evolve over time, the most optimistic of which would increase nuclear capacity by 4,556 MWe, while the least optimistic would have a 292 MWe increase.

Table 19. Potential for Large Nuclear Capacity Changes in Eastern Interconnection next Ten Years

Plant Name	Shutdown Capacity	Plant Name	New Capacity	Plant Name	EPU Capacity	Plant Name	Financial Risk Capacity	Plant Name	Political Risk Capacity
Kewaunee	(556)	Vogtle	2200	Peach Bottom	260	Vermont Yankee	(620)	Indian Point 2	(1000)
Crystal River 3	(860)	VC Summer	2200	LaSalle	300	Clinton	(1065)	Indian Point 3	(1000)
Oyster Creek	(619)	Watts Bar	1180	Limerick	306	Ginna	(580)		
				Cooper	146	Fitzpatrick	(855)		
Total	(2035)		5580		1012		(2265)		(2000)

Indian Point Energy Center is currently involved in a contentious relicensing process with the Governor of New York wanting the units shut down in 2014 and 2016 upon expiration of the original operating licenses. Opponents of the plant have also been successful in overturning the NRC's waste confidence rule. The revised rule will be required to consider the lack of permanent spent fuel repository and is not expected to be forthcoming until September 2014.

2.3 *Cancelled Plant Locations*

Approximately 120 nuclear power plant orders have been cancelled since the mid-1970s and their proposed locations are shown on Figure 14.

Figure 14. Cancelled Nuclear Power Plant Orders Approximate Locations[103]

[103] Complete list included as part of project database

Due to the decrease in forecasted demand from the mid-1970s oil crisis and recession as well as the higher construction costs for nuclear power relative to other forms of baseload generation, the majority of nuclear plants were cancelled for economic reasons prior to and after the accident at Three Mile Island. However, there were some such as Malibu, California and Bodega Bay, California that were cancelled due to local opposition.

Most of the proposed plants were to be located in the State of New York to serve the needs of the state's metropolitan area. It was even proposed that some of these plants float off the coast of New Jersey to serve the metropolitan area or be located within New York City itself. The majority of other cancelled plants were proposed by utility companies that had been part of the AEC development programs and were spread across the country**.** Table 20 identifies the top five states for proposed nuclear plants.

Table 20. Top States for Cancelled Nuclear Orders

State	Number of Cancelled Nuclear Plant Orders
NY	11
MI	7
OH	7
NC	6
TN	6

The resurgence of interest in nuclear power has led some utilities to "recycle" nuclear power plant plans for these same sites in addition to planning on Greenfield sites. Included in this list are Detroit Edison in Newport, Michigan; Dominion in Louisa County, Virginia; Duke Energy in Cherokee County, South Carolina; and Florida Power & Light in Miami-Dade County, Florida. The decades-long integrated planning cycles for power plants and transmission assets encourages the "recycling" of previously identified sites for both nuclear and natural gas-fired power plants. The practice of integrated resource planning ensures the generation and transmission functions within vertically integrated utilities coordinate with natural gas pipeline companies or in the case of RTO and ISO regions that utilities, natural gas pipeline companies, and regional transmission organizations harmonize planning activities to ensure long-term projects are completed in parallel.

Combining the results of the incentives analysis discussed in the Section 4. of this report with the list of cancelled nuclear plant orders, Navigant has developed a list of potential sites prioritized by market structure. This list is found in the Appendix.

2.4 U.S. Nuclear Outlook

The previous round of U.S. nuclear construction utilized a two–step licensing process. The initial step secured the construction permit and built the plant while the final step required proving the plant was built as designed, had a workable emergency plan, and was safe to operate. Watts Bar 2 is currently under construction and remains part of the two-step licensing process system. This two-step process exposed the owners to regulatory delays and increased construction costs in addition to adding uncertainty to the development process; therefore, one of the recommendations of the President's Commission on the Accident at TMI was to develop a combined construction and operating license process.

All of the new reactor designs under consideration in the U.S. today are pursuing the combined construction and operating (COL) license. While this approach significantly reduces the potential for licensing basis changes during construction, it requires significantly more detailed attention to precise license compliance during the construction phase as well as increased NRC review and oversight. Another new process for an Early Site Permit (ESP) allows a utility to identify a specific location to be approved for building a new nuclear power plant without a company actually committing to building a reactor or using any specific reactor design. Instead, the site is approved for a range of designs. An ESP can be "banked" and is usually valid for 20 years with the option to renew.

Design Certification of new nuclear power plants by the NRC is required prior to licensing and construction. Reactor vendors are estimated to spend $50-$100 million for design certification if their design is based on light water reactor technology.[104] The NRC has no experience licensing any other type of reactor, so other design certification costs are unknown. This has real limitations for nuclear reactors in the United States. For example, if a U.S. utility wanted to build a heavy water reactor based on the CANDU design used in Canada or a High Temperature Gas Reactor such as the type used in Britain, the NRC would not be able to license the plant based upon its current models, policies, and procedures.

The NRC has finalized design certification for only two of the new generation reactor designs, the Westinghouse AP1000 and General Electrics Advanced Boiling Water Reactor (ABWR). The ABWR was certified by the NRC in 1997 and three reactors of this design are operating in Japan. Six AP1000 reactors are under construction worldwide, four are in the United States and two are in China. Design Certification for the three reactor designs currently in the NRC's COL queue is not expected until mid-2015 for Areva's US-EPR, early 2016 for Mitsubishi's US-APWR, and an undetermined date for the GE-Hitachi's ESBWR. In addition to Design Certification challenges, projects planned for Calvert Cliffs and South Texas have been notified by the NRC that their current ownership structures to not meet the U.S. domestic ownership requirements for licensure. While still in the NRC's COL queue, on May 2, 2013, Duke Progress Energy requested the NRC suspend COL activities for the two planned reactors at its Shearon Harris site, citing changes in demand growth outlook.

Table 21 shows the current status of active COL applications under review by the NRC. These applications represent 14 new units in addition to plants Vogtle and VC Summer.

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[104] http://atomicinsights.com/2011/12/examples-of-regulatory-costs-for-nuclear-energy-development.html

Table 21. Status of U.S. Nuclear COL Applications

Utility	Site	State	Reactor Type	No. Units	COL Dates		Review In Progress	
					Submitted	Status	Safety 4	Environ.5
Progress Energy	Levy	FL	AP1000	2	7/30/2008	WCR	Ph. D	Completed
STP Nuclear Operating Co.	South Texas Project	TX	ABWR	2	9/20/2007	Schedule Review	Ph. 4	Completed
Luminant (TXU)	Comanche Peak	TX	US-APWR	2	9/19/2008	DC US-APWR 2/16	Ph. 2	Completed
UniStar	Calvert Cliffs	MD	US-EPR	1	3/14/2008	Schedule Review	Ph. 2	Completed
DTE Energy	Fermi	MI	ESBWR	1	9/18/2008	Design Cert-TBD	Ph. B	Ph. 3
Duke Energy	William States Lee	SC	AP1000	2	12/13/2007	Schedule Review	Ph. B	Ph. 3
Florida Power and Light	Turkey Point	FL	AP1000	2	6/30/2009	Schedule Review	Ph. A	Ph. 2
PPL (UniStar)	Bell Bend	PA	US-EPR	1	10/10/2008	DC 6/15/ Water Use	Ph. A	Ph. 2
Progress Energy	Shearon Harris	NC	AP1000	2	2/19/2008	Suspended 5/2/2013	Ph. B	Ph. 2
Dominion Energy	North Anna	VA	US-APWR	1	11/27/2007	Schedule Review CP	Ph. A	Ph. 2

Table 22 lists the phases for Safety and Environmental Reviews.

Table 22. COL Review Phases

Review Type		Review Phases					
4 Safety Review:	*R-COL*→	*Phase 1* Issue RAIs	*Phase 2* SER w/Open Items	*Phase 3* ACRS Review	*Phase 4* Advanced SER/ No OI	*Phase 5* ACRS Review	*Phase 6* Final SER
	S-COL→	*Phase A* Issue RAIs and supplemental RAIs	*Phase B* Advanced SER/ No OI	*Phase C* ACRS Review	*Phase D* Final SER		
5 Environmental Review Phases:		*Phase 1* Environmental Scoping Report	*Phase 2 Draft EIS*	*Phase 3 Public comment*	*Phase 4 Final EIS*		

None of the developers of small modular reactors (SMRs) has yet applied for NRC Design Certification; however, both Westinghouse and Babcock & Wilcox have stated they intend to do so within the next five years. Westinghouse is partnering with Ameren Missouri, Exelon, Dominion and FirstEnergy to build its prototype 225 MWe SMR at Ameren Missouri's Callaway site near Fulton, Missouri. And, Babcock & Wilcox was recently awarded matching funding of $150 million over five years to build its prototype mPower SMR at TVA's Clinch River site in Tennessee.

Other developers of SMRs have not identified specific sites for SMR development outside of possibly building prototypes at DOE's Savannah River site. None of the SMR developers expects an operational commercial SMR in the U.S. prior to 2020.

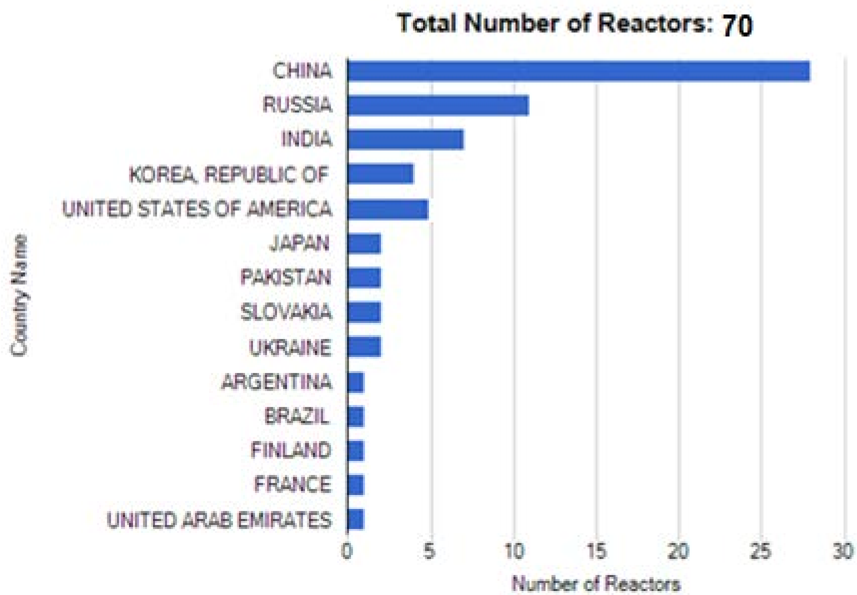
2.5 *World Nuclear Outlook*

According to the International Atomic Energy Agency's PRIS database, there are 435 nuclear power reactors listed as operational in 31 countries, with a combined capacity of over 370 GWe. However, 47 of these operational reactors, representing 42 GW of nuclear generation, are located in Japan and are currently shut down pending a national policy decision on nuclear power. The situation in Japan is in a state of flux as the population confronts the high cost of energy without nuclear power. At the time of this writing, a vigorous national debate over the future of nuclear power within Japan was taking place. Other countries such as Germany, Italy, Sweden, Belgium, Austria, and Switzerland have all passed laws phasing out nuclear power. To date, only Austria has been successful in phasing out nuclear power because it prevented its only nuclear plant from ever operating after it was constructed. Other countries such as Belgium, Sweden, and Switzerland have extended or reversed positions on a phase-out in order to meet emissions goals or maintain energy prices. Italy has successfully shut down domestic plants, but has invested in nuclear plants located in France and Slovakia[105]. Germany intends to shut down all of its nuclear plants by 2020; however, rising energy prices and an increase in the use of coal-fired generation have certain factions within Germany calling for a reversal of the phase-out decision.

[105] http://en.wikipedia.org/wiki/Nuclear_power_phase-out

Regardless, according to the World Nuclear Association, worldwide nuclear capacity is expected to rise to 630 GW by 2035. Seventy reactors, the vast majority of which are pressurized water reactors (PWRs), are currently under construction in fourteen countries. The other types of reactors under construction in Figure 15 reflect the national policies of those countries. For example, the PHWR (heavy water PWR) reactors under construction in India reflect that nation's desire to develop a thorium-based fuel cycle.[106]

Figure 15. Current Worldwide Nuclear Construction by Country (IAEA)



China, aiming to at least quadruple its nuclear capacity by 2020, leads the world with 27 reactors under construction, four of which are Westinghouse AP1000s and several of which are its domestic CPR-1000 designs. It also has a prototype high-temperature gas-cooled reactor plant under construction. China is also financing reactor construction in Pakistan.

Russia has eleven reactors under active construction, one being a large fast neutron reactor and another a small floating plant expected to reach completion in 2014. Thirteen reactors are planned, some to replace existing plants, so that by 2017, ten new reactors totaling at least 9.2 GWe should be operating. An additional 5 GW of nuclear thermal capacity is planned as well.

India has an estimated 20 planned reactors and seven currently under construction, including a large prototype fast breeder reactor. It has almost a third of the world's thorium reserves and is attempting to develop a thorium-based fuel cycle. The first two steps involve the use of heavy water reactors and fast breeder reactors to generate fissile material. The fissile material is then used in an advanced reactor to covert thorium into fissile material for use as fuel.

[106] http://en.wikipedia.org/wiki/India%27s_three_stage_nuclear_power_programme

South Korea plans to bring four more reactors into operation by 2017, and another five by 2021. All Korean reactors are APWR 1400 MWe designs.

The United States has four AP1000 and one additional PWR under construction. Applications for 14 additional units are under review by the NRC.

Japan has two reactors under construction and two of its operational reactors are producing power. At the time of this writing, 47[107] reactors remain shut down awaiting a national decision on Japan's future nuclear policy. The Japanese nuclear situation is still in flux and these numbers could change in the near future.

Slovakia is attempting to complete two reactors that it began constructing in 1982.

Ukraine has two PWRs under construction with completion expected in 2016 and 2017.

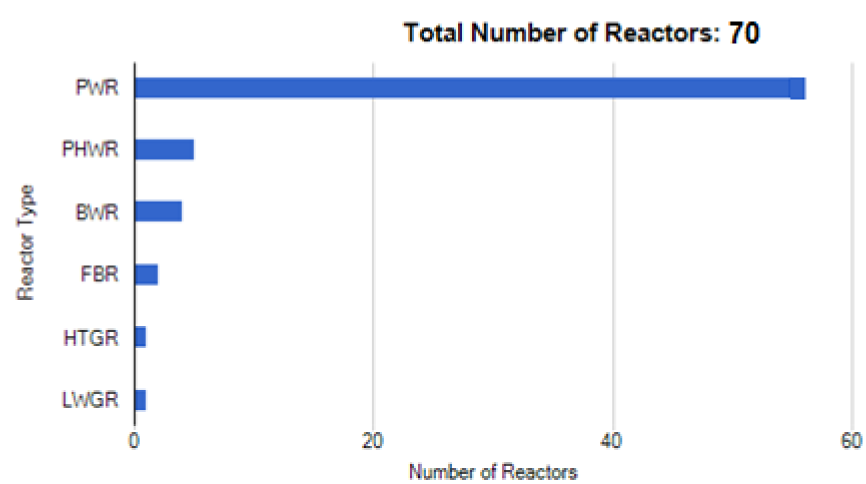
Argentina is attempting to complete construction of a PHWR started in 1981.

Brazil is half-way through construction of a 1245 MWe PWR scheduled to be completed in 2016.

Finland and France are both trying to complete construction of EPR reactors. Construction has dragged on for at least nine years for both reactors.

The UAE has contracted for four Korean APWRs to be completed by 2020, one of which is under construction.

Figure 16. Worldwide Construction by Reactor Type (IAEA)



[107] World Nuclear Industry Status Report Jan 2013

3. NUCLEAR POWER GENERATION ECONOMICS

When first developed, nuclear power was anticipated to be a disruptive technology that would rapidly become the predominant source of electrical generation. The primary reason it has failed to fulfill that expectation is its economic performance. Large capital costs were to be offset by extremely low operating costs; however, neither the historic capital costs nor historic operating costs have been shown to be predictable. Operating costs have stabilized over the past decade and this current round of domestic nuclear new construction may show more predictable cost and schedule adherence. Changing regulations have been the largest cause of unpredictable costs. Recent examples include capital cost increases for "backfit" modifications; increased plant staffing through requirements such as Fitness for Duty; Fukushima-driven plant emergency planning modifications; and environmental requirements for thermal limits and fish habitat. Some of these are not unique to nuclear generation and others such as a carbon tax would favor it.

Radioactive waste management, plant decommissioning, plant licensing, security, spent nuclear fuel disposal, and detailed emergency planning are unique to nuclear power and directly impact operational costs. Examples include the 1 mill/Kwh charge on electricity to fund the Nuclear Waste Fund, utility fees to FEMA to support planning, plant decommissioning funds, and very large security staffs.

3.1 Construction Costs

The benefits of economies of scale were to be reaped by building larger power plants. Unfortunately, the larger plants took longer to build and the additional construction time more than offset anticipated savings.[108] In a detailed study of this phenomenon, DOE recognized that construction duration is a surrogate for a number of factors that influence costs, such as design changes, safety and environmental backfits, and labor productivity; however, it found the duration of the construction period to be one of the most statistically significant variables in explaining why larger plants did not have lower costs per unit of capacity.[109]

The table below shows Navigant's calculation of the average construction cost of individual reactor types normalized to 2012 dollars and illustrates the same conclusions as the DOE with regard to economies of scale.

[108] EIA Analysis of Nuclear Power Plant Construction Costs DOE/EIA 0485, 1986
[109] Ibid page ix

Table 23. Construction Cost by Reactor Type (Source NCI)

Reactor Type	Average 2012 Cost of Construction $/KW	Average Nameplate Rating MWe	# of Plants
B&W LLP	1,483	886	7
CE	2,461	914	10
CE80-2L	3,064	1,323	3
COMB CE	4,463	1,315	1
GE 2	942	641	2
GE 3	947	851	6
GE 4	2,522	1,089	19
GE 5	4,855	1,268	4
GE 6	5,494	1,282	4
WEST 2LP	1,014	573	6
WEST 3LP	2,493	942	13
WEST 4LP	3,770	1,233	32

Nuclear plant owners have also been frustrated by the inaccuracy of initial construction costs estimates. Figure 17 shows that individual project construction estimates did not improve as the number of projects increased. This reflects the lack of standardization in nuclear plant design and failure to adequately share information across construction projects.

The accuracy of cost estimates has not improved over time. In the years that have passed since the Energy Policy Act of 2005 initiated the "nuclear renaissance", overnight cost estimates have doubled or tripled for the reactors currently under consideration. A chart comparing the construction costs of all U.S. nuclear power plants referenced to year 2012 dollars is found in the Appendix and shows the high cost of early plants and the dramatic effects of the Three Mile Island accident on follow-on plants.

Figure 17. Construction Cost Overruns[110]

CONSTRUCTION STARTS		AVERAGE OVERNIGHT COSTS[a]		
YEAR INITIATED	NUMBER OF PLANTS[b]	UTILITIES' PROJECTIONS (THOUSANDS OF DOLLARS PER MW)	ACTUAL (THOUSANDS OF DOLLARS PER MW)	OVERRUN (PERCENT)
1966-1967	11	612	1,279	109
1968-1969	26	741	2,180	194
1970-1971	12	829	2,889	248
1972-1973	7	1,220	3,882	218
1974-1975	14	1,263	4,817	281
1976-1977	5	1,630	4,377	169
OVERALL AVERAGE	13	938	2,959	207

There are four new AP1000 nuclear power plants currently under construction in the United States. Utilities have delayed starting other projects as they observe the progress and construction experience of Georgia Power's Plant Vogtle and South Carolina Electric & Gas's VC Summer. These are the first plants to be built under the NRC's combined construction and operating license. Previous construction, including current work on Watts Bar 2, required that the plant be licensed for operation after it was completed. This led to significant delays and increases in cost. The most notable casualty of this process was the Shoreham nuclear plant on Long Island that was completed but never operated.

The combined construction operating license requires that the plant be built as designed and minimizes opportunities for "field run" solutions. Changes in the new process require license amendments that are reviewed and approved by the NRC, which can cause delays in the construction process. Currently, the VC Summer project is on schedule[111,112] and the Vogtle project is approximately seven months behind schedule.[113] Plant Vogtle is estimated to be approximately $90 million over budget[114] (< 1% of budget) and in a lawsuit with its contractors over $900 million in disputed cost overruns (<5% of original cost estimate)[115]. SCE&G has requested recovery of an additional $453 million in planned escalation.[116]

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110 Congressional Budget Office (CBO) based on data from Energy Information Administration, An Analysis of Nuclear Power Plant Construction Costs, Technical Report DOE/EIA-0485 (January 1, 1986)
111 World Nuclear News March 12, 2013, Construction officially starts at Summer
112 South Carolina Office of Regulatory Staff, January 2013, Review of SCE&G VC Summer Status of Construction
113 Direct Testimony of William R. Jacobs, Jr., Ph.D. Docket No. 29849, Seventh Semi-Annual Vogtle Construction Monitoring Period, December 2012
114 http://lake.typepad.com/on-the-lake-front/2013/03/hb-267-would-limit-georgia-powers-profits-on-vogtles-cost-overruns-ga-sierra-club.html
115 http://www.ajc.com/news/news/new-900-million-vogtle-lawsuit-filed/nSwWx/
116 Public Risk, Private Profit Ratepayer Cost, Utility Imprudence, Mark Cooper, Institute of Energy and Environment Vermont Law School, March 2013

Early nuclear plant subsidies were described in the Background section of this document and were meant to help develop a commercial nuclear industry. A similar strategy has been followed by the government to subsidize renewable energy through production tax credits, Smart Grid technology through grant programs, and other technologies through loan guarantees.

The Energy Policy Act of 2005 authorized the Department of Energy's Loan Guarantee Program to support innovative clean energy technologies including nuclear power. Section 1703 of the Act requires that the recipients pay a credit subsidy fee to protect the Federal government from a potential default[117]. This fee is not inconsequential for billion dollar nuclear projects. The DOE required a credit subsidy fee of $880 million when it extended a loan guarantee offer to Constellation Energy for its proposed $10 billion Calvert Cliffs Project. Constellation rejected the offer.[118]

Southern Company has applied for nuclear loan guarantees for their current projects and DOE has conditionally offered one for plant Vogtle; however, as of this writing no nuclear loan guarantees have been finalized.[119] Plant Vogtle is being built by a consortium of Georgia Power (45.7%), Oglethorpe Power Corporation (30%), the Municipal Electric Authority of Georgia (22.7%), and Dalton Utilities (1.6%). VC Summer is being built through a partnership of Santee Cooper (45 %) and South Carolina Electric & Gas (55%). Santee Cooper agreed to sell a portion of its ownership to the South Mississippi Electric Power Association in April 2012.[120]

Very few firms will have the financial capacity to build large nuclear plants; however, small modular reactors may provide less well capitalized utilities with a nuclear option. Figure 18 shows the relationships between December 2012 corporate capitalization book values for major utilities and the cost of a dual unit AP1000 nuclear power plant.[121]

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[117] https://lpo.energy.gov/?page_id=39

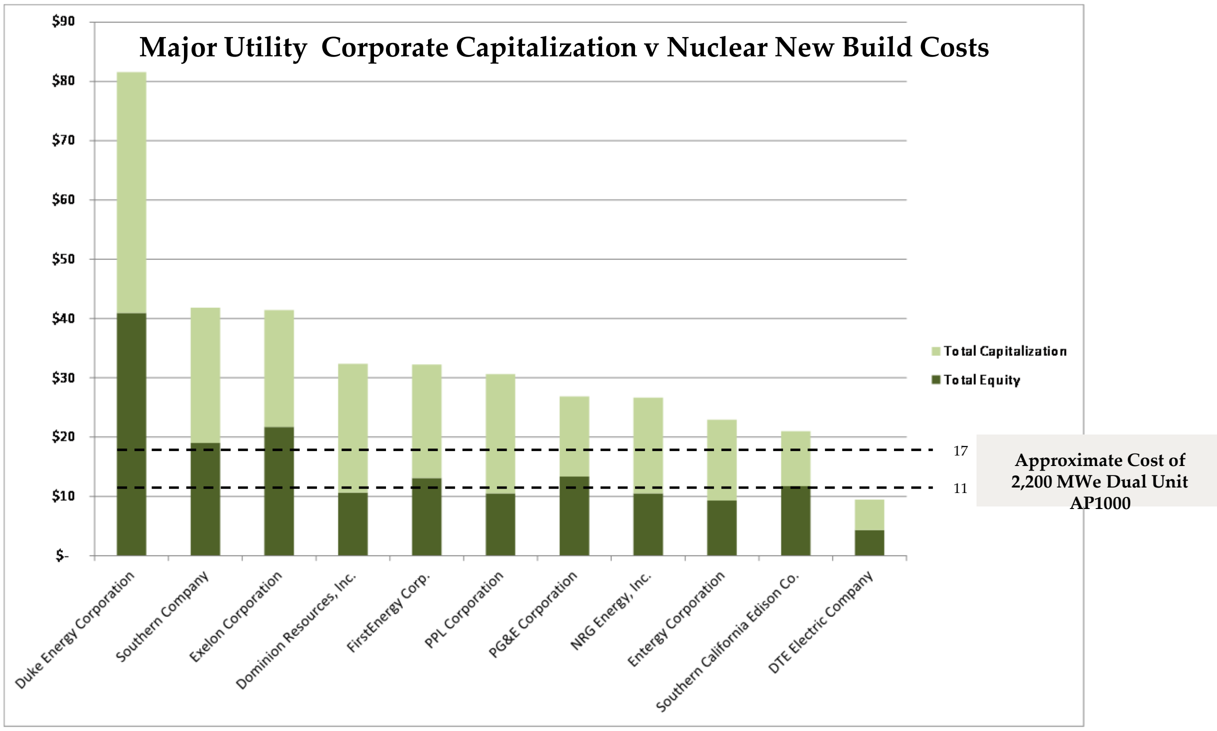
[118] Nuclear Loan Guarantees: Good Energy Policy? Snake River Alliance , August 2012

[119] http://www.ajc.com/news/business/southern-co-ceo-optimistic-on-vogtle-loan-guarante/nWwmj/

[120] http://www.power-eng.com/articles/2012/04/agreement-reached-for-share-of-new-vc-summer-nuclear-units.html

[121] Source of capitalization values-SNL

Figure 18. Corporate Capitalization v Nuclear Build Costs



All Figures in Billions

Figure 19 compares recent large nuclear plant overnight construction cost, which is defined as the cost to build the plant without considering inflation, escalation, or financing estimates from several data sources[122]. The OECD information is from an International Energy Agency (IEA) survey taken prior to the Fukushima accident. Korea and China cost estimates show the dramatic effects of lower labor costs.

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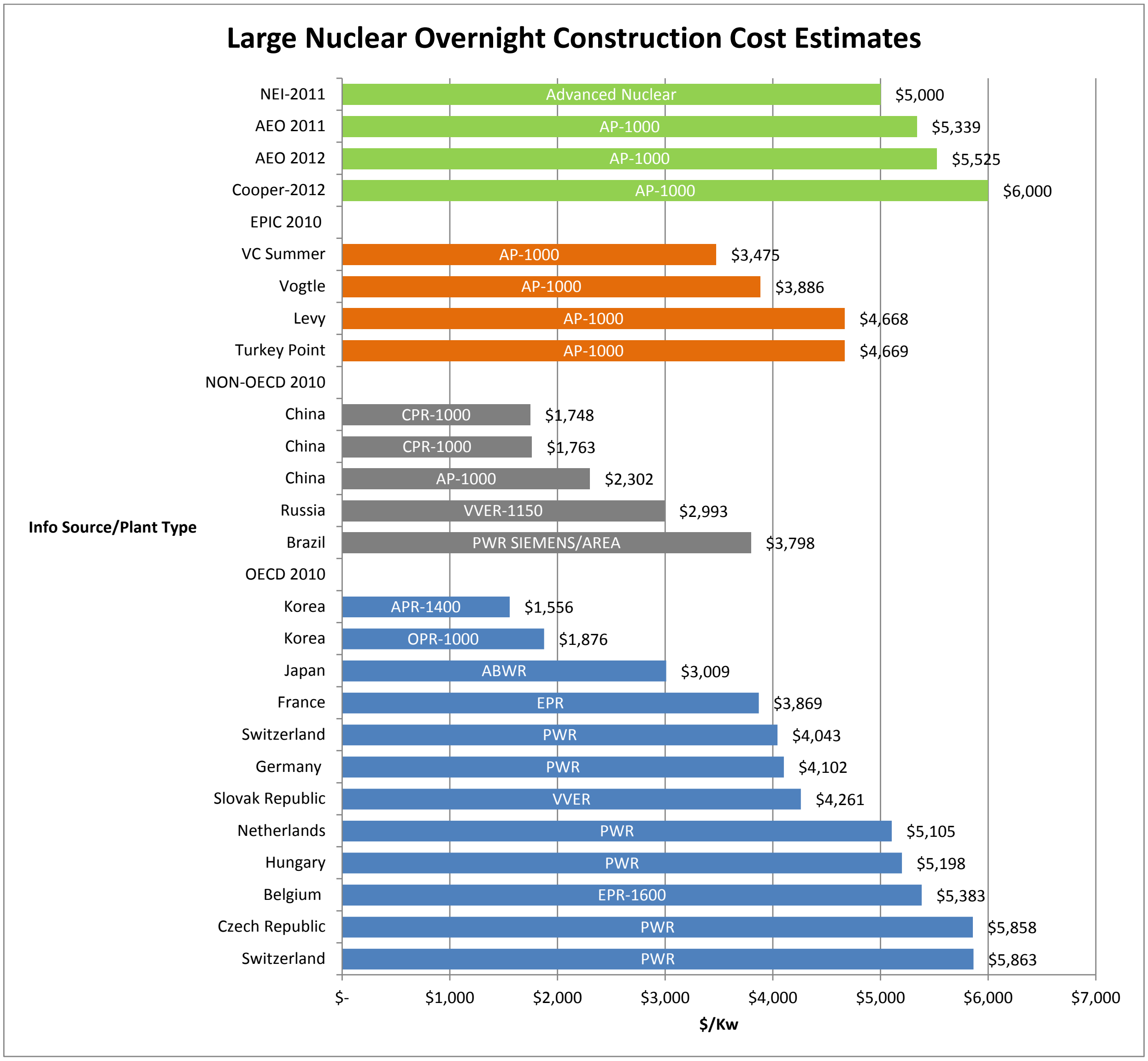
[122] OECD/Non-OECD/EPIC 2010 data from Analysis of GW-Scale Overnight Capital Costs, EPIC, November 2011;NEI 2011 from Nuclear Energy Institute, The Cost of New Generating Capacity in Perspective, January 2012; EIA Annual Energy Outlook 2011, AEO2012-EOP III Task 1606, Subtask 3 – Review of Power Plant Cost And Performance Assumptions For NEMS, SAIC December 2012;Cooper-2012, Public Risk, Private Profit Ratepayer Cost, Utility Imprudence, Mark Cooper, Institute of Energy and Environment Vermont Law School, March 2013

Figure 19. Recent Large Nuclear Overnight Construction Cost Estimates



A recent Energy Policy Institute of Chicago study estimated overnight costs for a lead small modular reactor at $7908/KW decreasing to $4778/KW for the 60th module[123]. High, uncertain, and escalating construction costs for nuclear plants have been the bane of the utility industry since the start of the AEC's demonstration program. Factory manufactured transportable modular reactors may provide the solution to this problem through the use of a consistent labor force and modern manufacturing techniques. Significant improvements are required in order to compete with the construction costs of

[123] Small Modular Reactors – Key to Future Nuclear Power Generation in the U.S, EPIC, November 2011

other baseload capable technologies as shown in the following table.[124] Navigant estimates that nuclear capital construction costs would have to be cut in half to be competitive on a LCOE basis with a natural gas combined-cycle plant based on today's market dynamics. If a U.S. policy towards carbon emissions were to evolve, nuclear power would become more economically competitive with carbon sequestered fuels as shown in Table 21. According to Southern Company Services, including CCS on combined-cycle systems results in nuclear power being more economic at 68% and higher capacity factors with moderate natural gas prices and $10/ton carbon prices (2008$).

Power uprates costs were reviewed in Section 3.2 and compare favorably with new nuclear plant construction costs. Exelon's $3000/KW overnight costs across various types of uprates is almost half the overnight cost for new U.S. nuclear construction shown in Table 24 and Figure 19.

Table 24. Overnight Costs Across Baseload Technologies (Source SAIC)

Technology	Capital Cost ($/KW)
IGCC with Carbon Sequestration	$6,599
Advanced Nuclear	$5,525
Advanced Pulverized Coal with Carbon Sequestration	$5,227
Integrated Gasification Combined-Cycle (IGCC)	$4,092
Advanced Pulverized Coal	$3,090
Hydroelectric	$2,936
Advanced NGCC with Carbon Sequestration	$2,095
Advanced NGCC	$1,023
Natural Gas Combined-Cycle (NGCC)	$917

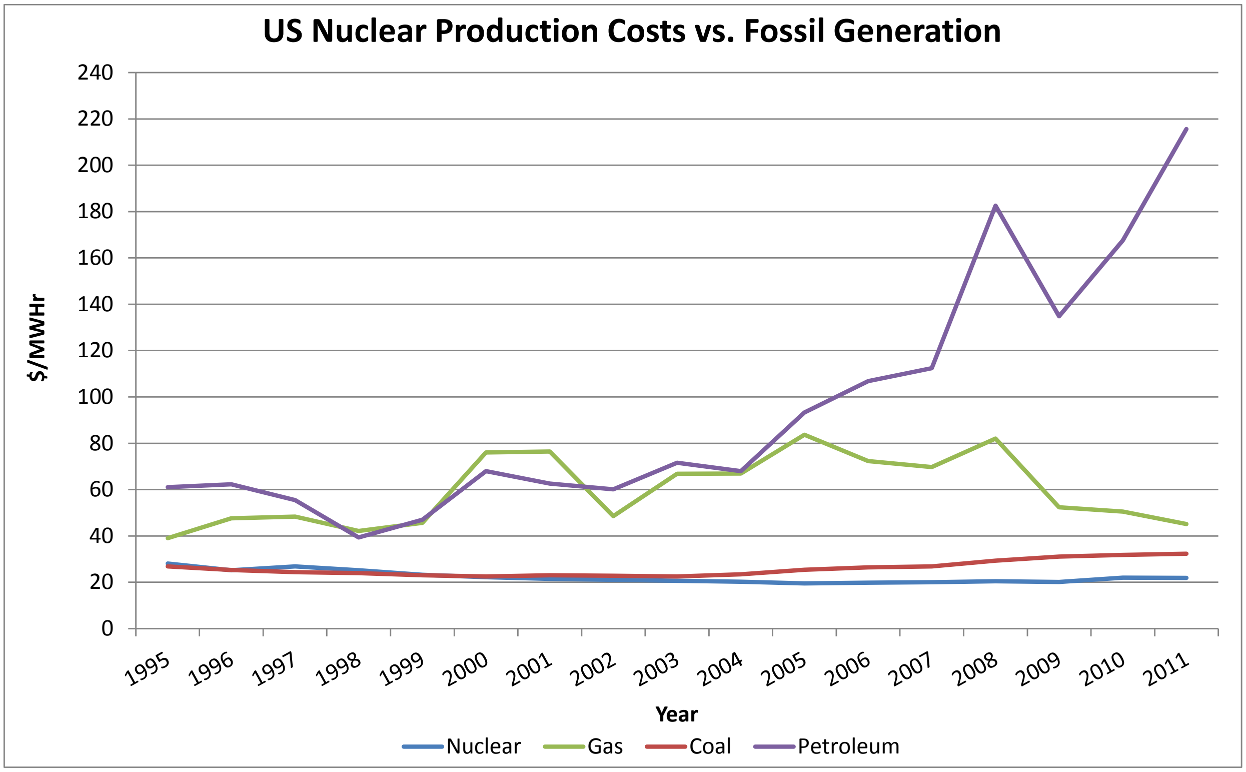
3.2 Operating Costs

The promise of nuclear power has always been that the high capital costs could be traded for extremely low operating costs. As shown in Figure 20, nuclear production costs, which include the cost of both fuel and operation and maintenance (O&M), compare favorability to those of fossil technologies. The production cost of nuclear power has been lower than coal-, gas-, and petroleum-powered generation for much of the last twenty years. It was only from 1987 to 1995 as the industry wrestled with Three Mile Island accident requirements that coal production costs were cheaper than those of nuclear production.[125]

[124] EOP III Task 1606, Subtask 3 – Review of Power Plant Cost And Performance Assumptions For NEMS, SAIC December 2012

[125] EIA Nuclear Outlook 1994

Figure 20. U.S. Nuclear Production Costs vs. Fossil Generation (1995-2011, in real 2011-$)

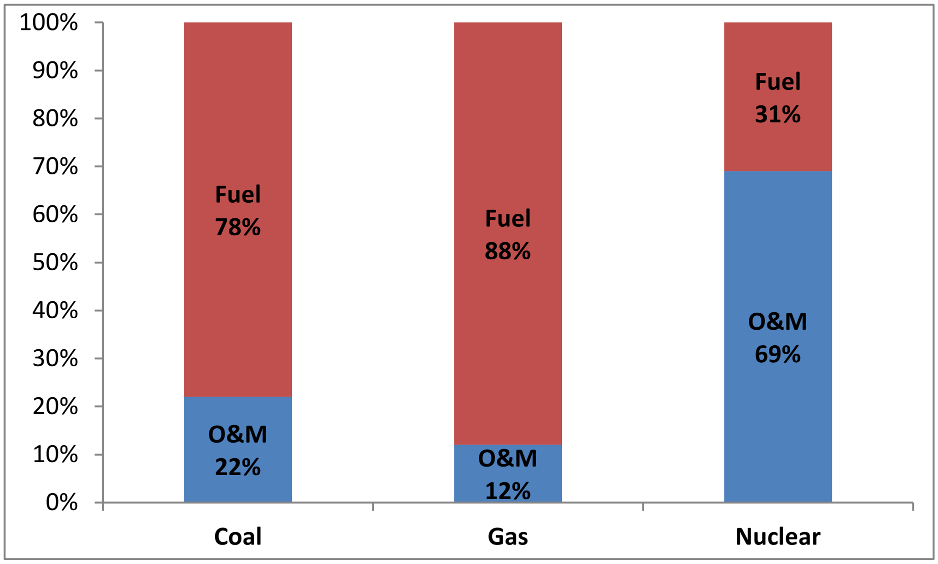


Source: NEI (2012); Ventyx Velocity Suite[126]

As shown in Figure 21, the production costs of nuclear power include a much higher concentration of non-fuel O&M costs than those of fossil generation.

[126] Production Costs = Operations and Maintenance Costs + Fuel Costs. Production costs do not include indirect costs and are based on FERC Form 1 filings submitted by regulated utilities. Production costs are modeled for utilities that are not regulated.

Figure 21. Fuel as a Percentage of Electric Power Production Costs (2011)



Source: *NEI (2012); Ventyx Velocity Suite*

Total production costs are often less volatile for nuclear generation than other fossil sources due to the reduced impact of fuel price uncertainty and sensitivity. Prices of electricity generated by coal- and natural gas-fired plants would be especially sensitive to a carbon tax. The Congressional Budget Office has estimated that a $21/metric ton tax on CO_2 would raise the average price of electricity 16% across the United States and as much as 27% in those states with significant coal-fired generation.[127]

Compared to other forms of generation, nuclear power plants employ more people on a local jobs/MWe basis. The fact that it is the most labor intensive source of generation in terms of local employment is reflected in its production costs. Table 25 shows a comparison of the local employment impacts of various generation technologies.

[127] COB May 2013, Effects of a Carbon Tax on the Economy and the Environment

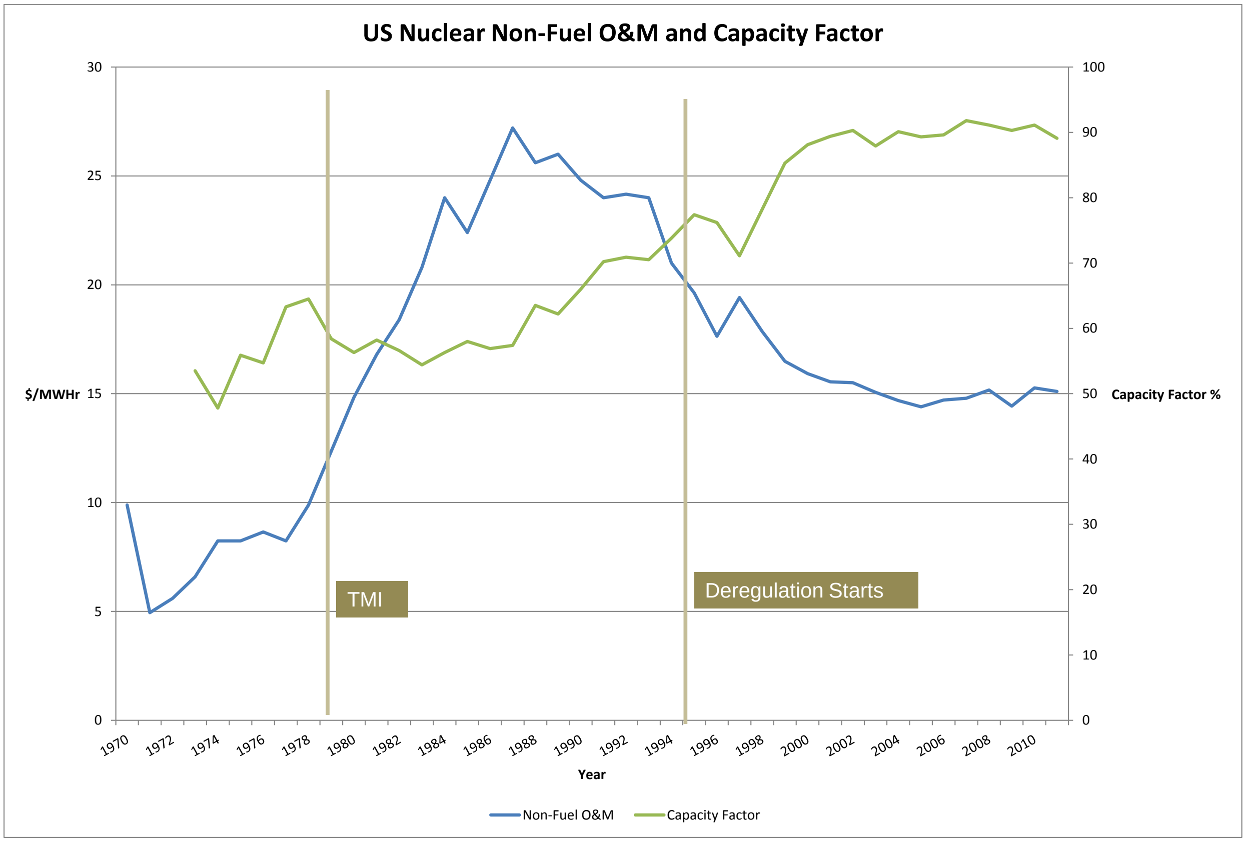
Table 25. Local Employment Effects of Various Generation Technologies

Technology	Jobs/MWe	Average Size (MWe)	Direct Local Jobs	Average Salary ($/hour)	Workforce Income ($/year)
Nuclear	0.5038	1000	504	$31	$32,485,024
Coal	0.1866	1000	187	$28	$10,987,904
Hydro > 500 MW	0.1137	1375	156	$33	$10,792,791
Hydro Pumped Storage	0.0954	890	85	$38	$6,696,842
Hydro > 20 Mw	0.19	450	86	$33	$5,790,470
CSP	0.47	100	47	$27	$2,618,990
Combined-Cycle	0.0544	630	34	$28	$2,018,100
PV	1.06	10	11	$15	$334,468
Micro Hydro < 20 MW	0.45	10	5	$35	$326,196
Wind	0.049	75	4	$35	$291,200

Throughout the history of nuclear power, certain events have caused dramatic shifts in non-fuel O&M costs. Most notable is the TMI accident's dramatic effect on nuclear non-fuel O&M costs during the 1980s. The myriad of requirements imposed by the NRC and INPO significantly increased nuclear plant staffing in a short period of time, which, when compounded with management problems, drove costs higher. As previously noted, nuclear production costs exceeded those of coal in 1987 and did not regain their cost advantage until 1995. The dramatic change in the industry's cost structure and competitive position led to increased focus on cost reduction and regulatory policy changes.

In 1995, the onset of deregulation forced the nuclear power industry to become more efficient, and the contemporaneous change in the NRC's regulatory philosophy allowed utilities the flexibility to reshape the workforce. The industry has done a remarkable job improving performance and driving down costs since the start of deregulation.

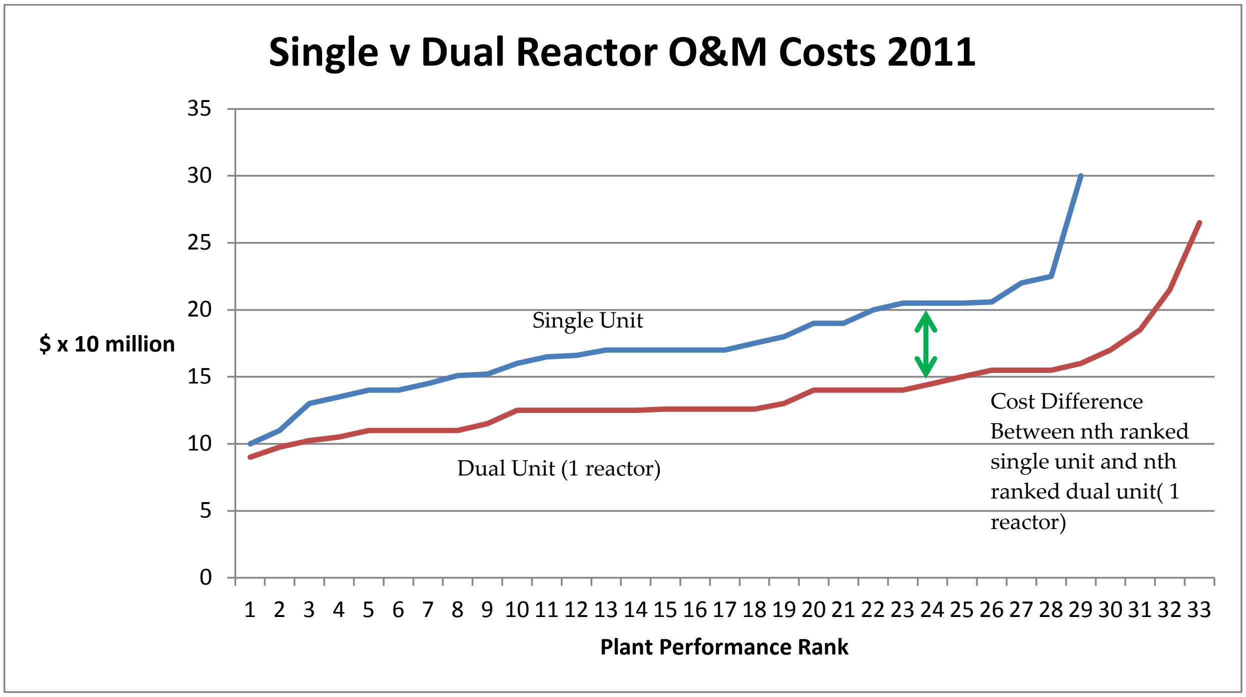
Figure 22. U.S. Nuclear Non-Fuel O&M Costs vs. Capacity Factor (1970-2011) (Source EIA, NEI, DOE)



During the period shown in Figure 22, capacity factors have consistently improved from the 50-60% range in the 1970s to a high of approximately 90% by the 2000s. This efficiency led to overall improvements in plant cost metrics (non-fuel O&M $/MWh), as fixed costs were spread over larger output due to increased capacity factors. It is somewhat unlikely that the capacity factors in the nuclear power industry will continue to improve, which is reflected by the minimal improvements shown over the past ten years. Therefore, any improvements in plant cost metrics will need to result from a reduction in non-fuel O&M expenses rather than increase in electrical output. Over the next decade, increasing pressures on general wage and material costs, plant aging related costs, healthcare reform costs, and Fukushima related modifications are likely to put pressure on nuclear utility margins.

