Benefits and Risks of Nuclear Power in California

By Roger Dunstan

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About the Author

Roger Dunstan is an Assistant Director for the California Research Bureau.

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Content

EXECUTIVE SUMMARY

As a result of California's electricity crisis during 2001, policy makers recognize that maintaining a reliable supply of energy at a reasonable cost is by no means an easy task. The task will be made harder as forecasts expect California's population to grow by six million by 2012. Electricity consumption will jump by an estimated 60,000 gigawatt hours as a result.

Nuclear power was very helpful to the state during the recent electricity crisis. Four operating reactors at two nuclear power plants produce approximately 18 percent of California's power. Given the dearth of in-state supplies of natural gas and coal, the volatile price of natural gas imported from out of state, and the expense of alternative energy sources, the media, industry analysts, and some legislators have broached the idea of building additional nuclear power plants.

This report outlines the benefits and risks associated with the production of nuclear power in California. The purpose is to provide policy makers with information necessary to determine whether additional nuclear power plants can help supply Californians with a reliable and safe supply of energy at a reasonable cost.

BENEFITS

Reduction in Air Pollution. Californians are clearly concerned with poor air quality, which is associated with a number of health problems and with global climate change. Nuclear power can also be part of a strategy to address carbon emissions. Nuclear power plants emit no carbon dioxide, sulfur dioxide, or nitrous oxides. A recent article in *Science* stated that one way to hold world carbon dioxide emissions constant given expected population growth of three billion people, is to increase nuclear energy production tenfold. The European Commission released a report that Europe would need at least 85 new plants to meet the emission targets outlined in the Kyoto Protocol to reduce global warming.

Price Stability. Since nuclear technology was first introduced in the 1950s, the cost of producing electricity from nuclear power (not including construction costs) has remained relatively constant, unlike prices of natural gas and petroleum. During this period, the industry has quietly found ways to improve plant performance, reduce operating costs, and increase capacity utilization.

Improved Safety. According to the U.S. Department of Energy, the number of events at nuclear power plants that trigger any of a multitude of safety systems have dropped from 2.37 in 1985 to .03 in 2000. In addition, recent research shows that the frequency of accidents and the number of deaths from nuclear power production is less than for energy production from coal, oil, natural gas, or hydropower.

Reduced Reliance on Energy Imports. Increased reliance on nuclear power in the United States means a reduced reliance on oil imported from other countries. Some countries even use nuclear power out of necessity because they do not have adequate domestic supplies of fossil fuels. France, Japan, and India have already followed this strategy.

Improved Fuel Reprocessing. Reprocessing nuclear fuel reduces the waste that must be disposed to three per cent of its original amount. If nuclear fuel is reprocessed, the radioactivity declines to that of coal ash in 400 years. The United Kingdom, Germany, Japan, and France all reprocess spent fuel. The U.S. does not currently reprocess fuel because of nuclear proliferation concerns. Reprocessing separates out plutonium from the waste, although it is not the optimal type for use in nuclear weapons.

Diversified Energy Supply. Approximately 95% of all power plants constructed or permitted in California in the last ten years are fired by natural gas. Since California imports most of its natural gas, fluctuations in the price can dramatically impact the ability of utilities to provide energy at a reasonable cost. The stability of the price of nuclear power could help to ensure that energy is always provided at a reasonable cost.

RISKS

Lack of Plan to Store Waste. According to the Natural Research Council, the growing volume of nuclear waste stored on-site at nuclear power plants requires attention. The Council reports, however, that both geologic disposal and monitored storage on or near the earth's surface are safe and feasible storage options. However, the federal government has spent billions of dollars studying Yucca Mountain in Nevada as a potential place to store nuclear waste, but opposition and technical problems have delayed the project. A recent General Accounting Office report concludes that there are substantial barriers to timely development of the site.

Risk of Catastrophe. The accidents at Three Mile Island in New York and Chernobyl in Russia confirmed the long-festering fear of many Americans that nuclear power was not a safe source of energy. As a result of these two accidents, utilities cancelled a number of proposed and partially constructed nuclear generating stations. Since that time, industry and government has worked to improve safety and reduce the risk of accident, but many still fear a catastrophe. These fears have only grown in the wake of the September 11 terrorist attack on the United States.

Lack of Public Support. Although recent polls in the U.S. have shown that a majority of the public supports an increase in nuclear power production, such numbers are highly uncertain. Many countries are struggling with the decision to decommission their existing plants, maintain existing plants, or build new plants. Italy, Sweden, and Germany all have, or will, shut down all their nuclear power plants. China, on the other hand, plans to build 50 nuclear power plants by 2020. France produces almost 80 percent of its energy from nuclear power and Finland, Japan, and Canada expect to expand their nuclear power production.

Cost. While the cost of producing a megawatt of electricity from an existing nuclear power plant is generally less than or equal to the cost of producing a megawatt of power from natural gas or coal, such estimates do not include construction, decommissioning, and insurance costs. The industry also has the benefit of federal government subsidies for research and insurance. Industry claims they can build new plants that will be competitive, but these claims have not been tested in the market.

I. OVERVIEW OF NUCLEAR POWER

To gain acceptance, nuclear power had to overcome its own unpromising economics and utilities' resistance to a new technology with uncertain impacts. Supporters of nuclear power saw it as a means of increasing the nation's stature and prestige in much the same way as the space program.[1] The federal government won over utilities with subsidies and a government-sponsored insurance mechanism. Utilities were also influenced with favorable forecasts of the low cost of producing electricity, although these forecasts benefited greatly from assumptions about future scale economies and cost reductions from greater experience.[2] A different view of safety regulation helped the economics. Nuclear proponents did not ignore safety considerations, but they did not place the same emphasis as they would today. The result of these factors was that nuclear power grew significantly and produced power at a competitive price, at least in its early days.

Nuclear power's success was short-lived and it suffered a near deathblow from the combination of several events. The first event occurred when the Organization of Petroleum Exporting Countries hiked oil prices in 1973. In the short run, higher oil prices gave a tremendous boost to nuclear power. However, this assistance was transitory as higher energy prices led to increased efficiency and conservation, reduced consumption, and a host of competing industries and technologies. The woes of the nuclear industry mounted when the reactor at Three Mile Island in Pennsylvania melted down. In the aftermath, utilities canceled a number of proposed and partially constructed nuclear generating stations. In the United States, nuclear power's fate was sealed when the Chernobyl nuclear reactor in the Ukraine caught fire and spewed radiation across a good part of Europe.

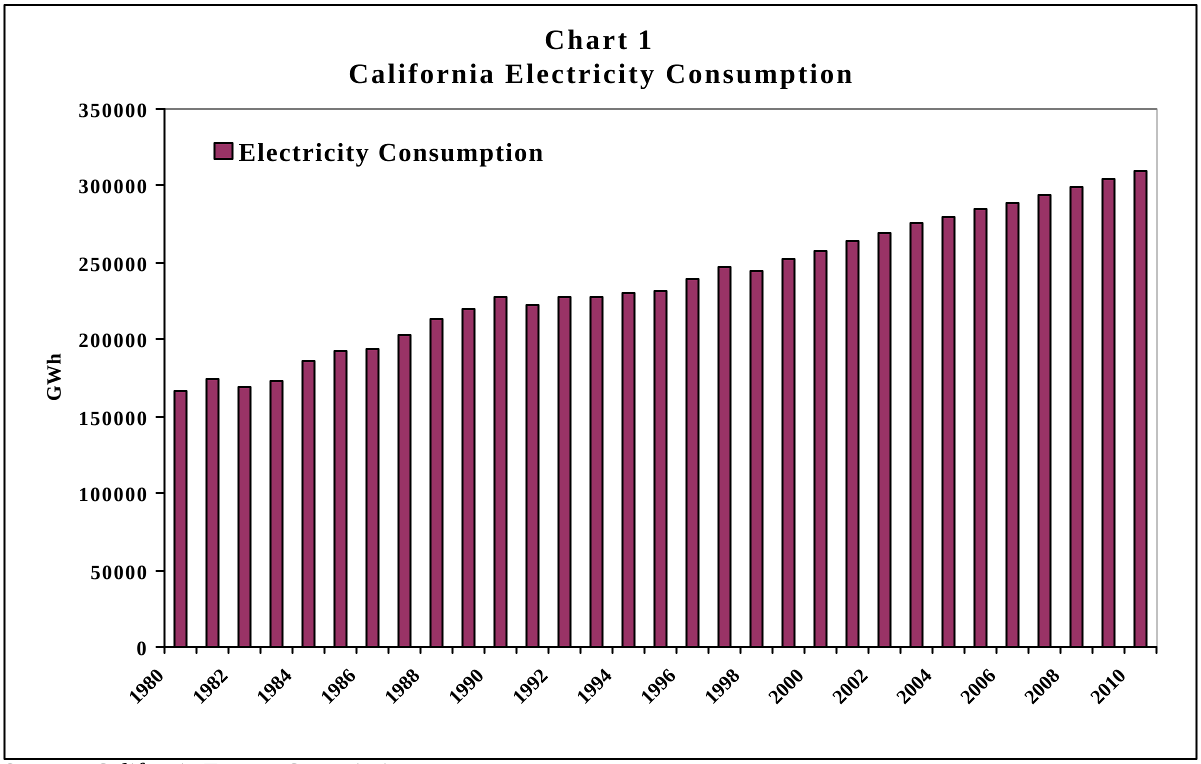
Despite these blows, industry analysts are talking about a resurgence for nuclear power. Nuclear power plants are a reliable and cheap source of electricity (if you don't count the cost of building the plant) in California and much of the rest of the country. Industry is hoping that engineers will be successful in developing an "inherently safe" reactor.[*]