This is especially true for well-performing single-unit nuclear power plants because they have higher production cost structures on a $/KW basis than their dual-unit counterparts. Figure 23 illustrates this point by comparing the 2011 relative O&M performance rankings of single-unit reactors to the relative 2011 O&M performance rankings of one unit in a dual-unit reactor site.

Figure 23. Single vs. Dual Reactor O&M Costs[128]



This figure indicates that the best run single-unit plant in the country spends slightly more in O&M dollars than one of the units in the best performing dual-unit plant. This difference in cost diverges to more than $50 million in O&M costs for the lower ranked units and explains why some single-unit plants may be financially vulnerable in deregulated markets.

EIA's 2012 cost assumptions for multiple technologies are provided in Figure 24 These costs reflect both fixed and variable O&M associated with various new-build generation technologies. From megawatt-hour operating cost perspective, nuclear generation is likely to remain competitive with most, if not all, future baseload and fossil technologies in the foreseeable future, and any carbon emission regulations or restrictions on shale gas extraction would enhance the economic attractiveness of nuclear generation.

[128] NCI generated using data from Figures 1 & 2 in Xcel Docket No. E002/GR-10-971,Exhibit___(DLK-1),Nuclear Operations, Testimony Mr. Dennis Koehl

Figure 24. EIA Technology Performance Specifications

Technology	Fuel	Nominal Capacity (kW)	Fixed O&M ($/kW-yr) (	Variable O&M ($/MWh)
Advanced Pulverized Coal	Coal	650,000	37.8	4.47
Advanced Pulverized Coal	Coal	1,300,000	31.18	4.47
Advanced Pulverized Coal with CCS	Coal	650,000	80.53	9.51
Advanced Pulverized Coal with CCS	Coal	1,300,000	66.43	9.51
NGCC	Gas	620,000	13.17	3.6
AG-NGCC	Gas	400,000	15.37	3.27
Advanced NGCC with CCS	Gas	340,000	31.79	6.78
Conventional CT	Gas	85,000	7.34	15.45
Advanced CT	Gas	210,000	7.04	10.37
IGCC	Coal	600,000	62.25	7.22
IGCC	Coal	1,200,000	51.39	7.22
IGCC with CCS	Coal	520,000	72.83	8.45
Advanced Nuclear	Uranium	2,236,000	93.28	2.14
Biomass Combined-Cycle	Biomass	20,000	356.07	17.49
Biomass BFB	Biomass	50,000	105.63	5.26
Fuel Cells	Gas	10,000	0	43
Geothermal – Dual Flash	Geothermal	50,000	132	0
Geothermal – Binary	Geothermal	50,000	100	0
MSW	MSW	50,000	392.82	8.75
Hydroelectric	Hydro	500,000	14.13	0
Pumped Storage	Hydro	250,000	18	0
Onshore Wind	Wind	100,000	39.55	0
Offshore Wind	Wind	400,000	74	0
Solar Thermal	Solar	100,000	67.26	0
Photovoltaic	Solar	20,000	27.75	0
Photovoltaic – Tracking	Solar	150,000	21.75	0
Photovoltaic – Tracking with 10% storage	Solar	150,000		
Photovoltaic – Tracking with 20% storage	Solar	150,000		

Source: *Review of Power Plant Cost and Performance Assumptions for NEMS (2012); EIA*

It is important to note that the "advanced nuclear" technology reflects two AP1000 PWRs. While there are several next generation advanced nuclear designs being discussed in the U.S. marketplace, the AP1000 is the furthest along in design certification and construction. Both power plants currently under construction in the United States (Georgia Power's Plant Vogtle and South Carolina Electric & Gas's VC

Summer) are AP1000 designs. While the nominal capacity and design features vary by design, the operating costs (per MWh) are not expected to be materially different. At this juncture, the best estimates for small modular reactors (< 300 MWe) assume that operating costs on a MWh basis will be similar to those of larger advanced reactors as shown above.

Table 26 shows the average levelized cost for plants entering service in 2018 based on EIA's 2013 Annual Energy Outlook. EIA added 3% to the cost of capital for non-sequestrated coal technology to illustrate the impact of a $15/metric ton CO_2 emissions fee. All values are in 2011 dollars.

Table 26. Levelized Cost of Electricity by Technology

Technology	2018 LCOE ¢/Kwh
Advanced Pulverized Coal	12.3
Advanced Pulverized Coal with CCS	13.55
Natural Gas Combined-Cycle (NGCC)	6.71
Advanced NGCC	6.56
Advanced NGCC with CCS	9.34
Conventional CT	13.03
Advanced CT	10.46
Advanced Nuclear	10.84
Hydroelectric	9.03
Onshore Wind	8.66
Offshore Wind	22.15
Solar Thermal	26.15
Photovoltaic	14.43

Source: EIA AEO 2013

3.2.1 Fuel Storage

Storage costs for spent nuclear fuel that remains onsite due to DOE's failure to create a geological repository are paid by the Department of Justice through the Federal government's Judgment Fund. Incremental costs to DOE for fuel stored at operating reactors are estimated at $1 million annually per site. Costs for stranded nuclear fuel where the reactor has been shut down are estimated at $4 to $8 million annually. The licensee's reimbursable costs are subject to reevaluation every few years and DOE's payments are adjusted accordingly.[129] A charge of $1 mill/Kwh is collected to fund the Nuclear Waste Fund for a future repository. This is discussed in greater detail in Section 7.

3.2.2 Fuel Cycle

The Massachusetts Institute of Technology investigated the economics of three different fuel cycles and determined that the current once-through cycle, in which spent nuclear fuel is disposed without

[129] Blue Ribbon Commission on America's Nuclear Future Section 8.5

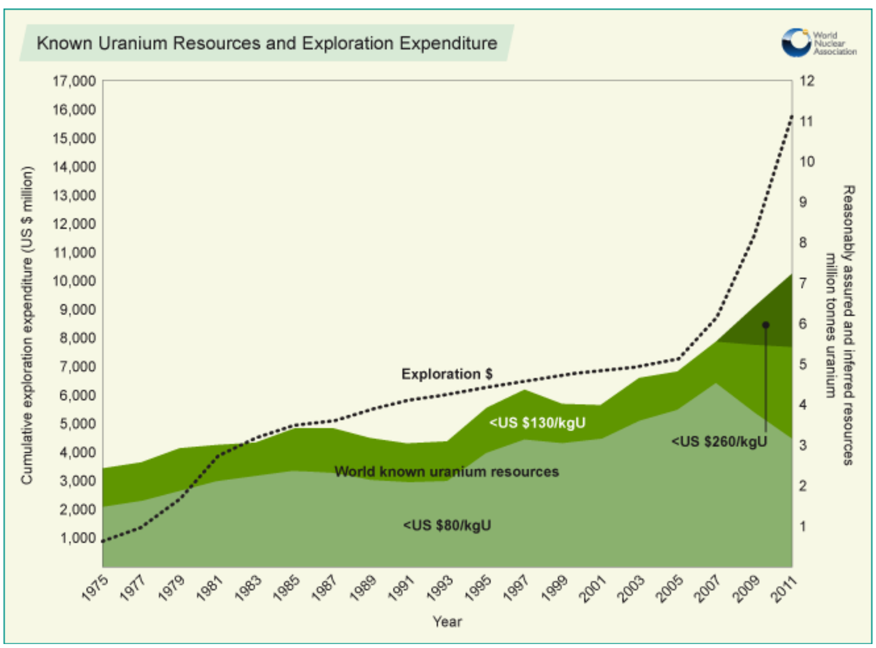
reprocessing, has the lowest LCOE on a mills/Kwh basis. The twice-through cycle refers to taking spent nuclear fuel and turning it into mixed-oxide fuel (uranium and plutonium) and then putting it back in a reactor for one cycle. The fast-fuel cycle refers to taking spent nuclear fuel and reprocessing it for use as fuel in a fast neutron reactor.[130]

Table 27. Cost Comparison of Nuclear Fuel Cycles

Fuel Cycle	LCOE mills/Kwh
Once-Through	83.81
Twice-Through (MOX)	85.38
Fast-Fuel	86.57

There is currently an abundant supply of uranium found throughout the world, with a third of proven deposits found in Australia while Russia, Canada, and Kazakhstan account for another third. Exploration is driven by the world price for uranium ore and as shown in Figure 25, as prices have increased, world reserves have increased threefold since 1975. It is estimated that there is an 80-year supply on hand to meet current needs, and IAEA estimates an additional 190-year supply could be found if ore prices were to increase.[131]

Figure 25. Proven Uranium Reserves (Source World Nuclear Association)

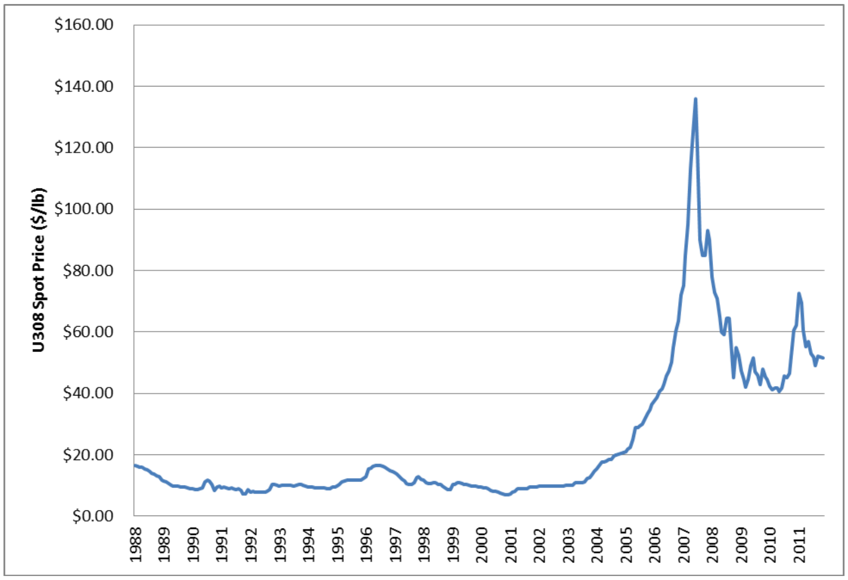


130 MIT The Future of the Nuclear Fuel Cycle 2011 Section 7

131 Worldnuclear.orghttp://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Uranium-Resources/Supply-of-Uranium/#.UWwSdsoZGmk

From 1994-2004, spot prices for uranium generally stayed within a range of $8-14/pound, in part due to dumping of blended weapons-grade uranium on the market. Beginning in 2005, prices began a long upward climb, peaking in late 2007. Since the late 2008 worldwide collapse in overall commodity prices, uranium oxide prices have drifted back to about $50/pound. This information is portrayed in Figure 26.

Figure 26. Uranium Price History (Source: Cameco Corp)



The continued release of weapons-grade uranium stockpiles has unnaturally depressed the uranium market and has postponed the cultivation of new mines. Under the Megatons-to-Megawatts ("M2M") program, the U.S. and Russia have agreed to reduce excess highly-enriched uranium (HEU) stockpiles through 2013. The amount of HEU blended down under this program has supplied 24%-35% of the world's fuel requirements over the past decade. On a global basis, current uranium mining output meets about 76% of demand, with the remainder coming from stockpiles and recycling of HEU from U.S. and Russian weapons-grade material. While the two countries have both announced further reductions in the number of deployed nuclear warheads, a commitment to further down-blend HEU beyond the amounts set forth in the Megatons-to-Megawatts program has not been reached. In anticipation of the program's expiration in 2013, market participants may drive uranium prices higher.

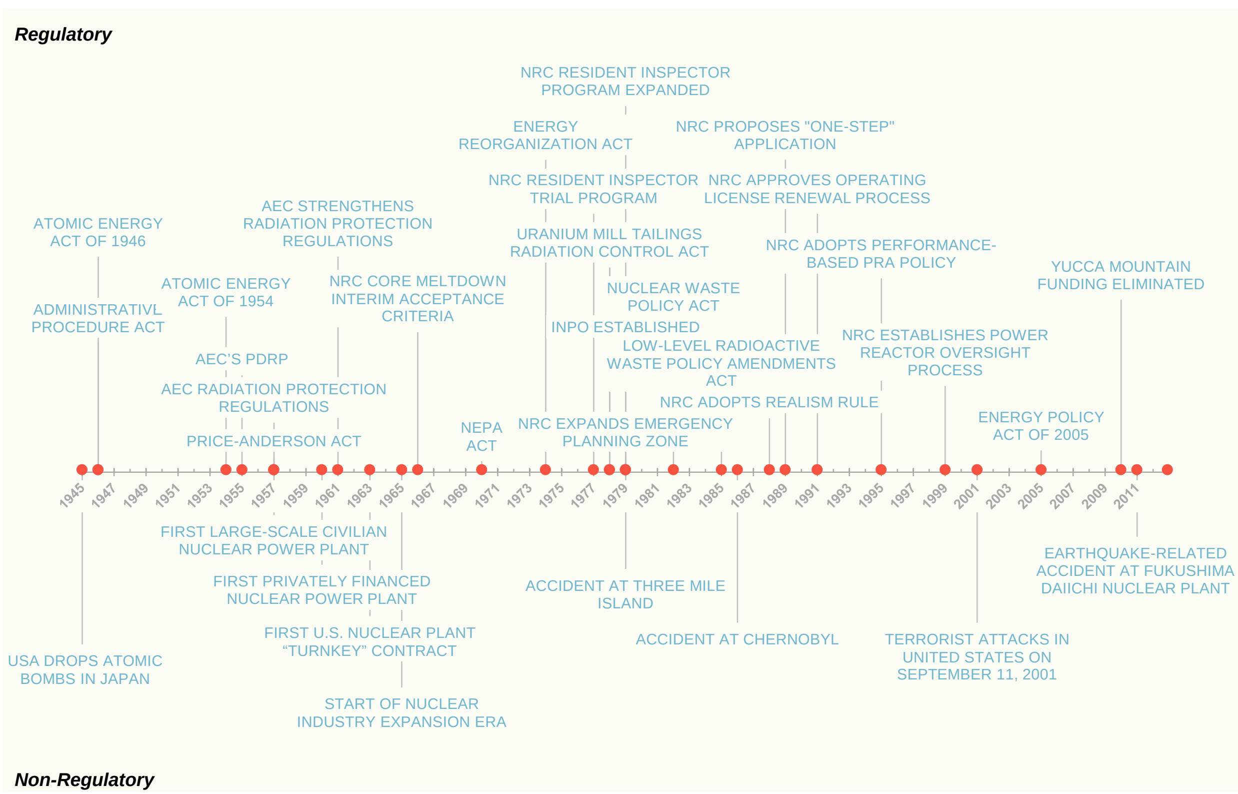
The U.S. civilian nuclear industry is reported to rely on HEU for 50% of its supply, and it has imported 80-85% of its uranium every year since the mid-1990s, reaching a high point of 92% in 2007. While the spike in prices that ended in 2007 reportedly prompted numerous new American claims, domestic mines are regarded as being toward the high end of the production cost range. Thus, if U.S. and Russian governments do not renew the M2M program beyond its 2013 expiration, thereby releasing additional HEU stockpiles for commercial use, there may be increased shortfall in global supply.

4. REGULATORY ISSUES

4.1 Introduction

At the end of World War II, the nation found itself the possessor of a vast infrastructure, technology, and knowledge base necessary to exploit the atom for military and civilian purposes. The Atomic Energy Act of 1946 transferred the wartime Manhattan Project facilities and personnel to the newly formed Atomic Energy Commission (AEC). In a sense, the personnel and facilities supporting the AEC never demobilized after World War II. For example, the Commission decided to adopt the Army's practice of hiring private corporations to continue to operate plants and laboratories, thereby extending into the postwar era the contractor system previously used by the Government only in times of national emergency[132]. Another example is the Commission's total control over the classification and dissemination of any information related to atomic energy. In addition to determining how to promote civilian use of nuclear power, the government had to determine how to regulate this novel technology. Figure 27 depicts a timeline of major regulatory and non-regulatory events.

Figure 27. Historical Timeline of Regulatory and Non-Regulatory Nuclear Industry Events



[132] History of the AEC Alice Buck July 1983 p.1

4.2 *Atomic Energy Commission Era*

The foundation for nuclear power regulation within the United States is found in the following three pieces of legislation.

1946 – Administrative Procedure Act

The Administrative Procedure Act (APA) enacted in 1946 governs the process by which Federal agencies develop and issue regulations and is one of the most fundamental laws to govern regulatory agencies.[133] The law established the requirements of publishing notices of rulemaking in the Federal Register and provides opportunities for public comment and standards for judicial review. The APA addresses many agency actions such as issuance of policy statements, licenses, and permits, and has thus been a primary governing legislation for the AEC/NRC. The Act has been amended often and now incorporates several other acts that cover a large range of processes.

1946 – Atomic Energy Act of 1946

The Atomic Energy Act (AEA) of 1946 established the U.S. Atomic Energy Commission (AEC) to promote the "utilization of atomic energy for peaceful purposes to the maximum extent consistent with the common defense and security and with the health and safety of the public." The Act enabled the AEC to manage and oversee the United States atomic energy programs, which included military and civilian programs. Under the Act, the Government retained ownership of all uranium and special nuclear material as well as the authority to classify and control all information it felt relevant.

1954 – Atomic Energy Act of 1954

The Atomic Energy Act (AEA) of 1954 (as amended in NUREG-0980), is the fundamental U.S. law on both the civilian and the military uses of nuclear materials. The Act directed the AEC to "encourage widespread participation in the development and utilization of atomic energy for peaceful purposes," and encouraged private industry to build its own nuclear plants using nuclear material leased from the U.S. Government. The Act also assigned the Commission three major functions:

- Continue its weapons programs;
- Promote the commercial uses of nuclear power; and
- Protect against the hazards of those peaceful applications.

Over time, the competing responsibilities and the precedence the AEC gave to its military and promotional duties damaged its credibility and undermined public confidence in its ability to protect public health and safety.

1955 – Atomic Energy Commission's Power Demonstration Reactor Program

The activities of the PRDP are described in the Background Section of this whitepaper.

[133] http://www.epa.gov/lawsregs/laws/apa.html

1957 – AEC Establishes Radiation Protection Regulations

Prior to this regulation, the AEC had used occupational limits in its government installations that were set by the National Committee on Radiation Protection (NCRP), and in 1957, this regulation extended these limits to commercial licensees. The AEC's radiation protection regulation followed NCRP's recommendations for radiation workers. The AEC then set the permissible dose for the general public to one-tenth of the occupational level. The purpose of these efforts was to develop standards for the first civilian nuclear power plants. By calculating the permissible radiation limits at the fence line, engineers and regulators could proceed with evaluating plant designs.

1957 – The Price-Anderson Act

In August 1957, Congress passed the Price-Anderson Nuclear Industries Indemnity Act (Price-Anderson Act) as an amendment to the Atomic Energy Act (AEA) of 1946 to govern liability-related issues at non-military nuclear facilities. The Price-Anderson Act established a government program to underwrite an additional $500 million of insurance beyond the limited amounts that reactor owners were able to secure at the time from private industry. The Act alleviated significant obstacles to private atomic development and included reforms to the AEC's licensing procedures. The Price-Anderson Act has since been renewed, amended, and extended in 1966, 1969, 1975, 1988, 2003, and 2005 (via Energy Policy Act of 2005) and provides $10 billion in insurance to the industry today. This amount is equivalent to covering the damage from a major hurricane like Hurricane Irene, which struck the East Coast in 2011.[134]
The Act also required public hearings on all reactor license applications and made ACRS reports on licensing public.

1958 – AEC Requires Applicants to Outline Radiological Emergencies Plans

In 1958, the AEC required applicants for nuclear power plant operating licenses to file plans and clarify procedures for dealing with radiological accidents and emergencies.[135]

1961 – AEC Strengthens Radiation Protection Regulations

In response to increasing public concern and the findings of scientific groups, the AEC reduced the limits for occupational exposure to an average of 5 rem per year (after the age of 18) and restricted general population exposure levels to 10% of the occupational levels (0.5 rem/yr) for individuals.

1965 – Start of Significant Nuclear Industry Expansion

The rapid increase in both the number of reactor applications and the unit size of the proposed plants significantly increased the burdens on the AEC's regulatory staff, which caused licensing delays. Between 1965 and 1970, the AEC's licensing and inspection caseload increased by approximately 600%, but the number of AEC regulatory staff increased only by about 50%. This discrepancy led to a bottleneck in the AEC permitting process, and the average time required to process a construction permit application stretched from about one year in 1965 to over 18 months by 1970.

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[134] http://www.nytimes.com/2011/08/31/us/31floods.html?pagewanted=all&_r=0
[135] http://www.nrc.gov/about-nrc/emerg-preparedness/history.html

1970 – AEC Proposes Changes to Emergency Planning
After a review of existing emergency preparedness regulations during the late 1960s, the AEC proposed a list of items that each nuclear plant emergency plan should contain. The items were included in a new Appendix E to 10 CFR Part 50.

1970 – National Environmental Policy Act (NEPA)
In 1970, President Nixon signed the National Environmental Policy Act (NEPA) into law, which required Federal agencies to consider the environmental impact of their activities. The AEC included non-radiological issues in its regulatory jurisdiction starting in 1970, but deferred to the environmental assessments of other Federal and State agencies rather than conducting its own. The AEC initially agreed to consider environmental issues in licensing board hearings only if a party to the proceeding raised the issues. This narrow view of responsibilities drew criticism from environmentalists and resulted in the AEC being ordered by the Federal courts to consider environmental impacts of the Calvert Cliffs nuclear plant in its licensing proceedings. The AEC was forced to delay all licensing activity for approximately one year as a result of this ruling.

1971 – AEC Releases "Interim Acceptance Criteria" for Emergency Core Cooling Systems to Prevent Core Meltdown
In existing smaller reactors, experts were confident that if a loss-of-coolant reactor accident led to a core meltdown that continued to melt through the pressure vessel, the containment structure would ultimately prevent a massive release of radioactivity to the environment. As proposed plant sizes continued to increase, concerns of a core meltdown leading to a breach of containment escalated. The AEC deemed the chances of such an accident in a newer larger unit as low, but conceded that it was possible if a failure with the emergency core cooling system (ECCS) were to occur. In 1966, the AEC chartered a task force to look into this potential issue, and the findings corroborated the AEC's concerns that a loss-of-coolant accident could cause a breach of containment if the ECCS failed to perform.
The AEC focused to ensure that each ECCS was properly designed and functioning, and through its safety research program, looked to test the reliability of emergency cooling. By 1970-1971, experiments at AEC's reactor test site in Idaho suggested that the ECCS may not always work as designed. The AEC soon chartered another task force to review this issue, but in June 1971, before the team had finalized its report, the AEC published "interim acceptance criteria" for ECCSs that licensees would be required to meet. The criteria imposed a series of requirements that the AEC believed would ensure successful ECCS operations, thus preventing a core meltdown after a loss-of-coolant accident. One requirement mandated that manufacturers and utilities set an upper limit on the amount of heat generated by reactors.

1973 – AEC Releases "Final Acceptance Criteria" for Emergency Core Cooling Systems to Prevent Core Meltdown
After news about the failed experiments circulated, the AEC was criticized for failing to fully evaluate the technical uncertainties of the problem before releasing the "interim acceptance criteria" for ECCSs in 1971. Critics charged that the AEC acted too quickly, hoping to prevent the issue from undermining public confidence in the nuclear industry or causing additional licensing delays. Due to increasing public outcry, the AEC decided to hold a rulemaking hearing on the ECCS issue during 1972-1973, and a final rule was released in 1973. The final rule made some small, but important updates to the "interim acceptance criteria."

4.3 Beginning of Nuclear Regulatory Commission

1974 – Energy Reorganization Act of 1974

Throughout the 1970s, the AEC had been criticized for its dual-responsibilities in both developing and regulating the civilian nuclear industry. The AEC had historically held responsibility for both components of the civilian nuclear industry as well as for the development and production of nuclear weapons.[136] Under the Energy Reorganization Act of 1974, Congress voted to divide the AEC's responsibility into two separate agencies: U.S. Nuclear Regulatory Commission (NRC), and the U.S. Energy Research and Development Administration (ERDA).

The NRC began operations in January 1975 with a statutory mandate clearly focused on ensuring the safety of nuclear power. While the NRC was the final arbiter for regulatory issues and continued to perform many of the existing AEC licensing and rulemaking functions, it no longer was burdened with developmental priorities. The separately aligned ERDA was granted the responsibility for the development and production of nuclear weapons, promotion of nuclear power, and other energy-related work.

1974 –NRC Resident Inspector Trial Program

In 1974, the NRC tested a trial program focused on improving utility practices and quality assurance (QA) programs and introduced a "higher incentive" for performance through increased fines for failures. The NRC stationed "resident inspectors" at two plant sites to provide regular onsite verification of utility compliance, instead of relying on data gathered during infrequent visits from regionally-based inspectors. In 1977, the NRC determined that the resident inspector concept was workable and expanded the program to more facilities.

1977 – NRC Publishes Emergency Planning Regulatory Guide

In 1977, the NRC published the Regulatory Guide 1.101 to provide additional clarity and detailed information on the development of nuclear plant emergency plans.

1978 – Nuclear Non-Proliferation Act of 1978

The Nuclear Non-Proliferation Act of 1978 was established to limit the spread of nuclear weapons. The Act established a framework for international cooperation to: ensure peaceful nuclear activities while still meeting global energy needs; to strengthen international safeguard systems; and to set criteria governing U.S. nuclear exports licensed by the NRC.[137]

1978 – Uranium Mill Tailings Radiation Control Act of 1978

The Uranium Mill Tailings Radiation Control Act of 1978 established programs to stabilize and monitor uranium and thorium waste mill tailings at inactive and active mill sites in order to minimize radon diffusion into the environment.[138] The Act outlines responsibilities for the Environmental Protection Agency (EPA), Department of Energy (DOE), and the Nuclear Regulatory Commission (NRC).

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[136] http://www.nrc.gov/about-nrc/governing-laws.html
[137] http://www.nrc.gov/about-nrc/governing-laws.html
[138] http://www.nrc.gov/about-nrc/governing-laws.html

Title I of the Act addresses inactive uranium mill tailing sites, depository sites, and vicinity properties. The EPA was given authority to set health, environmental, and protection standards to govern the stabilization, restoration, disposal, and control of effluents and emissions. The DOE was tasked with implementing the EPA's standards and the NRC was tasked with reviewing the compliance of completed site cleanups and license sites for perpetual care.

Title II of the Act covers operating uranium processing sites licensed by the NRC. The EPA was given authority to set disposal standards (in compliance with Subtitle C of the Solid Waste Disposal Act) and the NRC was given the implementation responsibility. In 1993, the Act was amended to extend EPA direction to promulgate general environmental standards for the processing, possession, transfer, and disposal of uranium mill tailings, which the NRC was required to then implement.

4.4 Post Three Mile Island

1979 – The Accident at Three Mile Island
In March 1979, an accident at the Three Mile Island Nuclear Station (TMI) near Harrisburg, Pennsylvania, fueled public concerns regarding the dangers of nuclear energy. The TMI accident focused industry attention on a much larger realm of potential nuclear accident root causes, and drove the NRC to reexamine its previous assumptions, safety programs, and mitigation strategies.

1979 – NRC Resident Inspector Program Expanded
Based on a review of TMI, which was partially caused by human errors, the NRC expanded its emphasis on the impact of "human factors" on plant operations. The NRC reevaluated the adequacy of its safety requirements and aimed to address deficiencies through new regulation, including requirements focused on improved operator training, testing, and licensing. The NRC also reviewed the adequacy of control rooms and instrumentation. One of the most significant changes introduced by the NRC in 1979 was the permanent expansion of its resident inspector pilot program, which required at least two of its inspectors stationed at each plant site. This move targeted an increase in the agency's onsite monitoring and independent assessment capability, and it is still in practice today.

The NRC established a new office to review and evaluate plant operations and performance data from licensees. The NRC also ramped up its review of radiation protection procedures and research initiatives focused on problems identified during TMI post-accident analysis.

1979 – NRC Expands Emergency Planning Zone
The NRC targeted improvements in emergency preparedness and planning after identifying deficiencies and gaps during TMI post-accident analysis. NRC actions were meant to both reduce the likelihood of future accidents and improve the collective response efforts of the NRC, the utility, and the public. The NRC required each nuclear utility to develop an "emergency planning zone" evacuation plan for the local population within a 10-mile radius of each plant. This rule applied to all operating and under-construction plants, and required plant owners to collaborate with State and local police, fire, and civil defense authorities to develop an emergency plan that would be tested and evaluated by the NRC and the Federal Emergency Management Agency (FEMA).

In 1980, a new emergency planning rule put a hold on new operating licenses until applicants provided a satisfactory emergency plan to the NRC. Existing nuclear power plant owners were required to develop satisfactory emergency plans by April 1981 to avoid further sanctions.

1979 – The Kemeny Commission & Institute of Nuclear Power Operations (INPO)
In 1979, President Jimmy Carter established the Kemeny Commission to investigate and evaluate the TMI accident. The Commission recommended that the nuclear power industry develop a program to systematically gather, review, and analyze operating data; identify and share best practices; specify safety standards; and conduct independent evaluations. It was also recommended that the program be integrated with an industry-wide communications network to promote better information flow and transparency.

1979 – Institute of Nuclear Power Operations (INPO)
Acting on the recommendations of the Kemeny Commission, the nuclear power industry established and funded the Institute of Nuclear Power Operations (INPO). INPO was chartered to set industry-wide performance objectives, criteria, and guidelines for nuclear power plant operations and assist the industry in plant evaluations, training and accreditation, events analysis, and information exchange.

1980 – 1988 NRC Implements Changes to Nuclear Plant Oversight Process
The Kemeny Commission recommended that "each operating licensee should be subject periodically to intensive and open review of its performance according to the requirements of its license and applicable regulations." Over the course of several years during the early-to-mid 1980s, the NRC instituted changes to the NRC oversight process.[139] Once implemented, the performance assessment process involved three processes:

- Systematic Assessment of Licensee Performance (SALP),
- Senior Management Meetings (SMM), and
- Plant Performance Review (PPR).

Systematic Assessment of Licensee Performance (SALP)
In 1980, the NRC developed and implemented the Systematic Assessment of Licensee Performance (SALP) process to formally evaluate integrated safety performance at each plant. The SALP program objectives (as amended) provided a framework to: (1) conduct an integrated assessment of licensee safety performance that focused on the safety significance of the NRC findings and conclusions during an assessment period; (2) provide a vehicle for meaningful dialogue with the licensee regarding its safety performance based on the insights gained from synthesis of NRC observations; (3) assist NRC management in making sound decisions regarding allocation of NRC resources used to oversee, inspect, and assess licensee performance; and (4) provide a method for informing the public of the NRC's assessment of licensee performance.[140]

[139] COMSECY-98-024, "Response to Issues Raised Within the Senate Authorization Context and July 17, 1998 Stakeholder Meeting; http://www.nrc.gov/reading-rm/doc-collections/gen-comm/admin-letters/1998/al98007.html
[140] Federal Register / Vol. 60, No. 147

While the NRC required onsite inspectors to prepare assessment reports for each plant approximately every six weeks, the SALP process required the NRC staff to perform a separate comprehensive assessment of each plant every 12 to 24 months and prepare a report with a description and numerical rating of plant performance in four key areas: plant operations, maintenance, engineering, and plant support. The NRC then used SALP reports as a guide for determining the plants' need for additional inspection attention.

Senior Management Meetings
In 1986, the NRC required a twice per year Senior Management Meeting (SMM) forum where NRC senior managers gathered to review industry data, assess plant performance, and discuss potential regulatory action needed at specific plants with declining performance. The primary goal of establishing the SMM was to identify declining trends in the safety performance of individual plants so that early corrective actions could be implemented.

The objectives of the SMM process were noted as follows: (1) to communicate the concerns of senior NRC managers to licensees of plants with poor performance or adverse performance trends; (2) to ensure that coordinated courses of action are developed and implemented for licensees of concern before problems reveal themselves as significant events; (3) to formally recognize nuclear power plants that have demonstrated superior operational safety performance; (4) to review significant generic issues affecting nuclear power plants, major fuel cycle facilities, and materials licensees; and (5) to inform the Commission, the Congress, and the public of senior management decisions.

"Watch List"
As part of the SMM oversight process, NRC senior managers designated certain plants thought to require heightened monitoring as being on a "watch list." Plants placed on the "watch list" were then discussed at a public meeting with the Commission, which often led to increased NRC oversight, additional inspections, and letters to licensees expressing NRC's concern about declining performance or other actions.[141]

The NRC "watch list" consisted of three categories. Category 3 included plants that have been shut down and require Commission authorization to restart. Category 2 listed plants still authorized to operate, but that required increased NRC monitoring. Category 1 tracked plants previously removed from the "watch list" (i.e., plants previously designated as Category 2) to ensure the maintenance of improved performance.

Plant Performance Review
In 1988, the NRC implemented the formal Plant Performance Review (PPR) process to provide a shorter term (semi-annual) integrated review of licensee performance than was provided by the SALP program. The NRC implemented PPRs every six months to assess events, inspection findings, and other data. The reviews integrated future inspections planning and identified those plants with declining performance that required further NRC attention and action. After completion, the NRC sent PPR results to licensees, and included relevant performance issues documented in a Plant Issues Matrix (PIM).

[141] http://www.gao.gov/assets/230/224271.pdf

Nuclear Plant Oversight Process Update:
In June 1996, the NRC directed the staff to assess the effectiveness of the SMM and Watch List processes. In June 1997, the NRC Commissioners approved the staff's plan to improve the SMM process based on recommendations from a related Arthur Anderson study (1996). The NRC initiated a robust and integrated review of the entire safety monitoring and assessment program, including the SALP, SMM, and the PPR. This initiative was called the Integrated Review of the Assessment Process (IRAP), and among other considerations was intended to address criticisms of the current process as expressed by multiple stakeholders, including Congress, the industry, and the public. In September 1998, the NRC suspended the SALP program to allow for a complete review of its process for assessing performance at nuclear power plants.[142] As the NRC revamped its safety monitoring program, the Reactor Oversight Process (ROP) replaced SALP, and the Action Matrix replaced the Watch List. Refer to "Reactor Oversight Process" discussion for more information.

1982 – Nuclear Waste Policy Act of 1982
In 1982, Congress passed the Nuclear Waste Policy Act (NWPA) and set a timetable and procedures for establishing permanent geologic repositories for the safe storage and/or disposal of nuclear industry radioactive waste. The NWPA assigned responsibilities to multiple agencies. The DOE was directed to site, build, and operate the repository. The EPA was directed to develop standards for environment protection from offsite radioactive releases of material. The NRC was directed to license the DOE to operate the repository once it passed EPA's standards and requirements.

In 1987, Congress amended the NWPA to designate the Yucca Mountain site in Nevada as the nation's first permanent nuclear waste repository. It should be noted that the DOE has spent billions of dollars to evaluate this project for potential use, but it has yet to become operational and accept waste. Ultimately, in early 2010, President Barack Obama proposed eliminating project funding; and later that year, the DOE filed a motion to withdraw its license application. No permanent nuclear waste repository has since been identified.

1986 – The Accident at Chernobyl
In April 1986, an accident at the Chernobyl nuclear power station in Ukraine. The accident at Unit 4 occurred during a planned test after operators turned off the plant's safety systems and subsequently lost control of the reactor reactivity. The plant had no emergency cooling or containment building to stop or minimize the impact of the accident, and the explosion destroyed the reactor and released large amounts of radioactivity directly into the environment. The Chernobyl accident again peaked public concerns regarding the dangers of nuclear energy and raised questions as to whether changes were needed to NRC regulations or guidance regarding reactivity accidents, operator training, and emergency planning.[143] After a detailed review of the accident, the NRC determined that due to significant design differences between U.S. and Soviet nuclear plants, no significant changes in safety regulations were needed.

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[142] NRC Administrative Letter 98-07; Interim Suspension of the Systematic Assessment of Licensee Performance (SALP) Program (10/2/1998) http://www.nrc.gov/reading-rm/doc-collections/gen-comm/admin-letters/1998/al98007.html
[143] http://www.nrc.gov/about-nrc/emerg-preparedness/history.html

1988 – NRC Adopts Realism Rule
In 1988, the NRC adopted a "realism rule" to confirm that in cases where the State and local government officials declined to participate in nuclear utility emergency planning exercises, the NRC and the Federal Emergency Management Agency would step in to review and evaluate plans developed by the utility.[144] The "realism rule" recognized that State and local officials generally do their best to protect the public health and safety and provided a contingency for states that had reservations about participating in emergency planning. The rule developed in response to the efforts by state and local officials who refused to participate in emergency planning preparations for nuclear plants. This became an issue for Shoreham Nuclear Power Plant which was completed, but could not be licensed over objections to its emergency plans.

1989 – NRC Proposes "One-Step" Application: Combined Construction Permit and Operating License
In 1989, the NRC revised licensing requirements and proposed a one-step licensing procedure to replace the traditional two-step process (construction permit and operating license applications). The NRC made this revision to ease the burden on applicants and streamline the regulatory process, which had become a deterrent to utilities considering new nuclear plant capacity. The new application combined the existing construction permit with an operating license and added much needed predictability to the process. NRC must still authorize specific acceptance criteria prior to commencement of plant operations.

The NRC also allowed for submission of an Early Site Permit prior to the one-step combined license, which added a greater degree of certainty to the process by allowing applicants to gain approval for reactor sites prior to finalizing reactor design specifics.

1991 – NRC Approves Operating License Renewal Process
In 1991, the NRC provided regulatory framework for renewal of the original 40-year operating licenses of nuclear power plants for a maximum length of 20 years. At this time, the first wave of nuclear plant installations was approaching license expiration and the NRC concluded it was reasonable to offer a renewal option provided that the "current licensing basis" was modified to account for age-related safety issues.

4.5 Shift in Regulatory Policies

1995 – NRC Adopts Performance-Based Probabilistic Risk Assessment Policy and Undergoes Policy Shift from "Prescriptive" to "Performance-Based" Regulation
In the late 1980s the NRC launched an initiative to shift from "prescriptive" to "non-prescriptive performance-based" regulation. The Commission also encouraged a greater focus on probabilistic risk assessment (PRA) applications, which it had first introduced to power plant owners in the 1970s. The NRC began to evaluate more opportunities to factor risk assessment and performance indicators into the regulatory process.

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[144] http://www.nrc.gov/about-nrc/emerg-preparedness/regs-guidance-comm.html

However, progress was slow and by the mid-1990s, the nuclear industry was calling for increased reform. A 1994 report prepared for the Nuclear Energy Institute (NEI) by Towers Perrin recommended an even greater emphasis on non-prescriptive performance-based regulations and assessments as a way to improve overall industry performance. The report claimed that NRC resident inspector evaluations often appeared inconsistent and arbitrary and that the agency's regulatory approach made little effort to distinguish between safety and non-safety issues

In 1995, the NRC's inspector general concluded that resident inspectors often lacked a clear understanding and approach for implementing performance-based regulation. The NRC responded by revising inspection guidelines and inspector training programs. It also adopted a policy statement encouraging broad implementation of PRAs in the regulatory process, favoring a risk-informed and performance-based approach to regulation.

2000 – NRC Establishes Reactor Oversight Process (ROP)

In 1996, the NRC directed the staff to assess the effectiveness of the SMM and Watch List processes. The following year, the NRC initiated a more complete and integrated review of the agency's entire safety monitoring and assessment programs, including the SALP, SMM, and the PPR. This initiative, called the Integrated Review of the Assessment Process (IRAP), was designed to address criticisms of the current oversight process expressed by multiple stakeholders, including Congress, the industry, and the public. These concerns included the following: increased number of Severity Level IV violations; perceived lack of NRC focus on priority safety issues; and overly subjective and inconsistent oversight process. In 1998, the NRC suspended the SALP program until it completed its review of its regulatory and safety monitoring program for nuclear power plants.[145]

After a successful pilot in 1999, the NRC implemented a new Reactor Oversight Process (ROP) to replace SALP in April 2000. The ROP was aimed at integrating inspection, enforcement and assessment of nuclear power plants in a risk-informed, performance-based system to ensure the appropriate level of NRC oversight of licensees. The ROP reflected a consolidation, refinement, and integration of several ongoing NRC initiatives, focused on issues such as: licensing activities; reactor licensee performance assessment; risk-informed, performance-based regulations; reactor inspection and enforcement; and NRC organizational structure.[146]

The ROP regulatory oversight framework is a risk-informed, tiered approach to ensuring plant safety, and it is still the guiding nuclear regulatory program today.[147] Within the regulatory framework are three key strategic performance areas: reactor safety, radiation safety, and safeguards. Within each strategic performance area are a total of seven cornerstones that reflect the essential safety aspects of facility operation.

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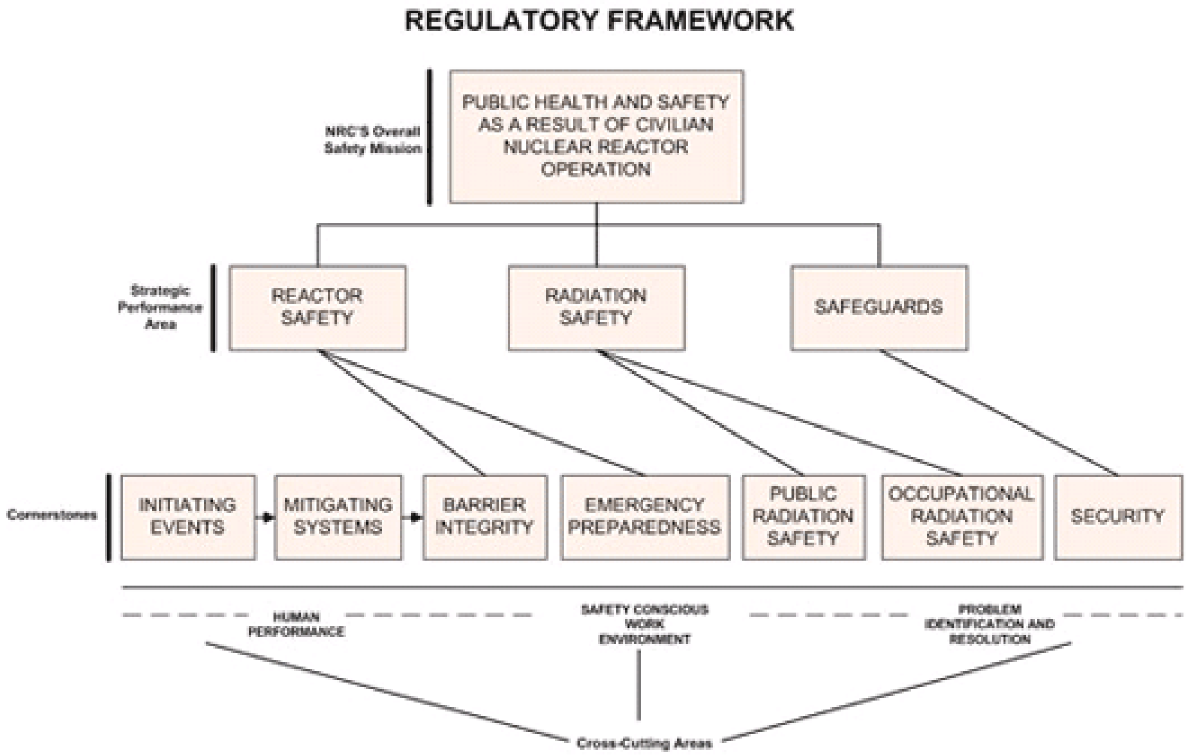
[145] NRC Administrative Letter 98-07; Interim Suspension of the Systematic Assessment of Licensee Performance (SALP) Program (10/2/1998) http://www.nrc.gov/reading-rm/doc-collections/gen-comm/admin-letters/1998/al98007.html

[146] COMSECY-98-024, "Response to Issues Raised Within the Senate Authorization Context and July 17, 1998 Stakeholder Meeting; http://www.nrc.gov/reading-rm/doc-collections/gen-comm/admin-letters/1998/al98007.html

[147] http://www.nrc.gov/reactors/operating/oversight/rop-description.html

Figure 28. Reactor Oversight Process Framework



Source: *U.S. Nuclear Regulatory Commission (2013)*

The NRC chose the set of cornerstones to: "limit the frequency of initiating events; ensure the availability, reliability, and capability of mitigating systems; ensure the integrity of the fuel cladding, reactor coolant system, and containment boundaries; ensure the adequacy of the emergency preparedness function; protect the public from exposure to radioactive material releases; protect nuclear plant workers from exposure to radiation; and, provide assurance that the physical protection system can protect against the design basis threat of radiological sabotage." Within this framework, the ROP provides a means to collect information about licensee performance, assess the information for its safety significance, and provide for appropriate licensee and NRC response. Satisfactory performance in each of the seven cornerstones provides the NRC reasonable assurance of safe facility operation.

Action Matrix

With the implementation of the ROP, the NRC phased in a more robust "Action Matrix" to replace the existing NRC "Watch List". Similar to the previous Watch List, the Action Matrix identifies reactors warranting focused NRC attention. However, the Action Matrix includes NRC's quarterly assessment of every operating reactor classified into one of five categories: Licensee Response; Regulatory Response; Degraded Cornerstone; Multiple/Repetitive Degraded Cornerstone; and Unacceptable Performance. The Licensee Response category includes those reactors receiving normal NRC attention, and the majority of operating reactors fall into this group. When the NRC detects a gradual performance drop, reactors move into the Regulatory Response category. If the performance decline persists, reactors can move into the Degraded Cornerstone category. If performance continues to worsen, reactors can get downgraded to the Multiple/Repetitive Degraded Cornerstone category, and finally the Unacceptable Performance category. The level of NRC oversight escalates as reactors drop from best to lowest performing categories of the Action Matrix.[148] A summary of the NRC Action Matrix and Response plan is included in Figure 29.

Figure 29. NRC Response Plan or "Action Matrix"

Assessment of Plant Performance (in order of increasing safety significance)	NRC Response
I. All performance indicators and cornerstone inspection findings GREEN Cornerstone objectives fully met.	No Response Needed Routine inspector and staff interaction Baseline inspection program Annual assessment public meeting
II. No more than two WHITE inputs in different cornerstones Cornerstone objectives fully met.	Response at Regional level Staff to hold public meeting with utility management Utility corrective action to address WHITE inputs NRC inspection follow-up on WHITE inputs and corrective action
III. One degraded cornerstone (two WHITE inputs or one YELLOW input or three WHITE inputs in any strategic area) Cornerstone objectives met with minimal reduction in safety margin	Response at Regional level Senior regional management to hold public meeting with utility management Utility to conduct self-assessment with NRC oversight Additional inspections focused on cause of degraded performance
IV. Repetitive degraded cornerstone, multiple degraded cornerstones, or multiple YELLOW inputs, or one RED input Cornerstone objectives met with longstanding issues or significant reduction in safety margin	Response at Agency level Executive Director for Operations to hold public meeting with senior utility management Utility develops performance improvement plan with NRC oversight NRC team inspection focused on cause of degraded performance Demand for Information, Confirmatory Action Letter, or Order
V. Unacceptable Performance Unacceptable reduction in safety margin	Response at Agency level Plant not permitted to operate Commission meeting with senior utility management Order to modify, suspend, or revoke license

Source: *U.S. Nuclear Regulatory Commission (2013)*

The NRC inspection staff has developed a procedure, called the "Significance Determination Process," to help inspectors determine the safety significance of inspection findings. As part of the performance assessment process, the resident inspectors and the inspection staff in the NRC regional office review the performance of all nuclear power plants in that region on a quarterly basis, as measured by the performance indicators and by inspection findings. The final outcome of the review – evaluating whether the finding is green, white, yellow, or red – will be used to determine what further NRC action may be called for and reactor placement within the Action Matrix.

[148] http://www.ucsusa.org/assets/documents/nuclear_power/20061122-pv-ucs-brief-naughty-list-1.pdf

2001 – The Impact of the Terrorist Attacks of September 11, 2001
On September 11, 2001, a terrorist attack on U.S. soil significantly impacted the way that several industries evaluate risk and security. Specifically, the NRC focused on two major issues: (1) the vulnerability of nuclear plants to terrorist attacks ultimately causing a release of radiation or nuclear material, and (2) the vulnerability and possible effects of an airplane crashing into a nuclear plant.

During the investigation, the NRC issued Orders in 2002 for all commercial nuclear power plants to implement interim compensatory measures for the high-level terrorist threat environment. This comprised a series of security measures that ordered licensees to tighten the control of access by plant workers, increase the number and capability of security forces, conduct more patrols, install physical barriers to the plant, move vehicle inspection points to a greater distance from the plant, and improve coordination efforts with military and law enforcement agencies. In 2002, the NRC created the Office of Nuclear Security and Incident Response to lead and coordinate these security programs.

2004 – NRC Establishes Emergency Preparedness Directorate (EPD)
Following the September 2001 terrorist attacks, the NRC identified the need for increased communication of its emergency preparedness activities with internal and external stakeholders, including the public, industry, the international nuclear community, and Federal, State and local government agencies. As a result, the NRC established the Emergency Preparedness Directorate (EPD) in 2004 to develop emergency preparedness policies, regulations, programs, and guidelines for both currently licensed nuclear reactors and potential new nuclear reactors.[149]

2005 – Energy Policy Act of 2005
In 2005, President George W. Bush signed into law the Energy Policy Act of 2005. Among other things, this provided the opportunity for loan guarantees and other subsidies on the construction of new power plants, aimed to reduce the financial burdens on utilities looking to install new nuclear capacity. By June 30, 2009, the NRC had received 18 combined operating license applications for 28 new nuclear plants.

2010 – Yucca Mountain Funding Eliminated
Since Congress designated Yucca Mountain, Nevada, as the only site to be characterized as a permanent repository for all of the nation's nuclear waste in 1987, billions of dollars to have been spent to evaluate the site for potential use as a nuclear waste repository, but limited progress has been made. In February 2010, President Barack Obama proposed to eliminate funding for Yucca Mountain nuclear waste repository project, and by March 2010, DOE filed a motion to withdraw its license application. At this time, no other permanent waste repository has been designated.

2011 – Japanese Earthquakes and Tsunami Impact at Fukushima Daiichi Nuclear Plant
In March 2011, a powerful earthquake hit northeast Japan and a resulting tsunami caused significant damage and a core meltdown at the Fukushima Daiichi nuclear plant. Soon after this event, the NRC created a Near-Term Task Force to review the accident and develop recommendations for proposed regulatory requirements for U.S. nuclear power plants. However, as of 2012, the NRC has not revised any requirements in light of the disaster.

[149] http://www.nrc.gov/about-nrc/emerg-preparedness/history.html

4.6 Impacts on Nuclear Industry Safety

As the nuclear power industry has evolved, and especially since the accident at the Three Mile Island Unit 2, the regulatory focus on improved operations and safety has had a dramatic effect.[150] Since the accident, there have been substantial regulatory changes as well as other improvements that have contributed to the enhanced safety of nuclear plants.

Some of these key changes that have strengthened NRC's regulation of public health and safety include the following:

- Placement of at least two NRC resident inspectors at each plant site,
- Immediate NRC notification by plants of serious events,
- Expanded emergency preparedness including an NRC Operations Center staffed 24/7,
- Increased identification, analysis and publication of plant performance information, and
- Recognizing human performance as a critical component of plant safety.

Over the last three decades, key indicators of plant safety performance have improved dramatically and problems have decreased. For example:

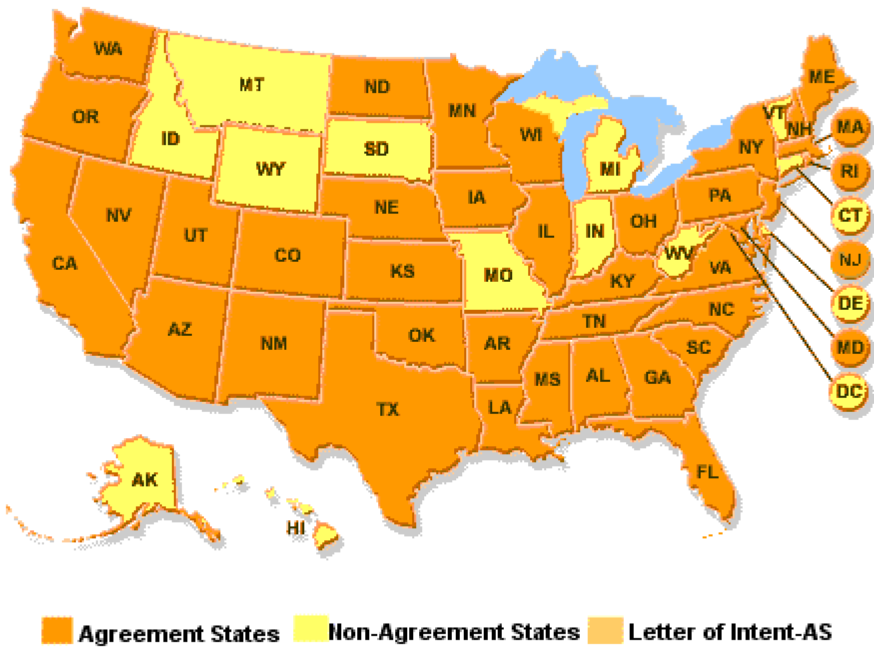
- The average number of significant reactor events over the past 20 years has dropped to nearly zero.
- Today there are far fewer, much less frequent and lower risk events that could lead to reactor core damage.
- The average number of times safety systems have had to be activated is about one-tenth of what it was 22 years ago.
- Radiation exposure levels to plant workers has steadily decreased to about one-sixth of the 1985 exposure levels and are well below Federal limits.

4.7 State Regulatory Issues

Beginning with Kentucky in 1962, the NRC – still the Atomic Energy Commission at the time –adopted a program in accordance with Section 274 of the Atomic Energy Act, whereby the Commission relinquished control of portions of its regulatory authority to states that would like to regulate by-product materials, source materials, and certain special nuclear materials within state lines. The Atomic Energy Act recognized "the interest of the States in the peaceful uses of atomic energy," and therefore sought to develop a medium that allowed for state participation in nuclear power production while still maintaining dominating control over its development and use. Figure 30 shows which states have signed letters of agreement with the NRC.

[150] http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/fs-plant-sfty-after-tmi2.html

Figure 30. NRC Agreement States



While these agreements give states no real control over the actual operation and safety of the generation facilities, they do give states strong controls over some environmental aspects of plant operations. For instance, Agreement States' control over the by-products of nuclear generation gives them the ability to control waste regulations, such as water usage and pollution, and also waste removal and storage. This bit of authority over the fuel and waste products of nuclear facilities can in theory allow states to create either looser or tighter regulations on nuclear power plants. The way that states enact regulations over the removal, transport, and storage of nuclear waste and by-product can have drastic effects over the ability of states to control whether nuclear generators seek to build a facility within state borders by either creating bridges to assist in solving problems or erecting barriers to hinder development – a topic that is discussed in more detail in the following paragraphs. This control over the materials aspect of nuclear generation does have the potential to give the states greater control over the continued operation and relicensing of nuclear power facilities.

This merit to control and regulate nuclear generation facilities has been the source of recent legal clashes between state and Federal authorities over the relicensing of the Vermont Yankee plant. As with the initial licensing and operation of nuclear plants, the relicensing process is under the control of the NRC. However, as part of Entergy's deal to buy the plant in 2002, "Entergy agreed to seek approval from the Vermont Public Service Board to extend the plant's license." The Vermont Yankee license was set to expire in the spring of 2012, and the plant is currently operating under an NRC-issued 20-year licensing extension. The battle over the relicensing of Vermont Yankee is indicative of the state's desire to more tightly control the regulation of utilities within its borders. The State of Vermont was fully determined to shut down the plant amid fears of operational safety hazards, stemming from a few minor incidents and the fact that the reactor is the same type as that in the Fukushima facility in Japan. The case was resolved in January 2012, when a Federal U.S. District Court judge issued an injunction against Vermont's attempt to shutter the plant. This is considered to be a victory for nuclear power in that the decision reaffirms that it is the NRC who has authority over the licensing of nuclear power facilities.

However, at the same time, it is potentially only the beginning of a more drawn-out and complicated legal battle. In the Court's decision, the judge included commentary that notes that this decision only rejects the idea that a state can shut down an existing nuclear facility because of safety concerns (an area of regulation strongly controlled by the NRC), but does not preclude a state from closing a nuclear facility for some reason that is allowed by Federal law, potentially such as pollution or waste removal. Further, on June 4, 2012 the Attorney General for the State of Vermont filed arguments before a Federal court of appeals, arguing that the lower court's judges based the previous ruling on the comments of only a "handful of legislators." This legal question over regulatory control has the potential to become a daunting issue; however, at this point in time, legislation gives the bulk of regulatory authority – including issues of licensing and operation – to the Federal government, leaving states with only the ability to make it either easier or harder for nuclear plants to conduct operations within their territory.

The majority of operating units are located in the Eastern Interconnection. Of the 37 states that comprise the Interconnection, 26 are home to currently operating nuclear power facilities. There are numerous factors that affect whether or not some states have a presence of nuclear power generation, a major one of which is the political constraints that are imposed upon owners who have built or are looking to build nuclear power facilities. While most of the regulation of nuclear power plants happens at the federal level, states can make it easier or harder for nuclear plants to come to fruition in their respective locations. States can accomplish this, and in effect create their own policies on nuclear plants, by using state statutes and codes of law to create incentives or disincentives for building nuclear power facilities.

The most common method by which states incentivize generation owners to site and build nuclear facilities is through creating beneficial financial incentives, such as establishing tax exemptions. This sort of tax-based incentive is exemplified in Section 40-9-22 of the Code of Alabama, which provides the owners of nuclear power facilities exemption from state, county, and municipal fees and taxes on nuclear fuel, and in Section 79-230 of the Kansas State Statutes by allowing any new nuclear facility to be exempt from paying property tax for ten years. These seemingly small cost exemptions are actually a significant matter for nuclear power facilities, given the enormous physical size of the facilities and the even more extravagant construction costs, compared with both conventional and renewable energy alternatives.

According to the Energy Information Administration (EIA), the Fixed O&M Cost, in 2010$/kW, of uranium generation is $88.75, whereas the same cost for an Advanced NCGG unit is $14.62 and a large photovoltaic unit is $16.70. This translates into the cost of a new nuclear power plant to be upwards of $2 billion, with some plants costing over $10 billion just for their construction (2012 USD). Comparatively, the cost to build a larger natural gas facility in the U.S. is noticeably less, with a price tag of only $820 million. It is due to this sort of cost structure that the potential to save hundreds of thousands of dollars in taxes and fees annually makes such offers particularly tempting.

Furthermore, some states create various methods to allow nuclear plants to recoup their initial construction costs through additions to their rates. Federal law already allows all public utilities (coal, natural gas, hydro, nuclear, etc.) to recoup costs incurred during construction through an allowance for funds used during construction (AFUDC). Currently, the AFUDC allows utilities to begin accruing these reimbursable charges when "(1) capital expenditures for the project have been incurred; and (2) activities that are necessary to get the construction project ready for its intended use are in progress." This guideline has come to be interpreted to cover a broad range of actions, but generally excludes any pre-licensing activities, such as siting and study costs. In an attempt to encourage nuclear generation, some states have opted to include development and construction costs for nuclear plants that are not allowed under standard AFUDC guidelines. The Kansas State Code Section 66-128q allows nuclear power plants to recover development and study costs by charging higher rates for their generated power, and Section 366.93 of Title 27 of the Florida Statutes allows for the cost recovery of the siting and design of nuclear power facilities.

Outside of creating incentives to attract nuclear generation, some states have included language in their state codes that is supportive of the use of nuclear generation, and seeks to provide for its adoption and use in-state. Chapter 1176 of the 2010 Public Acts of Iowa requires that certain rate-regulated public utilities undertake a program to analyze and prepare for the possible construction of nuclear facilities; this promotion of nuclear generation is followed by current legislation in the Iowa state legislature that is supposed to encourage the use of nuclear power electric power because of its "long-term proven record of providing a safe, reliable, and secure source of electricity" (House Bill 124, 2012).

Contrarily, some states have incorporated text into their state codes that discourages generation owners from seeking to build nuclear power plants in their state. This is done using a few differing methods, including adding more stringent siting requirements and adding stipulations about exploring other generation options before nuclear power plants can be considered for approval. For instance, to be granted a site permit in North Carolina, the owners of the nuclear facility must show that there are not any Energy Efficiency/Demand-Side Management programs, renewable resource generation options, or combination heat/power generation options that would "establish or maintain a more cost-effective and reliable generation system." Rhode Island has passed into law legislation stipulating that:
no electric utility may include as part of its rate base any expense for advertising, either direct or indirect, which promotes the construction of a nuclear facility…and no utility so regulated may furnish support of any kind, direct or indirect, to any subsidiary, group, association, or individual for advertising (State of Rhode Island General Laws, Section 39-3-12.2).

Potentially the most detrimental legislation to the construction of nuclear power facilities is in the definition of what states consider to be a renewable energy source. Only two states in the Eastern Interconnection consider nuclear power to be a clean or renewable energy source, Indiana (State Code 8-1-37) and Ohio (129th State Legislature, Senate Bill 315). All other states, including those with strong pro-nuclear legislation, do not count nuclear power towards meeting the states Renewable Portfolio Standards (RPS). The current trend in energy generation in the United States is toward clean, renewable energy, a solution to both fossil fuel reliance and pollution problems. As such, in order to ensure that electricity generators undertake programs to achieve such renewable goals, a majority of states have implemented RPS legislation requiring that a certain percentage of generation is from renewable resources by a specified year (Ohio requires that 25% of electric generation come from renewable sources by 2025). However, as nuclear is not considered to be a renewable energy source many producers will expend their limited resources to meet this regulatory requirement, instead of on the extravagant price tag that accompanies the construction of nuclear facilities.

Agreement States' ability to have control over waste disposal is an area where the state can obtain control over owners' decision to build and operate a nuclear facility. This control can be either beneficial or detrimental to the nuclear plants. In regard to shaping pro-nuclear or anti-nuclear policies based upon waste removal, for Agreement States (the only ones who control such regulations) it is more difficult for them to incorporate overly explicit language or legislation because it is an authority that is granted to the states from NRC under the auspice that they will conduct the operation of said waste sites with the same regulation and quality as would be present under Federal regulation. However, even with this background, states have still found a few ways to promote or discourage nuclear generation through manipulating state waste removal. In Louisiana, RS 30:2105 creates requirements that must be met for someone to engage in any sort of handling of nuclear material – among other qualifications, it sets technical, insurance, and financial requirements. Such wording allows for the state government to create licensing requirements that can be either more lax or more stringent depending on the sort of nuclear-power atmosphere the state is trying to create. On the other side of the Eastern Interconnection, Maine requires that for a nuclear facility to receive certification to be built, there must be a "demonstrable or means for the disposal of high-level nuclear waste" and said site must be in operation at the time its use would be required by the nuclear power plant. Essentially, this statute rules out the building of more nuclear power facilities because of issues regarding waste disposal.

An aspect of nuclear power, almost as regulated as the operation itself, is the decommissioning of retired nuclear plants. As with the regulation during their operation, the decommissioning of nuclear facilities is regulated by the NRC, through Federal regulation in the U.S. Code of Federal Regulations (CFR). By definition, decommissioning involves not only closing the facility and ceasing operation, but cleaning the site and materials used in order to make it acceptable for future use. There are currently three NRC approved methods of decommissioning. The first is immediate dismantlement (DECON), whereby the equipment and materials used are decontaminated and removed from the site shortly after the facility ceases operation. The second method is delayed decontamination (SAFSTOR); under this method the facility and equipment is monitored and kept in a steady state over time that allows the radioactive isotopes to decay naturally until it reaches a low enough threshold that allows for use of the site for other purposes. Afterwards, the materials are removed for storage off-site. The third method, entombment (ENTOMB), is the most recent to gain NRC approval; with this method, the radioactive elements are permanently encased onsite until they have decayed sufficiently to be suitable for other use. To date, no decommissioned nuclear plants have chosen this last option.

Decommissioning of nuclear facilities is governed by CFR Title 10 Part 20 Subpart E and Parts 50.75, 50.82, 51.53, and 51.95. While the actual decommissioning of nuclear power plants is regulated wholly at the federal level, some states have gained a small amount of authority over this process in regard to the funding of the decommissioning process. The cost to decommission one nuclear unit usually ranges from $300 million to $400 million, but can also exceed $500 million; this cost is wholly the responsibility of the generation owner to cover, with the Federal government and the states possessing no responsibility for any portion of it. These funds are accumulated over the lifetime of the nuclear facility. While there are various methods used to accumulate the proper funds, they all in essence involve an account separate from the assets of the plant that can only be used for decommissioning. CFP 50.75(c) lays out a formula for determining the amount of decommissioning funds that a nuclear plant must have, including adjustments for changing costs of materials and labor.

To ensure that these funds are available some states may craft legislation that requires nuclear facilities to submit filings or special plans on how the plant expects to fund and execute a decommissioning. Connecticut requires that within the first year of commercial operation, the owner of a nuclear power facility is to submit a financing plan for decommissioning, including a description of how the owners intend to fund the future decommissioning after the plant's operating license expires. New York requires a plan for the decommissioning of nuclear power plants to be included with their initial application for a certificate of public good (Laws of New York, Section 18-109). Two states that have come to assert a larger amount of control over the process than usual are Missouri and Illinois. Section 393.292 of the Missouri Statutes stipulates that "the public service commission shall have the power…to review and authorize changes to the rates and charges contained in the schedules of an electric corporation as the result of a change in the level or annual accrual of funding necessary." In Illinois, an electric utility may increase or decrease its rate case to reflect changes in the cost of decommissioning. Further, the Maine State Statutes, under Section 4353 (4), describe that the state shall determine its own cost of decommissioning and that nuclear power generators must make monthly deposits into the plant's decommissioning trust fund.

States that have legislation that hinders the development of nuclear power can be broken into four broad categories. Those that have banned the development of nuclear power, those that tie nuclear power development to the disposal of spent nuclear fuel, those that require legislative approval, and those that require a referendum. Figure 31 depicts individual states in each of these categories[151]. A detailed breakdown of each state's statutes is found in the Appendix.

[151] Hawaii not shown

Figure 31. States with Nuclear Disincentives

Ten states have enacted legislation that ties future nuclear development to permanent disposal of spent nuclear fuel. One state, Minnesota, has banned the construction of all new nuclear power plants. States that have tied nuclear development to long-term spent fuel disposition can be divided into three broad categories. Two states, Oregon and West Virginia, require a spent fuel repository to be in operation prior to considering local nuclear plants. Three states, Kentucky, Maine, and Massachusetts, require that a repository exists or will exist by the time it is needed. Lastly, five states, California, Connecticut, Illinois, New Jersey and Wisconsin, require that the technology for spent fuel has been demonstrated and approved by the Federal Government. Kansas will prohibit cost recovery for excess nuclear capacity unless high level radioactive waste technology exists; however dry cask storage appears to meet the requirement. Hawaii, Rhode Island, and Vermont require approval of the state legislature prior to construction of a new nuclear power plant. Montana requires voter approval prior to the construction of a nuclear power plant.

State incentives for new nuclear power plant construction include tax incentives in Alabama and Kansas and treatment of nuclear power as renewable energy for RPS targets in Ohio and Indiana.

The most salient characteristics of a state's energy profile that affect the building of next generation nuclear power plants are regulatory policies which allow the utility to mitigate the risks associated with the asset. The most common approaches to mitigating regulatory risk involve pre-approval for the proposed asset in advance of construction. Furthermore, many states with regulated electricity markets also provide for the use of Construction Work in Progress (CWIP) for ratemaking purposes instead of Allowance for Funds Used During Construction (AFUDC) CWIP improves a utility's credit rating (or at least helps maintain it), which results in lowered borrowing costs, thereby benefitting customers both through lower interest rates on the utility's debt and by not having to pay "interest on interest" as would be the case with AFUDC financing.

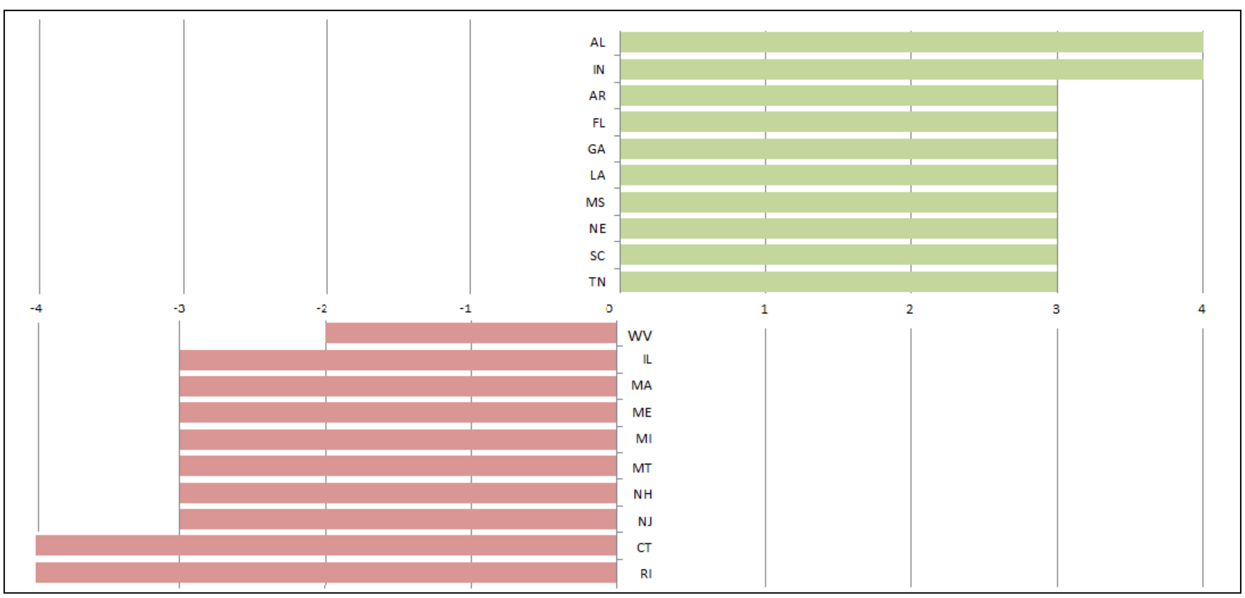
Deregulated energy markets place risk for construction delays, project financing, project cost estimation, operating activities, and market energy prices all on the power plant investor. It is not surprising that alternative forms of base load generation are built in deregulated electric markets rather than newly designed but untested nuclear power plants.

Lastly, the concentration of renewable wind energy and level of demand management resources to which a state aspires will encourage or discourage the development of new nuclear power plants. The intermittent nature of wind and current energy market rules require that mid-level generation be able to cycle in response to fluctuations in wind generation output. This load following capability has not traditionally been incorporated into baseload nuclear generation plant designs, and Navigant has estimated that wind energy may cause curtailment of base load generation in rare instances. More importantly, wind generation and demand response programs tend to flatten electric market prices and lessen the opportunity for base load generating plants to reap extraordinary profits during peak demand periods.

Each of the above attributes were investigated for states within the Eastern Interconnection and assigned a positive or negative rating based upon their perceived incentive. The ten states with the most incentive attributes and the ten states with the lowest incentive attributes are shown in Figure 32.

Figure 32. State Incentives Comparison

Top Ten Nuclear Power Incentives/Disincentives Comparison by State



Legislation, CWIP, Market Structure, RE Goals

It is not surprising that the states of Georgia, South Carolina, and Tennessee, are represented in the top ten and are currently the states with ongoing nuclear construction projects. The combination of regulated electricity markets, low wind penetration, and CWIP ratemaking favor the southeastern portion of the country. Indiana's ranking reflects its regulated electricity market, CWIP ratemaking, modest clean energy portfolio goal and the fact that nuclear energy can account for up to 30% of the state's clean energy target. Alabama ranked the highest because in addition to the attributes already mentioned it exempts owners of nuclear power facilities from state, county, and municipal fees and taxes on nuclear fuel.

States with deregulated electricity markets, aggressive renewable energy standards and legislative impairments ranked the highest in disincentives. Because Minnesota has banned all new nuclear power plant construction it was not ranked against other states. Rhode Island was ranked as least attractive because in addition to being deregulated and requiring legislative approval for nuclear power plants, it has a scalable RPS and a ban on utilities promoting nuclear power through advertising.

4.8 International Regulatory Structures[152]

The International Atomic Energy Agency (IAEA) and the Nuclear Energy Agency (NEA) are the main global organizations generating nuclear regulations. The IAEA is a United Nations autonomous body, while the NEA is an Organization for Economic Cooperation and Development (OECD) agency. The World Association of Nuclear Operators (WANO) is an international equivalent to INPO in that its mission is to promote excellence in global nuclear power operations. WANO was formed after the accident at Chernobyl and is a non-regulatory agency.

The IAEA espouses three main principles for nuclear regulation. The first is independence of the regulatory body promoting nuclear energy. This was the lesson learned by the United States when it proved impossible for the AEC to be both a promoter and regulator of the nuclear industry. The second principle is public participation in the licensing process for nuclear power plants and the third is maintaining high levels of safety.

Not all countries have implemented all of these principles. In Japan, Germany, and Switzerland the regulator is part of the national government. In Canada and France, as in the U.S., the regulator is independent of the government and reports to the national governing body. Britain is unique in that its regulatory scheme has a mixture of both.

In France, Japan, Germany, and Switzerland the government is the licensing authority for nuclear power plants and grants licenses without expiration. These governments are also responsible for enforcement actions against nuclear operators. In Canada, the regulator issues renewable operating licenses that expire every 5 years and are renewed through a public process.

Japan and Britain are unique in that they do not have specialized nuclear regulators. In Japan, the Japanese Nuclear and Industrial Safety Agency regulates the general energy industry including

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[152] A Comparison of International Regulatory Organizations and Licensing Procedures for New Nuclear Power Plants, Alexandre Bredimas & William J. Nuttall, EPRG Working Paper.

electricity, natural gas, petroleum and nuclear energy. Britain is even more atypical in that its Health and Safety Executive (HSE) is responsible for all industrial safety with the exception of the rail and aviation industries. Britain also follows a safety policy culture of ALARP- As Low As Reasonably Practical vice the U.S. culture of ALARA -As Low As Reasonably Achievable. This leads to greater flexibility for licensees and allows operational practices to differ from one site to another as long as HSE targets are met.

With regards to public participation in plant licensing, Canada and Switzerland have the most participatory processes. In Switzerland, a national referendum can be held on licensing if 50,000 signatures are collected on a petition. In Canada, the nuclear safety agency pays underfunded interveners to prepare their cases and encourages them to participate in the site environmental assessment process.

In part these regulatory schemes reflect the nature of each nation's tradition of participatory democracy and the general public's trust in its regulatory agencies.

5. NUCLEAR SAFETY EVENTS

5.1 Overview of Emergency Planning Criteria

Both lessons learned from nuclear power plant accidents and incidents and advances in the understanding of fundamental aspects of reactor thermodynamics, radiation exposure, material science, and human behavior have contributed to the evolution of Emergency Planning Criteria. The design safety basis, the foundation for Emergency Planning Criteria, must be maintained by nuclear power plant operators and is one of the most significant differences between nuclear power plant operations and that of other power plants. For example, if a nuclear power plant were operating normally at 100% power and one of its backup emergency diesel generators was found to have less than a 7-day supply of fuel oil, because the safety basis analysis assumes all diesel generators will have seven days of fuel in the event of an accident, the operators would have 72 hours to refill that tank or they would be required to shut down the plant.[153] The management of the safety basis in addition to the operation and monitoring of standard power plant control systems are factors that increase the complexity of nuclear power plant operations.

The design safety basis for each nuclear power plant assumes three barriers between the radioactive fuel and the environment. These barriers are the fuel cladding, the reactor coolant system vessel and piping, and the containment. In the United States, each nuclear power plant is required to develop procedures, train personnel, and conduct exercises for two emergency planning zones (EPZ) outside the plant boundary.

5.1.1 Plume Exposure Pathway Emergency Planning Zone

If the containment were breached or vented and radioactive materials were released, people in the plume exposure pathway EPZ, which covers a radius of approximately 10 miles from the plant, are to be provided with emergency planning information. Additionally, the utility, in coordination with the local government is required to develop predetermined actions to protect the public. These predetermined protective actions, which are designed to avoid or reduce radiation dose from potential exposure to radioactive materials, include sheltering, evacuation, and the potential use of potassium iodide.

5.1.2 Ingestion Exposure Pathway Emergency Planning Zone

The ingestion exposure pathway EPZ has a radius of about 50 miles from the reactor site and is designed to avoid or reduce dose from potential ingestion of radioactive materials. Protective actions include coordinated efforts by local government agencies aimed at protecting the public from ingesting radioactive materials by both sampling water and crops and implementing mitigation actions.

In the United States, power plant control room operators communicate directly and quickly with state agencies and the Nuclear Regulatory Commission if an abnormal condition exists that challenges any of the three barriers. In conjunction with government agencies, these operators use a graduated scale of

[153] Westinghouse Standard Technical Specifications

emergency classifications to communicate to the public the severity of risk associated with abnormal events at a nuclear power station. There are four levels of emergency classification[154] and in general, the severity is assessed by the number of fission product barriers challenged in the incident.

Notification of Unusual Event - Under this category, events that indicate potential degradation in the plant's safety level are in progress or have occurred. No release of radioactive material requiring offsite response or monitoring is expected unless further degradation occurs.

Alert - If an alert is declared, events that involve an actual or potential substantial degradation in the plant's safety level are in progress or have occurred. Any releases of radioactive material from the plant are expected to be limited to a small fraction of the Environmental Protection Agency (EPA) Protective Action Guides (PAGs).

Site Area Emergency - A site area emergency signifies that events, which will result in or will likely yield major failures in plant functions that are required for public protection, are in progress or have occurred. Except for locations near the site boundary, any releases of radioactive material are not expected to exceed the EPA PAGs.

General Emergency - A general emergency involves actual or imminent substantial core damage or the melting of reactor fuel coinciding with the potential for loss of containment integrity. It is reasonable to expect radioactive releases during a general emergency to exceed the EPA PAGs for an area larger than the immediate site.

5.1.3 International Nuclear Event Scale

The International Atomic Energy Agency developed the International Nuclear and Radiological Event Scale (INES) to harmonize communications concerning a nuclear accident's degree of severity. In practice, the INES level of an incident is assigned well after the incident occurs, so the scale has a very limited ability to assist in disaster-aid deployment.

[154] http://www.nrc.gov/about-nrc/emerg-preparedness/about-emerg-preparedness/emerg-classification.html

Table 28. INES Scale

Level	Description
ZERO	Events known as "deviations" that have no safety significance
LEVEL ONE: Anomaly	Minor problem with safety components at a nuclear facility, but significant safety margin remaining
LEVEL TWO: Incident	Radiation levels in an operating area of a nuclear facility of more than 50 millisieverts (mSv) per hour. Exposure of a member of the public to radiation in excess of 10 mSv, exposure of a worker in excess of statutory annual limits.
LEVEL THREE: Serious Incident	Severe contamination in an area of a facility, with non-lethal injuries such as radiation burns. Low probability of significant public exposure.
LEVEL FOUR: Accident with local consequences	Partial meltdown or damage to fuel, release of significant quantities of radioactive material within an installation. No counter-measures likely to be needed other than local food controls.
LEVEL FIVE: Accident with wider consequences	Severe damage to reactor core, large quantities of radioactive material released within a site. Limited release of material to the wider environment, requiring implementation of some planned countermeasures.
LEVEL SIX: Serious accident	Significant release of radioactive material likely to require implementation of planned countermeasures.
LEVEL SEVEN: Major accident	Major release of radioactive material with widespread health and environmental effects, requiring implementation of planned and extended countermeasures.

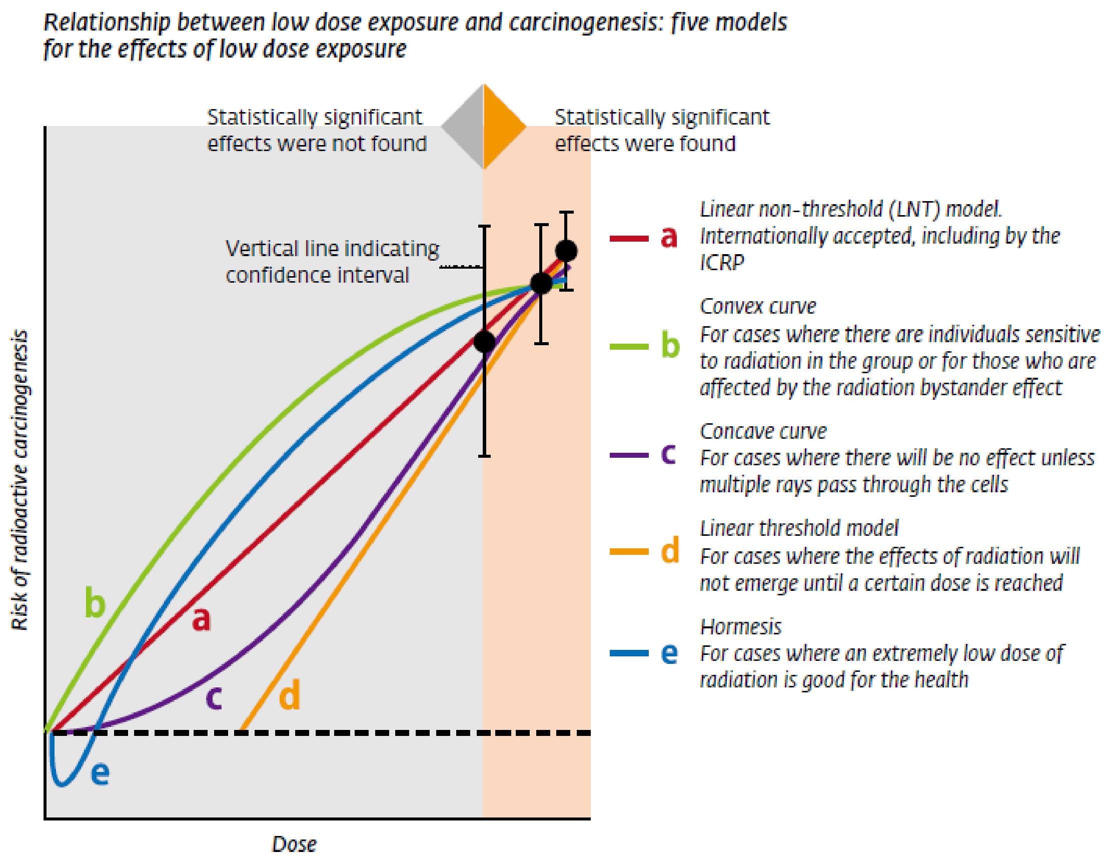
5.1.4 Radiation Exposure

Protection of general public safety is one of the main tenets of Emergency Planning Criteria. Much of that criterion is based upon what are considered to be safe radiation exposure levels for nuclear workers and the general public. The accident at Fukushima Daiichi and Japan’s subsequent decisions to raise the acceptable level of radiation exposure for nuclear workers and to allow resettlement in areas with elevated radiation levels has re-opened the debate on “safe” radiation levels.

The relationship between cancer and radiation dose has been the subject of research since atomic bombs were dropped on Hiroshima and Nagasaki. This research has led to the conclusion that a linear relationship exists between cancer deaths and radiation dose above ten rem (100 mSV).[155] A correlation between dose and cancer deaths is statistically inconclusive for radiation exposure below that level; however, international organizations have adopted the linear model as the basis for protective actions. While four alternative models have been proposed by various experts, Japan’s experience with prolonged exposure to low-level radiation from Fukushima Daiichi will be closely monitored over the coming decades to determine if a shift in perspective regarding acceptability of long-term exposure to low levels of radiation is warranted.

[155] The National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission Chap 4 page 72

Figure 33. Carcinogenic Risk Assessment Models vs. Radiation Dose[156]



5.2 *Accident Overviews*

Each of the accidents described in the following sections changed the way the public and national authorities viewed nuclear power. In hindsight, some of the lessons learned, such as a need for containments or strict operational protocols seem obvious; however, nuclear power is little more than a generation old and these events reflect the experience level of the industry at the time of their occurrence. Each of the accident narratives provides a detailed timeline of the accident events, a summary of the emergency response, a narrative on radiation exposure, and lessons learned by the nuclear industry.

[156] Ibid. page 73

5.2.1 Windscale Fire[157]

Figure 34. Windscale Chimneys

As was the case in the United States, early atomic power development in Britain focused on production of plutonium for atomic weapons as part of its national defense program. After World War II, Britain quickly built two plutonium production facilities, Windscale Piles No. 1 and No. 2, near Seascale in Cumberland, England. On October 10, 1957, Windscale Pile No. 1 caught fire and deposited significant amounts of radioactive material in the surrounding countryside. The Windscale fire was the first major release of radioactive material requiring protective actions to ensure general public safety that occurred in the non-communist bloc.[158]

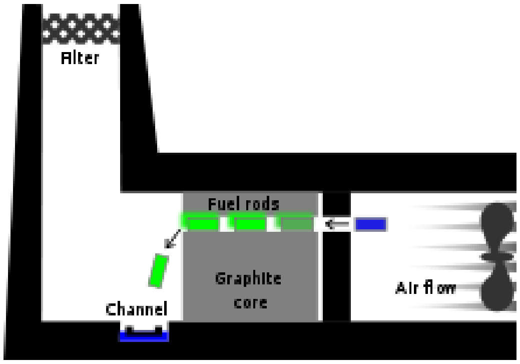
Windscale Pile No. 1 was graphite moderated, air-cooled reactor with horizontal channels filled with uranium metal rods clad in finned aluminum cans. Graphite blocks surrounded channels in which 11 tons of uranium fuel and other materials were inserted to be irradiated. The reactor core was cooled by blowing a large volume of air through the channels and out a 400-foot high chimney. Fuel and isotopes were fed into the channels in the front of the reactor, the charge face, and spent fuel was then pushed all the way through the core and out of the back, the discharge face, into a water duct for initial cooling prior to retrieval and processing to extract the plutonium. The fuel cans could be replaced while the reactor was operating and different material could be inserted into the reactor to produce other nuclides such as tritium.[159]

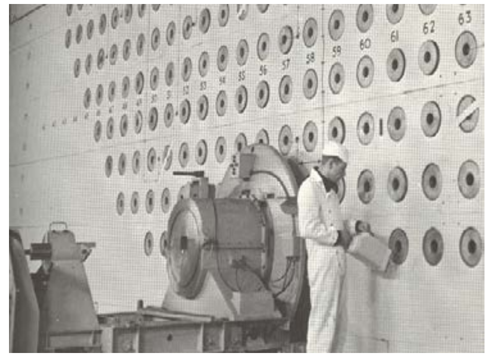
[157] A Revised Transcript Of The Proceedings Of The Board Of Enquiry into The Fire At Windscale Pile No.1, October 1957,UKAEA, 1989

[158] In September 1957, a radioactive waste decay tank exploded at the Mayak nuclear weapons production complex in the Ural Mountains of the former Soviet Union. This became known as the Kyshtym disaster and released 20 million curies of radioactive material, contaminating 8880 square miles (23, 000 square kilometers) with Cesium-137 and Strontium-90. Approximately 8000 people were relocated over the next two years. This area is now known as the Eastern Urals Radioactive Trace. The Mayak site was characterized by the open dumping of highly radioactive materials directly into the environment. A joint US-Russian project is tabulating the health effects of long-term exposure to ionizing radiation in the local workers.-Source US NRC Commissioner Dicus speech, 1997.

[159] The Windscale reactor accident—50 years on, Journal of Radiological Protection, (http://iopscience.iop.org/0952-4746/27/3/E02)

Figure 35. Operational Schematic and Charge Face





An operational issue associated with graphite moderated reactors is that neutron bombardment of the graphite displaces some of the atoms, thereby changing the material's crystalline structure. This creates a buildup of potential energy, Wigner Energy, within the graphite that can cause significant spontaneous temperature increases in the graphite as the energy is released. To counter this operational issue, an annealing process is performed in which the temperature of the graphite is raised to the point that the potential energy can be released in a controlled manner and held there for several days. It was during this annealing process that the uranium fuel caught fire.

The Wigner Energy is released in pockets and air flow adjusted to keep the temperature of "hot spots" below 400°C. The power of the reactor is reduced or raised as needed to supply nuclear heat in combination with the thermal energy provided by the Wigner Energy release. There was no set pattern as to how the reactor responded each time it was annealed. In the words of one of the operators "'You cannot lay down a set pattern for Wigner Release. It is really one experiment each time we do it. We have found on a number of occasions in the past that graphite temperatures tend to fall and that the release can be started up again by putting in some nuclear heating.'"[160]

Filters within the chimneys had been installed late in the construction process at the insistence of Sir John Cockcroft, head of the Atomic Energy Research Establishment (AERE). Many designers and engineers thought these filters were a waste of time and money, but they prevented the radioactive release of October 1957 from becoming much worse.

As first generation reactors, the Windscale Piles were plagued by some of the same issues as American reactors, the most common being failure of the aluminum cladding that surrounded the uranium fuel. At Windscale this became a common problem and resulted in several radioactive releases, referred to as "burst cartridges" to the environment[161]. When there was a burst, radioactivity in the chimney would increase and the pile would be shut down and the burst cartridge removed.

[160] A Revised Transcript Of The Proceedings Of The Board Of Enquiry into The Fire At Windscale Pile No. 1, October 1957,UKAEA, 1989 page 1.7
[161] Ibid p 212

On Monday, October 7, 1957, the operators of Windscale Pile No. 1 started the annealing process by using nuclear fission to raise the graphite moderator's temperature. 92 thermocouples, some of which were manually read and located on the top of the pile, were positioned throughout the core to monitor temperature. Their distribution did not allow operators to monitor temperatures throughout all sections of the pile.

Nuclear heating of the pile concluded at 1100 on Tuesday, October 8. From that point forward, any increases in temperature were initially thought to be due to the release of Wigner Energy. On Thursday, October 10, a high activity reading in the chimney was noticed, but was first thought to be normal because stack activity was known to increase when the fans were started. It was also thought that the activity increase might have been related to operations on Pile No. 2 because Pile No. 1 was shut down. After noon, stack activity increased again and dampers were opened. When stack activity went high off the instrument scale, operators realized an abnormal condition existed.

At first they thought there was a burst fuel cartridge, so dampers were opened and blowers started to cool the pile. Temperature initially behaved as expected after the blowers were started; however, at approximately 1600 Thursday afternoon, started to increase rapidly. Operators recognized something was seriously amiss and visually inspected one of the high temperature channels. The metal cartridges were glowing red hot.

The operators made unsuccessful attempts to push the cartridges out of the pile so they removed various plugs from the charge face of the pile in order to define the size of the glowing area. They also attempted to create a firebreak by removing unaffected cartridges. These efforts proved effective in the short-term, but ultimately failed. At 0845 Friday morning, the pile was flooded with water in a last ditch effort to put out the burning uranium. They were successful and water injection stopped at noon on Saturday.

5.2.1.1 Emergency Response

Operators coordinated with local police prior to starting water injection and closely monitored radiation levels. Ultimately, due to Iodine-131 released from burning uranium fuel during the fire, milk was banned for a month from farms within 200 square miles of the plant. Both reactors were permanently shut down and subsequent analysis has put the Windscale Fire as an INES Level 5 event.

5.2.1.2 Radiation Exposure

Because of the secrecy surrounding the weapons program at the time, the inquiry into the accident was not declassified until 1989, the public has little information about the dispersion of other nuclides such as Polonium-210 and Cesium-137. Subsequent studies have identified dispersion of nuclides as far as Belgium and the Netherlands.[162]

Lessons learned from the Windscale Fire include:

[162] The Windscale reactor accident—50 years on, Journal of Radiological Protection, (http://iopscience.iop.org/0952-4746/27/3/E02

- Need for development of protective action guidelines for radioactive releases. At the time of the accident, health physics personnel had to develop their own guidelines;
- Need for better core monitoring instrumentation;
- Need for better communications within plants and with local authorities;
- Need for better emergency planning; and
- Need for containments.