Pollsters are finding signs that the public's attitudes are shifting under the threat of sky-high electricity prices and rolling blackouts. One recent statewide poll showed that 59 percent of those surveyed supported building new nuclear power plants in the state.[3] Thirty-six percent opposed the idea. This level of support almost matches the approval rating that nuclear power received during the 1950s.[4] The results are a reversal of a 1984 poll when a two to one majority disapproved of new nuclear power plants.

An industry group, the Nuclear Energy Institute, has formed a task force of manufacturers, contractors, and utilities to explore reviving nuclear power.[5] In particular, they are looking at how regulators might license new nuclear generating technologies. The President buoyed their hopes when the administration released the President's National Energy Policy. The plan treats nuclear favorably.

[*] "Inherently safe" reactors are described that way because they do not require active intervention and controls to maintain safe generation; rather, they rely on physical laws to maintain their safety.

California’s electricity problems and forecasts of rapidly increasing demand have also raised the hopes of proponents. The accompanying chart shows the growth over the last twenty years as well as the forecast for California.



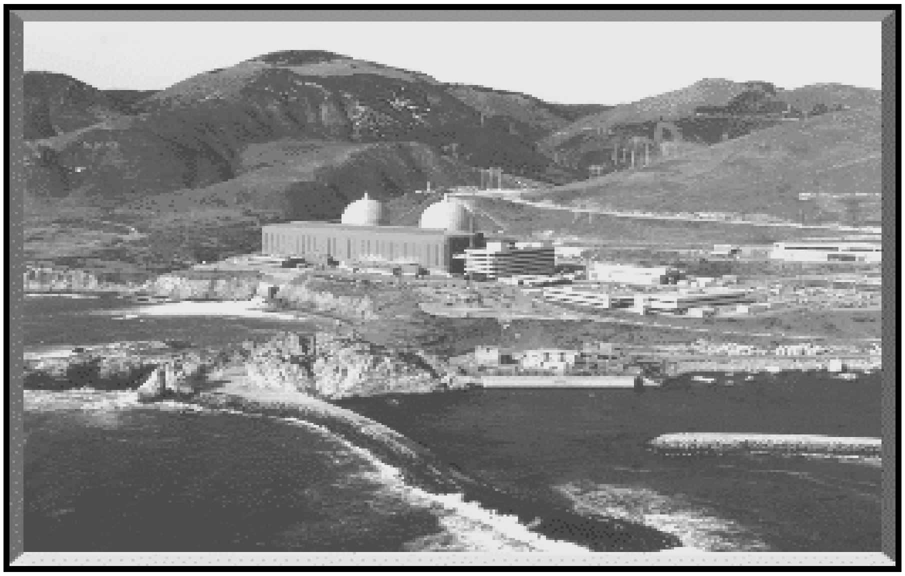
Source: California Energy Commission
Note: GWh means Gigawatt hours

BRIEF HISTORY OF NUCLEAR POWER IN CALIFORNIA

After the war, scientists proposed generating electricity from nuclear power. It was not until Congress enacted the Atomic Energy Act of 1954 that the civilian industry was ready for growth. That same year, researchers began operating the first civilian prototype nuclear generating station.

At the time, nuclear power seemed particularly important for California. As the state grew, it was running out of options for generating its own electricity. Relatively few additional sites for hydropower were going to be developed. Competition for out of state hydropower sources was increasing, especially from a rapidly growing Arizona. California's oil and natural gas production was declining. The state could rely on imported petroleum, but that raised energy security questions. California did not have its own source of coal and it was very expensive to haul it into the state. Nuclear fuel, unlike coal, is compact, hence the cost of transporting the fuel for civilian reactors was insignificant.