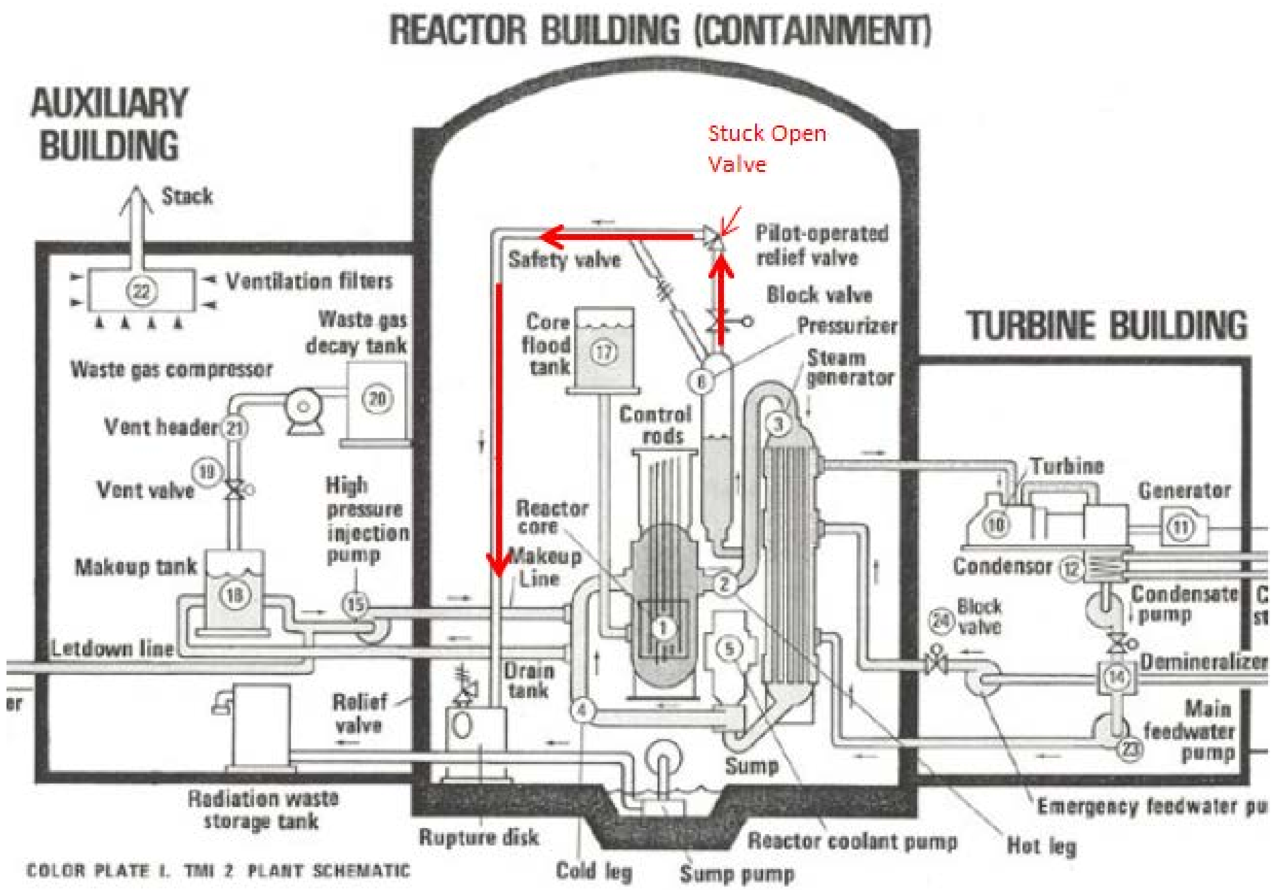
5.2.2 Three Mile Island[163]

The accident at Three Mile Island (TMI) in 1978 is often said to be the result of "operator errors." However, the Report of the President's Commission on the Accident at Three Mile Island identifies systemic failures of procedures, practices, and most importantly *attitudes* within the Nuclear Regulatory Commission and nuclear industry as the main cause of the accident. For example, in September 1977, an identical incident in which the same valve stuck open and operators made the same operational errors occurred at the Davis-Besse nuclear power station in Ohio. The Davis-Besse incident occurred at only 9% reactor power vice the 97% reactor power at TMI. Babcock and Wilcox (B&W) engineers had correctly forecasted that such an incident would lead to reactor core damage unless operators were taught the correct response. However, B&W did not share this information with other utilities and it was not given urgent attention by the NRC.

Three Mile Island Unit 2 was an 850 MWe B&W two-loop PWR that entered commercial service on December 1, 1978. At 0400 on March 28, 1979, TMI-2 was operating at 97% power when pumps supplying water to the non-nuclear side of the steam generators stopped operating. The loss of water to the steam generators generated a protective signal that shut down the electrical generator, steam turbine, and reactor. This rapid transient caused reactor system pressure to rise to the point that a relief valve on the pressurizer opened, as designed, to relieve system pressure, but the valve failed to reclose when pressure dropped below its setpoint. This essentially created a small opening in the reactor coolant system pressure boundary and provided primary coolant a leak into the containment building. The leak went unnoticed for almost two and one half hours and reduced the primary coolant inventory by approximately one-third. Figure 36 identifies the relevant components.

[163] The President's Commission Report on the Accident at Three Mile Island, October 1979

Figure 36. TMI Accident Schematic



As the main pumps supplying water to the steam generator had stopped, three auxiliary feedwater pumps started to supply water to the steam generators and remove the decay heat from the reactor. Unfortunately, the valves that allow the auxiliary feedwater to reach steam generators were closed. The operators did not notice these valve indications for eight minutes.

At approximately 0402, pressurizer level was still rising while pressure in the reactor coolant system dropped sharply, signs that are indicative of a loss of coolant accident (LOCA). Two high pressure ECCS pumps automatically started and began pumping approximately 1,000 gallons per minute of additional water into the reactor coolant system. These ECCS pumps, called high pressure injection (HPI) pumps, are designed to cool the core in the event of a LOCA. If no further operator actions had been taken at this point the accident may have only been a minor incident. However, operators were concerned with the pressurizer "going solid", which would complicate reactor pressure control, so they reduced flow from the HPI pumps at 0404, approximately two minutes after the pumps had started. This enabled the loss of coolant accident to continue, the core to uncover, and fuel to melt.

By 0405, the reactor coolant system reached the saturation point, meaning that reactor pressure had reduced and temperature had increased to the point that boiling could begin. As steam bubbles formed in the core, they forced the water level in the pressurizer to increase. This increase in level made operators believe the core was covered and there was plenty of water in the reactor coolant system. This belief caused them to drain additional coolant from the system as pressurizer level increased using the plant's "letdown" system. Operators remained oblivious to actual core conditions for over four hours.

When the generator, turbine, and reactor first stopped operating at 0400, over 100 alarms illuminated in the Unit 2 control room. This was a normal response to a unit trip, however additional alarms began to illuminate that should have raised operators' concerns.

At 0411, an alarm signaled high water in the containment building's sump. The high water was caused by water leaking through the stuck open power operated relief valve (PORV), overflowing a drain tank and leaking onto the containment floor.

At 0415, a rupture disc on the drain tank burst as pressure in the tank rose. Containment sumps automatically started pumping this water into the auxiliary building. Local indication in the auxiliary building confirmed the elevated water level in the containment, and operators decided at 0439 to shut down the containment sump pumps to prevent further pumping of the water into the auxiliary building.

At 0420, nuclear power level instruments indicated a higher shutdown power level than normal. This was caused by steam replacing water in the core allowing more neutrons to reach the power instruments.

At approximately 0500, one hour into the incident, the four reactor coolant pumps began to vibrate and alarm in the control room because they were now pumping a steam/water mixture. Operators were concerned that the pumps would be damaged, so they shut down two pumps at 0514 and the remaining pumps at 0541. This action stopped all forced steam/water circulation and its attendant cooling from reaching the core.

By 0600, radiation alarms in the containment building indicated that the nuclear fuel cladding had failed and radioactive gases entrained in the coolant had leaked through the stuck open PORV. Some hydrogen gas, which is formed through a high temperature fuel cladding water reaction, entrained in the coolant also escaped into containment through the PORV leak path.

The TMI plant manager, Metropolitan Edison, and B&W representatives had been notified that there was a problem with the plant; however, whether these discussions or independent operator action identified the stuck open PORV is open to debate. What is known is that at 0622 the block valve for the PORV was shut and the leak path into the containment closed. After the leak path was closed at 0622, reactor pressure began to increase again due to boiling from decay heat. Subsequent analysis has shown that the top of the core was uncovered at 0615 and two thirds of the core uncovered by 0648.

Radiation level began to rise in the containment and neighboring auxiliary building. A radiation technician reported 1 rem/hr, many times normal, in the auxiliary building at approximately 0650.

At 0654, one of the reactor coolant pumps was restarted and ran for 19 minutes before being shut down because of high vibrations. More radiation alarms went off and shortly before 0700, a site emergency was declared and appropriate notifications made to state, county, and U.S. Department of Energy. At that time, TMI's emergency plans required a site emergency whenever "an uncontrolled release of radioactivity to the immediate environment was threatened."

At 0720, an alarm indicated that the containment radiation dome monitor was reading 800 rem/hr. Almost simultaneously operators restarted the HPI system.

At 0724, three and half hours since the initial minor incident had occurred, the plant manager declared a General Emergency. At that time, a general emergency meant an "incident which has the potential for serious radiological consequences to the health and safety of the general public". The plant dispatched radiation monitoring teams to monitor the radiation levels on the island and both sides of the Susquehanna River. Early reports indicated no release of radiation.

At 0738, operators shut down the HPI system stopping the flow of cooling water into the core. This was due to a lack of understanding of the situation and a concern with damaging the pumps.

At 0826, the ECCS's high pressure injection pumps were restarted and remained running. Subsequent analysis has shown that it took approximately two hours to recover the damaged core.

At 1100, all nonessential personnel were ordered off the island.

In an attempt to establish a natural circulation flow path between the core and steam generators, operators opened the PORV block valve at 1138. This depressurized the reactor coolant system and uncovered the core again. For almost 4 hours operators attempted to establish natural circulation. The attempt was stopped at 1508 and the block valve reclosed.

At noon, operators attempted to reenter the auxiliary building and found highly elevated dose rates of 50 mrem/hr to 1,000 rem/hr. A life threatening level is 100 rem/hr.

At 1350, hydrogen, which had been entrained in coolant and leaked in to the containment through the open PORV, exploded. However, at the time, this was not recognized as an explosion. Some thought the "thud" they heard was a ventilation damper slamming shut; it was not until late the next day that it was determined to be a hydrogen explosion.

From then on, the plant remained in a damaged, but essentially stable condition, and the primary worry of all concerned was a radiological release affecting the public. However, there were still several "housekeeping" items to which the plant needed to attend.

Soon after the accident, the plant stopped discharging both wastewater from sources such as toilets, showers, laundry facilities, and leakage in the turbine, control, and service buildings into the Susquehanna River. Normally, this water contains little or no radioactivity, but as a result of the accident, some radioactive gases had contaminated it.

Also, the water drained from the reactor coolant system via the "letdown" system was stored in tanks in the auxiliary building. Because these makeup tanks were at a lower pressure than the reactor coolant system, radioactive gases come out of solution and are then compressed and sent to waste gas decay tanks. The gas normally remains in the tanks for a prescribed period of time, waiting for radioactive decay to take place, to ensure it meets environmental limits prior to discharge. If the waste gas decay tanks are full their relief valves may open and allow a direct release to the environment.

5.2.2.1 Emergency Response

In 1978, a main tenet of nuclear plant siting policy and emergency planning was the calculation of the low population zone (LPZ). This was the area surrounding the plant in which the local population was at risk of receiving 25 rem total exposures during the course of a major accident coinciding with a release of radioactive material. In the case of TMI, the LPZ was a 2 mile ring around the plant and constituted the emergency planning baseline. Pennsylvania had adopted a stricter standard of a 5 mile emergency planning zone for its preparedness plans.

State and local officials were notified of the accident at approximately 0700 when the site emergency was declared and again at 0724 when the general emergency was declared. They began to mobilize resources and take actions in accordance with their emergency plans.

By 0800, regional NRC officials had established telephone contact with the TMI-2 control room; activated their Incident Response Center at King of Prussia, Pennsylvania; opened a direct telephone line to the Emergency Control Station in the TMI-1 control room; and notified NRC staff headquarters in Bethesda, Maryland.

The White House was notified of the accident at 0915.

At 0922, the survey team in Goldsboro, on the west bank of the Susquehanna, reported low levels of radioactive iodine-131. This was later found to be a false reading; however, it added to the general confusion concerning the seriousness of the accident.

At 1005, a team of five NRC inspectors arrived at the site.

At 1245, at the request of the state's Bureau of Radiation Protection, the police closed Route 441 to traffic near Three Mile Island.

At approximately 1345, the U.S. Department of Energy helicopter arrived and began to monitor external radiation levels.

At 1427, radiation readings in Middletown, Pennsylvania, approximately 3 miles to the north of the site, ranged from 1-2 mrem/hour.

The next day, Thursday, mid-morning radiation readings were stable at 1-3 mrem/hr on the western shore of the Susquehanna. TMI island radiation levels were 5-10 mrem/hr. No radioactive iodine had been detected at any locations.

At 1410 Thursday afternoon, a helicopter detected and reported a brief burst of radioactive gas measuring 3 rem/hr at 15ft over the stricken plant’s vent. This was duly noted by the NRC.

The news media found out about the accident through several methods. At 0825 on the 28, a local radio station broadcasted the problem at the site after a reporter found out about the accident through monitoring fire and police radio channels. The station news director called the plant and was told they had a “general emergency”, the plant was shut down and there was no danger to the public.

At 0906, the Associated Press filed a story quoting the Pennsylvania State Police about the general emergency, no danger to the public, and the utility’s request for a helicopter to carry a monitoring team. Many public officials found out about the accident through the news media.

Pennsylvania Lieutenant Governor William Scranton announced the accident to the press at a mid-morning news conference. He stated that Metropolitan Edison had informed him the plant was under control, there was no danger to the public, and a small release of radioactive material had occurred; however, radiation levels were normal.

Contradicting information concerning the erroneous radioactive iodine created some confusion in State communications with the media. Metropolitan Edison also had issues with miscommunications in that its senior representatives stated that there had been a small release, while lower level representatives were denying a release had occurred. Contradictory communications within and across organizations became a major concern in the days following the immediate accident as conflicting information was provided on the need for an evacuation and who had authority to direct plant operations. For example, on Wednesday evening, local NRC representatives told Metropolitan Edison officials that they had no concerns with discharging some of the slightly contaminated, but within specifications, water from the plant’s nearly overflowing wastewater tanks. Discharge was started after the plant notified the state Bureau of Radiation Protection. After discharge commenced, the chairman of the NRC ordered it stopped without knowing the source of the water. However, discharge was allowed to proceed after the state’s Department of Environmental Resources issued a press release.

Late Thursday afternoon, the Governor and local NRC representatives held a press conference in which the NRC stated that the danger had passed for those living off the island. Although there had been no changes in the plant during the 24 hours since the accident, the NRC had become more aware of the severity of the event and by 2200, had to inform the Governor's Office that chemistry results indicated that the damage to fuel was much worse than anticipated and an increased possibility of radiation releases existed.

On Friday, a more serious miscommunication occurred, which resulted in senior NRC officials recommending the evacuation of citizens within ten miles downwind of the plant. What prompted this chain of events was the plant's decision to perform the "housekeeping" chore of compressing some of the radioactive gas that had built up in the makeup tank and transferring it to the waste decay tanks. Plant staff knew there would be some release of radioactive gas because of small leaks in the system. The transfer began at 0710 and a helicopter monitoring the release reported 1 rem/hr at 0756 and 1.2 rem/hr at 0801 130 feet above the plant ventilation stack.

Shortly before 0900 at NRC Headquarters, an erroneous report was received that the plants waste decay tanks had been filled to capacity and a meeting was being held to discuss the potential off-site dose rates should the waste decay tanks relief valves open. The potential off-site ground level dose rate was calculated to be 1.2 rem/hr. As this was being discussed, a report came in from the plant of the 1.2 rem/hr dose rate above the plant ventilation stack. Without confirming the source or location of the radiation readings, senior NRC staff decided to recommend an evacuation to the Director of the Pennsylvania Emergency Management Agency. This recommendation went to the Governor. When the Director of the State's Bureau of Radiation Protection heard of the evacuation recommendation order, he already knew of the source of the 1.2 Rem/hr reading and contacted the NRC representative at the plant. He assessed the situation and personally argued to the Governor that the evacuation was unnecessary.

The Director of Emergency Preparedness for Dauphin County was notified of the radiation release at 0834 by the utility and at 0854 he was told of the radiation release by the Pennsylvania Emergency Management Agency and that no evacuation was needed. He was contacted by the Director of PEMA after the NRC had recommended an evacuation at 0925, and told to expect an evacuation order in 5 minutes. As part of the preparatory actions, Dauphin County alerted all fire departments within 10 miles of the plant and broadcast a warning over the local WHP radio station. This broadcast added to the anxiety and confusion of the general public.

An NRC inspector at the plant was confronted by an agitated plant employee who said his wife had just heard the NRC was recommending an evacuation. The NRC inspector checked plant conditions and contacted NRC Headquarters in an effort to stop the evacuation recommendation.

At 1000, the Chairman of the NRC talked with the Governor and assured him no evacuation was necessary; however, he recommended that personal within five miles of the plant stay indoors. The Governor subsequently issued an advisory that people within ten miles downwind of the plant stay inside. During the course of this conversation the Governor asked for a single NRC expert to provide him with technical support.

At approximately 1100, the President of the United States called Governor Thornburgh and said he would send Harold Denton, NRC Director of Nuclear Reactor Regulation, as his representative and establish a communications network among the plant, the Governor's Office, the White House, and the NRC.

At 1120, the Chairman of the NRC again called the Governor, apologized for the staff evacuation recommendation and concurred with a state recommendation to evacuate pregnant women and children under age two within five miles of the plant. The Governor's order was issued at 1230.

The NRC had learned of Wednesday's hydrogen explosion on Friday morning and the formation of a gas bubble was Mr. Denton's primary concern when he arrived at TMI Friday afternoon at 1400. He brought a cadre of experts with him focused on ways to eliminate the gas bubble. The best information at the time indicated they had 5-8 days before another hydrogen explosion might occur.

Friday evening after 2030, a joint press conference was held in which the Governor lifted the advisory on staying indoors but reiterated the recommendation pregnant women and children less than two years of age to evacuate within five miles of the plant.

The NRC followed two separate paths with regard to analysis the threat of a hydrogen explosion. One team local to the plant thought the natural recombination of free hydrogen and free oxygen, which had also been released by radiolysis, would mitigate the probability of an explosion. Other teams' analyses at NRC Headquarters initially agreed with the assessment that there were several days before hydrogen would be a concern.

At 1445 Saturday afternoon, the Chairman of the NRC held a press conference in which he stated that an evacuation of up to 20 miles might be required if operators attempted to force out the hydrogen bubble and an explosion occurred.

At 2023 Saturday evening, the Associated Press issued a note based upon the Chairmen's press conference that officials were concerned about a spontaneous hydrogen explosion.

At a later press conference that evening, Harold Denton and the Governor Thornburgh stated that there was no imminent threat to the facility and that a combustible mixture did not exist in the containment. The President was scheduled to visit TMI the next day. Throughout Saturday night and the early hours of Sunday, county emergency preparedness offices were deluged with telephone calls from citizens concerned by the conflicting reports about the hydrogen bubble.

When the President arrived at 1300 Sunday afternoon, Harold Denton informed him about the uncertainty with the hydrogen bubble analysis. By 1500 that afternoon, the NRC and its outside experts had reached a consensus opinion that there was no danger of a hydrogen explosion. However, they did not share their analysis with the press, public or Governor Thornburgh.

At a Monday morning press conference, the NRC announced that the bubble had undergone a dramatic reduction in size and that NRC initial calculations were overly conservative.

5.2.2.2 TMI Commission Recommendations

The President's TMI Commission made recommendations in seven broad areas to improve nuclear safety within the NRC and the nuclear industry. Many of the recommendations were implemented and the complete set can be found in the TMI report. Highlights of the recommendations are still relevant today and include:

The Nuclear Regulatory Commission
The Commission found a number of inadequacies in the NRC and proposed a restructuring of the agency by abolishing the five commissioners and appointing a single administrator. It also recommended:

- Plant licensing should be conditioned upon review and approval of the state and local emergency plans;
- Licensing procedures should foster early and meaningful resolution of safety issues before major financial commitments in construction can occur;
- The agency should be authorized to conduct a combined construction permit and operating license hearing whenever plans can be made sufficiently complete at the construction permit stage; and
- There should be an improved program for the systematic safety evaluation of currently operating plants in order to assess compliance with current requirements, to assess the need to make new requirements retroactive to older plants, and to identify new safety issues.

The Utility and Its Suppliers
Utility rate-making agencies should recognize that implementation of new safety measures can be inhibited by delay or failure to include the costs of such measures in the utility rate base. Therefore, the Commission recommended that state rate-making agencies give explicit attention to the safety implications of rate-making when they consider costs based on "safety-related" changes.

Training of Operating Personnel
The Commission recommended the establishment of agency-accredited training institutions for operators and immediate supervisors of operators. These institutions should have highly qualified instructors who will maintain high standards, stress understanding of the fundamentals of nuclear power plants and the possible health effects of nuclear power, and train operators to respond to emergencies.

Technical Assessment
The Commission recommended that as a part of the formal safety assurance program, every accident or every new abnormal event be carefully screened, and where appropriate be rigorously investigated to assess its implications for the existing system design, computer models of the system, equipment design and quality, operations, operator training, operator training simulators, plant procedures, safety systems, emergency measures, management, and regulatory requirements.

Worker and Public Health and Safety
To ensure the best available review of radiation-related health issues, NRC should be subject to mandatory review and comment by the Secretary of the Department of Health and Human Services. A time limit for the review should be established to assure such review is performed in an expeditious manner.

An adequate supply of the radiation protective (thyroid blocking) agent, potassium iodide for human use, should be available regionally for distribution to the general population and workers affected by a radiological emergency.

Emergency Planning and Response
Before a utility is granted an operating license for a new nuclear power plant, the state within which that plant is to be sited must have an emergency response plan reviewed and approved by the Federal Emergency Management Agency (FEMA). The agency should assess the criteria and procedures now used for evaluating state and local government plans and for determining their ability to activate the plans. FEMA must assure adequate provision, where necessary, for multi-state planning.

Research should be expanded on medical means of protecting the public against various levels and types of radiation. This research should include exploration of appropriate medications that can protect against or counteract radiation.

Plans for providing federal technical support, such as radiological monitoring, should clearly specify the responsibilities of the various support agencies and the procedures by which those agencies provide assistance. Existing plans for the provision of federal assistance, particularly the Interagency Radiological Assistance Plan and the various memoranda of understanding among the agencies, should be reexamined and revised by the appropriate federal authorities in the light of the experience of the TMI accident, to provide for better coordination and more efficient federal support capability.

The Public's Right to Information
Federal and state agencies, as well as the utility, should make adequate preparation for a systematic public information program so that in time of a radiation-related emergency, they can provide timely and accurate information to the news media and the public in a form that is understandable. There should be sufficient division of briefing responsibilities as well as availability of informed sources to reduce confused and inaccurate information.

State emergency plans should include provisions for the creation of local broadcast media networks that will supply timely and accurate information during emergencies. Arrangements should be made to make available knowledgeable briefers that can be aired on the radio to dispel rumors and explain conditions at the plant. Communications between state officials, the utility, and the network should be prearranged to handle the possibility of an evacuation announcement.

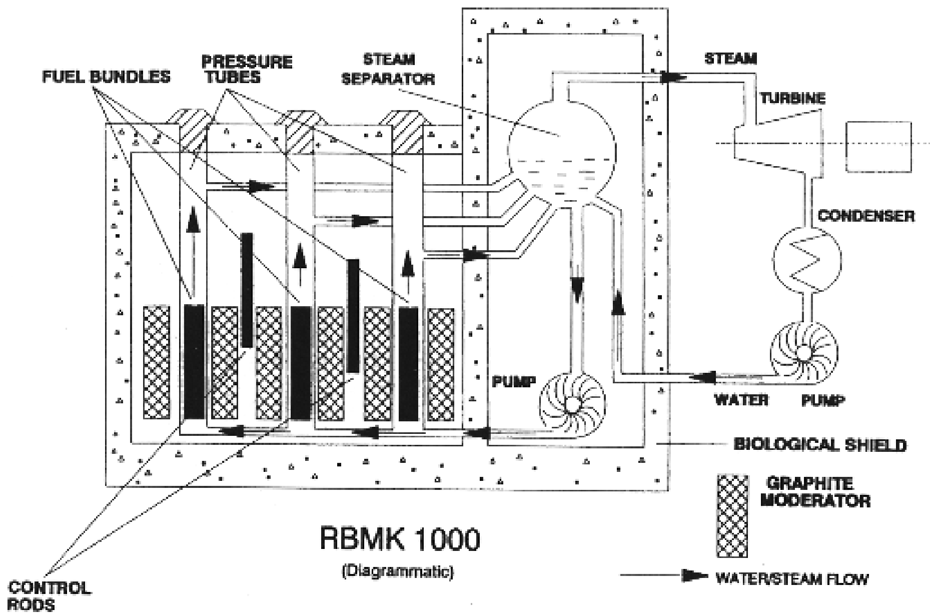
The Commission recommends that the public in the vicinity of a nuclear power plant be routinely informed of local radiation measurements that depart appreciably from normal background radiation, whether from normal or abnormal operation of the nuclear power plant, a radioactivity cleanup operation such as that at TMI-2, or other sources.

5.2.3 Chernobyl

On April 26, 1986, an accident occurred at Unit 4 of the nuclear power station in Chernobyl, Ukraine, in the USSR. The accident resulted in 31 direct deaths from radiation, the evacuation of 135,000 people within 18 miles (30 km) of the plant, and the release of 50 million curies of radioactive material covering various portions of the globe.

The 1000 MWe Chernobyl reactors are pressure tube light boiling water graphite moderated reactors called model RBMK-1000. A gas mixture of helium and nitrogen is used to transfer heat between the graphite moderator and pressure tubes. As the Soviet Union did not have western-style containment structures, it used a unique design that evolved from its plutonium production reactors. It is unlike any operational nuclear power plant in the United States. Chernobyl Unit 4 entered commercial operation in 1983.

Figure 37. RBMK Reactor Schematic



Reasons for pursuing this particular design included:

- Installed manufacturing base and familiarity with component fabrication;
- Previous experience with this reactor design and operation;
- A serious loss-of-coolant accident was thought to be virtually impossible because of the use of numerous pressure tubes rather than a single pressure vessel;
- Very efficient fuel use of 2% enriched uranium; and
- Online refueling could achieve high plant capacity factor.

Operational, regulatory, and public safety philosophies in the Soviet Union differed from those found in the United States. For example, the Soviets placed a heavy reliance on systems testing to verify safety analysis conditions were met vice reliance on computer modeling and code validation, which was used in the U.S.

The accident occurred during the performance of a test to determine how a newly installed regulator would supply electrical power to safety systems after a reactor trip without backup diesel generators. This test had already been successfully performed at similar plants in the USSR.

Chernobyl Unit-4 plant operators felt a sense of urgency and focused on completing the test while losing sight of larger operational and plant management concerns. There were no major equipment failures or protective system malfunctions that promoted core damage; rather, root causes of the disaster were related solely to operator actions.

5.2.3.1 Accident Timeline

On April 25, 1986 at 0100, operators began reducing power for the coastdown test prior to the start of a maintenance outage. Approximately 12 hours later, the reactor was at 50% power and the emergency core cooling system, in accordance with the test procedures, was defeated to prevent interference with the test. The plant remained in this condition for 9 hours after the load dispatcher requested that the plant remain on-line.

At 2310, the power reduction resumed and an operator error in setting a rod control system set point quickly dropped reactor power to 30 MWt. The large power transient initiated the buildup of xenon poisoning within the core, which forced operators to withdraw control rods in an effort to counter the xenon buildup and return reactor power to the 700-1000 MWt range in accordance with the test procedure.

Power level was successfully raised to 6% (200 MWt) at 0100, and a decision was made to proceed with the test. It was a violation of Soviet operating procedures to continuously operate the reactor at power levels less than 700 MWt. In accordance with the test procedure, two additional main circulation pumps were started at 0103, this led in an increase in flow rate that exceeded operational limits and caused decreases in steam pressure and steam drum water level.

In order to avoid an automatic reactor scram on steam drum parameters and ruin the test, the operators bypassed the reactor trip system. Operators also increased feed water flow to the steam drum, introducing negative reactivity, which caused the control rods to withdraw further from the core.

At 0122, plant conditions were outside the parameters for conducting the test, but operating conditions were relatively stable and the decision was made to conduct the test by shutting the main steam isolation valves to the turbine and initiating coast down. The reactor scram signal for steam isolation valve closures was overridden in the mistaken belief that the test could be repeated if unsuccessful. Approximately thirty seconds later, a computer printout from the reactivity monitoring system stated that the reactor should be shut down immediately; however, operators ignored it in order to complete the test.
At 0123, the test was initiated by shutting the main steam isolation valves. The generator and half of the main recirculating pumps began to coast down. As the pumps coasted down, core power began to increase as steam voids from reduced coolant flow were formed in the core. 36 seconds after the main steam isolation valves were closed, the shift manager ordered the reactor scrammed by inserting all control rods into the core. After the scram was initiated, the control room felt a number of severe shocks and noticed not all control rods had been inserted into the core. Control rods were then deenergized in the hope that the rods would fall into the core. Within three seconds another loud noise was heard in the control room.

Subsequent analysis has shown that at 0123, a large power excursion peaking at 100 times the nominal full power occurred. This disintegrated the fuel and when the disintegrated fuel contacted the coolant, a large pressure excursion occurred, which lifted the 1000 ton reactor cover plate and severed all 1661 fuel channels. The refueling machine and crane collapsed into the reactor, the reactor building was destroyed, and hot segments of the core including fuel and graphite moderator were ejected from the site and started over 30 fires in surrounding structures.

Local fire departments responded and extinguished all fires outside of the core by 0500. Operators attempted to cool the core by injecting water using the ECCS system and auxiliary feedwater systems. Over the next 14 days, over 5000 metric tons of boron, dolomite, sand, clay and lead were dropped on the core by to ensure fuel rubble remained subcritical and to minimize radioactive release.

Construction of the sarcophagus covering the destroyed Chernobyl Unit 4 was started in May 1986 and completed by the Soviet authorities in an extremely challenging environment 6 months later. It was built as a temporary fix to channel remaining radiation from the reactor through air filters before being released to the environment. After several years, uncertainties about the actual condition of the sarcophagus, primarily due to the high radiation environment, began to emerge.

In 1997, the countries of the G-7, the European Commission, and Ukraine created the Chernobyl Shelter Implementation Plan as a multilateral funding mechanism to help Ukraine transform the existing sarcophagus into a stable and environmentally safe system. The Chernobyl Shelter Fund was established to finance the Plan and the European Bank for Reconstruction and Development was entrusted with its management. The Plan was intended to protect, over the long-term, the personnel, population, and environment from the threat of the very large inventory of radioactive material contained within the existing sarcophagus. First, the existing sarcophagus will be stabilized, and then it will be replaced with a new safe shelter (confinement) designed to remain functional for 100 years.

5.2.3.2 Emergency Response

Because of the severity of the accident, ad hoc responses were developed to protect public health and safety in the most expeditious manner. The 18 mile (30-km) evacuation zone at Chernobyl was developed on an ad hoc basis. The general public alert and notification systems leveraged the system of Soviets in each apartment building and block and included notification through wired radios in each home near the plant and door-to-door visits. This latter system also appears to have been used to distribute potassium iodine.

At a conference on Chernobyl in Vienna, the Soviet delegation indicated ad hoc planning enabled the evacuation of 45,000 people from the village of Pripyat in three hours and the evacuation of the remaining 90,000 people over a number of months. As most of the rural population refused to leave their animals, the Soviet government also evacuated approximately 19,000 cattle.

A unique Soviet solution to protecting the public from contamination during evacuation was covering the land areas along evacuation routes with a polymer substance that significantly limited the radiation exposure of evacuees. Another unique attribute of the response was the apparent widespread availability and distribution of potassium iodine (KI). The Soviets also engaged in seeding clouds with silver iodine in the weeks following the accident to break them up in an attempt to prevent rainfall and the resulting spread of contamination.

5.2.3.3 Radiation Exposure

Almost immediately, the Chernobyl accident caused many severe radiation effects. Among the approximately 600 workers present on the site at the time of the accident, two died within hours of the reactor explosion from non-radiological causes, and 134 received high radiation doses and suffered from acute radiation sickness. Of these, 28 workers died in the first four months after the accident. Another 200,000 recovery workers involved in the initial cleanup work of 1986-1987 received doses of between 1-100 rem. The number of workers involved in cleanup activities at Chernobyl rose to 600,000; however, only a small fraction of these workers were exposed to dangerous levels of radiation.

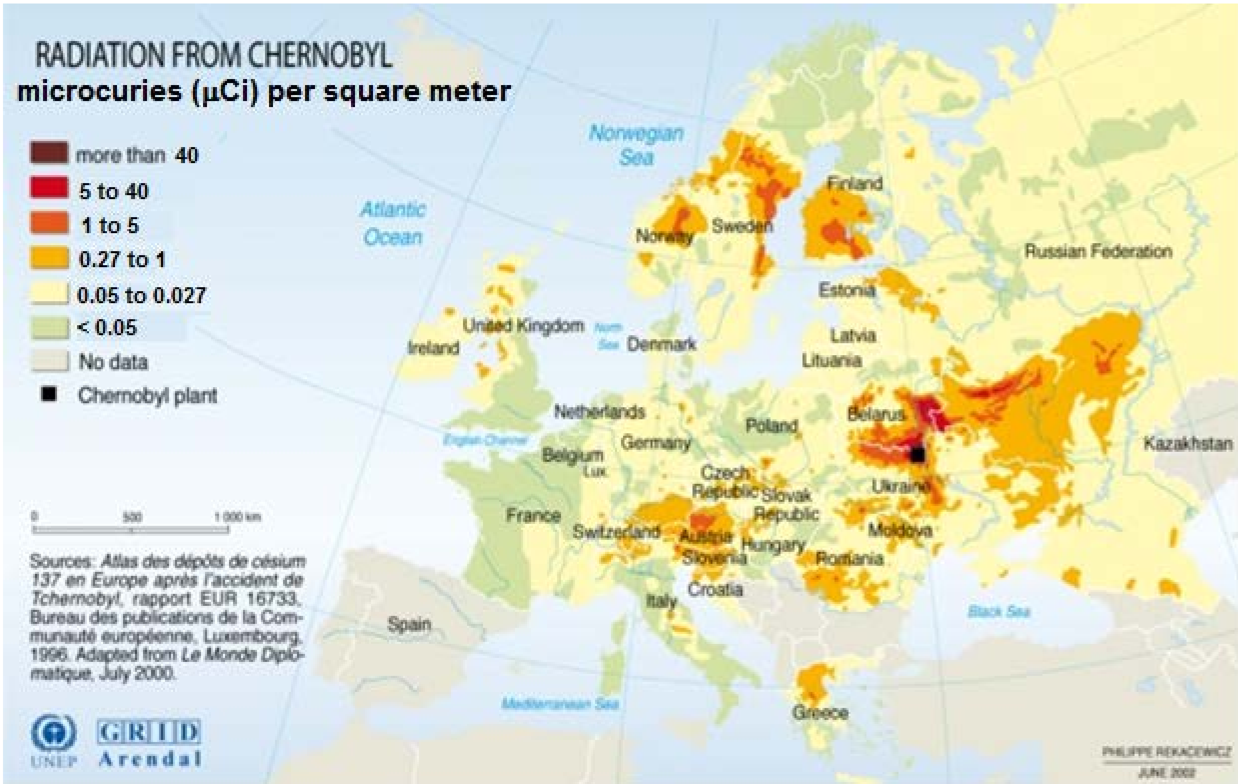
The 45,000 evacuees from Pripyat received an average whole-body dose of 3.3 rem, which reflects the effectiveness of the evacuation and the relatively low dose rates during the accident's first day. The other 90,000 evacuees residing within 3-30 km (1.9 to 18.6 mi) received an average whole body dose of 16 rem and an average thyroid dose of less than 30 rem. A 24,000 person subgroup within 3-15 km (1.9 to 9.3 mi) received an average dose of 43 rem. These large doses reflect the fact that many of these persons were not evacuated until later. Part of the delay was caused by the reluctance of individuals to abandon their animals.

There have been at least 1,800 documented cases of thyroid cancer in children who were between zero-14 years of age when the accident occurred, which is far higher than normal. However, long-term health studies of the registered cleanup workers (so-called "liquidators") have failed to show any direct correlation between their radiation exposure and an increase in other forms of cancer or disease. The psychological effects of Chernobyl were and remain widespread and profound, and have resulted in suicides, drinking problems, and apathy.

Apart from the increase in thyroid cancer after childhood exposure, no increase in overall cancer or non-cancer diseases has been observed that can be attributed to the Chernobyl accident and exposure to radiation. However, it is expected that over the lifetime of the emergency workers, evacuees, and residents living in the most contaminated areas, some cancer deaths may eventually be attributed to the Chernobyl accident. While these reported negative health effects are far lower than initial speculations that radiation exposure would claim tens of thousands of lives, they are not significantly different from Soviet scientists' estimates made in 1986.

Figure 38. Radiation Hotspots

Figure 39. Worldwide Chernobyl Radiation



Sources: UNEP/GRID-Arendal, European Environment Agency; *AMAP Assessment Report : Arctic Pollution Issues*, Arctic Monitoring and Assessment Programme (AMAP), 1998, Oslo; European Monitoring and Evaluation Programme (EMEP); Co-operative programme for monitoring and evaluation of the long range transmission of air pollutants in Europe, 1999. Adapted from *Le Monde Diplomatique, July 2000*.

5.2.3.4 U.S. Response

The NRC conducted a review of the accident, issued three regulatory guidelines (NUREGs), and concluded no immediate changes were needed regarding the design or operation of US commercial nuclear power plants.

The Chernobyl Health Effects Studies were originally established on April 26, 1988 through a bilateral agreement between the United States and the Soviet Union to study the health consequences of the Chernobyl accident. After the dissolution of the Soviet Union, the United States signed separate agreements with Belarus and Ukraine to continue these projects.

Currently, the DOE is co-funding with the National Cancer Institute (NCI) several studies, all of which are conducted jointly by both scientists at NCI and Columbia University and investigators from Ukraine and Belarus.

5.2.4 Fukushima[164]

On March 11, 2011, a magnitude 9 earthquake generated a series of large tsunami waves that struck the east coast of Japan. The earthquake and tsunami waves caused widespread devastation and more than 16,000 people were killed and an additional 3000 went missing[165].

Eleven nuclear reactors at five sites shut down as designed due to the earthquake's force.[166]

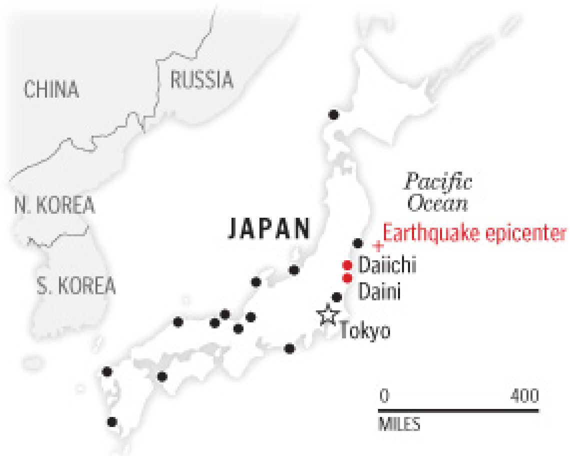
Table 29. Five Sites with Reactors Shut Down

Plant	Condition at time of earthquake	Earthquake affect
Tokai	1 unit operating/ Plant had 18 foot high seawall	Operating unit automatically shut down by earthquake. 16 foot tsunami.
Higashi Dori	Shut down at time of earthquake	
Onagawa	3 units operating / Plant had 46 foot high seawall	Operating units automatically shut down by earthquake
Fukushima Dai-ichi (Fukushima I)	3 units operating/ 3 units Shut down Plant had 16 foot high seawall	3 Operating units automatically shut down by earthquake/42 foot high tsunami
Fukushima Dai-ni (Fukushima II)	4 Operating/ Plant had 21 foot high seawall	Operating units automatically shut down by earthquake 42 foot high tsunami

As a result of the tsunami's effects on the off-site electrical grid infrastructure, all five sites suffered degraded off-site electrical service. Emergency diesel generators were required to supply the power necessary to remove decay heat from affected reactors or spent fuel pools. Tokyo Electric Power Company's Fukushima Dai-ichi and Fukushima Dai-ni plants were struck with the largest tsunamis and both plants were inundated with seawater.

[164] The National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission
[165] http://earthquake-report.com/2012/03/10/japan-366-days-after-the-quake-19000-lives-lost-1-2-million-buildings-damaged-574-billion/
[166] http://www.bbc.co.uk/news/science-environment-12711707

Figure 40. Locations of Fukushima I & II Nuclear Plants



The Fukushima Dai-ni (Fukushima II) plant, which has a total electrical output of 4,400 MWe, consists of four BWR/5 series reactors with Mark II containments designed by Hitachi and Toshiba. All reactors achieved initial criticality in the 1980s.

After the tsunami, one of the four reactor's decay heat removal systems remained operable and plant staff was able to place the unit in cold shutdown, defined as having the reactor coolant temperature less than 212° Fahrenheit, the next day.

One transmission line remained intact and served operable portions of the plant. However, the three other reactors had flooding in their essential service water pump rooms, and due to the loss of those systems, they were unable to transfer reactor heat to the ocean. Thus, heroic efforts on the part of plant staff were required to restore the heat removal capability of those reactors. Workers restored power by hand laying five miles of heavy temporary electrical cables to support restoration of decay heat removal capability and by installing new pump motors transported from off-site. Fortuitous circumstances had placed 2,000 workers at the site at the time of the disaster greatly enhancing the staff's response capability.[167] The temporary electrical cable was transported to the site by helicopter and staff cleared a landing zone and positioned personal vehicles to illuminate the "heliport" for night landings.

[167] http://en.wikipedia.org/wiki/Fukushima_II_Nuclear_Power_Plant#cite_note-WNN18-13

Figure 41. Mark II Containment at Fukushima II

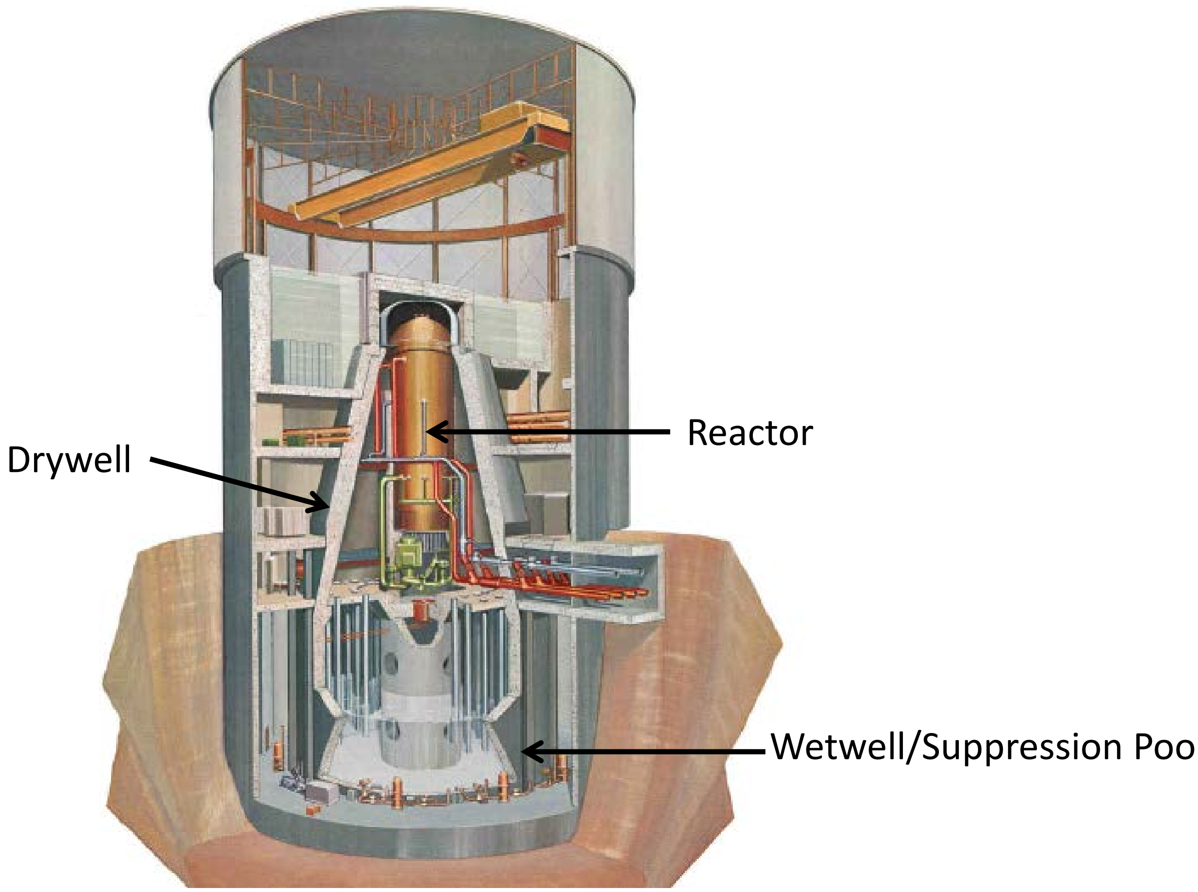
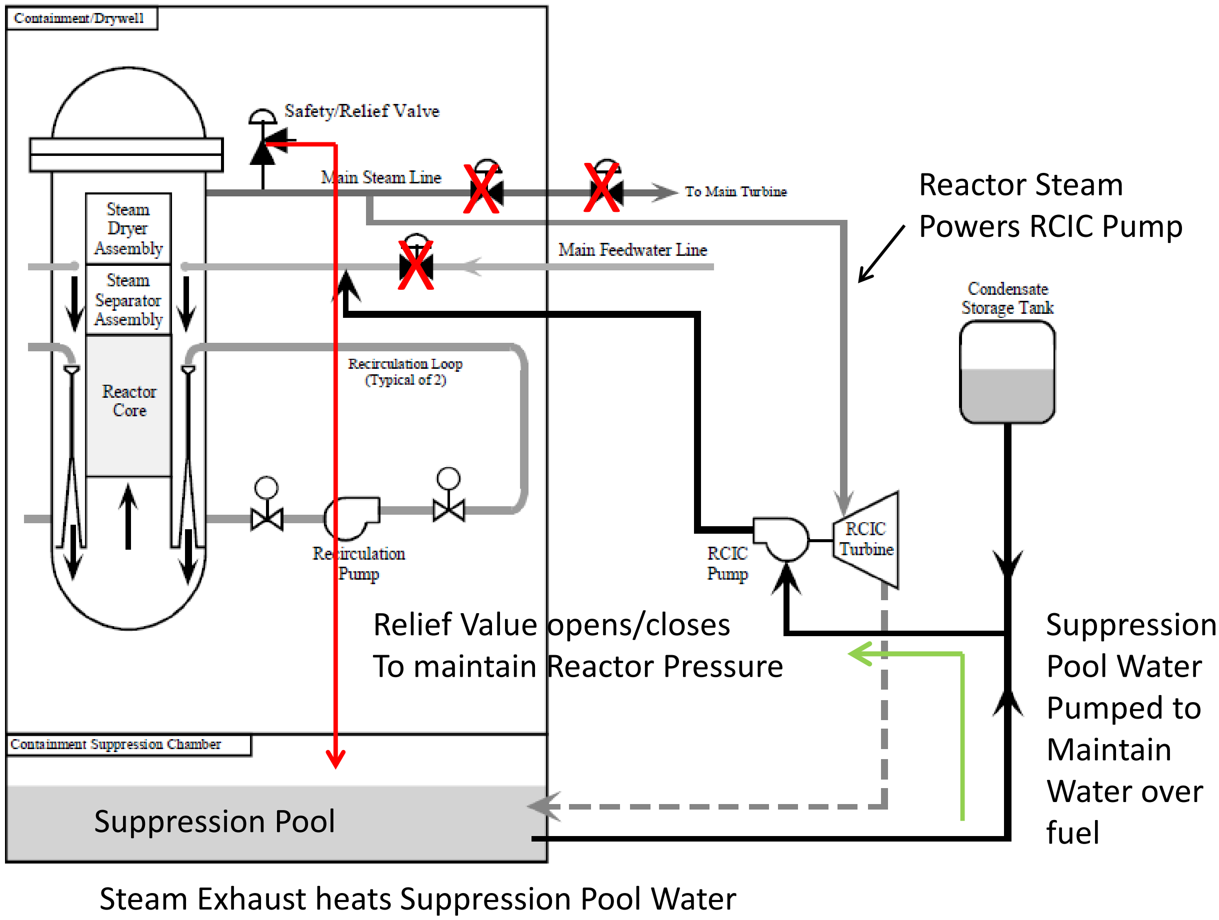


Figure 42 depicts the situation of the three affected reactors while awaiting repairs to their essential service water systems. Isolated from any heat sink, the reactor core isolation cooling system (RCIC) recirculated water from the suppression pool back into the reactor as necessary to maintain water level above the nuclear fuel. Pressure in the reactor was controlled by dumping steam into the suppression pool as required. The urgent requirement to restore the decay heat removal capability was driven by the fact that the RCIC pump cannot be used after suppression pool temperature reaches 212° F and the suppression pool was being heated by the steam released to control reactor pressure. As this point approached plant operators used secondary systems, the makeup water condensate system and the makeup water purification and filtering system, to cool the reactor and drywell while repairs were made to the essential service water system.[168]

[168] Chronology of Main Events at Fukushima Daini Nuclear Power Station, http://www.tepco.co.jp/en/press/corp-com/release/betu11_e/images/110810e22.pdf

Figure 42. Situational Overview Damaged Nuclear Plants Fukushima II



All reactors were placed in cold shutdown by March 15. The loss of cooling water at reactors 1, 2, and 4 was classified a level 3 (serious incident) on the International Nuclear Event Scale by Japanese authorities as of March 18.[169] Preparations for drywell venting were made including the evacuation of all residents within 1.8 miles (3 km) of the plant. However venting and evacuation were not required and no radiation was released.[170] All units have remained shut down since March 11.

[169] http://www.iaea.org/newscenter/news/2011/fukushima150311.html
[170] Chronology of Main Events at Fukushima Daini Nuclear Power Station, http://www.tepco.co.jp/en/press/corp-com/release/betu11_e/images/110810e22.pdf

Figure 43. Fukushima I (Tokyo Electric)

Tokyo Electric Power Company's Fukushima Dai-ichi (Fukushima I) site contains six BWR reactors of various vintages and suppliers.

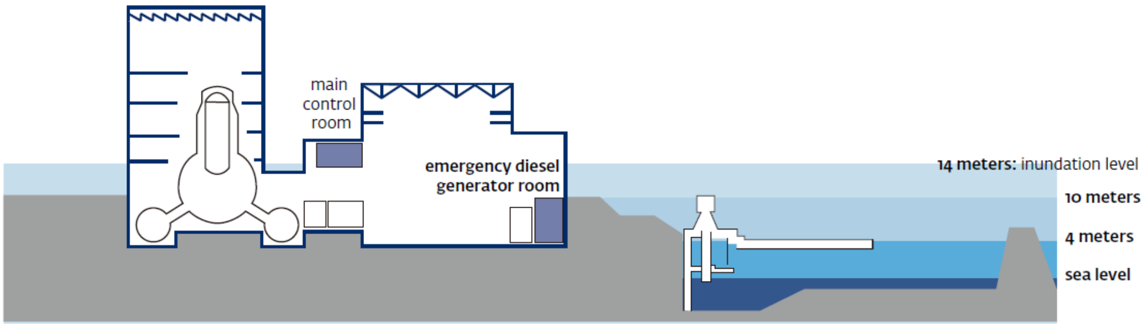
Table 30. Fukushima I Reactors

Unit	Type	Containment	First criticality	Capacity	Reactor supplier
1	BWR-3	Mark I	October 10, 1970	460 MW	General Electric
2	BWR-4	Mark I	May 10, 1973	784 MW	General Electric
3	BWR-4	Mark I	September 6, 1974	784 MW	Toshiba
4	BWR-4	Mark I	January 28, 1978	784 MW	Hitachi
5	BWR-4	Mark I	August 26, 1977	784 MW	Toshiba
6	BWR-5	Mark II	March 9, 1979	1,100 MW	General Electric

Units 1, 2, and 3 were operating at the time of the earthquake and were successfully shut down by their reactor protection systems. Due to the loss of all off-site power, emergency diesel generators started. Approximately 45 minutes later, a tsunami wave three times larger than the wave assumed in the plant's design basis struck the facility.

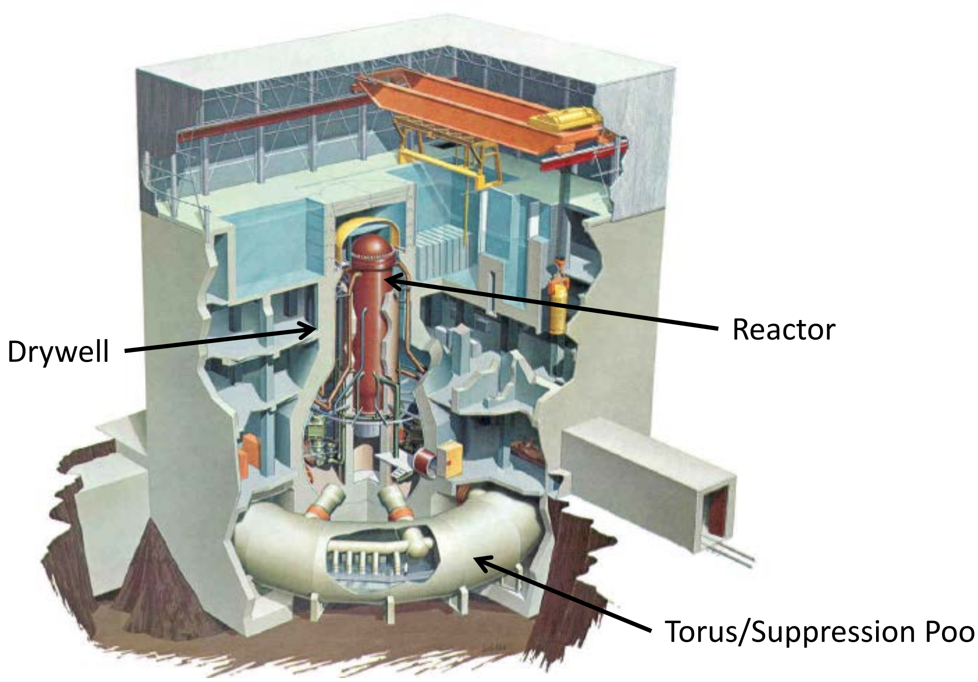
Units 1-4 were inundated and all six units lost use of the ocean as a heat sink. The waves had also destroyed the surrounding infrastructure to such an extent that the plant was effectively isolated. With the exception of one air-cooled diesel generator at Unit 6, all diesel generators shut down due to a combination of flooded switchgear, loss of cooling water, and general flooding. Units 1-5 lost all AC power and Units 1-4 would also lose all DC power. Loss of AC and DC power meant loss of control room indications, lighting, control functions and communications. As accident planning criteria encompassed the loss of AC power, but not that of DC, operational staff had to make immediate response decisions based upon training and experience.

Figure 44. Plant Cross Section versus Flooding Level



Significant physical damage to buildings and equipment surrounding the plant and periodic aftershocks complicated response efforts.

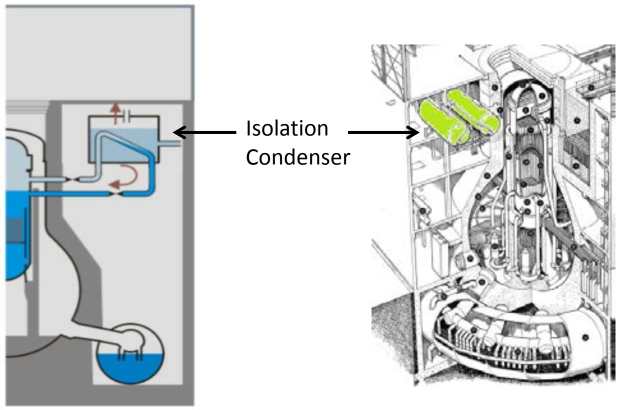
Figure 45. Mark I Containment



5.2.4.1 Unit 1

With the exception of Unit 1, all of the units at Fukushima I had Reactor Core Isolation Cooling Systems (RCIC) similar to those previously described earlier for Fukushima II. Unit 1 is an early BWR/3 design that used an isolation condenser (IC), which is a heat exchanger that uses natural circulation as a passive decay heat removal system. Steam from the reactor enters the IC and is cooled and condensed by water from a condensate system. To maintain natural circulation, the IC requires electric power to provide it with makeup water.

Figure 46. Unit 1 Isolation Condenser



It is possible that the Unit 1 ICs were damaged during the earthquake; however, 11 minutes after Unit 1 shut down due to the earthquake and prior to the tsunami, the reactor operator manually stopped both trains of the IC cooling.[171] TEPCO officials told the Independent Commission that this was the first time the IC system had automatically started and ever been used since the plant started operation in 1971.[172]

Reactor pressure was decreasing at the time the IC, was isolated implying the possibility of a small break loss of coolant accident (SB-LOCA) caused by the earthquake; however, this has not been definitively confirmed.[173] Japan's Independent Investigation Commission used fault tree analysis to examine possible accident scenarios rather than direct site inspections. And, it may be years before inspection by robots or other remote means determines why reactor pressure was decreasing or the exact sequence of events that caused the station blackout.

Operators controlled reactor pressure by cycling flow from the IC prior to the tsunami. At the time the tsunami struck, the IC valves were closed and they remained closed upon loss of AC and DC power. The reactor was without a heat sink to remove decay heat, and approximately three hours later, core damage started to occur. As a reactor core melts it creates a lava-like substance called Corium, which contains fuel, cladding, control rods and other structural parts of the reactor. Zirconium cladding for reactor fuel has superior performance during normal operations; however when fuel temperature reaches approximately 1800° F, a rapid exothermic reaction takes place in the presence of steam. The reaction generates large quantities of hydrogen gas.

Eleven hours after the tsunami the struck (0230), the Unit 1 reactor pressure vessel failed and equalized pressure with the containment. The resulting transient blew hydrogen gas and radioactive airborne materials into the reactor building and external environment. After vessel melt-through, Corium-concrete reactions generated additional hydrogen and carbon monoxide gas.

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[171] The National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission Chap 2 p.64
[172] Ibid p83
[173] Ibid p.72

At 0514, the evacuation zone around the plant was expanded to six miles (ten km). Through the evening of March 11, plans to vent the containments of Units 1-3 to the atmosphere had been occurring and at 0300 on March 12, a press conference was held to announce the containment venting. However by that time, Unit 1's pressure was already decreasing and site radiation levels were increasing. Unit 1's condition continued to degrade throughout the day and its containment was finally vented manually at 1410. Procedures did not exist for manual venting, so they had to be developed in situ by the operators. Additionally, radiation levels had climbed to the point where workers could exceed their emergency dose limits while manually opening valves, so careful planning was required.

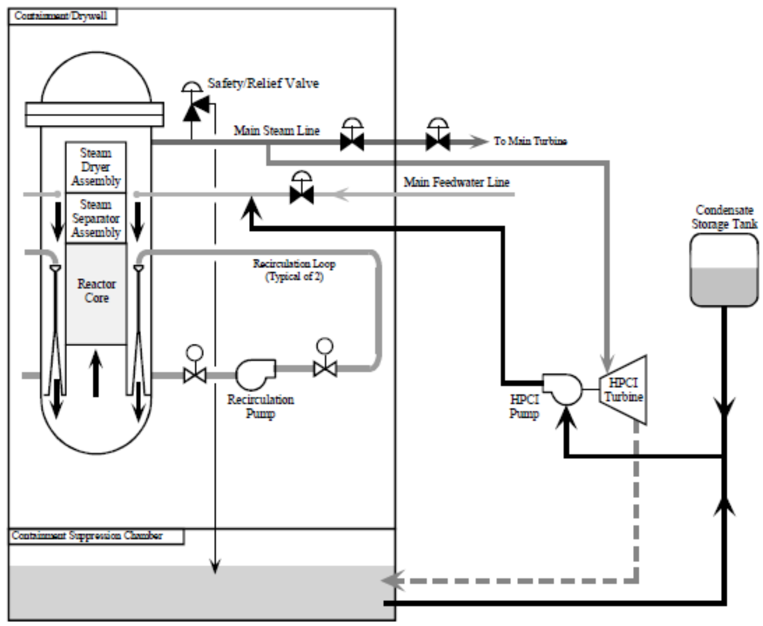
At 1516, the reactor building of Unit 1 exploded due to hydrogen gas buildup. The explosion injured five workers and damaged temporary cables that were being routed to Unit 2 to provide makeup water for the Unit 2 reactor. To facilitate the laying of Unit 2's temporary cables, the common Unit 1-2 control room door was open at the time of the explosion, which blew radioactive material into the control room, further complicating response efforts.

By that evening, the evacuation zone was expanded to 12 miles (20km) and a fire engine was able to pump seawater into the Unit 1 containment. Off-site power to Unit 1 was restored on March 20, nine days after the earthquake.

5.2.4.2 Unit 3

Unit 3 maintained DC power for a significant period of time, allowing reactor operators to use control panel instrumentation and monitor reactor water level and pressure from the control room. The RCIC system and Safety Relief Valves (SRVs), similar to those described at Fukushima II, were used to maintain reactor water level and pressure until its shutdown at 1136 the next day. Unit 3 operators were unsuccessful in their attempts to arrange for a fire truck to provide injection water, but an hour after the loss of the RCIC system, the High Pressure Coolant Injection System (HPCI) automatically started due to a low reactor water level signal. As shown in the following figure, the HPCI system is almost identical to the RCIC system, with the exception of the pumps characteristics. The HPCI system raised reactor water level and lowered reactor pressure.

Figure 47. Generic HPCI System



At 0242 on March 13, the HPCI failed as DC power was lost when the batteries ran low at Unit 3. With the loss of HPCI, reactor pressure increased to the point that injection by a diesel driven fire pump was not possible and the reactor was left without a heat sink. Approximately two hours later, the core started to uncover and core damage began. By 0730, the core was completely uncovered and reactor pressure was increasing. At 0855, operators were able to open a safety relief valve and depressurize the reactor. At approximately the same time, operators succeeded in opening a vent path for the containment, which was vented four times due to pressure increases caused by core melting. At 1101 on March 14, immediately after the fourth venting, an explosion occurred. The force of the explosion destroyed the secondary containment, injured 11 workers, and stopped seawater injection efforts for Units 1, 2, and 4. The high radiation levels found on the Unit 3 debris and the force of the explosion have led to the hypothesis that Corium-Concrete byproducts contributed to the explosion, thus indicating melt-through of the reactor pressure vessel.

At 1630, seawater injection was restored by a fire engine, and off-site power was restored March 22, 11 days after the earthquake.

5.2.4.3 Unit 2

Unit 2 lost all AC and DC power within an hour of the tsunami and operators were unable to use the HPCI system or confirm the operation of the RCIC system. Unit 2 was given the highest priority for response efforts because it was postulated that water level would drop to the top of the fuel by 2140 that evening. This spurred the first evacuation order (2 km) by the Prefecture and a second (3 km) shortly thereafter by the national government.

Batteries and generators were brought to the control room in an attempt to restore reactor water level indication, lighting, and other indicators. These efforts succeeded at approximately 2200, and the reactor water level was found to be 11 feet above the fuel. Operators were able to confirm that the RCIC system was operating through local gauge inspection in the reactor building.

Radiation dose rates were increasing in the control room due to problems with Unit 1 and this forced control room operators to don coveralls and full face masks for protection. This made communications difficult and further degraded the ability of operators to respond to the accident. Efforts were being made to connect a temporary cable for water injection via the standby liquid control system when the Unit 1 reactor building exploded. The explosion also destroyed Unit 2’s secondary containment.

The RCIC system was continuously monitored while fire engines and hoses were staged as seawater injection sources should the RCIC system fail. At 1101 on March 14, the Unit 3 reactor building exploded, damaging the staged fire engines and hoses.

The RCIC system failed at 1325 after operating for approximately 70 hours and it was estimated that fuel would start to uncover at 1630. Aftershocks caused operators to suspend recovery work until 1600. The core was completely uncovered by 1822 and reactor pressure was lowered by opening a safety relief valve (SRV). The reactor depressurized; however, the containment pressure did not increase, indicating a leak between the containment and reactor building.

Attempts to inject seawater to recover the core were initially stymied by the fire truck running out of gas. Eventually two fire engines started pumping seawater into the reactor, but they were ineffective in raising the water level above the top of the fuel.

Simultaneous to the hydrogen explosion that occurred in Unit 4’s reactor building at 0600 on March 15, a loud noise was heard in the Unit 2 torus room and radiation levels spiked to 58 mrem/hr at the main gate. An evacuation of approximately 650 non-essential personnel to the Fukushima Daini (Fukushima II) plant was ordered and no monitoring of Unit 2 took place for four hours. A breach of the containment had occurred.

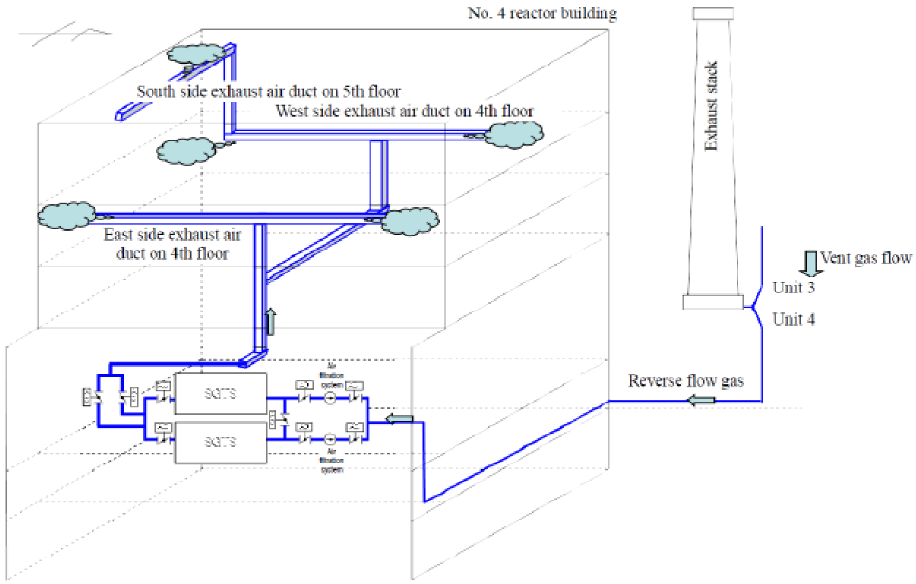
Seawater injection was eventually prepared and off-site power was restored on March 20.

As Unit 2 did not have a hydrogen explosion like the other three units, it is likely that the Unit 1 explosion destroyed Unit 2’s secondary containment, preventing hydrogen accumulation.

5.2.4.4 Unit 4

Unit 4 was shut down at the time of the earthquake and the core was unloaded and all fuel located in the spent fuel pool. Unit 4 suffered a hydrogen explosion at 0600 on March 15, and initial speculation centered on a loss of water level in the spent fuel pool. However, later analysis presumes that when the Unit 3 containment was vented, hydrogen gas flowed into the Unit 4 reactor building through the standby gas treatment system.

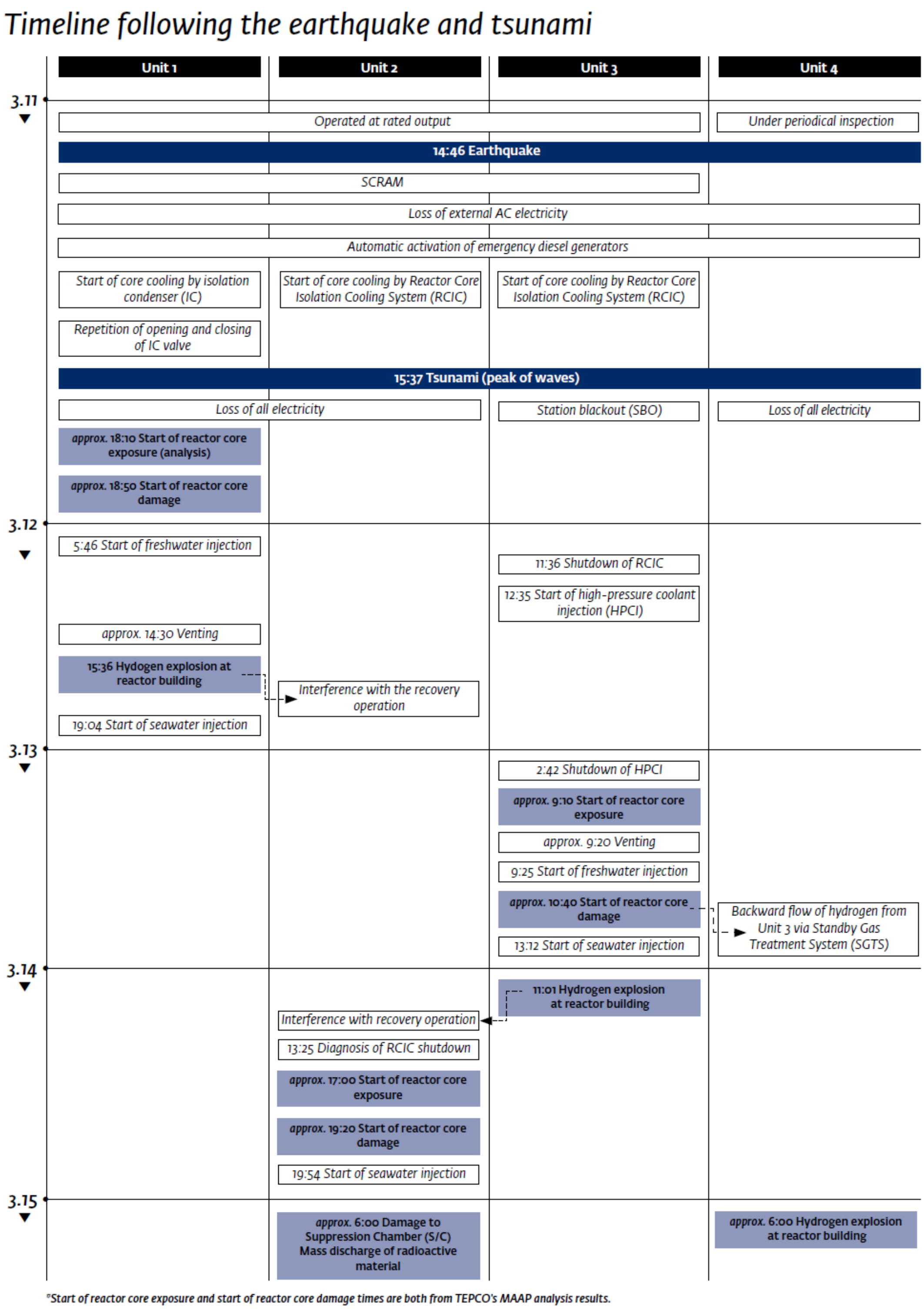
Figure 48. Unit 4 Standby Gas Treatment System Hydrogen Flow Path (Source INPO)



5.2.4.5 Spent Fuel Pools

All units at Fukushima I were designed with spent fuel pools located on the upper floor of the reactor building. Given the high radiation levels, there was concern that the earthquake may have uncovered spent fuel through loss of spent fuel pool water inventory. Subsequent information showed that all spent fuel at all units remained covered throughout the disaster and up until this point in the recovery. The removal of spent fuel from the pools of the damaged reactor buildings is the primary concern of the recovery crews. Loss of water in the pools, which may initiate a zirconium cladding fire causing widespread contamination, or failure of the building's structural integrity, could precipitate another accident.

Figure 49. Accident Timeline



5.2.4.6 Emergency Response

The recovery phase of the accident is still ongoing. Approximately 146,520 people were evacuated as a result of the accident at Fukushima I; of that, approximately 78,000 are from the 12-mile (20 km) “exclusion zone” and an additional 10,000 from a highly contaminated area to the northeast of the site beyond the 12-mile zone. The accident is estimated to have released 24 million curies of radioactive material into the air and contaminated an area of 684 square miles. This is approximately one sixth of the radiological release and area of Chernobyl disaster, but approximately the same number of evacuees due to Japan’s higher population density.

Japan has not announced any permanent forced relocation of individuals, but has set up “temporary” shelters and embarked on an aggressive decontamination campaign. Where possible, topsoil is being removed from schoolyards, parks, and residential areas in an effort to reduce annual radiation exposure. Homes and buildings are being decontaminated and an aggressive food and water monitoring program has been enacted to protect the food chain. It may be decades before residents or their descendants are allowed to return and live within the current exclusion zones. In 2012, TEPCO began making payments to evacuees to compensate them for losses.

In December 2011, Tokyo Electric announced a 40-year recovery plan for the site.[174] Plan milestones include:

- 2012- Install equipment that removes radioactivity migrating into underground water and seawater. The land must be repeatedly mapped for contamination because rain distributes the material unevenly in the soil.

- 2014-Begin to remove debris using remotely controlled robots. Tokyo Electric has already purchased some industrial demolition robots to tear down irradiated buildings. Contractors extended the 4300-pound robots' range, added video cameras, and hardened them against radiological contamination.

- 2015- Workers use newly invented chemical sealants to plug holes in areas of the plant flooded with radioactive water. They drain the water from the reactor building and employ custom-made underwater robots to collect debris from inside the spent fuel pools.

- 2016 -Cover for the reactor building is installed to enclose the space. Additional video cameras monitor remote work inside the reactor and turbine buildings, which are drained and repaired.

- 2022-Removal of the fuel rods from the damaged reactors begins. The rods have melted and fallen apart, complicating the cleanup.

- 2030 and Beyond -The last of the fuel is removed from the reactor buildings. Demolition crews then dismantle the entire facility, a process that takes decades.

[174] http://www.popularmechanics.com/science/energy/nuclear/40-years-of-fukushima-cleanup-timeline-7210953

Figure 50. Joint US/Japan Aerial Survey Data April 29, 2011[175]

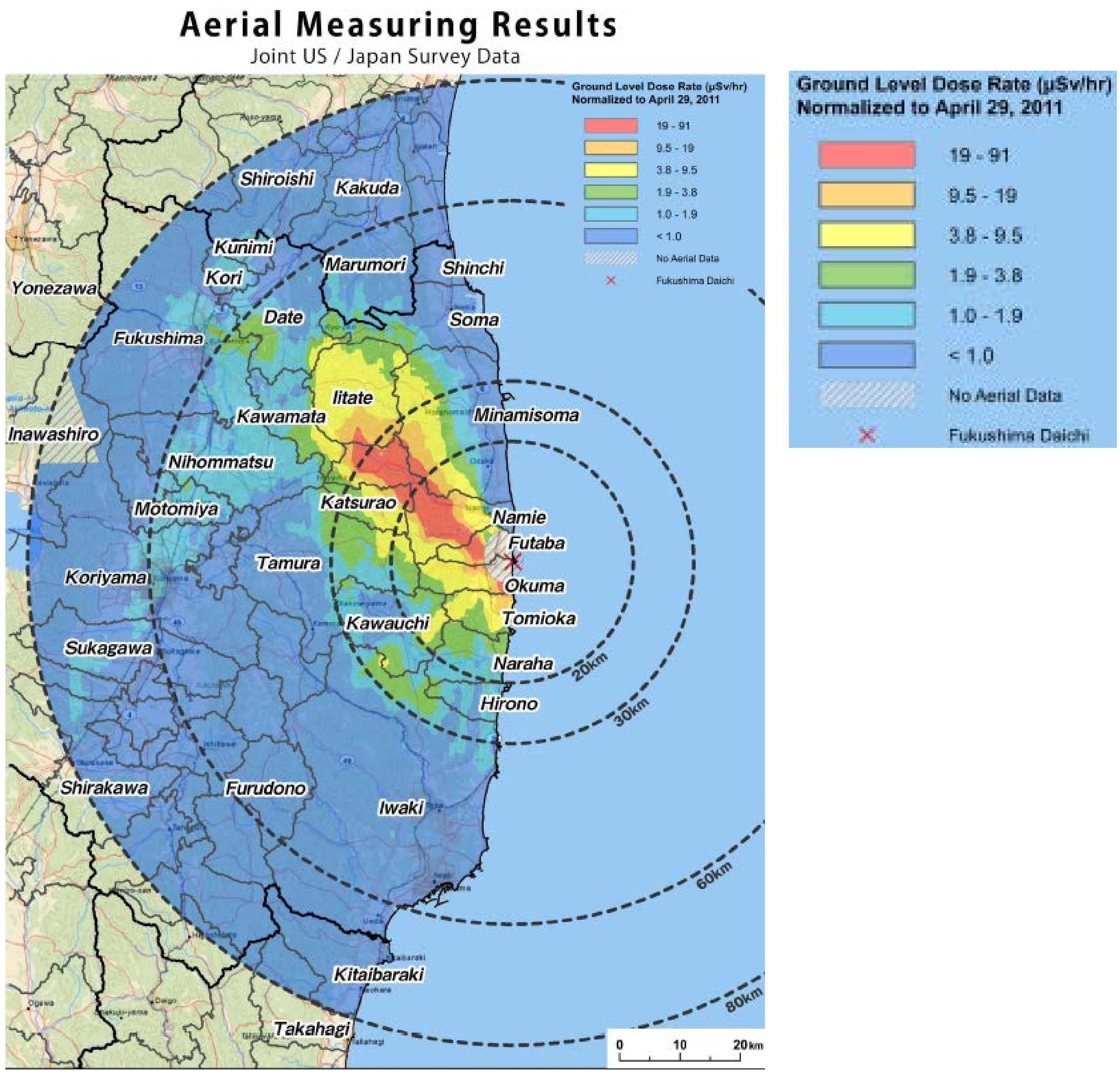


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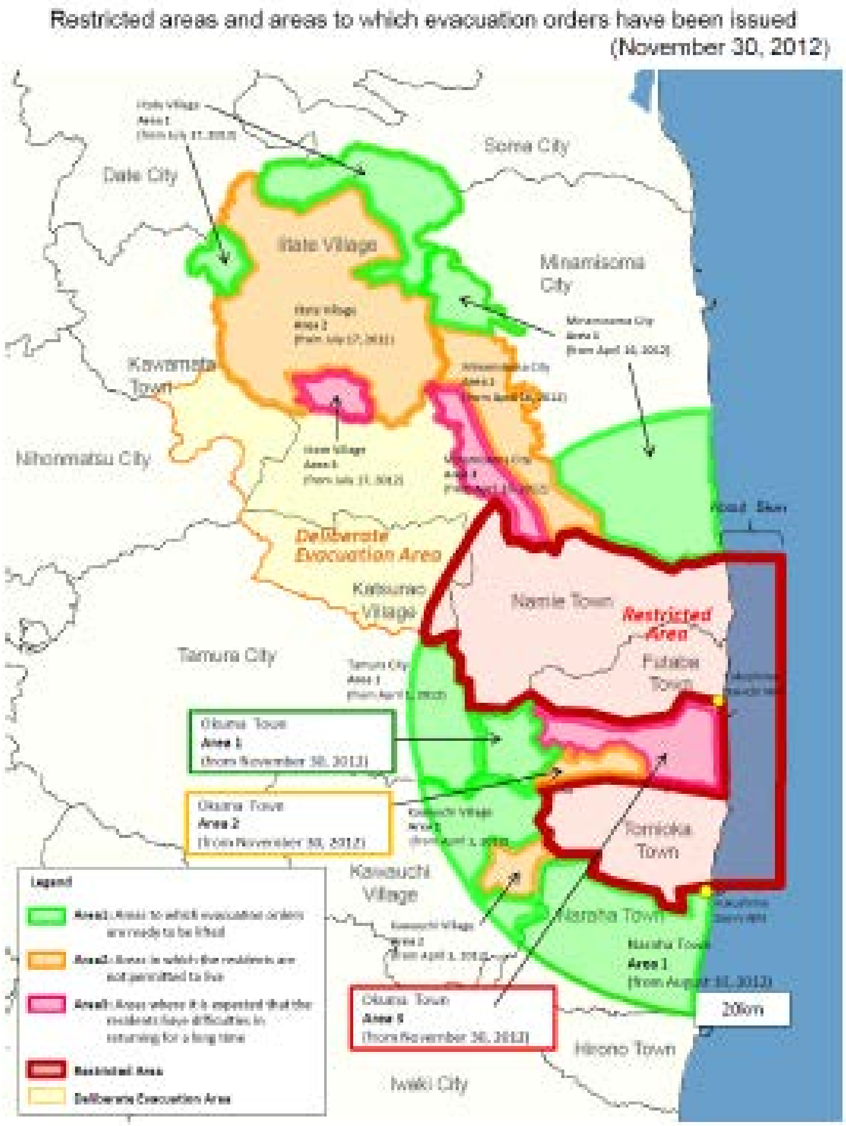
Figure 51. Evacuation Zone Status Dec 2012[176]



5.2.4.7 U.S. Response

U.S. Government personnel from multiple agencies assisted Japan with its response to the earthquake, tsunami, and nuclear accident. The NRC established a senior level task force to review lessons learned and assess what actions, if any, were required to improve the safety of U.S. nuclear power plants. Recommendations from the task force were prioritized and implementation guidance is currently being developed. On March 12, 2012 the NRC issued the first regulatory requirements for the nation's 104

[176] IAEA Fukushima Status Report Dec 2012

operating reactors based on the lessons learned at Fukushima Dai-ichi[177]. The NRC is still developing implementation guidance for the new requirements so construction deadlines have not been finalized.

Table 31. Tier 1 Recommendations –To be implemented without unnecessary delay[178]

Rec #	Recommendation	Action
2.1	Reevaluations of Seismic and Flooding Hazards	Licensee's will be requested to reevaluate the seismic, flooding, and other external hazards at their site using present day methods and guidance. The results will determine whether additional regulatory actions are necessary
2.3	Facility Walkdowns Related to Seismic and Flooding Hazards	Licensee's will be requested to develop a methodology and acceptance criteria to perform walkdowns. The walkdowns will incorporate an integrated approach, including procedures, training, and staffing; along with the underlying strategy to address the hazard
4.1	Rulemaking Regarding Station Blackout Events	
4.2	Mitigating strategies for beyond design basis events	Develop, implement, and maintain strategies and equipment to mitigate the effects of beyond design basis challenges to core, containment, and spent fuel pool cooling functions
5.1	Order Related to Reliable Hardened Vents for Mark I and II Containments	Enhanced reliability during prolonged station blackout (SBO) conditions
7.1	Order Related to Spent Fuel Pool Instrumentation	For beyond design basis events; Instrumentation must support maintaining SFP inventory for safety functions Instrumentation must support adequate prioritization of event mitigation or recovery
8.0	Rulemaking on Integration of Emergency Operating Procedures, Severe Accident Management Guidelines, and Extensive Damage Mitigation Guidelines	
9.3	Enhanced Emergency Preparedness Staffing and Communications	Request information about communications equipment power during multiunit emergency events with prolonged SBOs (>72 hours)• Request information about staffing necessary for response to multiunit events with a prolonged SBO

Second Tier Recommendations- Actions which could not be initiated in the near-term due to factors that include the need for further technical assessment and alignment, dependence on Tier 1 issues, and/or availability of critical skill sets. These actions do not require long-term study and can be initiated when sufficient technical information and applicable resources become available.

- Spent fuel pool makeup capability
- Emergency preparedness regulatory actions
- Other External Hazards Reevaluation (tornados, hurricanes, drought, etc.)

[177] Individual plant responses are at http://www.nrc.gov/reactors/operating/ops-experience/japan/byorders/
[178] NRC 2011-0137SECY

Third Tier Recommendations- Actions that require further staff study to support a regulatory action, have an associated shorter-term action that needs to be completed to inform the longer-term action, are dependent on the availability of critical skill sets, and/or are dependent on the resolution of NTTF Recommendation 1.

- Ten-year confirmation of seismic and flooding hazards
- Potential enhancements to the capability to prevent or mitigate seismically-induced fires and floods (long-term evaluation)
- Reliable hardened vents for other containment designs (long-term evaluation
- Hydrogen control and mitigation inside containment or in other buildings (long-term evaluation)
- Emergency preparedness enhancements for prolonged station blackout and multiunit events (dependent on availability of critical skill sets)
- Emergency Response Data System capability
- Additional emergency preparedness topics for prolonged station blackout and multiunit events (long-term evaluation)
- Emergency preparedness topics for decision-making, radiation monitoring, and public education (long-term evaluation) Reactor Oversight Process modifications to reflect the recommended defense-in-depth framework
- Staff training on severe accidents and resident inspector training on severe accident management guidelines
- Basis of emergency planning zone size
- Pre-staging of potassium iodide beyond ten miles
- Transfer of spent fuel to dry cask storage

6. LONG-TERM FUEL STORAGE

6.1 Background

Up until 1964, the Federal government retained ownership of all fissionable material within the United States for national security purposes. Operators of nuclear power plants leased uranium from the Federal government and the AEC was responsible for disposing of spent nuclear fuel. The Atomic Energy Act of 1954 was amended in 1964 to allow private ownership of fissionable materials under special license by the Federal government. At that time, it was thought that a viable commercial fuel reprocessing industry would be available to deal with spent nuclear fuel. Reprocessing extracts uranium and plutonium and concentrates the volume of the remaining high-level radioactive waste.

From 1966-1972, Nuclear Fuel Services operated a reprocessing plant in West Valley, New York for defense program spent fuel. General Electric, Exxon, and Allied General all applied for commercial reprocessing licenses, but never operated or completed their plants. General Electric's proposed reprocessing facility near Morris, Illinois became a wet interim storage facility.[179]

In October 1976, President Ford placed a delay on all reprocessing activity because of plutonium proliferation concerns, and in 1977, President Carter banned reprocessing commercial spent nuclear fuel. The overriding concern at the time was the diversion of plutonium to weapons program. The ban was lifted by President Regan in 1981, but no subsidies were provided to restart commercial reprocessing efforts in the U.S.

Reprocessing commercial spent nuclear fuel is currently carried out in France, England, Russia, Japan, and India, and China is planning on it as part of its long-term energy strategy[180]. In France, the remaining high-level material comprises just 0.2% of the country's nuclear waste by volume; it accounts for 95% of its total radioactivity.[181] Other countries have decided to dispose of high-level radioactive waste via direct disposal into geological repositories; however, none of these has yet been completed. The first to be operational may be in 2025 near Finland's Olkiluoto Nuclear Power Plant[182]. Regardless of whether reprocessing is carried out and a closed fuel cycle is used as a matter of national policy, all nations will need to use geological repositories for their residual high-level radioactive waste.

In the U.S., the national problem created by accumulating spent nuclear fuel and radioactive waste prompted Congress to pass the Nuclear Waste Policy Act of 1982 (NWPA). It required the U.S. Department of Energy to accept and dispose of spent nuclear fuel and high-level radioactive waste beginning no later than January 31, 1998 in return for fees paid by owners of nuclear power plants. In

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[179] Nuclear Fuel Reprocessing: U.S. Policy Development, CRS, March 2008 Anthony Andrews

[180] China's Spent Nuclear Fuel Management: Current Practices and Future Strategies, CISSM at University of Maryland, Yun Zhou, March 2011 working paper

[181] http://www.smartplanet.com/blog/intelligent-energy/what-france-plans-to-do-with-its-nuclear-waste/2345

[182] Nuclear Waste Management in Finland ,Finnish Energy Industries; http://energia.fi/en/publications/nuclear-waste-management-finland

order to meet this deadline, the U.S. Department of Energy selected ten locations in six states for consideration as potential repository sites. In 1987, Congress amended the Nuclear Waste Policy Act and directed DOE to study only Yucca Mountain. It was approved as the nation's spent fuel repository by President Bush and Congress over the State of Nevada's veto in 2002. However, President Obama and Congress defunded Yucca Mountain in FY2010. In March 2010, the Secretary of Energy chartered a Blue Ribbon Commission on America's Nuclear Future to conduct a review and recommend a new plan of action for the management and disposal of the nation's spent nuclear fuel and high-level radioactive waste. The Commission issued its report in January 2013 and recommended a consent-based approach to siting starting with a pilot interim storage facility, then a full-scale interim storage facility, and finally one or more geological repositories.

As it became apparent that the 1998 deadline stipulated in the Nuclear Waste Policy Act of 1982 would not be met, industry groups sued the government for breach of contract. By 2004, every nuclear utility had filed suit to recover costs associated with storing spent nuclear fuel beyond the 1998 date. The Federal courts have found the government liable for "partial breach" of contract and the Federal government has paid approximately $2 billion in penalties through December 2011. Total liabilities are estimated to be $20 billion through 2020 and forecast to be $500 million annually for each year of schedule slippage beyond that date.[183] These penalties are paid through the Department of Justice administered Judgment Fund. Monies collected through the Nuclear Waste Policy Act electricity surcharge cannot be used to pay these judgments.

The current situation within the U.S. with regards to civilian nuclear power spent fuel and high-level radioactive waste disposal can be summarized as follows:

- Federal government is in default on a contractual obligation to dispose of spent fuel from nuclear utilities and estimates its financial penalties at $20 billion through 2020[184]. It has paid out approximately $2 billion in judgments through December 2011.
- Surcharges of 1 mill/Kwh collected from nuclear power plant operators in accordance with the NWPA of 1982 are being collected and diverted from their intended purpose in order to offset the Federal deficit. This annual revenue stream is approximately $750 million.[185]
- Expenditures of the approximately $32 billion in the dedicated Nuclear Waste Fund are now limited to discretionary appropriation rules adopted by Congress in the 1980s and 1990s.[186] This effectively cuts off access to these funds for their intended purpose.
- Approximately 65,000 metric tons of spent civilian nuclear fuel is located at 76 sites (65 operating reactors, ten shutdown reactors, one storage site[187]) across the United States. Operating nuclear power plants continue to generate an additional 2,000 metric tons of spent fuel annually.
- Ten states have enacted moratoriums against building new power plants until a SNF repository is operational.[188]

183 BRC on America's Nuclear Future Section 8.5. These figures do not include an estimated $188 million the government has spent litigating this issue.
184 Ibid
185 Ibid
186 Financial Statement of the United States FY2012, Notes
187 General Electric, Morris, IL, Un-used reprocessing plant converted to wet storage

- Recent announcements to close Kewaunee and Crystal River nuclear power plants in 2013 will increase the number of “stranded” sites. Stranded sites are estimated to cost the Federal government $4.5 -$8 million annually vice an incremental annual charge of $1 million for operating sites.[189]
- Even if the decision to abandon Yucca Mountain were reversed, the legislated capacity of Yucca Mountain is 70,000 metric tons until a second geological repository is opened.[190] This capacity is inadequate to handle the inventory of spent and operating fuel currently being used in commercial nuclear power plants.
- In June 2012, the U.S. District Court of Appeals for D.C. invalidated the NRC’s waste confidence rule, effectively stopping re-licensing activity dependent on interim fuel storage. The NRC anticipates a revised rule by September 2014.
- The Blue Ribbon Commission on America’s Nuclear Future has recommended the creation of an independent waste management organization, reversion of revenue streams and expenditures to their intended purpose, and the development of a consent-based siting policy for a pilot interim storage facility, a full scale interim storage facility, and one or more geological repositories.
- In January 2013, the DOE’s Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste supported the goal of consent-based siting and commencing operations at a pilot interim storage facility by 2021 consolidated interim storage facility by 2025.

6.1.1 Storage Issues

The primary issue concerning spent fuel and high-level radioactive waste disposal is location. There do not appear to be any unknown technical or scientific challenges to protecting the public and the environment from very long-lived radioactive materials. In 1995, the U.S. National Academy of Sciences stated:

> Geological disposal remains the only scientifically and technically credible long-term solution available to meet the need for safety without reliance on active management…a well-designed repository represents, after closure, a passive system containing a succession of robust safety barriers. Our present civilization designs, builds, and lives with technological facilities of much greater complexity and higher hazard potential.[191]

MIT’s Future of the Nuclear Fuel Cycle study encouraged 100-year planning for interim fuel storage as part of the nuclear fuel cycle and stated that “managed storage can be done safely at operating reactor sites, centralized storage facilities, or geological repositories designed for retrieve ability (an alternative form of centralized storage)”[192].

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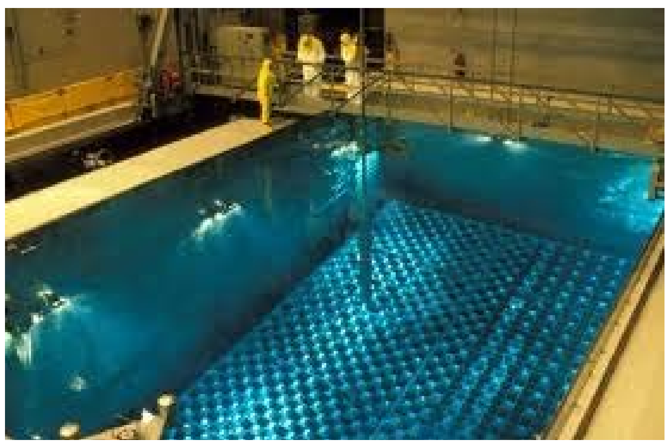
[188] Connecticut, Illinois, Kentucky, Maine, New Jersey, Oregon, West Virginia, Wisconsin, California, Massachusetts
[189] BRC Section 5.2.1
[190] BRC Section 4.5
[191] Disposition of High Level Waste and Spent Nuclear Fuel: The Continuing Societal and Technical Challenges, National Academy Press, Washington, D.C., 2001.
[192] The Future of the Nuclear Fuel Cycle, MIT 2011

This reasoning is based upon the commercial nuclear industry's performance in safeguarding and monitoring over 65,000 metric tons of spent nuclear fuel at 76 sites throughout the United States. 50,000 tons of this spent fuel resides in spent fuel pools and the remaining 15,000 tons is stored in dry casks while waiting to be accepted by DOE.

6.2 Wet Storage

Water pool storage has been used for storage of spent fuel as an established practice since the early days of nuclear power. It has excellent radiation shielding characteristics and thermal efficiency in addition to being abundant and cheap. Spent fuel pools are designed to have large safety margins and robust construction to cope with seismic events and allow adequate time for operator response in the unlikely event of a breach of the pool. All pools are located within the owner's protected area and some pools are located within the containment building. A typical spent fuel pool is more than 36 feet deep in order to maintained at least 20 feet of water over a 14-foot tall fuel assembly.

Figure 52. Spent Fuel Pool



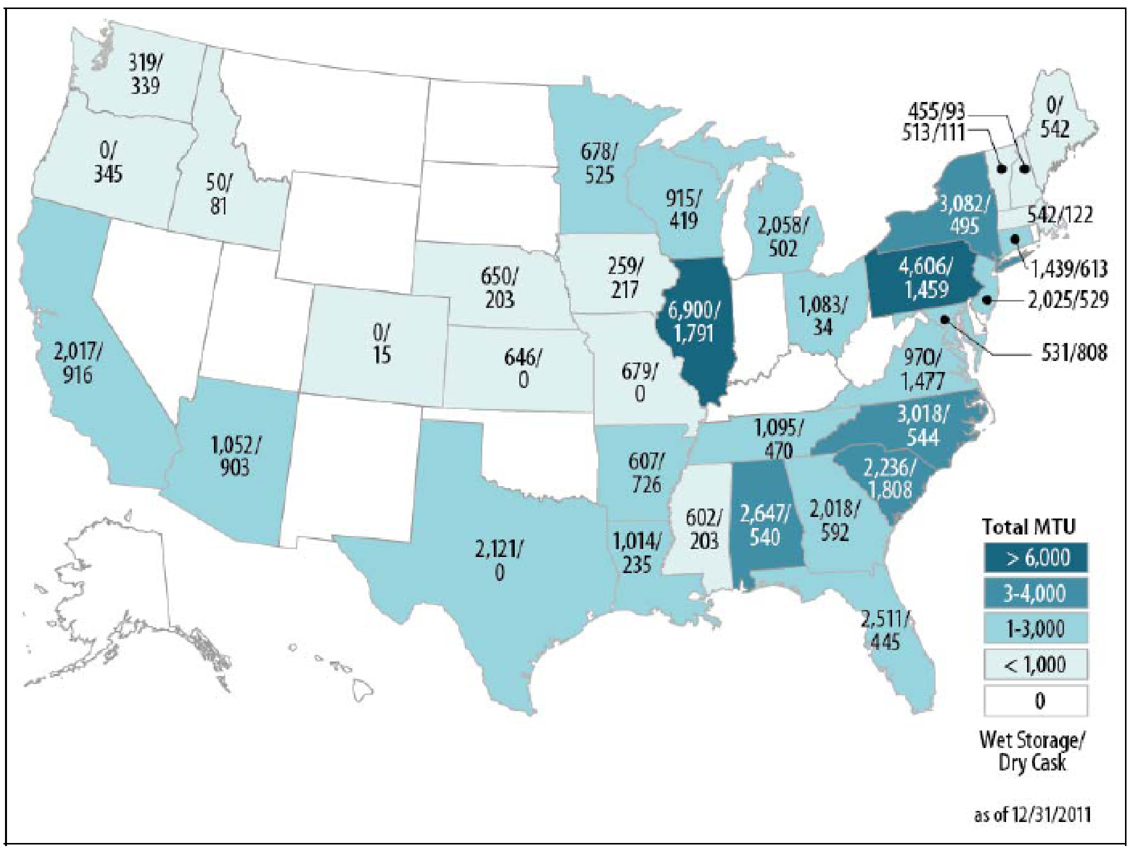
Spent fuel pools require active management, maintenance and a heat removal system. Most pools have a stainless steel inner pool lining and monitoring program to locate and detect any leakage during pool operation. Any leakage from the pool is monitored either by an integrated leakage collection system or via the inter-space in pools with two walls. Recovered pool water is cleaned up and returned to the main pool. Water chemistry is controlled with an ion exchanger, and in some cases more active chemical management. Pools can be cleaned with underwater vacuum cleaners to prevent accumulation of particles and to maintain water clarity. In the U.S., pools were originally designed to hold spent fuel for an approximately 5-year decay heat cooling off period prior to shipment to DOE. Because of delays with fuel shipments, utilities "re-racked" their spent fuel pools in order to increase the amount of spent fuel in the pool. The "re-racking" process involved updating the plant safety analysis and license modifications by the NRC.

After 9/11, the NRC ordered all nuclear power plants to develop strategies to mitigate the effects of large fires and explosions that could result from aircraft crashes or other causes. These mitigation strategies included the spent fuel pool. The specific requirements were developed to improve firefighting capabilities, spent fuel pool inventory control, and cooling capabilities.

The primary concern with spent fuel pools is that the loss of water inventory could allow decay heat to potentially ignite the zirconium fuel cladding and cause a widespread fire within the pool and a release of a large amount of radioactive material off-site. Loss of water inventory also reduces the amount of shielding for spent fuel radiation, which can deny operators access to the spent fuel building in the event of an emergency.

In response to the Fukushima accident of March 2011, the NRC has ordered licensees to install additional instruments to monitor spent fuel pool water levels and develop ways to easily maintain or restore spent fuel pool cooling in an emergency. The structural condition and cooling of the spent fuel pools remain the primary concern of recovery operations at Fukushima. It will be several years before the spent fuel can be removed from the site's pools.

Figure 53. Source CRS U.S. Spent Nuclear Fuel Storage May 2012



All operating nuclear power plants within the United States are at the full capacity of their spent fuel pools with the exception of those listed in the following table. As their spent fuel pools reach full capacity, these plants intend to start dry cask storage in the year indicated in the table. Older fuel will be moved to dry cask storage in order continue the refueling process.[193]

Table 32. Remaining Spent Fuel Capacity

Plant	Year	State	Type
Clinton	2014	IL	BWR
Nine Mile Point 2	2014	NY	BWR
Beaver Valley 1	2015	PA	PWR
Salem 2	2015	NJ	PWR
Vogtle 2	2013	GA	PWR
Comanche Peak 1	2017	TX	PWR
Comanche Peak 2	2017	TX	PWR
Vogtle 1	2013	GA	PWR
V.C. Summer	2018	SC	PWR
Watts Bar	2018	TN	PWR
Callaway	2019	MO	PWR
Wolf Creek	2025	KS	PWR
Beaver Valley 2	2026	PA.	PWR
South Texas Project 1	2026	TX	PWR
South Texas Project 2	2026	TX	PWR

6.3 Dry Cask Storage

The delay in shipping spent fuel to the DOE caused nuclear plant operators to investigate other interim means for spent fuel storage. After several years in the pool, spent fuel has cooled and its radioactivity decreased to the point that it can be moved to dry cask storage. Dry casks or Independent Spent Fuel Storage Installations (ISFSIs) typically have a sealed metal cylinder to contain the spent fuel that is enclosed in a metal or concrete outer shell to provide radiation shielding. In some designs, casks are set vertically on a concrete pad, while in others, they are placed horizontally. Casks typically hold 32 PWR or 68 BWR spent fuel assemblies.

In the most widely used type of dry storage system, a canister containing used fuel is placed inside a concrete structure. The canister typically consists of ½-inch to 5/8-inch thick stainless steel containment boundary and the reinforced concrete structure provides shielding from radiation and protects the canister. The total weight of the canister and concrete structure is typically between 160-180 tons. Dry casks are licensed by the NRC and are required to resist earthquakes, projectiles, tornadoes, floods,

[193] NEI Fact Sheet, Southern Company

temperature extremes, and other scenarios. Residual heat from the spent fuel is removed by passive air cooling.

The sheer weight of the dry cask system has required some plants to reinforce reactor buildings and other structures to support cranes and safety analysis scenarios involving dropped casks at considerable expense.[194] Approximate construction cost of dry cask systems averages $1 million per cask. Annual operation costs average $1 million for onsite storage at operating reactors and up to $8 million for ISFSIs at shutdown reactor sites.

Dry cask storage systems have been tested by at least two natural disasters. In 2011, a 5.8 magnitude earthquake struck Virginia and caused the North Anna nuclear power plant to trip offline. Subsequent investigation showed that 25 of the 27 115-ton dry cask storage units shifted between 1-4 inches on their base mat and none of the casks were damaged.[195] The dry cask storage system at Fukushima Daiichi was located near the shoreline and wetted by the tsunami. Nine casks of spent fuel were in dry storage and none of them were damaged by the earthquake or tsunami[196].

Figure 54. Dry Cask Storage Source NRC

The stainless steel canisters are placed directly into the spent fuel pool for loading, which can take up to one week for a single canister. After they are loaded, they are drained, dried, and filled with an inert gas (typically helium). The loaded units are then removed from the spent fuel pool and their outer surfaces are decontaminated. They are then moved to the dry storage facility on the reactor site. The drying process is the longest step in the loading process.[197] Helium detectors are incorporated into the design to detect leakage from the canisters.

[194] http://m.monroenews.com/news/2012/mar/23/fermi-fuel-shift-again-delayed/
[195] http://articles.washingtonpost.com/2011-09-01/national/35273195_1_fuel-rods-casks-nuclear-storage-containers
[196] Brattle Group Centralized Dry Storage of Nuclear Fuel August 2012
[197] http://www.nirs.org/reactorwatch/security/nasrptsfp6.pdf

Figure 55. Cask Construction, Transportation, and Placement

In December 2010, the U.S. Nuclear Regulatory Commission (NRC) decided that spent fuel could be stored in pools or dry casks for up to 60 years beyond the operating lifetimes of the reactors that produced it. Given that U.S. reactors are now being licensed to operate up to 60 years, there is a corresponding interim storage period of up to 120 years.[198]

However, in June 2012 as part of Indian Point 3 relicensing litigation, the U.S. Court of Appeals for D.C. found that some aspects of the NRC's 2010 decision did not satisfy the NRC's NEPA obligations and vacated the decision. The court indicated that in making either a Finding Of No Significant Impact based on an Environmental Assessment or in an Environmental Impact Statement supporting the rulemaking, the Commission needed to add additional discussions concerning the impacts of failing to secure permanent disposal for spent nuclear fuel, and potential spent fuel pool leaks, and spent fuel pool fires. In response to the ruling, the NRC stopped all licensing activities that relied on the Waste Confidence Decision and Rule. The NRC expects to issue a revised rule by September 2014.[199]

6.4 Consent-Based Siting

Finding sites for geological repositories has proven politically difficult across numerous countries. Almost all countries that have tried to site repositories have had one or more failures. The "top down" approach has always resulted in some form of strong opposition eventually leading to the abandonment of the effort. In 1981, intense opposition in the UK to further investigate candidate sites for a high-level repository resulted in a decision to abandon the effort for 50 years[200]. In the U. S., opposition at the state level has ended the Yucca Mountain project in Nevada; the Private Fuel Storage venture in Utah; and the consideration of alternate geological repository sites in Texas and Washington.

The Waste Isolation Pilot Plant (WIPP)a geological repository near Carlsbad, New Mexico, was originally slated to be a candidate for a high-level radioactive waste and spent nuclear fuel repository. However, local opposition grew against this plan and in 1979; Congress prohibited the permanent storage of spent fuel and high-level radioactive waste, but inflamed the local community by taking away New Mexico's veto power over the siting decision. Instead of high-level radioactive waste and spent nuclear fuel, waste material disposed of at WIPP would include rags, clothing, tools, and other materials

198 Spent Fuel from Nuclear Power Reactors, International Panel on Fissile Materials (IPFM), June2011June 2011
199 NRC
200 Spent Fuel from Nuclear Power Reactors, International Panel on Fissile Materials (IPFM), June2011June 2011

that have been contaminated with low levels of plutonium or other long lived transuranic nuclides. New Mexico brought several lawsuits against the Department of Energy over the intervening years and won an injunction against the DOE in 1991. The Land Withdrawal Act of 1992 mollified the state by placing the EPA in charge of standards verification and granting the state the authority to issue the hazard waste permit and regulate mixed waste at the site. As a repository for defense-related low-level long-lived transuranic wastes, WIPP started to receive waste in 1999; 20 years after the process started, and is now supported by the local community and state government.[201] It is now considered to be a siting success after belatedly incorporating consent-based attributes into the process.

Figure 56. Waste Isolation Pilot Plant

Finland will probably be the first nation to successfully site and operate a SNF geological repository on the island of Olkiluoto. The island also has both an operating nuclear power plant and one under construction, and also contains a substantial portion of Finland's spent nuclear fuel. The Finnish siting process involved the local communities and placed the responsibility of developing the repository on the nuclear plant operators. In 1983, environmental assessments began, three years later preliminary site investigations commenced, in 1993 detailed site studies for 4 sites began, and in 2000 the local community of Eurajoki voted in favor of hosting the site. The Finnish parliament ratified the decision in 2001 and construction started in 2004 with operations scheduled to begin in 2025.[202] Thus, compared to our national experience, the timeline for site selection has been relatively short.

After false starts with identification of repository sites in 1977 and 1992, Sweden began a process in 2001 in which it approached three geologically-appropriate sites that already had nuclear facilities. One municipality voted to opt out of the process. A unique feature of the Swedish process was that both of the remaining municipalities were offered a share of $300 million in financial incentives to remain committed to process. The community that was <u>not</u> selected would receive a larger amount of

[201] BRC
[202] Ibid

compensation ($225 million) than the community that was selected ($75 million). Their rationale was that the selected community would continue to reap additional economic benefits as the project was constructed and operated. The community of Forsmark, which also hosts a nuclear power plant and low level radioactive waste repository, was selected as the site.[203]

Spain's efforts to elicit volunteer communities for an interim spent fuel and high-level waste storage facility included development of a collocated research laboratory dedicated to studying waste reprocessing and disposal. Eight communities volunteered to be considered for the facility and final siting selection was made in 2011 after a 6-year process.[204]

The Blue Ribbon Commission on America's Nuclear Future has recommended that the nation requires a new approach to siting that restores trust in the process and affords local communities and states the opportunity to participate in the decision making process and control of the facility. Recommended elements of the new process include:

- **Consent-based**—in the sense that affected communities have an opportunity to decide whether to accept facility siting decisions and retain significant local control.
- **Transparent**—in the sense that all stakeholders have an opportunity to understand key decisions and engage the process in a meaningful way.
- **Phased**—in the sense that key decisions are revisited and modified as necessary along the way rather than being pre-determined.
- **Adaptive**—in the sense that the process itself is flexible and produces decisions that are responsive to new information and new technical, social, or political developments.
- **Standards and science-based**—in the sense that the public can have confidence that all facilities meet rigorous, objective, and consistently-applied standards of safety and environmental protection.
- **Governed** by partnership arrangements or legally enforceable agreements between the implementing organization and host states, tribes, and local communities.

The Department of Energy has agreed that, with the support of Congress, it will use this process over the next ten years to:[205]

- Site, design, license, construct, and begin operation of a pilot interim storage facility by 2021 with an initial focus on accepting used nuclear fuel from shutdown reactor sites.
- Advance the siting and licensing of a larger interim storage facility to be available by 2025 that will have sufficient capacity to provide flexibility in the waste management system and allows for acceptance of enough used nuclear fuel to reduce expected government liabilities.
- Make demonstrable progress on the siting and characterization of repository sites to facilitate the availability of a geological repository by 2048.

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[203] BRC
[204] Ibid
[205] Strategy for the Management and Disposal Of Used Nuclear Fuel and High-Level Radioactive Waste DOE Jan 2013

6.5 Repositories

Maintaining the ability to retrieve fuel from a repository drives its design characteristics and provides for future use of the waste, if needed. In its Future of the Nuclear Fuel Cycle study, MIT recommended that spent fuel retrievability should be considered for any repository to preserve options and that maintaining options is important because resolution of major uncertainties over time will determine whether light water reactor spent nuclear fuel is to be considered a waste destined for direct geological disposal or a valuable fuel resource for a future closed fuel cycle.[206]

Other nations have expressed an interest in keeping underground disposal reversible. In Canada, the national waste management organization recommended a retrievable period of approximately 240 years.[207] France's 2006 radioactive waste law specifies that no license for a repository for long-lived high-level radioactive wastes shall be granted if the reversibility of such a facility is not guaranteed.[208] Those national programs that require retrievability have mentioned three main reasons for requiring this feature according to the Nuclear Energy Agency of the Organization for Economic Co-Operation and Development:[209]

- Having an attitude of humility or open-mindedness towards the future;
- Providing additional assurance of safety; and
- Heeding the desires of the public not to be locked into an "irreversible" situation.

The requirement for retrievability forces the use of a mined geological repository, such as Yucca Mountain, that allows personnel and equipment to access the disposed material. All nations contemplating geological repositories have developed plans for mined repositories.

Deep boreholes represent another form of geological disposal that the Blue Ribbon Commission has recommended for further study. Deep boreholes are cased holes, similar to oil well shafts, approximately two feet in diameter drilled into crystalline basement rock up to a depth of three miles (five km). In most designs, the bottom half mile is filled with either vitrified high-level radioactive waste or spent fuel. Backfill or sealant would be added to fill in the gaps between the wastes and the well casing.[210]

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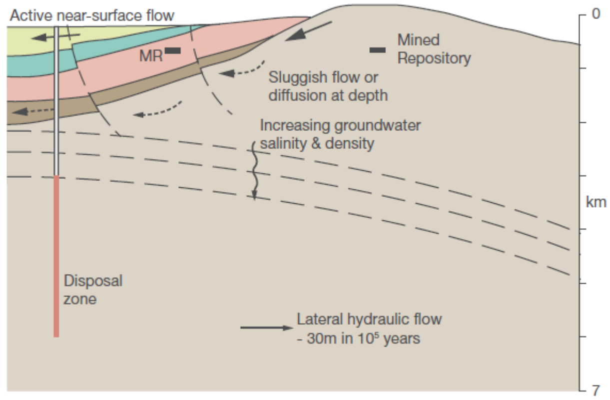
[206] MIT Future Fuel Cycle p.52
[207] Spent Fuel from Nuclear Power Reactors, International Panel on Fissle Materials, June 2011
[208] http://fissilematerials.org/blog/2011/06/managing_nuclear_spent_fu.html
[209] Reversibility of Decisions and Retrieveability of Radioactive Waste, OECD 2012, NEA No. 7085
[210] BRC Section 4.3

Figure 57. Deep Borehole Concept Source BRC



Some advantages to deep boreholes include:[211,212]

- Boreholes can be drilled based on demand for disposal space
- Ability to leverage improvements in oil and natural gas drilling technologies to drive down costs
- Required geology of crystalline basement rock is relatively common at 2-5 km depth across the U.S.
- Widespread geology could facilitate local onsite disposal and/or regionalization of disposal sites minimizing transportation costs
- May be possible to leverage information in existing nuclear site siting and environmental studies
- Extremely low rock permeability and water content prevents mobility of any leakage
- Anticipated to be very cost effective
- No land use restrictions after disposal
- Space efficient- approximately 1,000 boreholes could dispose of 100,000 MTHM of SNF or HLW
- May facilitate greater state/local control over a consent-based disposal process

Disadvantages to deep borehole include:[213]

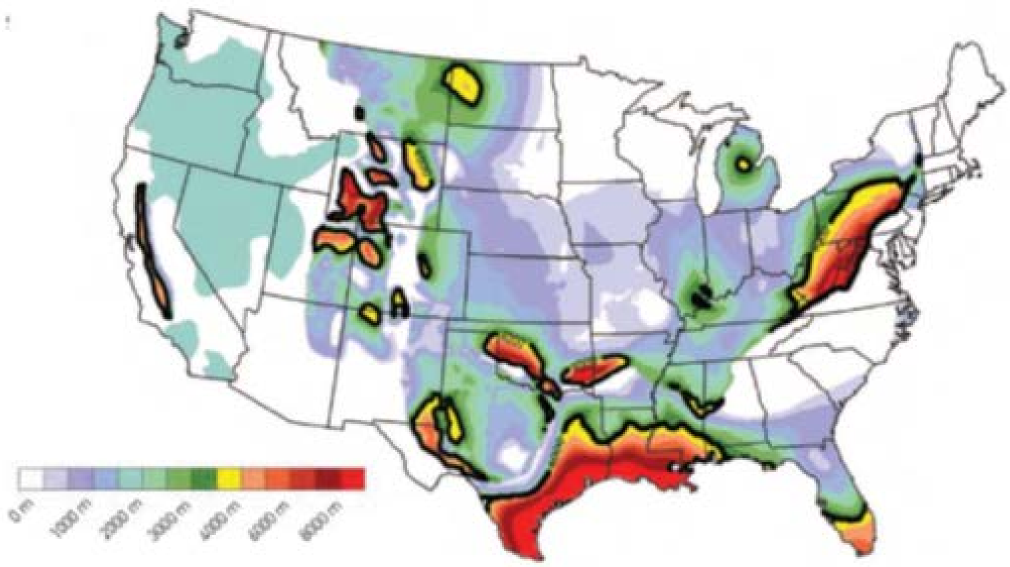
- Retrievability extremely expensive or impossible
- Not applicable to large contaminated components
- Currently prohibited by Section 161 of the Nuclear Waste Policy Act of 1987
- Lacks a regulatory framework for demonstration and licensing

Should the new consent-based siting process prove more time consuming and contentious than anticipated and deep boreholes are proven feasible, it is plausible that deep borehole suitability may become part of the siting criteria for future nuclear power plants. This could also enable local or regional

[211] Presentation: A Case for Disposal of Nuclear Waste in Deep Boreholes, Michael Driscoll, MIT 2010
[212] Deep Borehole Disposal of High-Level Radioactive Waste, Sandia Report, SAND2009-4401, August 2009
[213] Ibid

disposition of spent nuclear fuel becomes as a standard practice. Figure 58 shows the widespread availability of 2-5 km crystalline basement rock across the nation[214].

Figure 58. Sedimentary Thickness across USA



6.6 Transportation

The Blue Ribbon Commission found that DOE's record of planning in cooperation with concerned stakeholders to address transportation issues has been quite successful. The Commission recommended that DOE or the new waste management agency accelerate efforts in providing technical assistance and training to future stakeholders in the transportation of radioactive materials. Specifically, it recommended DOE finalize procedures and regulations for providing technical assistance and funds for training to local governments and tribes pursuant to Section 180(c) of the NWPA and begin to provide such funding, independent from progress on facility siting.

Additionally, the BRC recommended that DOE seek to increase the authority under Section 180(c) to match that found in the WIPP Land Withdrawal Act in order to expand the good practices developed under that program to the national transportation network for SNF. This expanded authority would allow:

- A program to provide information to the public about the transportation of spent fuel or high level waste to or from a repository or storage facility;

- Authority and direction to assist states, tribes, and local governments through monetary grants or contributions in-kind (subject to appropriation) in acquiring equipment for responding to an

[214] Ibid

incident involving shipments covered by the law; and

- Broad authority and direction to provide in-kind, financial, technical, and other appropriate assistance (subject to appropriations) to states and tribes whose jurisdictions would be traversed by shipments of spent fuel to interim storage or to a repository, for the purpose of transportation safety programs related to such shipments that are not otherwise addressed in the law.

Even if a repository or interim storage facility were opened tomorrow, significant amounts of SNF and HLW could not be transported until the NRC develops a technical basis and modifies current regulations to allow the transportation of high burn up fuels. In response to market needs, the capacity of spent fuel canisters increased to support loading casks in a more cost-effective manner. This market demand led cask designers to focus on certifying the higher capacity systems for storage under 10CFR72. Transportation certification under 10CFR71 was postponed until the probability of shipment materialized. The transportability of these numerous high-capacity casks filled with higher burn up fuel still needs to be resolved.[215]

Additionally, rail shipments of spent fuel cannot occur until rail cars with required safety features are developed to meet new railroad regulations. It is estimated it will take 5-7 years to design and place this equipment in service.[216]

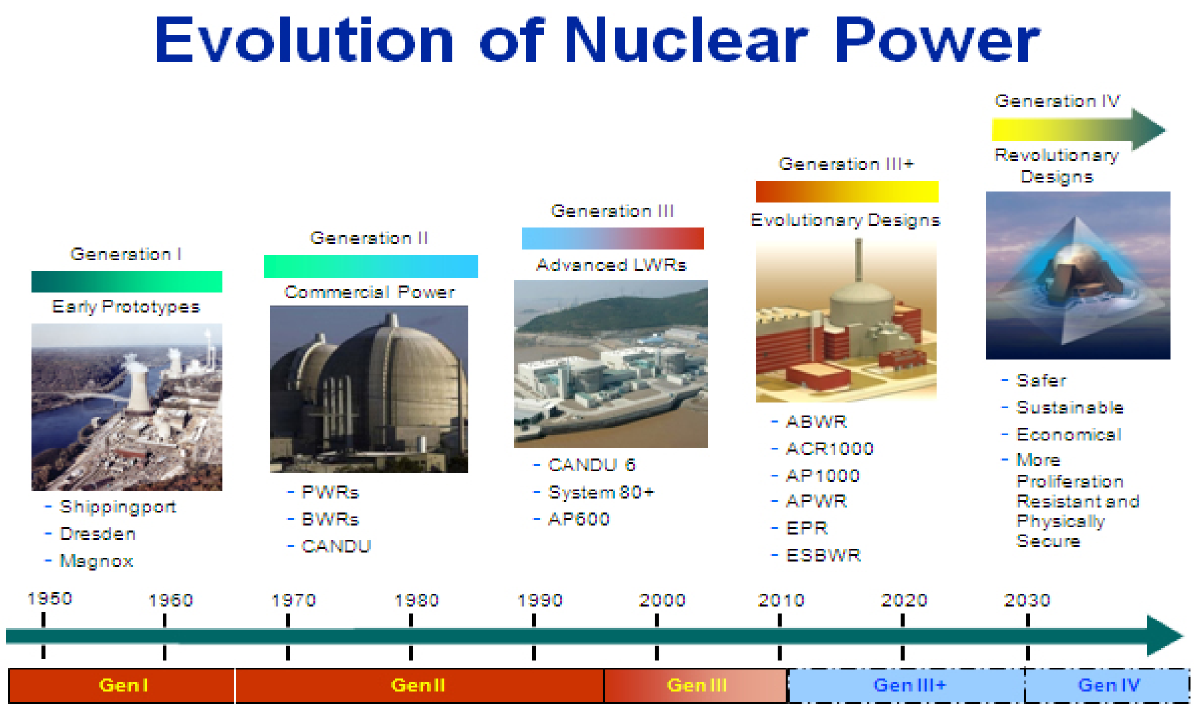
[215] Transportation of Commercial Spent Nuclear Fuel Regulatory Issues Resolution, EPRI 2010 Technical Report
[216] BRC Section 9.3

7. ASSESSING NUCLEAR TECHNOLOGIES

7.1 Overview of Types of Nuclear Reactors

Nuclear technology has evolved to a point where Generation III+ simplified designs implement improved "passive" safety systems and support advanced construction methods. As the Generation III+ technologies undergo licensing and construction, Small Modular Reactors (SMRs) and a new wave of advanced technologies are being developed as Generation IV reactors. This evolution is depicted graphically in the following figure.

Figure 59. Evolution of Commercial Nuclear Power in the United States and Canada[217]



The basic nomenclature of nuclear reactors includes several important terms. The first part of the description is the type of coolant used to remove heat from the reactor core. Typical coolants are:

- Light water – This is regular water (H_2O). All operating power reactors in the U.S. employ light water as a coolant.
- Heavy water – This is water in which the hydrogen atom contains a proton and a neutron and is called Deuterium (D_2O). Operating power reactors in Canada employ heavy water as a coolant.
- Gas – Carbon dioxide or an inert gas such as helium may be used as a coolant.

[217] http://www.gen-4.org/Technology/evolution.htm

- Liquid metal – Liquid metal may be sodium, a combination of sodium and potassium, lead and bismuth, or some other metal(s). Metal-cooled reactors may have a "loop" or "pool" design.
- Molten salt - In a Molten Salt Reactor (MSR), the fuel is dissolved in a fluoride salt or other salt coolant.

The second descriptor refers to the neutron moderator used to decelerate the neutrons. The presence of a moderator indicates that it is a thermal (slow) neutron reactor. Typical moderators include:

- Light Water (most widely used moderator)
- Heavy Water (predominant in Canadian CANDU reactors, allows use of natural un-enriched uranium)
- Graphite (United Kingdom, Russia)

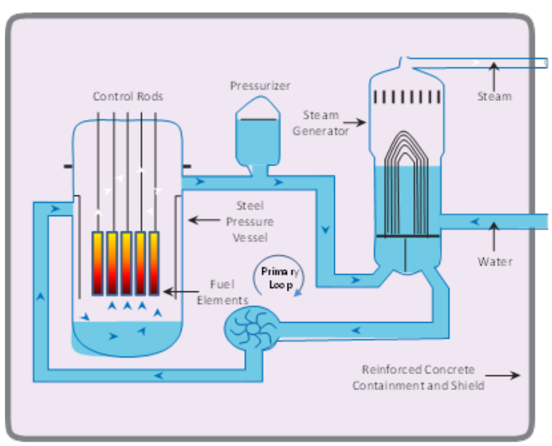
If there is only one descriptor such as light water, it implies that it is both the coolant and the moderator. So for example, in the U.S., pressurized light water reactors (PWR) and boiling light water reactors (BWR) use light water both as the coolant and the moderator.

Should the term "fast" appear in the name of the reactor, it implies that high energy neutrons are used to fission uranium and plutonium isotopes that would not normally fission with slow neutrons. Fast reactors do not have moderators, only coolants. If the term "small" appears in the name of the reactor it is understood to be less than 300 MWe unless noted otherwise.

In the U.S., commercially operating nuclear power plants are all light water technology, either Pressurized Light Water Reactors (PLWRs or PWRs) or Boiling Light Water Reactors (BLWRs or BWRs). Canadian reactors are all Pressurized Heavy Water Reactors (PHWR).

7.1.1 Pressurized Water Reactors

Figure 60. Pressurized Water Reactor PWR



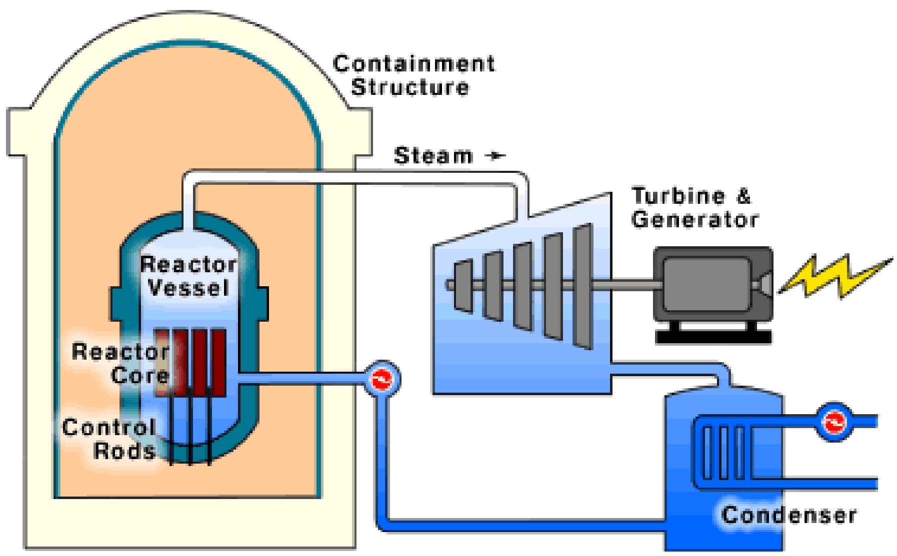
Pressurized Water Reactors operate with a "primary loop" and a "secondary loop". Water in the primary loop circulates through the reactor core where it is heated. The primary coolant then flows through a steam generator and transfers its heat to water on the opposite side of tubes (secondary loop), creating steam, which turns a turbine-generator. Steam exiting the turbine is condensed back into water and pumped to the steam generator to begin the secondary cycle.

The primary water, after passing through the steam generator, returns to the reactor core where it is reheated and flows back to the steam generator. Water in the primary loop is pressurized by a large heated vessel called a pressurizer to preclude boiling and allow for a high operating temperature in the primary loop. The PWR is the most predominant nuclear power plant design used worldwide.

7.1.2 Boiling Water Reactors (BWR)

Water in the BWR is heated by the reactor core and allowed to boil and produce steam. When the steam rises to the top of the pressure vessel, water droplets are removed, and the steam is sent to the turbine to turn the electric generator.

Figure 61. Boiling Water Reactor



The boiling water reactor (BWR) was designed by General Electric (GE-Hitachi) to compete with Westinghouse's PWR design. Advantages to the BWR include operating at a lower pressure removes the need for a high pressure reactor vessel and direct transfer of reactor steam to the steam turbine eliminates the need for the steam generator found on PWRs. One drawback is that BWR operators are exposed to higher radiation levels.

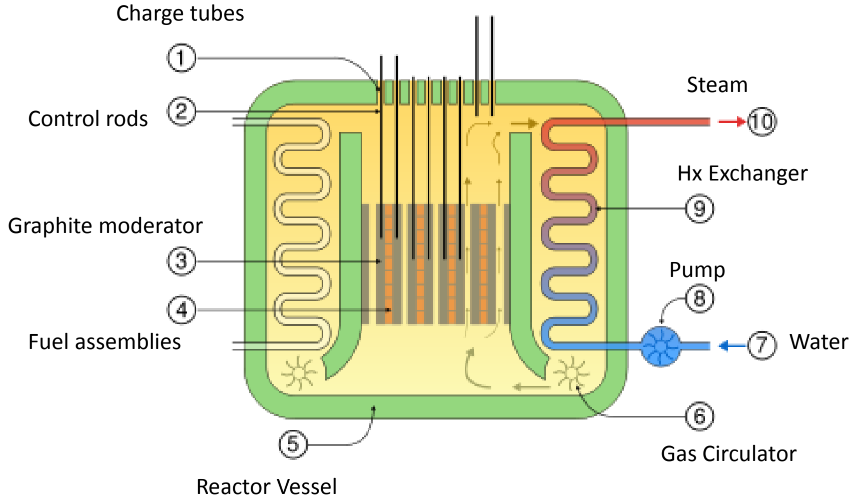
7.1.3 High Temperature Gas Reactors

While there are variations, the High Temperature Gas Reactor (HTGR) is comprised of three major components: a gas cooled nuclear reactor, a heat transfer system (steam generator), and a cross vessel that routes the gas between the reactor and the heat transport system. The gas can be helium or another inert gas. The British have the largest gas reactor fleet in the world and use carbon dioxide[218]. A

[218] http://www.euronuclear.org/info/encyclopedia/r/reactor-gas-cooled.htm

circulator (similar to a fan) moves the gas through the reactor core where it is heated, then through the Steam Generator where the water on the opposite side of the steam generator tubes is converted to steam that is used to turn a turbine generator. Steam at the outlet of the turbine is condensed into water and pumped back into the steam generator, continuing the cycle.

Figure 62. HTGR (UK AGR)



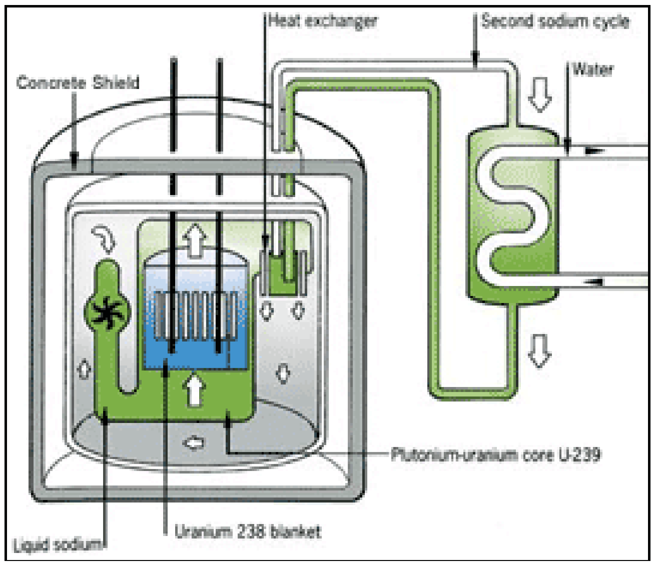
In some advanced and developing HTGR designs, the hot helium is piped directly to a gas turbine to generate electricity. Because of the higher coolant temperatures, HTGRs operate at a higher thermal efficiency than water cooled reactors and are able to use the same steam turbines as conventional fossil power plants. Two attempts at nuclear superheating steam were made during the AEC's power demonstration program, but proved unsuccessful.

HTGRs at Peach Bottom 1 and Fort St. Vrain operated in the U.S. during the sixties, seventies, and eighties. However, these General Atomic designs could not compete with the wave of General Electric and Westinghouse designs. Britain preferred the gas cooled reactor design over light water reactors and built 14 advanced gas reactors. Perceived advantages included on-line refueling (since stopped), nuclear safety, higher efficiency, and the ability to use the same steam turbines as coal plants. The only HTGR currently under construction is China's 211 MWe Shidaowan 1.

7.1.4 Liquid Metal Fast Breeder Reactors

As the name implies, a Fast Breeder Reactor employs fast neutrons and it "breeds" fissile[219] material in the form of Plutonium 239. In most cases, fast reactors use uranium-238 as well as the fissile U-235 isotope. Liquid metal coolant has very good heat transfer properties so that the reactor can be operated at much lower pressures and higher temperatures, which contributes to operational safety. Argonne National Laboratory's EBR-1 and II and Detroit Edison's Fermi I were based on this design concept. EBR-II operated successfully from 1964 to 1994 at Idaho National Laboratory.

Figure 63. Fast Breeder Reactor



Two FBRs are currently under construction, one in India and another in Russia. Russia has one operational FBR and China has another. Other nations such as the U.S., UK, and France have shut down and abandoned their FBR programs. One of the primary concerns with fast reactor technology is the proliferation of plutonium for use in nuclear weapons programs.

7.1.5 Molten Salt Reactors

In a typical Molten Salt Reactor (MSR), the uranium fuel is dissolved in a sodium fluoride salt coolant, which circulates through graphite core channels to achieve some moderation and a thermal neutron spectrum. In some cases, the MSR design is fuel-agnostic in that it can operate on either uranium or thorium. It also may use spent fuel from conventional light water reactors. Molten salt reactors can achieve much higher fuel burn up factors (greater than 50%) than conventional uranium reactors, which harness only approximately 3% of the available energy in a volume of uranium.

219 Capable of undergoing fission induced by low-energy neutrons

7.1.6 Small Modular Reactors

Small modular reactors (SMRs) are modular nuclear reactors capable of producing no more than 300 MWe. Many utilities are interested in SMRs as their size makes them well-suited to replace units of the aging fossil-fueled fleet. Size and other features also make SMRs attractive for a number of applications that are inappropriate for large nuclear plants or fossil-fired units. Many consider them a solution to a number of challenges associated with large nuclear generating and other power generating facilities.

7.2 Commercially Available Advanced Reactors

Different nuclear power plant designs are being developed by individual companies. Important issues for comparison of these technologies include licensing status, prior construction, and operating experience with the design, cost, and contract terms. First movers with a particular technology may expect favorable pricing and contract terms, which must be balanced with first-of-a-kind licensing, construction, and operating risks. Pricing of the various designs is proprietary and highly speculative until project completion when the true project is determined. The predominant technologies available in the U.S. and Canada within the next ten years are discussed in the following sections.

7.2.1 Advanced Boiling Water Reactor (ABWR)[220]

The Advanced Boiling Water Reactor is a single-cycle, force-circulation, boiling water reactor (BWR), with a rated power of approximately 1500 MWe. Initially designed by GE Nuclear Energy and Toshiba, the ABWR incorporates features of the BWR designs in Europe, Japan, and the U.S. and uses improved electronics, computer, turbine, and fuel technology. Improvements include the use of advanced components, microprocessor-based digital control and logic systems, and digital safety systems. The design also includes enhancements such as full digital control, modular construction and improved operability and maintainability. The ABWR was certified by the U.S. NRC in 1997.[221]

The development of the modular ABWR design was unique in that it was co-developed by Toshiba and GE, which then worked with Hitachi to construct the first two units in Japan the late 1990s. GE and Hitachi went on to form joint ventures of their nuclear businesses, resulting in two daughter firms: GE-Hitachi and Hitachi-GE. Thus, three different companies can build an ABWR, both joint ventures as well as Toshiba, although its version differs in some technical respects due to intellectual property issues.[222] There are currently three operational ABWRs, all in Japan and a fourth, Hamaoka-5, had been operating, but was shut down in 2011 because of potential tsunami concerns. Three units are currently under construction, two in Taiwan and one in Japan. Lifetime capacity factors for the operational units have all been less than 75%.[223]

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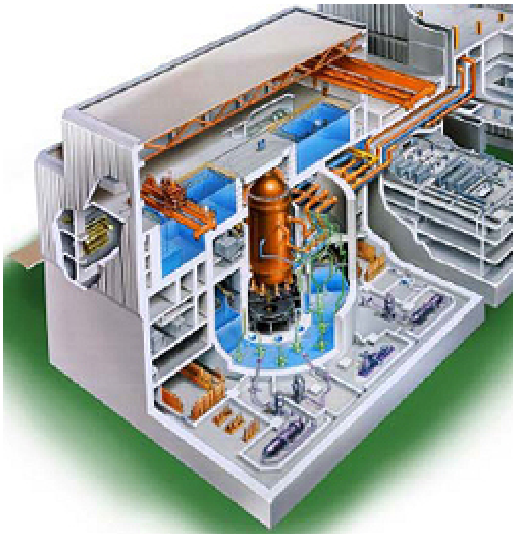
[220] GE http://www.ge-energy.com/products_and_services/products/nuclear_energy/advanced_boiling_water_reactor_abwr.jsp
[221] U.S. NRC http://www.nrc.gov/reactors/new-reactors/design-cert/abwr.html
[222] World Nuclear News 15 January 2013, ABWR set for UK assessment
[223] http://en.wikipedia.org/wiki/Advanced_boiling_water_reactor

Figure 64. ABWR Source NRC



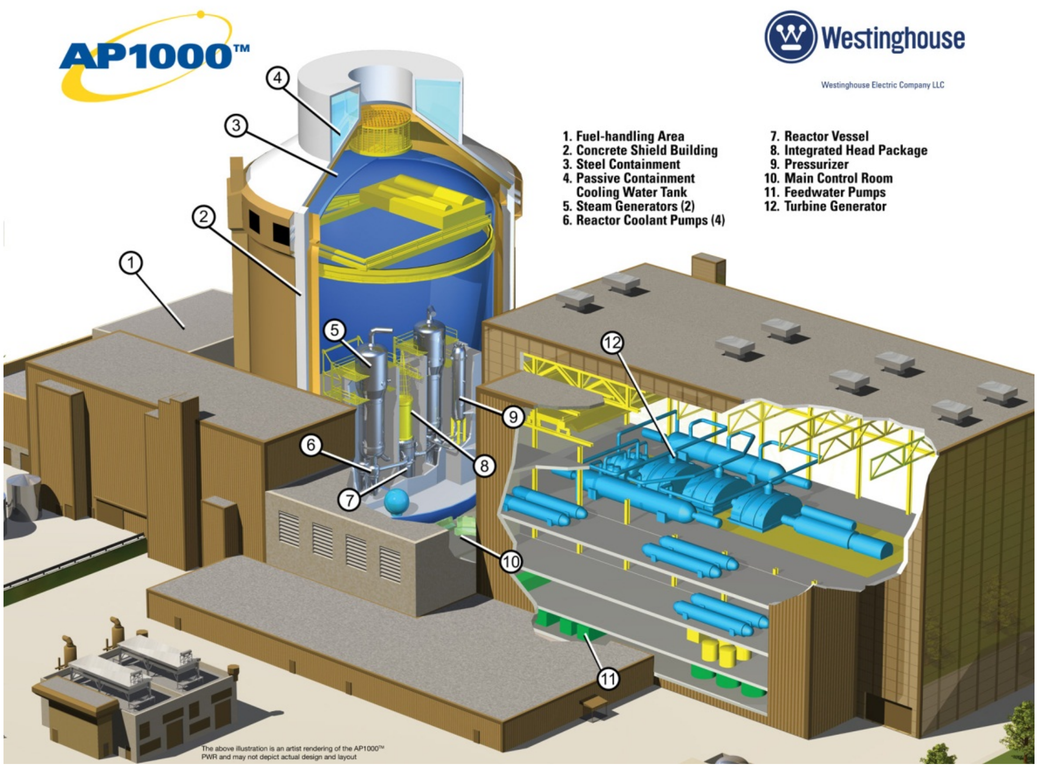
7.2.2 Advanced Passive 1000 (AP1000)[224]

The Advanced Passive 1000 reactor system is an 1154 MWe unit based on earlier Westinghouse PWR designs. It uses the forces of nature (e.g. gravity, evaporation, condensation) for safety systems, reducing the need for active pumps and valves. The simplified AP1000 design has fewer active components such as valves and pumps, which should significantly reduce maintenance, staging, and testing and inspection requirements. The plant has a 60-year design life.

There are currently eight AP1000 reactors under construction worldwide. Four are being built in China and four in the United States. The plants in the U.S. are Georgia Power's Vogtle 3 & 4 and SCE&G's VC Summer 2 & 3.

[224] Westinghouse http://www.ap1000.westinghousenuclear.com/

Figure 65. AP1000



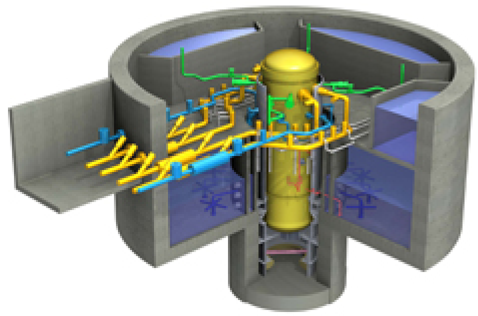
7.2.3 Economic Simplified Boiling Water Reactor (ESBWR)[225]

The Economic Simplified Boiling Water Reactor is a simplified 1520 MWe BWR designed by GE-Hitachi that relies on natural forces like gravity, evaporation, and condensation rather than "active" pump and valve systems. The design is derived from work on the Advanced Boiling Water Reactor (ABWR) discussed earlier. The ESBWR design lifetime is anticipated to be 60 years with 24-month refueling cycles, but it has not yet been certified by the NRC over concerns with steam dryer modeling.

Detroit Edison has picked the ESBWR design as the basis for a potential new unit at its Fermi site in Michigan, but has yet to decide whether to actually build a reactor.

[225] U.S. NRC: http://www.nrc.gov/reactors/new-reactors/design-cert/esbwr/overview.html
GE-Hitachi: http://www.ge-energy.com/products_and_services/products/nuclear_energy/esbwr_nuclear_reactor.jsp

Figure 66. ESBWR



7.2.4 Advanced CANDU Reactor 1000 (ACR-1000)[226]

The Advanced CANDU Reactor 1000 is a nominal 1100 MWe design that evolved from the operating CANDU 6 heavy water cooled reactor systems. The ACR employs light water as a coolant and continues to employ heavy water as a moderator. It also uses slightly enriched uranium and involves enhanced passive safety features.

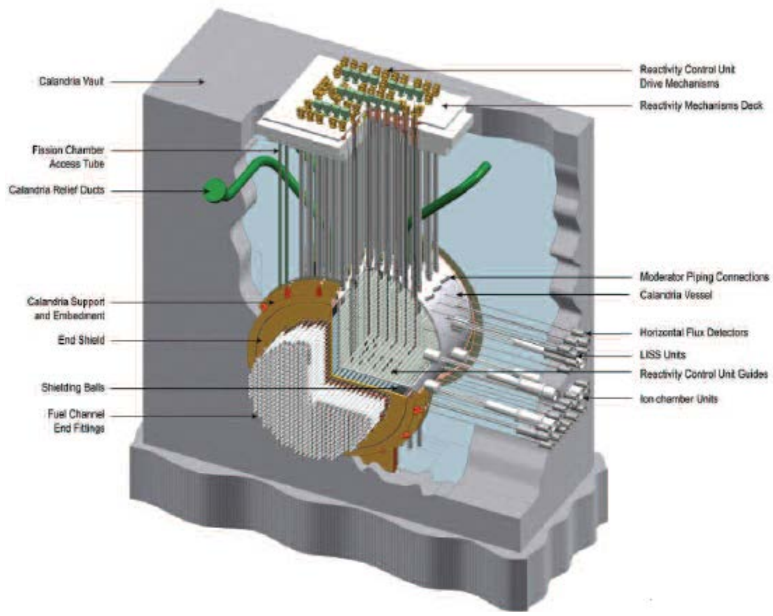
The reactor itself consists of a horizontal steel cylinder (calandria) approximately 24 feet in diameter and about 18 feet long filled with heavy water at near atmospheric pressure and temperature, which acts as a moderator to decelerate the neutrons and enable the nuclear reaction to take place. Tubes, or channels, that contain the uranium fuel pass through the calandria in the axial direction and connections are made at both ends so that the light water at high pressure can pass through and take away the heat from the nuclear reaction. Fueling machines at each end of the reactor can select any of the channels and replace used or damaged fuel with fresh fuel while maintaining full power.

The ACR-1000 has completed Phase 3 of the Canadian Nuclear Safety Commission's (CNSC) pre-project design review. However, in the U.S., CANDU reactors have never been licensed and there is no ACR-1000 licensing activity.

CANDU, Inc. maintains that the ACR-1000 program has been completed to the point that the design is ready for bidding or for discussion with interested utilities.

[226] CANDU Energy, Inc. http://www.candu.com/en/home/candureactors/acr1000.aspx
AECL Presentation March 2007
http://www.reak.bme.hu/MTAEB/files/konferencia_20070308/tpresent/AECL_ACR1000.pdf

Figure 67. ACR-1000

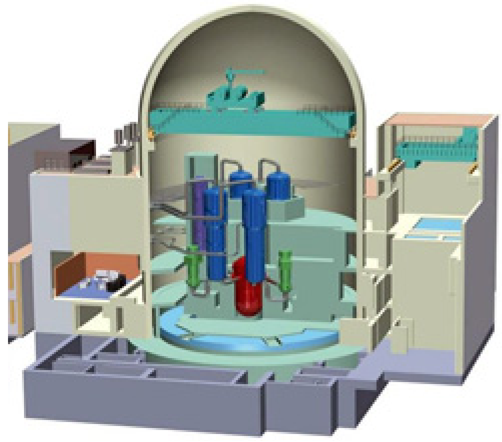


7.2.5 U.S. Advanced Pressurized Water Reactor (APWR)[227]

Mitsubishi Nuclear Energy Systems is pursuing a license for the 1700 MWe U.S. Advanced Pressurized Water Reactor with the U.S. Nuclear Regulatory Commission. Based on a similar design that has been operating in Japan, the four-loop U.S. APWR is considered to be more efficient with greater output than any previous power plant. The U.S. APWR uses more advanced steam generators, which create drier steam, allowing for the use of higher efficiency turbines. The large size of the APWR requires a first-of-a-kind large steam turbine, which is also being developed by Mitsubishi.

[227] Mitsubishi Nuclear Energy Systems http://www.mnes-us.com/htm/usapwrdesign.htm
U.S. NRC http://www.nrc.gov/reactors/new-reactors/new-licensing-files/new-rx-licensing-app-legend.pdf

Figure 68. USAPWR



A four-train redundant safety system provided to enhance safety and improve reliability. NRC design certification for the U.S. APWR is underway and currently projected for completion in 2015. In the meantime, both Dominion Energy (North Anna) and Luminant (Comanche Peak) have COL applications before the Nuclear Regulatory Commission.[228]

7.2.6 U.S. Evolutionary Power Reactor (US EPR)[229]

French company Areva's U.S. Evolutionary Power Reactor is expected to produce more than 1650 MWe of electricity. It relies on a combination of active and passive safety systems in four independent trains. This includes four redundant 100% capacity emergency diesel generators (EDG). In addition, the EPR's onsite water and fuel reserves provide full autonomy of the safety systems for more than seven days. In December 2007, AREVA submitted a Design Certification Application to the U.S. NRC and that application is under review. Several applications for Combined Construction and Operating Licenses have been submitted by Ameren UE, PPL Generation, and Unistar. However, as the NRC will not license a nuclear power plant without a U.S.-based partner, efforts to deploy the U.S. EPR technology hit snags when Constellation Energy pulled out of the Unistar joint venture with French Utility EDF.

Significant cost overruns and schedule delays have been encountered at similar EPR plants being built in France (Flamanville-3, eight-year construction timeline) and Finland (Olkiluoto-3, ten-year construction timeline). Areva claims that such problems are unique and not representative of future EPR projects' costs and schedules.[230]

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[228] NRC New Reactor Licensing Schedule http://www.nrc.gov/reactors/new-reactors/new-licensing-files/new-rx-licensing-app-legend.pdf

[229] US NRC http://www.nrc.gov/reactors/new-reactors/design-cert/epr.html
AREVA http://us.areva.com/EN/home-933/us-epr-reactor-generation-iii-nuclear-reactor-solution-for-united-states.html

[230] Areva http://www.areva.com/EN/operations-1663/construction-of-the-steam-supply-systems-and-nuclear-islands.html

Figure 69. US EPR

7.2.7 Small Modular Reactors

Several vendors are anticipated to deploy small modular reactors in the U.S. over the next ten years. Most rely on DOE funding for development, so there is some uncertainty as to the level of support they will receive under Federal budget constraints. Major features of SMRs are discussed in the following paragraphs.

Cost and Schedule

After their production becomes routine, SMR units are anticipated to be less costly than large nuclear plants, thereby facilitating financing and reducing risk exposure. Many SMRs can be "mass produced" in factory settings and shipped to the installation site by rail, barge, or large transport vehicle. Shop building SMRs in an assembly-line process, similar to the auto industry, has the potential to revolutionize the global nuclear power industry.

Safety

Most SMR designs involve passive safety systems, requiring no electricity or off-site water supply for safe shut down. The smaller size also reduces the potential amount of radioactive release should a catastrophic accident occur.

Applications

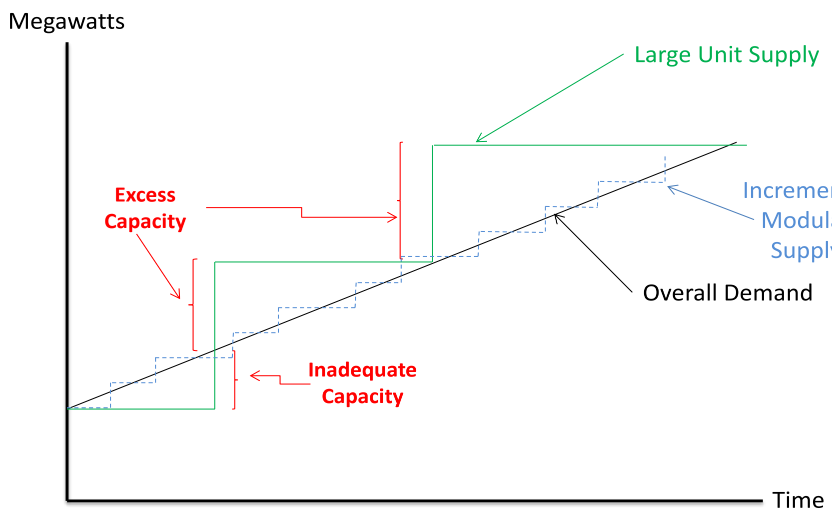
Because of their small size and transportability, individual SMRs can be located in remote or isolated "off-grid" sites to support facilities such as mines and shale oil recovery installations.

Load Following

SMR developers indicate that, within limits, their technology can ramp up and down to adjust to grid demand, a capability large nuclear plants and coal plants do not have. Load following becomes more important as intermittent sources of supply (e.g. wind and solar) are added to the grid.

Modularity
Multiple SMR units can be combined in a modular fashion to create incrementally larger "clusters" of power production capacity at a particular site. The ability to incrementally add capacity allows for more cost effective and timely matching of supply and demand than that achieved by larger units and reduces the risk of over- or under-building.

Figure 70. Capacity Additions Compared to Demand Growth for Large and Small Reactors



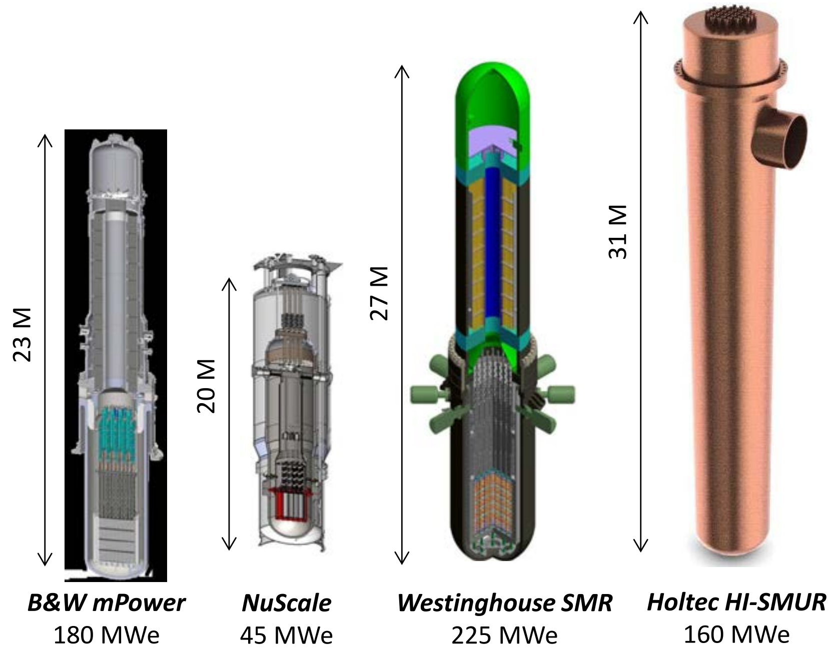
Transmission Infrastructure
SMRs can be located to optimize transmission system capacity, eliminate load pockets, minimize local "Not in My Back Yard" (NIMBY) opposition, and decrease environmentally challenging transmission capacity additions or upgrades.

In 2012, the U.S. Department of Energy (DOE) issued a "Funding Opportunity Announcement" (FOA), requesting proposals from SMR technology developers. The intent was for DOE to award $552 million, split between two applicants, to further the development of SMR technology. One of the requirements of the solicitation was that full-scale SMR commercial operation must be achieved prior to 2022. Because of the current processes and expertise found at the NRC this requirement eliminated technologies that were not light water reactors.

Four firms submitted proposals for the FOA. To date, only mPower has been selected for an award and there is some question as to whether there will be further awards. The DOE had planned to use the Savannah River site as a host for various SMR projects; however, in late 2012 DOE announced that it would no longer use environmental management (EM) funds to support site preparations.

The four technologies that submitted applications for the DOE funding are depicted in the following figure. These technologies have similar features such as shop fabrication, underground siting, relatively small output (less than 300 MWe), pressurized water designs, and passive safety systems. While none has submitted an application to the NRC to certify the design, they are expected in the next few years and commercial operation can be expected in the early 2020s. Salient aspects of each technology are addressed in the following sections.

Figure 71. SMR Technologies



mPower SMR

The mPower SMR is a 180 MWe pressurized water reactor system. It is an underground configuration with an integral design: the core, pressurizer and steam generators are within one vessel, thereby eliminating the need for external piping and components. Generation mPower, LLC, a joint venture between Babcock & Wilcox and Bechtel touts a 14-day "coping time" under station blackout conditions and a Core Damage Frequency of $1x10^{-8}$. It has integral reactor coolant pumps with external electric motor drives to circulate coolant through the core and internal steam generators. mPower recently received a grant from DOE to facilitate commercialization of the design at the Clinch River site in the Tennessee Valley Authority's territory.

Figure 72. mPower Conceptual Underground Installation Source B&W

NAVIGANT

NuScale SMR
NuScale, a privately held company based in Oregon whose majority owner is the international engineering and construction firm Fluor Corporation proposed a 45 MWe SMR. Although the smallest of the group, the NuScale design contemplates twelve 45 MWe modules that can be installed in a structural facility when the owner requires increased capacity, thereby providing flexibility in timing the construction and financing of new capacity. Its size also eliminates the need for extensive custom designed components, allowing for an “off-the-shelf” supply chain. NuScale claims to be “walk away safe”, requiring no external water supply, operator actions, or power source for safe shut down. It calculated the Core Damage Frequency to be $1x10^{-8}$. NuScale has stated that it may apply for NRC Design Certification in 2015.

A video of NuScale operations is provided at http://nuscale.com/video_operation.php .

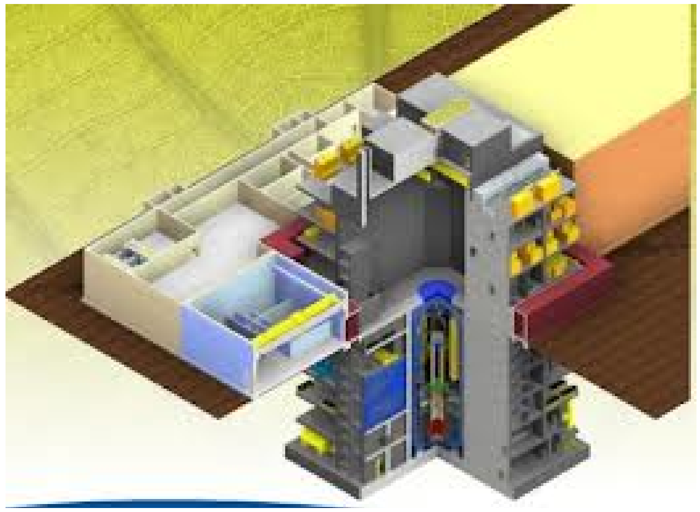
Figure 73. NuScale SMR

Westinghouse SMR
The Westinghouse 225 MWe SMR is an integral pressurized water reactor based on Westinghouse’s 1100 MWe AP1000 design. It employs electric driven pumps to circulate coolant through the core and steam generator. Safety analysis has shown the reactor can go for seven days without AC power. Westinghouse’s goal is to make the SMR competitive with large reactors, so it has simplified the reactor’s design as much as possible. For example, by omitting the need for large forgings, the SMR components can be produced by more suppliers. Westinghouse wants to have 100% of the SMR American-made and plans on submitting for NRC Design Certification in 2014.[231]

An interesting graphic of the safety system in operation is found at http://www.westinghousenuclear.com/SMR/smr_safety.swf.

[231] Westinghouse presentation 3rd Annual SMR conference Mr. John Goossen

Figure 74. Westinghouse SMR Underground



Holtec Inherently Safe Modular Underground Reactor (HI-SMUR)
The SMR-160 is a 160 MWe reactor based on Holtec's HI-SMUR technology. It is the industry's first truly passive power plant, according to the release, because it does not require a pump or external source of power during normal operation, abnormal excursion, or in response to accidents. Holtec has designed the system to be safer by using gravity as the motive energy in all the reactor's critical safety systems. The majority, including the spent fuel pool, of the SMR-160 is located underground. The SMR-160 uses a canister type fuel and is designed to operate for four years without refueling, which may take as little as five days based on the proposed fuel design. Holtec is exploring the option for air-cooled condensers and anticipates applying for NRC Design Certification in late 2016.[232]

7.3 *Advanced Technologies*

All of the technologies previously described are based on proven light water or heavy water technologies that have operated successfully for decades. Some of these designs are still awaiting or have yet to apply for NRC design certification. The following are very early-stage conceptual designs, which may be feasible in the next 20-30 years. Some of these designs utilize concepts that were first developed during the AEC's Power Reactor Demonstration Program.

NGNP HTGR
An organization called The NGNP Industry Alliance Limited evolved out of government funding initiatives to commercialize high temperature gas cooled reactor (HTGR) technology. The group is comprised of utilities, petroleum companies, chemical companies, and others. Last year, the Alliance selected an HTGR design advanced by French company Areva. The design is a two-loop HTGR with a conventional steam system, producing approximately 200 MWe of electricity; however, its primary purpose is to provide process heat for industrial procedures. The Alliance members believe that the

232 Holtec presentation 3rd Annual SMR Conference Mr. Pierre Onied

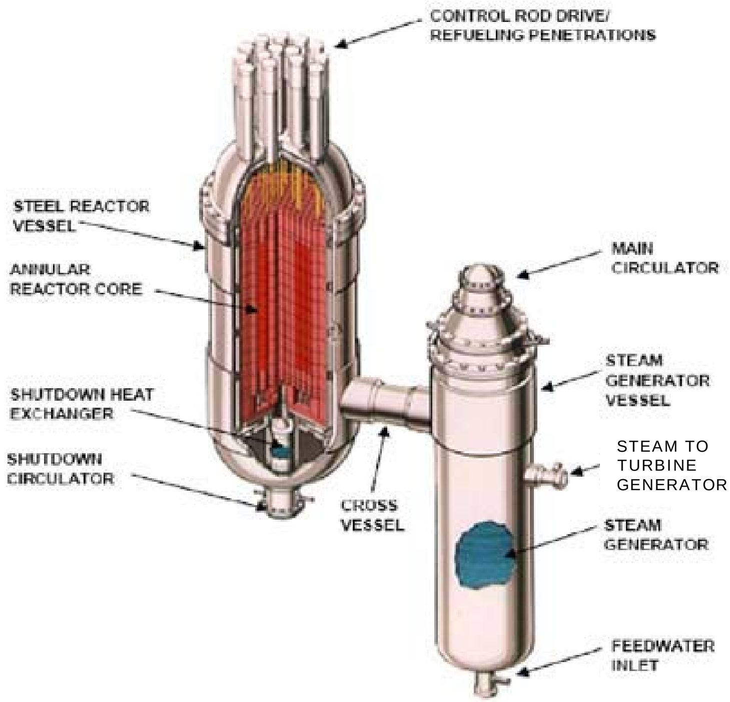
process can be competitive with natural gas-fired process heat at $6-$8/MMBTU and they are backing development as a hedge against natural gas price volatility.[233]

The HTGR nuclear heat supply system (NHSS) is comprised of three major components: a helium cooled nuclear reactor, a heat transport system, and a cross vessel that routes the helium between the reactor and the heat transport system. Inherent properties of the reactor core render the plant inherently safe, so no electrical power, coolant flow, or other active systems or operator actions are required to limit power levels and fuel temperatures under any condition.

In January 2013, DOE awarded $1 million to the NGNP Industry Alliance Limited for a 50/50 cost shared contract (plus follow-on options) to continue business and economic analysis for the use of HTGR technologies.

At this time, there is no design certification review planned by the U.S. NRC for a HTGR. Therefore, the earliest such a technology will be available for commercial operation is likely sometime well into the 2020s.

Figure 75. NPNG HTGR



EM2 HTGR

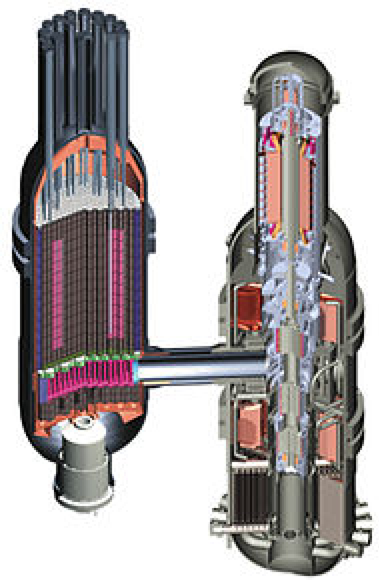
The EM2 is a fast neutron HTGR capable of producing 240 MWe of electricity and high temperature process steam at 850^{o}C. A 50% thermal efficiency is contemplated by employing Brayton Cycle (Gas

233 NGNP presentation 3rd Annual SMR Conference presentation Mr. Kim Stein

Turbine) technology. General Atomics, the developer, claims the ability to burn used light water reactor fuel and to achieve a 30-year period of continuous operation without refueling or opening the reactor. If this is achievable, considerable value will be realized in sealing the reactor system for non-proliferation purposes, thus facilitating deployment in remote countries.

General Atomics, a privately held defense contractor in Southern California, announced in 2010 that it will launch a 12-year program to develop the EM2. However, significant challenges including obtaining development funding of over $1 billion, dealing with high temperature metallurgical issues, reactor core design issues, and licensing issues for advanced technology must still be surmounted.

Figure 76. EM2 HTGR Concept

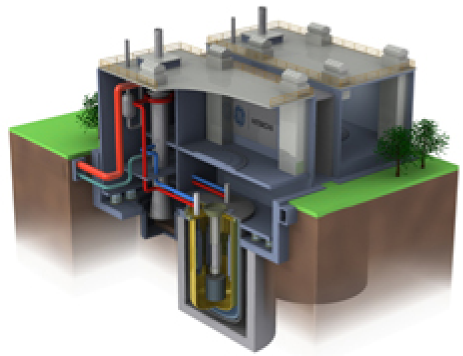


Power Reactor Innovative Small Modular (PRISM)

Power Reactor Innovative Small Modular is a sodium-cooled pool-type fast reactor with passive design features that increase plant safety. Its modular design allows factory fabrication and ultimately lower construction costs. PRISM consumes used nuclear fuel while generating 622 MWe.

GE-Hitachi (GE-H) is developing PRISM and is reportedly talking with UK government agencies about the potential use of PRISM technology dispose of the UK's plutonium stockpile. As submittal of a Design Certification Application to the NRC is not on NRC's planning horizon, the commercialization of PRISM technology is more than ten years away.

Figure 77. Conceptual PRISM Reactor



Waste Annihilating Molten Salt Reactor (WAMSER)

The Waste Annihilating Molten Salt Reactor draws from earlier technology developed at the Oak Ridge National Laboratory. It produces 200 MWe of electric energy in a fast reactor system, fueled by nuclear waste that is dissolved into a molten salt suspension. Suspending the fuel in a liquid and creating a fast neutron flux allows the system to capture more of the fuel's energy. Like other advanced reactor systems, WAMSER is inherently safe, requiring no operator action, external electric power, or active safety systems to prevent damage in accident scenarios. Like most SMRs, it is also shop-fabricated and transported to the site by rail.

WAMSER is being developed by Transatomic Power, Inc. of Boston, Massachusetts, which claims that the technology, if fully deployed, can dispose of all existing worldwide stockpiles of high-level waste and produce $7.1 trillion worth of electricity, enough electricity to power the entire world for 72 years. WAMSER is in early stage development with little likelihood of commercialization for the next 15-20 years.

Gen4 (formerly Hyperion)

The Gen4 reactor module is a 25 MWe lead-bismuth cooled fast reactor concept using 20% enriched uranium nitride fuel without moderation. In addition to its relatively small output, the Gen4 module is physically small. The reactor vessel housing the core and primary heat transfer circuit is about five feet wide and 7.5 feet high. It is easily portable, sealed and has no moving parts. Heat is transferred to an external steam generator by a secondary cooling circuit. The reactor module is capable of producing electricity or process heat continuously for up to ten years without refueling, at which time, the full module can be removed and replaced with another. With fuel burned down to about 15% enrichment, the old module would be put in site dry storage to cool down for up to two years before being returned to the factory for refueling. This reactor is targeted at the diesel generator market and has been described as a "nuclear battery".[234]

Colorado based Gen4 Energy, Inc. (formerly Hyperion) is developing the technology under license from the Los Alamos National Laboratory (LANL).

[234] Gen4 presentation 3rd Annual SMR Conference presentation Mr. Bob Prince

Terra Power Traveling Wave Reactor (TWR)

TerraPower, Inc. is developing a unique reactor system that uses waste from uranium enrichment (depleted uranium) as fuel to generate 100 MWe to 1000 MWe of electric power. It accomplished this in a "traveling wave reactor" (TWR), which converts fertile material (e.g. U238) to its fissile fuel (e.g. PU239). The wave is started with enriched material (e.g. U235). It then progresses at a rate of approximately one centimeter per year, creating fissile fuel where and when it needs it. The TWR is said to be capable of operating for decades without refueling. There are currently 700,000 metric tons of leftover enrichment products in the United States. Using the TWR, eight metric tons of depleted uranium could generate 25 million megawatt-hours of electricity, enough to power 2.5 million U.S. households for one year.

TerraPower is a private company, based in Bellevue, Washington and Microsoft's Bill Gates is one of its primary investors. Presently there is no NRC schedule for accepting and reviewing a Design Certification Application.

8. POLICY CONSIDERATIONS

Economic Development

For those states whose policies include economic development considerations in regulating and siting power plants, nuclear power plants provide more direct permanent local jobs than other technologies as shown below. Additional jobs are provided during plant outages and new nuclear plant construction.

Labor Skills Assessment

Assembling, training and managing the workforce to build and operate a nuclear power facility is a major challenge. Personnel engaged in building and operating a nuclear power plant not only require significant technical skills; they also require a strong understanding of all quality assurance and regulatory program requirements. In addition, they must accept extensive third party oversight which can be contentious on occasion. This obviously takes extensive training and a mindset to adopt the nuclear safety culture. Very few workers from the last round of nuclear build are available for today's construction projects.

Much has been written and discussed about the availability of the workforce to accommodate the next wave of nuclear build. And much of the rhetoric focused on the availability of nuclear engineers. In fact, only 5% to 10% of the employees who work on a nuclear plant hold a nuclear engineering degree. Nuclear engineering specialists work on the reactor core design, safety analyses and various thermo-hydraulic analyses. There are many other types of engineers at nuclear plants and the companies that service, design and construct them, including civil, structural, mechanical, and electrical engineers. There are also a numerous jobs for workers in the construction trades: welders, pipefitters, labors, iron workers, carpenters, painters, electricians, boilermakers, millwrights and a host of others and their respective supervisors.

Staffing requirements change as a project progresses. Early stage design, permitting and licensing requires a strong engineering staff. Construction activities progress from early civil work requiring equipment operators to structural work requiring iron workers, carpenters, crane operators and laborers to equipment placement requiring millwrights and boilermakers; to mechanical and electrical systems construction requiring pipefitters and electricians. Then testing and startup activities take place leading to plant operations. Therefore, certain skill sets are not in high demand throughout the life of a project. This helps with staffing and retention issues. Contractors often try to transfer the better performers to other jobs or extend their employment on the first unit so they are available for the second at the same site.

In anticipation of challenges, the industry proactively instituted recruiting and training programs to fill the anticipated need. Since a number of new nuclear facilities originally contemplated have been delayed and the overall job market is down, current new projects face few staffing problems. However some critical skills such as "golden arm" welders who possess the required certifications for performing certain nuclear welds are in very high demand. Retention as well as recruiting and training become important as individuals may acquire certification at the expense of one employer and then move on to another for higher compensation. Wage rates, overtime, benefits, job security and site location are factors that affect recruiting and retention.

The two plants currently under construction in the U.S. have indicated that effective planning and the lack of competing concurrent projects have eliminated most of their staffing concerns.

Within the Southeastern Unites States, the Regional Center for Nuclear Education and Training (RCNET), consists of 15 colleges, three universities, and 27 industry partners across Alabama, Florida, Georgia, North Carolina, South Carolina, Tennessee, and Virginia. In concert with local utility needs their main goal is to create a comprehensive curriculum for training programs to provide career paths in nuclear technology. South Carolina has an especially active program called "NUHub" dedicated to creating local jobs that has active involvement from state and local government officials in addition to local utility support.

Nuclear Power Differences

To the extent possible policy makers should consider the differences between nuclear power and other forms of generation. One of the recommendations to come out of the accident at Three Mile Island was the recognition that ….." rate-making agencies should recognize that implementation of new safety measures can be inhibited by delay or failure to include the costs of such measures in the utility rate base. The Commission, therefore, recommends that state rate-making agencies give explicit attention to the safety implications of rate-making when they consider costs based on "safety-related" changes".

Recognition of the difference between conventional technologies and nuclear technology includes recognition of the "culture" that permeates the industry. The following sample of requirements highlights some of the difference between nuclear power and other industries.

Fitness for Duty[235] In 1989, the NRC established requirements for Fitness-for-Duty (FFD) Programs, requiring nuclear power plant licensees to implement a (FFD) Program for all personnel having unescorted access to the protected areas of their facilities and other personnel with particular types of access. This program not only concentrates on drug use, but also addresses a full range of other worker fitness issues such as training, fatigue, record keeping, and sanctions.

Nuclear power plant construction activities also require Fitness for Duty Programs. In 2009, the Nuclear Energy Institute published Fitness for Duty Program Guidance for New Nuclear Power Plant Construction Sites[236], which has been endorsed by the NRC.

Failure to strictly comply with FFD requirements has ramifications. For example, in 2010 at the new nuclear plant construction site in Georgia, an internal audit conducted by contractor showed it failed to have its workers personally complete a written questionnaire asking about past or current drug and alcohol abuse. That questionnaire is required by the Nuclear Regulatory Commission. Even though workers were asked about drug and alcohol abuse, the supervisors filled out the forms during a verbal screening and all other required background checks were completed, the contractor temporarily stopped its workers from placing backfill inside excavated footprints that would house the foundation of two additional nuclear reactors. This contributed to a delay in construction activities.

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[235] 10 CFR 26

[236] Source: http://www.nrc.gov/reactors/operating/ops-experience/fitness-for-duty-programs/industry-guid-nei-06-06-r5.html

Nuclear Safety Culture (NSC) It is the NRC's policy that individuals and organizations performing or overseeing regulated activities establish and maintain a positive safety culture commensurate with the safety and security significance of their activities and the nature and complexity of their organizations and functions.

The Nuclear Regulatory Commission defines Nuclear Safety Culture as:
"the core values and behaviors resulting from a collective commitment by leaders and individuals to emphasize safety over competing goals to ensure protection of people and the environment."[237]

This requirement has led utilities, contractors, engineering firms, et al to develop, document and sustain an appropriate nuclear safety culture. It is likely that an effective NSC saves time and money by avoiding preventable errors.

Safety Conscious Work Environment (SCWE) The NRC's policy statement "Freedom of Employees in the Nuclear Industry to Raise Safety Concerns Without Fear of Retaliation," May 14, 1996, describes SCWE as:

"A work environment where employees are encouraged to raise safety concerns and where concerns are promptly reviewed, given the proper priority based on their potential safety significance, and appropriately resolved with timely feedback to the originator of the concerns and to other employees."

In response to this policy, the industry has established programs to ensure employees are forthcoming and that their concerns are appropriately addressed. Very often concerns stem from misconceptions or inadequate information. However, the industry fully supports an environment where issues are not hidden.

Market Regulation
In analyzing incentives and disincentives for new nuclear power plant construction it is apparent that those states with deregulated electricity markets will not be attractive to merchant nuclear power plant developers. It also became apparent that existing nuclear plants cannot be assumed to prevail over the market forces fostering the rapid expansion of natural gas. The closure of Kewaunee Nuclear Power Plant may be a harbinger of things to come for older single unit nuclear power plants. MISO did not designate Kewaunee as a System Support Resource (SSR) so it was able to close without delay. The question may arise in the future for closing merchant units that are designated as an SSR as to whether or not the independent investors are entitled to earn a profit while the unit must operate or if it is to operate at "break even" economics. In regulated markets nuclear power plant operators may request rate increase to cover increased costs due to infiltration of renewable energy sources and potentially lower energy prices.

Spent Nuclear Fuel
If states could gain greater influence over nuclear plant waste streams via a court decision or revision to the NRC's waste confidence rule, they must develop policies to implement that influence. Currently the

[237] http://www.gpo.gov/fdsys/pkg/FR-2011-06-14/pdf/2011-14656.pdf

Federal government is responsible for paying for dry cask storage at stranded sites and operating sites through the Federal government's Judgment Fund. States should enact policies that ensure "stranded" spent fuel is properly monitored and maintained by the NRC. Additionally, consent-based siting for pilot, interim and long-term repositories may increase the states' ability to form regional compacts to address spent nuclear fuel disposal.

Renewable Energy

Nuclear power is the only form of carbon free base load generation known; yet only two states, Ohio and Indiana credit nuclear power towards clean energy targets. Other states should consider expanding nuclear power into the category of clean or renewable energy to recognize its emission free attributes.

Uprate Economics and Operational Flexibility

Nuclear power uprates can extend the life of existing plants and create incremental increases in unit output. The overnight cost of extended power uprates is estimated to be half that of new nuclear construction. This cost can still exceed the cost of alternative generation with more dynamic load response than a nuclear power plant. In addition to cost, policy makers should consider attributes such as load following response capabilities in their deliberations as applicable to their local power market characteristics.

Early Plant Retirements

If power prices remain low for an extended period of years, it will become more probable that marginally performing nuclear power plants will retire prior to the expiration of their operating license. Two plants, Kewaunee and Crystal River 3, retired unexpectedly in May 2013. Kewaunee operated in a deregulated power market and retired because of an inability to find a suitable power purchase agreement. Crystal River 3 operated in vertically integrated utility environment and retire because of prohibitive repair costs to its containment structure.

Nuclear Regulatory Commission Licensing Capability

The NRC is considered the "gold standard" in terms of licensing expertise with light water reactors. However, long lead times for design certification of light water reactors may push reactor developers to build new designs, such as SMRs, in other countries. Additionally, the NRC's lack of experience and current capabilities to license technology other than a light water reactor may push developers of non-light water reactor technology overseas or into Canada to build their prototypes.

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Appendix A. Glossary

A

Active Safety Systems
Use pumps or valves and rely on AC or DC power to fulfill their safety function. Passive systems refer to emergency cooling systems that use natural circulation or gravity to fulfill their function.

Atomic
Refers to the use of atoms, the smallest component of an element having the chemical properties of the element, consisting of a nucleus containing combinations of neutrons and protons and one or more electrons bound to the nucleus by electrical attraction; the number of protons determines the identity of the element.

Atomic Energy Commission
Agency of the United States government established after World War II by Congress to foster and control the peace time development of atomic science and technology.

B

Base Load
The minimum energy level a company must provide to its customers on a constant basis. The exact amount varies each day because aggregate customer loads vary from day to day and month to month. For example the base load for low electricity use in the spring and fall months is lower than in the winter and summer. Consumer loads mirror utility generating requirements. As a result, the phrase "base load" also is used to characterize customer needs. Specifically, power suppliers are interested in each customer's base loads in order to identify the minimum quantity of power to sell. Both generators and power suppliers also characterize loads in terms of peak load, the maximum amount of power needed.

Base Load Plants
Plants that run at full capacity year round to meet a utility's base load are called base load plants. For base load plants, utilities select plants with the lowest generating costs, construction, and operating costs. Traditionally, base load plants were fueled with coal purchased in very large volumes on long-term contracts.

British Thermal Unit (BTU)
This is the standard unit for measuring quantity of heat energy, such as the heat content of fuel. One BTU equals the amount of heat necessary to raise the temperature of one pound of water by one degree Fahrenheit. There are 1.03 million BTUs in 1 Mcf of natural gas (an Mcf is a unit of volume meaning 1,000 cubic feet). There are 3,412 BTUs in 1 kilowatt hour. MMBTU is one million BTUs.
Bulk Power Market or Wholesale Power Market
The bulk power system consists of the generation and transmission system and the wholesale financial

transactions associated with power and transmission transfers on the system. It includes wholesale purchases and sales of electricity, transmission reservations to wheel that power, and potential interactions with power pools and independent system operators (ISOs). Access to the bulk power market is reserved for vertically integrated utilities wholesalers, including power producers, power retailers, and a few very large direct-use customers. Some Federal agencies have access to the bulk power market at selected sites.

C

Capacity
The physical capability of a pipeline, power plant, or other facility. In the electric industry, generating capacity is measured in terms of kilowatts (1,000 watts) or Megawatts (1,000 kilowatts) and transmission capacity is measured in kilo-volt-amperes (kva). In general conversation, capacity is used to indicate a maximum; for example "The capacity of the generating plant is 500 Megawatts (MW)." The adjective maximum is assumed.

Capacity Market
Power demand varies from day-to-day and season-to-season. The power system has to have enough capacity in it to provide for the maximum demand for both power and delivery. Since this capacity is only used during peak periods, it may sit idle the rest of the time. Nevertheless, it has to be paid for. Unfortunately, simple kWh billing doesn't reflect the fact that some generation, transmission, and distribution capacity is just sitting in reserve for peak demand periods. Utilities try to recover those costs through a "demand charge." Currently in regions of the U.S which have maintained vertical utility integration or prior to deregulation in other regions of the US, retail customers paid the local utility for energy (kWh) and demand (kW) based on the costs of the utility's generation. Now that wholesale markets are deregulated, the utility may purchase capacity, as a separate commodity, from a competitive market that trades just capacity (or access to stand-by generation).

Capital Investments or Utility Assets
These include generating plants, transmission and distribution systems, and other infrastructure such as office buildings. Utilities raise capital for investments by borrowing from lenders and issuing stock to investors. Investor-owned utilities earn a rate-of-return for capital they invest in utility facilities. These assets are called the rate base.

Cladding
Protective coat of metal surrounding uranium fuel pellets usually a long tube of zirconium metal

Combined-Cycle Combustion Turbines. See Gas Turbines.

Combustion Turbines. See Gas Turbines.

Contamination
Radioactive material that is present within other material and cannot be easily separated and its presence is unwanted. Contamination can be mitigated by disposal, painting over the contamination or attempting to clean the material. For example, at Fukushima top soil is being removed to dispose of contaminated soil. See Radiation

Coolant
The fission process raises the temperature of the fuel rods used in the nuclear reactor. Coolant transfers the heat from the fuel rods to an intermediate heat exchanger or turbine depending on the design of the power plant. Modern U.S. reactors use water as the coolant. Other reactors use heavy water (deuterium), liquid sodium, or helium.

Core Damage Frequency
An expression of the likelihood that, given the way a reactor is designed and operated, an accident could cause the fuel in the reactor to be damaged.

Curie
A unit of activity of radioactive substances equivalent to 3.70 × 10^10 disintegrations per second: it is approximately the amount of activity produced by 1 gram of radium-226.

D

Decay Heat---Unlike conventional fueled power plants, nuclear reactors continue to generate up to 7% of their power level immediately after shut down due to energy produced by fission byproducts within the reactor. This heat level rapidly reduces to less than 1% 24 hours after shutdown. This energy requires the continuous circulation of coolant to prevent possible damage to fuel cladding and is the basis for emergency core cooling systems and their support equipment. Spent nuclear fuel remains in pools of water for up to 5 years to allow this heat source to dissipate.

Demand
A measure of customer or system load requirements over a measured period of time. Demand is used to establish requirements for both generating and transmission capacity. In economic terms, this is the inverse relationship between the price of a good and the quantity of the good that is demanded by consumers (high prices drive down demand and vice versa). Demand is for consumers what capacity or base load is for suppliers.

Design margin
Refers to the relationship of the nuclear power plants normal operating parameters (temperature, pressure, flow) compared with the maximum allowable engineering design parameters.

Deregulation
The process of removing price regulations on price regulated utilities. In general, only price regulations are removed, all other aspects remain regulated. The term deregulation is used outside the United States to refer to the sale of government-owned or controlled assets to private-sector operators. U.S. based

utilities are not government owned to start with so there is no need to go through this phase of deregulation. Under deregulation, generation is separated from transmission and distribution. Local utilities are still required to provide transmission and distribution, which remains regulated, but the generation of power has been deregulated, rates are no longer fixed and power generators compete for customers. Deregulation and industry restructuring are often used interchangeably; however, it is useful to draw a distinction between the two. Deregulation is something regulators may do to utilities. Restructuring is the industry-driven adaptation to deregulation, including preparing for competition, seeking new products and markets, and merging with other firms. Restructuring is what the industry does to itself.

E

Electric Generation
Electricity can be generated through a wide variety of processes, although far and away the most common is by the rotation of a generator shaft, or rotor, through opposing magnetic fields. Shaft rotation induces the flow of electricity in the generator. An external energy source is required to rotate a generator shaft, and that can come from a wide variety of sources. There are four major generator designs based on the primary source of energy, or prime mover, used to turn them. These are water turbines, engines, gas turbines, and steam turbines. Water turbines in hydropower plants direct water flow through dams containing turbine blades attached to one end of a generator rotor. When the water turns the turbine, it also turns the rotor and electricity is generated. Steam turbines are turned by steam from water heated by heat from controlled nuclear reactions or from the burning of fossil fuels. Fossil-fired generators vary in efficiency from 30 to 65%, i.e., a 30% efficient plant uses over twice as much fuel as a 65% efficient one. Modern plants tend to be much more efficient than older ones.

Electricity Generator
An electric power generating plant or the owner or operator of such a plant or plants. When reference is made to a plant, the term usually refers to a single or specific plant. For example, "When the generator trips off-line…" When reference is made to a source of supply (the person or firm selling power) the term is generally not plant specific but refers to the power resources available to the plant owner, typically multiple plants and/or power contracts. For example, "When the generator sells power to the PX …"

Embedded Costs
This refers to the historical costs of all the capital assets (equipment and facilities) used in an electric utility's system. Each asset goes on the books at its initial cost. Capital assets are depreciated over time, so the value carried forward on the books declines over time. The resulting value is called "book value." Book value for an asset may be less than the value of the asset if it were sold on the open market, i.e., the market value. One of the benefits of cost of service regulation as is used in vertically integrated utilities is that current prices are tied to the low embedded costs of existing assets. Generally, this means power costs are lower than they would be in an open market.

Energy, U.S. Department of (DOE)
An agency created by the Federal government in 1977. It provides information to achieve efficiency in energy use, diversity in energy sources, a more productive and competitive economy, improved

environmental quality, and a secure national defense. Before 1977 these functions were provided by various predecessor Federal organizations. Most states have an agency, sometimes called the state energy office or energy department, tasked with some of the same missions, especially energy conservation. Also included under the U.S. DOE umbrella are the Federal power marketing administrations, oversight of the Tennessee Valley Authority, and the Federal Energy Regulatory Commission.

Enrichment
Natural uranium ore is 99 % U-238 and 1% U-235. The process of increasing the ratio of U-235 to U-238 is called enrichment. The enrichment process is very energy intensive and requires a highly sophisticated workforce and infrastructure. The enrichment process raises proliferation concerns because highly enriched material can also be used in nuclear weapons as well as reactors.

F

Fission
All nuclear reactors generate heat with the energy released by splitting atoms with neutrons. These neutrons have different energy levels. Three isotopes Uranium-233, Uranium-235, and Plutonium-239 are fissionable by neutrons of all energies and called fissile material. Uranium- 235 is the only one that occurs naturally and in very small amounts.

Two other materials Thorium-232 and Uranium-238 are abundant naturally and are fissionable only if split with highly energetic neutrons. However, these materials can be converted to fissile isotopes within a reactor.

Fixed Price
A price that remains the same for a set time period. Energy buyers can solicit bids for energy supplies based on a fixed price for a specific contract term. This contrasts with price quotes that are tied to an index that floats up and down, typically a fuel cost index.

G

Gas Turbine
Gas turbines are based on jet airplane engine designs. Air is sucked into the gas turbine where it is compressed. This increases the density of the air (which increases combustion efficiency) and heats it. Gaseous fuel is introduced in a combustion chamber and the resulting exhaust is used to drive a turbine attached to a generator rotor. Electric generators based on this design are usually called simple-cycle combustion turbines, or simply combustion turbines (CTs). CTs are used as rapid start "peaking" units by utilities to service infrequent periods when there is high electrical demand. Steam generators are often used in conjunction with gas turbines in what are called combined-cycle combustion turbines, or CCCTs. Natural gas is used to fuel most new plants and is partly responsible for the high heat rate of new plants. Coal is an abundant native fuel that can be converted into gas similar to natural gas for use in gas turbines. Plants that include coal gasification are called integrated gasified combined-cycle plants (IGCCs). IGCC plants are cleaner burning than old-style coal plants.

Green Power
Electricity that is produced from sources that are thought to be environmentally cleaner than traditional sources. Green power is usually defined as power from renewable energy that comes from wind, solar, biomass energy, etc. There are various definitions of green resources. Some definitions include power produced from waste-to-energy and wood-fired plants that may produce air emissions as bad as conventional fuels. Some states have defined certain local resources as green that other states would not consider green. For example, the State of Texas has defined power from efficient natural gas-fired power plants as green. Some northwest states include power from large hydropower projects as green although these projects damage fish populations.
Various states and the Federal government are working to clarify labeling for green power. GSA and DESC both request bids for green products that fit the environmentally beneficial guidelines used by the government. Any agency can purchase green power from GSA or DESC and be confident of the source. Further clarification of green power purchasing will be forthcoming as a result of Executive Order 13123. FEMP, GSA, and DESC will provide Federal agencies with information as deregulation proceeds.

H

Heat Rate
The efficiency of a plant is reflected in a metric called the heat rate, which is expressed in terms of Btus per kilowatt of power (e.g., 9,500 Btus/kWh). One kWh of power produces 3,412 Btus of energy, so a plant with a heat rate of 3,412 would be perfectly efficient. This is an ideal unlikely to be achieved, although improved heat rates are the focus of intense research sponsored by DOE and industry. The heat rate of best-of-class machines is approximately 6,500 Btus/kWh whereas the average heat rate for all generators in service today is about 11,500. Thus, new machines burn roughly half the fuel of the typical plant, with a similar reduction in carbon dioxide and other air emissions.

Heavy Water
Some or most of the hydrogen atoms in heavy water contain a neutron, causing each hydrogen atom to be about twice as heavy as a normal hydrogen atom. Heavy water is also called deuterium oxide- D2O

Hedge. See Power Purchase Agreement

Holding Companies
A holding company may own a number of utilities that provide retail service in multiple states, usually adjacent states. Each utility owned by a holding company is a separate corporate entity, with its own board of directors. A good example is the Southern Company, which owns Georgia Power, Mississippi Power, and others. About two dozen IOUs operate as holding companies. The retail utility subsidiaries are regulated by state PUCs; however, dealings with the parent holding company cannot be regulated by individual states because they are interstate transactions. Instead, they are regulated by the Interstate Commerce Commission. The wholesale transactions of holding companies are also regulated by the FERC. The Public Utility Holding Company Act of 1935 (PUCHA) was passed to restrict the activities of holding companies due to abuses by holding companies early in the history of the industry. As a result, holding companies couldnot participate in certain other utility businesses (water and telephone, for example). Utilities that are not part of a holding company may engage in these activities with the consent of the state PUC.PUCHA was repealed in the Energy Act of 2005. .

I

Integrated Gasified Combined-Cycle Plants. See Gas Turbines.

Integrated Resource Planning (IRP)
A planning process in which utilities look at multiple sources to meet demand for power. In addition to traditional fossil fuel plants, utilities would give equal or greater weight to alternative supply options, such as renewable energy, demand response, and energy efficiency. IRP was fashionable in the 1980s and early 1990s because it engaged all stakeholders in utility planning. However, it fell from favor in most but not all states when natural gas prices fell in the late-1980s, making new generating plants and new power supplies relatively inexpensive.

Intermediate Plants
In between combustion turbines used for peak load and base load plants is a class of plants called intermediate or mid-merit plants. These plants are run more often than peaking plants but not as often as base load plants. They are generally based on a combined-cycle combustion turbine design. Hence they use a higher cost fuel than a base load plant but these higher fuel costs are offset by better heat rates.

Intervene
To intervene is to participate in the regulatory process through which utility rates are set.

Investor-Owned Utility (IOU)
Any company owned by stockholders that provides utility services. IOUs are for-profit firms. They raise capital by issuing stock and debt to investors, hence the term investor-owned. . IOUs provide power to almost 70% of all consumers. Because they are for-profit firms with a responsibility to provide reliable and economic electric service to customers while simultaneously earning profits for investors they are regulated by state commissions. Holding companies are IOUs with multiple utility subsidiaries in different states.

K

Kilowatt (kW) of Demand
This is equal to 1,000 watts. It is used as a measure of demand for electricity independent of time. Ten 100-watt light bulbs use one kW (10 times 100) of electricity.

Kilowatt-hour (kWh)
The basic unit of electric energy for which most customers are charged. It incorporates the kW demand and the duration of use in one metric. For example, ten 100-watt light bulbs left on for one hour use 1,000 (10 times 100) Watt-hours, or 1 kWh. If they burn for a total of 5 hours, they will use 5 kWh. If all 10 burn for 5 hours and only 5 burn for the next 5 hours, they will use a total of 7.5 kWh. This ability to integrate demand and duration demonstrates why kWh is favored as a way to measure and calculate electricity use. Consumers are charged for electricity in cents per kilowatt-hour.

L

Levelized Cost of Energy (LCOE)
Iis the cost of generating electricity over the lifetime of the powerplant. It is an economic assessment of the cost of the power plant including all the costs over its lifetime: initial investment, operations and maintenance, cost of fuel, and cost of capital. LCOE is used to compare technologies to determine the lowest cost production option.

M

Manhattan Project
The World War II code name for American and its Allies efforts to produce the atomic bomb. The project created the entire infrastructure that has evolved into the nation's national laboratories.

Marginal Cost
The change in total costs associated with a one-unit change in the quantity supplied. For an electric utility, this would be the cost of providing an additional kilowatt hour of electricity to a consumer. Marginal cost is an economic concept that assumes quantities of a commodity can be provided in single unit increments. Utility plants are generally large and long-lived. Adding an entire new plant to meet an extra kilowatt of demand is very expensive. Prior to deregulation the cost of this avoided plant was used to determine marginal (or avoided) cost. Presently, commodity markets (or power pools) play this role. In commodity markets, power owners (many of whom are speculators) offer to sell power to power buyers (again, many of whom are speculators). The owners have secured rights to power capacity that they are willing to sell when the price is right. Prices get bid up by buyers, usually in response to anticipated power demand. If prices are too high, buyers can refuse to purchase and force speculators to sell off supplies at a loss (since power is best used as it is produced). Customers are always able to avoid using power or reduce consumption during periods of high pricing.

MBtu (MBTU)
This stands for one million British Thermal Units (BTUs). MBTUs are a common unit of measure for natural gas and provides a convenient basis for comparison of the energy content of natural gas and electricity. One Megawatt hour of electricity (1,000 kWh) is equivalent to 3.413 MBTUs. Natural gas is measured in cubic feet. One cubic foot of gas is nominally equal to 1,000 BTUs. Thus, 1,000 cubic feet of gas (normally called one MCF or Mcf (M is the Roman numeral for 1,000; cf is an abbreviation for cubic feet) is equal to 1 MBTU. However, the heat (BTU) content of a unit of natural gas varies. Accordingly, natural gas is usually measured in "therms." One therm of gas is always equal to 100,000 BTU or .1 MBTU. Most major natural gas users purchase gas in quantities measured in tens of thousands of Decatherms. One Decatherms is equal to 1 MBTU.

Moderator
The purpose of the moderator is to slow down high energy neutrons created during the fission process in order to increase the probability of fission within a thermal reactor. Water is the most common moderator used in modern US reactors. Other materials used in reactors include heavy water (deuterium) and graphite.

Municipal Utility
A provider of utility services owned and operated by a city government is called a municipal utility. Municipal utilities are generally not subject to state regulation under the belief that consumers can control the actions of the utility through the electoral process. Municipal utilities currently are able to raise capital by issuing tax-exempt bonds which reduces their cost of operations. Because most states do not regulate municipal utilities, state deregulation legislation does not generally apply. However, if a municipal utility opts to deregulate itself, it is often covered by the same legislation as a regulated investor-owned utility. Municipal utilities usually take one of two forms. They can be a part of the municipal government or a separate entity under the control of the municipal government, or they can operate as a municipal corporation granted by the State altogether separate from the local municipality.

N

National Association of Regulatory Utility Commissioners (NARUC)
This is an advisory council composed of utility regulatory agencies of the 50 states, the District of Columbia, Puerto Rico, and the Virgin Islands. The primary objective of NARUC is to serve the consumer interest "by seeking to improve the quality and effectiveness of public regulation in America." NARUC holds periodic meetings of regulators, has standing committees, and advises state and Federal bodies on utility legislation.

North American Reliability Council (NERC)
The New York blackout of 1965 was a wake up call to the power industry. The industry responded to the blackout by creating a voluntary, utility-managed reliability organization, the North American Electric Reliability Council (NERC). NERC divided the nation into ten reliability regions, with each region covering multiple states (except for the Texas-specific Electric Reliability Council of Texas, ERCOT). The largest council is the Western States Coordinating Council (WSCC), which covers the entire Western Interconnection, including 11 western states, two Canadian provinces, and the northern portion of Baja California in Mexico. The smallest is the Mid-Atlantic Coordinating Council (MAAC) covering New Jersey, the District of Columbia, and most of Pennsylvania and Maryland.

Nuclear Power
Nuclear energy is produced using steam driven turbines, just like fossil-fueled plants. However, the steam is produced from the heat of controlled nuclear reactions. Nuclear reactors produce radioactive waste but little or no air pollution.

O

Off-Peak/On-Peak
Blocks of time when energy demand is low (off-peak) or high (on-peak). Typically, on-peak power prices are higher both because production costs are greater and as a means to discourage on-peak power use and growth. Historically, on- and off-peak periods were defined by utilities and/or regulators. In competitive markets demand drives prices, but so does other factors. As a result, peak demand periods will not be the only times when market prices are high. As a result, on-peak periods will not be as predictable as they are with present utility time-of-use rate schedules.

Operating Expenses
Operating expenses consist primarily of generating-plant fuel costs and labor. They contrast with fixed costs, such as debt repayments. Fuel costs are typically the largest operating expense and they vary depending on how much power is produced (i.e., the more power generated, the more fuel needed to fire the plant). Labor costs vary somewhat with power production, but are mostly constant (i.e., the same amount of people are needed to run the plant whether it is operating at full capacity or half capacity).

P

Passive Safety Systems
Passive systems refer to emergency cooling systems that use natural circulation or gravity to fulfill their function. Active systems use pumps or valves and rely on AC or DC power to fulfill their function.

Peak Demand or Peak Load
Power demands on a system vary. The maximum demand (kW or MW) on the system over a specific interval (i.e., a year, month, day, etc.) is the system peak demand and the magnitude of the load is the peak load. The time it occurs (i.e., hour, 15-minute interval within an hour, etc.) is the peak demand period.

Plutonium
A dangerous non-naturally occurring element produced as fission byproduct in nuclear reactors. It is radioactive with an 88 year half-life and can be as nuclear fuel and in making nuclear weapons.

Power Purchase Agreements
Contract between an electricity generator and electricity buyer. The PPA defines all of the commercial terms for the sale of electricity between the two parties, including price, duration and scheduling. PPAs are used to mitigate financial risk by both parties.

Production Costs or Variable Costs
A utility's dominant production costs are its fuel costs. These controllable costs are referred to as variable costs. Plants are generally dispatched (started and run) to serve loads based on production costs in what is called merit order, i.e., lowest production costs first. That way the most efficient plants run the most, often minimizing production costs. Since fixed costs are sunk, this has the effect of minimizing total costs.

Public Safety Philosophy
Modern nuclear power plants use several lines of defense to protect the public from the release of radioactive material. The first is conservative operating practices and strict equipment reliability requirements. The second is a robust fuel design that attempts to minimize release of fission products into the coolant during normal plant operations. The third is the reactor coolant system which is designed to remove heat from the fuel rods. Should the primary coolant pumps fail, design criteria require multiple secondary safety system activate to remove decay heat. The final barrier is the containment vessel that surrounds the reactor coolant system. In event of a coolant system rupture the containment and it pressure suppression system are designed to prevent the release of radioactive

material.

R

Radiation
Unstable materials change into stable materials through the process of radioactive decay. Three types of radiation are of most concern for human health: alpha particles, beta particles, and gamma rays. Each of these forms of energy can interact at the cellular level and cause varying degrees of biological damage. Alpha and beta particles are typically considered only an internal hazard. Therefore, appropriate precautions are taken to prevent ingestion of material that emits them through radioactive decay. Gamma radiation accounts for almost all of the small amounts of radiation nuclear workers receive.

Rate Base
The rate base is the value of a utility's assets, established by state regulations, upon which the utility is allowed to earn a specified return. Utilities raise capital from investors and invest in utility assets that benefit their customers, such as power plants, distribution systems, and other facilities. In order to attract investors, the utility must pay them an incentive like interest that is paid on borrowed money. This incentive is called the rate-of-return and is set by the PUC to be competitive with private-sector investments with similar risk. Regulators only allow the rate-of-returnof-return to be earned on specific investments. These are called the rate base. The rate base changes constantly as utilities make new investments. The rate of return can be changed by the PUC when it feels an adjustment is justified. Similarly, the PUC can add or remove investments in the rate base. Historically, regulators have followed utility recommendations on what investments should be included in the rate base and on an acceptable rate of return. In some states, commissions have gotten more critical recently and have been more willing to remove items from the rate base and reduce the rate of return.

Rate Making
Utilities need to recover sufficient revenues to pay all of the expenses incurred, including debt service, returns to investors, and operations and maintenance. The total of these requirements sets the rate level. The process of ratemaking involves translating the rate level into specific rates for each customer, a process called rate design. The rate making ideal is for the cost of service to be perfectly allocated to each customer; that philosophy is one of “cost follows cause.” However, customizing rates for each individual customer is far too expensive and cumbersome. Instead, rate design approximates customer-specific costs by grouping customers into similar customer classes. Rates are then designed to recover costs from a representative customer for each class. Typical rate classes include residential, small commercial, large commercial, industrial, and street lighting

Rate of Return
Regulators allow utilities to earn a rate of return on invested capital raised from investors, a sum that is called the rate base. Regulators set the rate of return in a range that allows a utility to earn a profit on its investment and attract capital at favorable rates (compared to bank borrowing). However, this rate is generally set at a level low enough to protect customers’ interests. Payment of the rate of return allows a utility (and its investors) to recover its investment through rates. Thus, the rate of return allows a utility to recover a return on its investments and a return of its investments, just like payments of interest and principal (respectively) on a bank loan.

Regulation
Broadly stated, a regulation is a rule or law established by the Federal or state government that a company must follow. In utility terms, regulation is the act of overseeing utility operations and finances. Utility regulation is a substitute for the discipline of competition in competitive markets. Markets regulate certain business practices so they conform to the will of the market, assumed to be composed of many consumers. Markets are assumed to stimulate the offering of new products and services at optimal prices and to discipline firms that do not do so by driving them out of business. Utilities are assumed to offer services that are needs (rather than wants) that should be made available to the entire population at reasonable prices. The reasoning behind utility regulation is that the vagaries of the marketplace are thought to be too volatile to ensure a socially acceptable result, thus firms were selected to provide these services without competition. To prevent expected monopoly abuses, prices and operations are subject to regulation by a public body representing consumer interests.

Regulatory Assets
Regulatory assets are investments the utility made with an understanding from regulators that the associated costs could be recovered, even though there may be no tangible asset. The most well-known example is investments in demand side management measures.

Renewable Portfolio Standard (RPS)
An RPS is an environmental requirement some states have adopted that specifies that a minimum fraction of generation must come from renewable resources, typically wind and solar power. Some state deregulation agreements require all power marketers to maintain this fraction; others allow marketers to trade with renewable power developers to meet the standard. For example, the state may require that all power suppliers meet an RPS of 3% by 2005. As a result, every power supplier must be able to document resources in its resource portfolio that are derived from renewable power equal to 3% of state retail power sales in 2005. These can be in the form of renewable resources owned, or output purchased from such sources. Generally, states that have an RPS requirement also plan to verify the renewable claims of power suppliers.

Renewable Power
Renewable power, often called green power, is electricity that is produced with environmentally clean power sources such as solar, wind, hydro and biomass. There are multiple definitions of renewable power although most do not include large hydropower resources and power from waste-burning facilities. Although green power is often used to mean renewable generation, this is often not the case. As a result, it is necessary to clearly specify the kind of resources included in either definition and to establish how environmental claims are verified.

Restructuring
Restructuring is the process of changing the structure of a utility industry from one of monopoly supplier and captive customer to one of competition among suppliers for customers. Deregulation of price and customer choice restrictions is a governmental action that allows competition. Restructuring occurs when organizations respond to the advent of competition. As such, it is self-induced. In a phrase, it is what the industry does to itself, rather than what regulators do to the industry. Typical restructuring responses include separating utilities into their separate functions -- transmission, distribution, and generation; adding new products and services; merging with other firms; and divesting assets that are

not considered to be central to the firm's new business direction.

S

Spent nuclear fuel
Uranium fuel that has been used in a power reactor and subjected to neutron bombardment or irradiation. The neutron interactions with the uranium atoms create "fission byproducts". Some of these byproducts are long lived radioactive materials such as plutonium. Spent fuel is stored in pools of water for approximately 5 years in order to allow these fission byproducts to decay to the point where thermal and radiation concerns allow dry storage.

Stranded Costs
Stranded costs consist of assets such as generation, power contracts, and regulatory commitments that are currently paid for by customers which may not be recoverable by the utility if customers switch to other suppliers. For example, a utility may have generating costs that are 3 cents higher because of their mortgage on new power plants. If customers of the utility find another supplier whose power is 2 cents cheaper, they may switch. If the existing utility is forced to discount its power by 2 cents to stay competitive, the 2 cents per kilowatt it loses would be a stranded cost.

Existing power plants were built by utilities to meet service requirements imposed by regulators. As a result the utilities argue they should be allowed to recover these stranded costs (the 2-cent difference in the example) from current customers. All of the deregulation agreements made thus far are allowing utilities to recover some or all of these costs through a surcharge on sales and sometimes through a bond sale, called securitization. Having established a precedent with generating costs, other parties have succeeded in attaching additional stranded cost surcharges for labor contracts, conservation programs, and other vestiges of regulation that are imperiled by deregulation. Fortunately, stranded costs end after a transition period to full competition. When stranded cost recovery ends, consumer prices are expected to fall, often by 15 to 20%.

Sunk Costs or Fixed Costs
A utility's fixed costs are predominately the costs associated with plant construction. These costs are similar to a home mortgage, which must be paid regardless of use. Although utilities are allowed to recover these costs, the costs themselves are sunk costs as nothing can be done to change them.

T

Turbine Generator or Combustion Turbine (CT)
Many power generators are steam driven. The steam turns the fan-like blades of a turbine and the spinning generates electricity. The current versions of gas-fired generators utilize a combustion turbine design that is derived from jet engines. In this design, the turbine includes a compressor element that concentrates the oxygen-fuel mix to increase combustion efficiency. Contemporary combustion turbines convert about 40% of their fuel into electricity in simple cycle mode. CTs can be designed to capture and reuse the waste heat from the simple cycle to generate additional power. This design is called a Combined-Cycle Combustion Turbine, or CCCT. CTs can run on oil as well as natural gas. They can

also burn gas, primarily methane, derived from the gasification of coal. These plants are called Integrated Gasification Combustion Turbines, or IGCTs.
Historically, natural gas and oil have been relatively expensive generating fuels. Deregulation of natural gas markets a decade ago resulted in significantly lower prices leading to the present popularity of CTs and CCCTs. These plants are comparatively inexpensive to construct, don't require large amounts of land, and produce comparatively low levels of air and water pollutants. Nevertheless, coal is an abundant and inexpensive fuel and IGCCs may become more common in the future.

U

Uranium
A naturally occurring element that can be found in low levels within all rock, soil, and water. Uranium is also the highest-numbered element to be found naturally in significant quantities on earth and is always found combined with other elements. Natural uranium ore is 99 % U-238 and 1% U-235 and is mined for use as fuel in nuclear reactors.

W

Waste Confidence Rule
Waste Confidence Decision and Rule represented the generic determination by the U.S. Nuclear Regulatory Commission (NRC) that spent nuclear fuel can be stored safely and without significant environmental impacts for a period of time after the end of the licensed life of a nuclear power plant. On June 8, 2012, the U.S. Court of Appeals for the DC Circuit found that some aspects of the Decision did not satisfy the NRC's NEPA obligations and vacated the Decision and Rule. The NRC is currently revising its rule.

Watt
This is a measure of the amount of electricity needed to power a device such as a light bulb. It is the primary unit of measure for electricity use. However, most electrical uses use many watts, so the most common unit of measure is 1,000 watts, or the kilowatt. Generating plants and very large customers use Megawatts (MW) as a measure. One Megawatt is equal to 1,000 kilowatts.

Wholesale
This is the sale of a commodity (such as electricity) in quantity for resale purposes. The distinction between wholesale and retail transactions is of interest primarily for regulatory purposes. Wholesale transactions often involve trade between parties in different states. As a result, wholesale transactions are considered interstate commerce and fall under the jurisdiction of the Federal government, not the states. The primary regulator of wholesale transactions is FERC. In contrast, retail transactions occur within state boundaries and are the jurisdiction of state agencies. The exception for electricity is the State of Texas, which is electrically isolated from the rest of the country, so virtually all wholesale transactions occur within the state. Accordingly, the State of Texas retains jurisdiction. Similarly, natural gas that is produced and transported wholly within a gas-producing state is also exempt from FERC jurisdiction. There are several states that have intra-state (as opposed to interstate) gas pipelines. FERC took the lead in deregulating both the wholesale natural gas and wholeseal electricity markets. This resulted in some

very large natural gas customers, called non-core customers, gaining direct access to wholesale gas markets. Many industrial firms would like similar access to wholesale electricity markets, but those desires have been frustrated by FERC to date. Some large customers can become true wholesale customers through petitions to FERC or local regulators. However, the standards are very strict. Generally, the customer must own and operate a distribution system similar to a retail utility and use that system to resell utility services to third parties for a fee that includes distribution charges, just like a utility. Customers with wholesale status are able to avoid paying some fees that may be levied by state regulators.

Wind Power

This is the use of wind to spin a turbine to generate electricity. Wind as slow as 5 mph can produce electricity. Isolated wind turbines were common in rural areas, especially in the Great Plains states, in the 1930s and '40s. Wind power today is a large-scale affair with multiple turbines being located in a wind farm. Wind farms produce power on a similar scale to conventional generating plants, namely 10s of megawatts. Although wind power is pollution free, the wind blows intermittently. Wind conditions are only right for wind power 30 to 40% of the time. Nevertheless, wind power is the most rapidly developing new power resource.

Appendix B. State Incentive and Disincentive Statutes

Table 33. State Incentive Statutes

State	Conditions	Citations
Alabama	No Tax on Nuclear Fuel	*Alabama Code 40-9-22* All nuclear fuel assemblies, together with the nuclear materials contained therein, and all reprocessed, recycled or residual nuclear fuel by-products, fissionable or otherwise used or useful in the production of electricity by persons regularly engaged in furnishing electricity to any person or persons shall be exempt from state, county and municipal taxes, excises, licenses, fees or other charges of any nature whatsoever. Nuclear fuel assemblies as used herein shall not include permanently installed equipment or structures. It is the intention of the Legislature of Alabama that the exemptions herein provided shall not be repealed or otherwise diminished unless the statute effecting such repeal shall make specific reference to this section and shall clearly demonstrate a legislative intention to repeal or otherwise affect the exemptions provided in this section.
California	- Waste disposal capability	*West's Ann.Cal.Pub.Res.Code § 25524.1* (a) Except for the existing Diablo Canyon Units 1 and 2 owned by Pacific Gas and Electric Company and San Onofre Units 2 and 3 owned by Southern California Edison Company and San Diego Gas and Electric Company, no nuclear fission thermal powerplant requiring the reprocessing of fuel rods, including any to which this chapter does not otherwise apply, excepting any having a vested right as defined in this section, shall be permitted land use in the state or, where applicable, certified by the commission until both of the following conditions are met: (1) The commission finds that the United States through its authorized agency has identified and approved, and there exists a technology for the construction and operation of, nuclear fuel rod reprocessing plants. (2) The commission has reported its findings and the reasons therefor pursuant to paragraph (1) to the Legislature. That report shall be assigned to the appropriate policy committees for review. The commission may proceed to certify nuclear fission thermal powerplants 100 legislative days after reporting its findings unless within those 100 legislative days either house of the Legislature adopts by a majority vote of its members a resolution disaffirming the findings of the commission made pursuant to paragraph (1).
Connecticut	- Waste disposal capability	*C.G.S.A. § 22a-136* No construction shall commence on a fifth nuclear power facility until the Commissioner of Environmental Protection finds that the United States Government, through its authorized agency, has identified and approved a demonstrable technology or means for the disposal of high level nuclear waste. As used in this section, "high level nuclear waste" means those aqueous wastes resulting from the operation of the first cycle of the solvent extraction system or equivalent and the concentrated wastes of the subsequent extraction cycles or equivalent in a facility for reprocessing irradiated reactor fuel and shall include spent fuel assemblies prior to fuel reprocessing.

State	Conditions	Citations
Florida	Cost Recovery	25-6.0423 Nuclear or Integrated Gasification Combined-Cycle Power Plant Cost Recovery. (1) Purpose. The purpose of this rule is to establish alternative cost recovery mechanisms for the recovery of costs incurred in the siting, design, licensing, and construction of nuclear or integrated gasification combined-cycle power plants in order to promote electric utility investment in nuclear or integrated gasification combined-cycle power plants and allow for the recovery in rates of all such prudently incurred costs. (2) Definitions. As used in this rule, the following definitions shall apply: (a) “Nuclear power plant” is an electrical power plant that utilizes nuclear materials as fuel, as defined in Sections 403.503(13) and 366.93(1)(c), F.S. (b) “Integrated gasification combined-cycle power plant” is an electrical power plant that uses synthesis gas produced by integrated gasification technology, as defined in Sections 403.503(13) and 366.93(1)(c), F.S. (c) “Power plant” or “plant” means a nuclear power plant or an integrated gasification combined-cycle power plant. ……omitted for brevity… (4) Site Selection Costs. After the Commission has issued a final order granting a determination of need for a power plant pursuant to Section 403.519, F.S., a utility may file a petition for a separate proceeding, to recover prudently incurred site selection costs. This separate proceeding will be limited to only those issues necessary for the determination of prudence and alternative method for recovery of site selection costs of a power plant. (5) Pre-Construction Costs and Carrying Costs on Construction Cost Balance. After the Commission has issued a final order granting a determination of need for a power plant pursuant to Section 403.519, F.S., a utility may petition the Commission for recovery of pre-construction costs and carrying costs of construction cost balance as follows: (a) Pre-Construction Costs. A utility is entitled to recover, through the Capacity Cost Recovery Clause, its actual and projected pre-construction costs. The utility may also recover the related carrying charge for those costs not recovered on a projected basis. Such costs will be recovered within 1 year, unless the Commission approves a longer recovery period. Any party may, however, propose a longer period of recovery, not to exceed 2 years…….omitted for brevity
Georgia	Nuclear Construction Cost Recovery	NCCR-3 The Nuclear Construction Cost Recovery Schedule (N CCR) will recover the cost of financing associated with the construction of a nuclear generating plant which has been certified by the Commission in accordance with O.C.G.A. § 46 - 2 - 25(c.1) and the Commission’s Certification Order in Dock et No. 27800. This schedule is applicable to and becomes a part of each retail rate schedule in which reference is made to the NCCR .
Hawaii	- Legislature approval	*Const. Art. 11, § 8* No nuclear fission power plant shall be constructed or radioactive material disposed of in the State without the prior approval by a two-thirds vote in each house of the legislature

State	Conditions	Citations
Illinois	- Waste disposal capability or - Legislature approval	*220 ILCS 5/8-406* (c) After the effective date of this amendatory Act of 1987, no construction shall commence on any new nuclear power plant to be located within this State, and no certificate of public convenience and necessity or other authorization shall be issued therefor by the Commission, until the Director of the Illinois Environmental Protection Agency finds that the United States Government, through its authorized agency, has identified and approved a demonstrable technology or means for the disposal of high level nuclear waste, or until such construction has been specifically approved by a statute enacted by the General Assembly. As used in this Section, "high level nuclear waste" means those aqueous wastes resulting from the operation of the first cycle of the solvent extraction system or equivalent and the concentrated wastes of the subsequent extraction cycles or equivalent in a facility for reprocessing irradiated reactor fuel and shall include spent fuel assemblies prior to fuel reprocessing.
Indiana	Clean Energy	*IC 8-1-37-4* "Clean energy resource" Sec. 4. (a) As used in this chapter, "clean energy resource" means any of the following sources, clean sources, alternative technologies, or programs used in connection with the production or conservation of electricity: (1) Energy from wind. (2) Solar energy. …Others omitted. For spacing (18) Nuclear energy.

State	Conditions	Citations
Kansas	Property Tax	Section 79-23-Kansas Code (a) The following described property, to the extent herein specified, shall be exempt from all property taxes levied under the laws of the state of Kansas: Any new nuclear generation facility property. (b) The provisions of subsection (a) shall apply from and after purchase or commencement of construction or installation of such property and for the 10 taxable years immediately following the taxable year in which construction or installation of such property is completed. (c) The provisions of this section shall apply to all taxable years commencing after December 31, 2006.
	High Level Waste	Nuclear fission electric generating facilities with excess capacity; presumption certain costs excluded when finding of no "technology or means for disposal of high-level nuclear waste" as defined in section. (a) If any portion of an electric generating facility is determined to be excess capacity and if the facility is a nuclear fission power plant, the state corporation commission shall determine whether there has been approved by the United States government through its authorized agency, a proven technology or means for the disposal of high-level nuclear waste which is available for use at or by the plant. If the commission finds that no such technology for disposal exists, it shall be presumed that the costs of acquisition, construction or operation of the facility were incurred due to a lack of prudence and the commission shall not include such costs in the reasonable value of the public utility property. (b) When used in this section, "technology or means for the disposal of high-level nuclear waste" means temporary onsite storage of high-level nuclear waste or an approved process for the retrieval of such waste.
	Nuclear Studies	66-128q. Proceeding to review application for recovery of prudent expenditures for certain costs of new nuclear generation facility; application for predetermination of rate-making principles authorized. On and after July 1, 2008, the state corporation commission, upon application and request, shall authorize an electric utility to recover the utility's prudent expenditures for development costs, which include preliminary engineering, study, feasibility, prepayments for major equipment and permitting costs for a new nuclear generation facility by an adjustment to the utility's rates. The application and request shall be subject to such procedures and conditions, including review of the prudence of the expenditures and the reasonableness of the measures, as the commission deems appropriate. The commission shall allow any electric public utility to apply and request a predetermination of rate-making principles and treatment applicable to the utility's rates to recover development costs for a new nuclear generation facility, which include preliminary engineering, study, feasibility, prepayments for major equipment and permitting costs, prior to construction of the facility. .

State	Conditions	Citations
Kentucky	- Waste disposal capability	*KRS § 278.605* No construction shall commence on a nuclear power facility in the Commonwealth until the Public Service Commission finds that the United States government, through its authorized agency, has identified and approved a demonstrable technology or means for the disposal of high level nuclear waste.
Maine	- Voter approval	*35-A M.R.S.A. § 4302* 1. Question submitted to voters. Prior to the construction of any nuclear power plant within the State, the question of approving that construction must be submitted to the voters of the State in the manner prescribed by law for holding a statewide election. This question must be submitted to the legal voters of the State at the next following statewide election. The municipal officers and plantation assessors of this State shall notify the inhabitants of their respective cities, towns and plantations to meet, in the manner prescribed by law for holding a statewide election, to vote on the acceptance or rejection of construction by voting on the following question: "Do you approve construction of the nuclear power plant proposed for (insert locations)?"
	- Waste disposal capability	*35-A M.R.S.A. § 4373* No construction may commence on a nuclear power plant, until the Public Utilities Commission has certified it under this subchapter. *35-A M.R.S.A. § 4374* The commission may certify a nuclear power plant if it finds that: 1. Federal Government identification and approval of technology. The Federal Government, through its authorized agency, has identified and approved a demonstrable technology or means for the disposal of high-level nuclear waste; 2. Waste storage facilities operational. Specific facilities with adequate capacity to contain high-level nuclear waste are in actual operation, or will be in operation, at the time the nuclear power plant being certified requires the means for the disposal of high-level nuclear waste; and 3. Proposal for disposal is in conformity. The disposal of high-level nuclear waste proposed for any nuclear power plant to be certified according to this subchapter is in full conformity with the technology approved by the authorized agency of the Federal Government.

State	Conditions	Citations
Massachusetts	Voter approval Legislature approval (when certain conditions are met)	*M.G.L.A. 164 App. § 3-3* No new nuclear power plant shall be constructed or operated within the Commonwealth unless: (a) construction and operation of the proposed nuclear power plant have been approved by a majority of the voters voting thereon in a state-wide general election; and (b) the General Court has found, and has so certified by resolution duly adopted by majority vote of the members of each House: (i) that there exists an operating, federally-licensed facility for the timely and economical permanent disposal of high-level radioactive wastes generated by the proposed nuclear power plant; (ii) that an adequate emergency preparedness plan for the proposed nuclear power plant has been developed, approved, and implemented by the Commonwealth; (iii) that effective emission standards applicable to the proposed nuclear power plant have been promulgated by the Commonwealth to protect the public against health and safety hazards of radioactive air pollutants traceable to nuclear power plants within the Commonwealth; (iv) that there exists a demonstrated, federally-approved technology or means for the timely and economical decommissioning, dismantling, and disposal of the proposed nuclear power plant; and (v) that the proposed nuclear power plant offers the optimal means of meeting energy needs from the combined standpoints of overall cost, reliability, safety, environmental impact, land-use planning, and avoiding potential social and economic dislocation.
Minnesota	Outright ban	*M.S.A. § 216B.243* Subd. 3b. Nuclear power plant; new construction prohibited; relicensing. (a) The commission may not issue a certificate of need for the construction of a new nuclear-powered electric generating plant. (b) Any certificate of need for additional storage of spent nuclear fuel for a facility seeking a license extension shall address the impacts of continued operations over the period for which approval is sought.

State	Conditions	Citations
Ohio	Renewable Energy	4901:1-40-04 Qualified resources. (A) The following resources or technologies, if they have a placed-in-service date of January 1, 1998, or after, are qualified resources for meeting the renewable energy resource benchmarks: (1) Solar photovoltaic or solar thermal energy. (2) Wind energy. (3) Hydroelectric energy. Others omitted for spacing (3) Clean coal technology. (4) Advanced nuclear energy technology, from: (a) Advanced nuclear energy technology consisting of generation III technology as defined by the nuclear regulatory commission or other later technology.
Oregon	- Waste disposal capability - Voter approval	*O.R.S. § 469.595* Before issuing a site certificate for a nuclear-fueled thermal power plant, the Energy Facility Siting Council must find that an adequate repository for the disposal of the high-level radioactive waste produced by the plant has been licensed to operate by the appropriate agency of the federal government. The repository must provide for the terminal disposition of such waste, with or without provision for retrieval for reprocessing. *O.R.S. § 469.597* (1) Notwithstanding the provisions of ORS 469.370, if the Energy Facility Siting Council finds that the requirements of ORS 469.595 have been satisfied and proposes to issue a site certificate for a nuclear-fueled thermal power plant, the proposal shall be submitted to the electors of this state for their approval or rejection at the next available statewide general election. The procedures for submitting a proposal to the electors under this section shall conform, as nearly as possible to those for state measures, including but not limited to procedures for printing related material in the voters' pamphlet. (2) A site certificate for a nuclear-fueled thermal power plant shall not be issued until the electors of this state have approved the issuance of the certificate at an election held pursuant to subsection (1) of this section.
Rhode Island	- Legislature approval	*Gen.Laws 1956, § 42-64-14.1* The final approval or denial of a project plan for the location and construction of an oil refinery or a nuclear plant within the state is hereby expressly reserved to the general assembly notwithstanding any general or public law or ordinance to the contrary, and exclusively within the jurisdiction of the general assembly. The exclusive jurisdiction is vested in the general assembly notwithstanding any other general, special, or public law to the contrary, including, but not limited to, those laws granting regulatory powers to the cities and towns, and any ordinances enacted pursuant to these laws.

State	Conditions	Citations
South Carolina	Base Load Review Act	In part..Section 58-33-225. (A) The provisions of this section apply to the preconstruction costs of a nuclear-powered facility. (B) At any time before the filing of an application or a combined application under this act related to a specific plant, a utility may file a project development application with the commission and the Office of Regulatory Staff. (C) In a project development application, the utility shall: (1) describe the plant being considered and shall designate: (a) the anticipated generation capacity (or range of capacity) of the plant; and (b) the projected annual capacity factors or range of factors of the plant; (2) provide information establishing the need for the generation capacity represented by the potential plant and the need for generation assets with the indicative annual capacity factors of the potential plant; (3) provide information establishing the reasonableness and prudence of the potential fuel sources and potential generation types that the utility is considering for the plant; and (4) provide such other information as may be required to establish that the decision to incur preconstruction costs related to the potential nuclear plant is prudent considering the information known to the utility at the time and considering the other alternatives available to the utility for supplying its generation needs. (D) The commission shall issue a project development order affirming the prudency of the utility's decision to incur preconstruction costs for the nuclear plant specified in the application if the utility demonstrates by a preponderance of evidence that the decision to incur preconstruction costs for the plant is prudent. In issuing its project development order, the commission may not rule on the prudency or recoverability of specific items of cost, but shall rule instead on the prudency of the decision to incur preconstruction costs for the nuclear plant described in Section 58-33-225(C)(1). (E) Unless the record in a subsequent proceeding shows that individual items of cost were imprudently incurred, or that other decisions subsequent to the issuance of a project development order were imprudently made considering the information available to the utility at the time they were made, then all the preconstruction costs incurred for the potential nuclear plant must be properly included in the utility's plant-in-service and must be recoverable fully through rates in future proceedings under this chapter. Remainder omitted for brevity

State	Conditions	Citations
Vermont	- Legislature approval	*30 V.S.A. § 248* (e)(1) Before a certificate of public good is issued for the construction of a nuclear energy generating plant within the state, the public service board shall obtain the approval of the general assembly and the assembly's determination that the construction of the proposed facility will promote the general welfare. The public service board shall advise the general assembly of any petition submitted under this section for the construction of a nuclear energy generating plant within this state, by written notice delivered to the speaker of the house of representatives and to the president of the senate. The department of public service shall submit recommendations relating to the proposed plant, and shall make available to the general assembly all relevant material. The requirements of this subsection shall be in addition to the findings set forth in subsection (b) of this section.

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State	Conditions	Citations
West Virginia	- Compliance with environmental protection laws	*W. Va. Code, § 16-27A-1* The Legislature finds and declares that the use of nuclear fuels and nuclear power poses an undue hazard to the health, safety and welfare of the people of the state of West Virginia, especially until there is an effective method to safely and permanently dispose of the radioactive wastes generated thereby. Therefore, it is the intent of the Legislature and the purpose of this article to ban the construction of any nuclear power plant, nuclear factory or nuclear electric power generating plant until such time as the proponents of any such facility can adequately demonstrate that a functional and effective national facility, which safely, successfully and permanently disposes of radioactive wastes, has been developed; that the construction of any nuclear facility in this state will be economically feasible for West Virginia rate payers; and that such facility shall comply with all applicable environmental protection laws, rules and requirements. For the purposes of this article, "nuclear power" means energy produced in any nuclear power plant, nuclear factory or nuclear electric power generating plant capable of a thermal output greater than one megawatt but shall not include electricity carried over interstate transmission lines. *W. Va. Code, § 16-27A-2* (a) No nuclear power plant, nuclear factory or nuclear electric power generating plant may be constructed or initiated until the public service commission has approved the application for the same in accordance with the provisions of chapter twenty-four, article two of this code. (b) Any person or organization seeking to construct or initiate any nuclear power plant, nuclear factory or nuclear electric power generating plant in this state shall, prior to any construction or initiation, submit to the public service commission an application for approval, together with the documentation required by this section. (c) An application for the construction or initiation of any nuclear power plant, nuclear factory or nuclear electric power generating plant shall not be considered for approval unless it contains documented reports or certification that: (1) A functional and effective national facility which safely, successfully and permanently disposes of any and all radioactive wastes associated with operating any such nuclear power plant, nuclear factory or nuclear electric power generating plant has been developed and that such facility has been proven safe, functional and effective by a minimum of twenty-four months' operation or experience; and (2) The construction of any nuclear facility in this state will be economically feasible for West Virginia rate payers; and (3) The proposed nuclear facility shall comply with all applicable environmental protection laws, rules and requirements.

State	Conditions	Citations
Wisconsin	Waste disposal capability	*W.S.A. 196.493* (1) Definition In this section, "nuclear power plant" means a nuclear-fired large electric generating facility as defined under s. 196.491 (1)(g). (2) Limits on certification. The commission may not certify under s. 196.49 (3)(b) or 196.491 (3) any nuclear power plant unless the commission finds that: (a) A federally licensed facility, or a facility outside of the United States which the commission determines will satisfy the public welfare requirements of the people of this state, with adequate capacity to dispose of high-level nuclear waste from all nuclear power plants operating in this state will be available, as necessary, for disposal of the waste; and
	- Economical feasibility	(b) The proposed nuclear power plant, in comparison with feasible alternatives, is economically advantageous to ratepayers, based upon: 1. The existence of a reliable and adequate nuclear fuel supply; 2. The costs for construction, operation and decommissioning of nuclear power plants and for nuclear waste disposal; and 3. Any other factor having an impact on the economics of nuclear power plants, as determined by the commission.

Appendix C. Potential New Nuclear Locations Based on Cancelled Plants

Table 34. Potential New Nuclear Locations Based on Cancelled Plants

Market Structure	State	Plant	Capacity	Location
Regulated	Alabama	Barton 1	1159	Clanton AL
Regulated	Alabama	Barton 2	1159	Clanton AL
Regulated	Alabama	Barton 3	1159	Clanton AL
Regulated	Alabama	Barton 4	1159	Clanton AL
Regulated	Indiana	Bailly	644	Porter Cty IN
Regulated	Indiana	Marble Hill 1	1130	6 miles NE of New Washington, IN
Regulated	Indiana	Marble Hill 2	1130	6 miles NE of New Washington, IN
Regulated	Florida	Crystal River 4	897	Crystal River FL
Regulated	Florida	Orange 1	1300	Orange County FL
Regulated	Florida	Orange 2	1300	Orange County FL
Regulated	Florida	South Dade 1	1100	Dade County FL
Regulated	Florida	South Dade 2	1100	Dade County FL
Regulated	Louisiana	River Bend 2	934	St Francisville, LA
Regulated	Louisiana	St. Rosalie 1	1160	20 mies south of New Orleans
Regulated	Louisiana	St. Rosalie 2	1160	20 mies south of New Orleans
Regulated	Mississippi	Grand Gulf 2	1250	20 miles SW of Vicksburg, MS
Regulated	Mississippi	Yellow Creek 1	1285	Corinth MS
Regulated	Mississippi	Yellow Creek 2	1285	Corinth MS
Regulated	Nebraska	Fort Calhoun 2	1136	Fort Calhon NE
Regulated	South Carolina	Cherokee 1	1280	Cherokee Cty SC
Regulated	South Carolina	Cherokee 2	1280	Cherokee Cty SC
Regulated	South Carolina	Cherokee 3	1280	Cherokee Cty SC
Regulated	Tennessee	Hartsville A1	1205	Hartsville TN
Regulated	Tennessee	Hartsville A2	1205	Hartsville TN
Regulated	Tennessee	Hartsville B1	1233	Hartsville TN
Regulated	Tennessee	Hartsville B2	1233	Hartsville TN
Regulated	Tennessee	Phipps Bend 1	1233	15 miles SW of Kingsport, TN

Market Structure	State	Plant	Capacity	Location
Regulated	Tennessee	Phipps Bend 2	1233	15 miles SW of Kingsport, TN
Regulated	Oklahoma	Black Fox 1	1150	Inola OK
Regulated	Oklahoma	Black Fox 2	1150	Inola OK
Regulated	Virginia	North Anna 3	907	40 miles NW of Richmond, VA
Regulated	Virginia	North Anna 4	907	40 miles NW of Richmond, VA
Regulated	Virginia	Surry 3	859	17 miles NW of Newport News, VA
Regulated	Virginia	Surry 4	859	17 miles NW of Newport News, VA
Regulated	Iowa	Vandalia (Iowa 1)	1270	Vandalia IA
Regulated	North Carolina	South River 1	1150	North Carolina
Regulated	North Carolina	South River 2	1150	North Carolina
Regulated	North Carolina	South River 3	1150	North Carolina
Regulated	North Carolina	Perkins 1	1280	10 miles N of Salisbury, NC
Regulated	North Carolina	Perkins 2	1280	10 miles N of Salisbury, NC
Regulated	North Carolina	Perkins 3	1280	10 miles N of Salisbury, NC
Regulated	North Carolina	Shearon Harris 2	915	New Hill, NC
Regulated	North Carolina	Shearon Harris 3	900	New Hill, NC
Regulated	North Carolina	Shearon Harris 4	900	New Hill, NC
Regulated	Missouri	Callaway 2	1120	Fulton MO
Regulated	Wisconsin	Haven 1	900	4.2 miles SSW of Fort Atkinson, WI
Regulated	Wisconsin	Haven 2	900	4.2 miles SSW of Fort Atkinson, WI
Regulated	Wisconsin	Tyrone 1	1100	Durand WI
Regulated	Wisconsin	Tyrone 2	1150	Durand WI
Deregulated	Delaware	Hope Creek 2	1067	18 miles SE of Wilmington, DE
Deregulated	Delaware	Summit 1	770	15 miles SSW of Wilmington, DE
Deregulated	Delaware	Summit 2	770	15 miles SSW of Wilmington, DE
Deregulated	Maryland	Douglas Point 1	1146	Charles County, MD
Deregulated	Maryland	Douglas Point 2	1146	Charles County, MD
Deregulated	Maryland	Perryman 1	845	Perryman, MD

Market Structure	State	Plant	Capacity	Location
Deregulated	Maryland	Perryman 2	845	Perryman, MD
Deregulated	New York	Bell	838	Lansing, NY
Deregulated	New York	Greene County	1212	Cementon NY
Deregulated	New York	Jamesport 1	1150	65 miles E of New York City, NY
Deregulated	New York	Jamesport 2	1150	65 miles E of New York City, NY
Deregulated	New York	NYSE&G 1	1250	New Haven NY
Deregulated	New York	NYSE&G 2	1250	New Haven NY
Deregulated	New York	Somerset 1	1200	Somerset, NY
Deregulated	New York	Somerset 2	1200	Somerset, NY
Deregulated	New York	Sterling	1150	Sterling NY
Deregulated	New York	Verplanck 1	1115	Verplanck NY
Deregulated	New York	Verplanck 2	1115	Verplanck NY
Deregulated	Ohio	Davis-Besse 2	906	Oak Harbor OH
Deregulated	Ohio	Davis-Besse 3	906	Oak Harbor OH
Deregulated	Ohio	Erie 1	1267	Berlin Heights OH
Deregulated	Ohio	Erie 2	1267	Berlin Heights OH
Deregulated	Ohio	Perry 2	1205	35 miles NE of Cleveland, OH
Deregulated	Ohio	Zimmer 1	810	Moscow OH
Deregulated	Ohio	Zimmer 2	1170	Moscow OH
Deregulated	Pennsylvania	Fulton 1	1160	17 miles S of Lancaster, PA
Deregulated	Pennsylvania	Fulton 2	1160	17 miles S of Lancaster, PA
Deregulated	Illinois	Carroll County 1	1120	Savanna IL
Deregulated	Illinois	Carroll County 2	1120	Savanna IL
Deregulated	Illinois	Clinton 2	950	Clinton IL
Deregulated	Massachusetts	Montague 1	1150	1.2 miles SSE of Turners Falls, MA
Deregulated	Massachusetts	Montague 2	1150	1.2 miles SSE of Turners Falls, MA
Deregulated	Massachusetts	Pilgrim 2	1150	4 miles SE of Plymouth, MA
Deregulated	Maine	Sears Isle	1150	Sears Isle, ME
Deregulated	Michigan	Fermi 3	1171	Lagoona Beach , MI
Deregulated	Michigan	Greenwood 2	1264	St Clair County MI
Deregulated	Michigan	Greenwood 3	1264	St Clair County MI

Market Structure	State	Plant	Capacity	Location
Deregulated	Michigan	Midland 1	492	S of City of Midland, MI
Deregulated	Michigan	Midland 2	818	S of City of Midland, MI
Deregulated	Michigan	Quanicassee 1	1150	6 miles E of Essexville, MI
Deregulated	Michigan	Quanicassee 2	1150	6 miles E of Essexville, MI
Deregulated	New Hampshire	Seabrook 2	1198	Seabrook, NH
Deregulated	New Jersey	Atlantic 1	1150	Great Bay NJ
Deregulated	New Jersey	Atlantic 2	1150	Great Bay NJ
Deregulated	New Jersey	Atlantic 3	1150	Great Bay NJ
Deregulated	New Jersey	Atlantic 4	1150	Great Bay NJ
Deregulated	New Jersey	Forked River 1	1070	Forked River NJ
Deregulated	Rhode Island	New England 1	1150	8.5 miles E of Westerly, RI
Deregulated	Rhode Island	New England 2	1150	8.5 miles E of Westerly, RI

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Appendix D. Nuclear Power Plant Construction Cost Comparison