Diablo Canyon Nuclear Generating Station

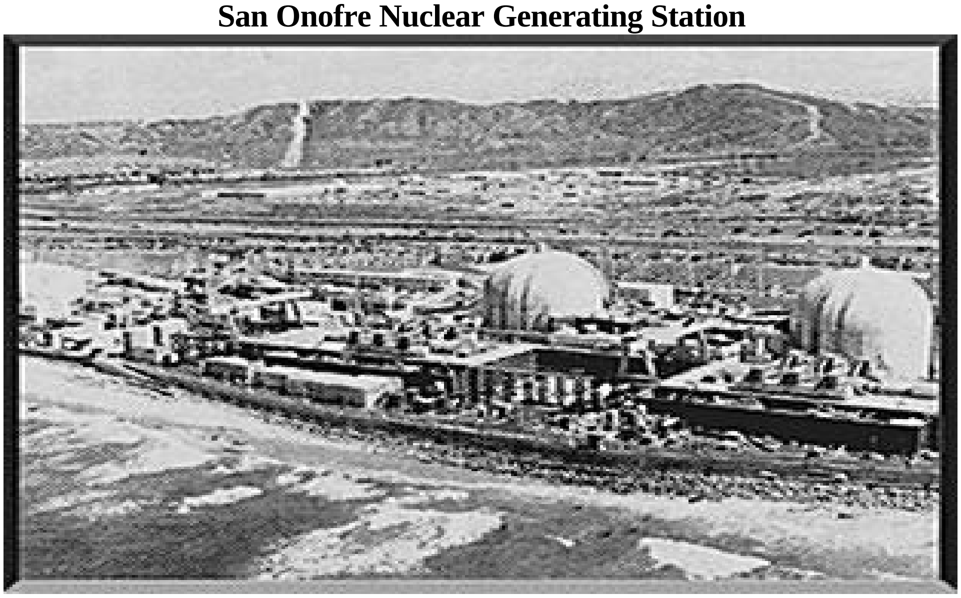


Source: Nuclear Regulatory Commission

The Atomic Energy Commission (AEC), the federal regulator and promoter of nuclear power, awarded one of the first large-scale reactor demonstration projects to PG&E. In 1959, the Public Utilities Commission (PUC) gave approval for this nuclear power plant, which PG&E built at Humboldt Bay.

The prospects of additional power plants led to the first controversies over nuclear power. The opposition began because opponents objected to the locations of the plants, although they eventually expressed safety concerns. Citizen protests halted PG&E's planned reactor at Bodega Bay over concerns about development in a scenic area and near an earthquake fault.

San Onofre Nuclear Generating Station



Source: Nuclear Regulatory Commission

By the early 1970s, California was facing a potential shortfall of electricity. The Assembly launched a special committee to look into the electricity quandary and hired Rand Corporation to study this issue. Rand prepared an analysis that saw 90,000 megawatts (MW) of nuclear energy by 2000, or about 90 plants, even though the state only had about 500 MW of installed nuclear plant capacity at the time.[6] Concerned that local governments would not issue permits for these plants led the Legislature in 1975 to establish the California Energy Commission and charged it with expediting the permitting of all power plants.

Controversies over nuclear power continued to grow. In 1976, the public qualified an anti-nuclear initiative, Proposition 15, on the ballot. The measure would have placed significant restrictions on the development and operation of nuclear power.

In an attempt to head of Proposition 15, the Legislature passed three statutes that Governor Edmund G. Brown Jr. signed into law.[7] As with the creation of the Energy Commission, the Legislature passed these bills with the support of a coalition of environmentalist and pro-nuclear members. These three statutes required the Energy Commission to study alternative designs, ensure that there was an ability to dispose of nuclear waste, and that there was fuel rod reprocessing. The statutes did allow exemptions for projects that were underway. The voters eventually voted down Proposition 15 by a two-to-one margin.

San Diego Gas and Electric's proposed Sun Desert nuclear power plant was the first nuclear power plant proposal to face these new laws. The Energy Commission soon angered many with its refusal to grant a license for the construction of the plant.[†] The commission noted that utilities themselves were in the process of scaling down their needs for the future in the face of slowing demand growth.[8]

At least some of California voters did eventually speak against nuclear power. In 1989, voters of the Sacramento Municipal Utilities District passed a measure that shut down the Rancho Seco nuclear generating station.

Nuclear Power in California

Nuclear supplies about 18 percent of the state's electricity, trailing natural gas and hydroelectric. There are four plants operating within the state.

[†] With the benefit of hindsight, this decision is widely credited with saving San Diego ratepayers several billion dollars, at least before the increase in electricity prices that began in the summer of 2000.

Table 1
California Nuclear Reactors

Name	Capacity Factor	Began Commercial Operations	Megawatts
Diablo Canyon 1	87	5/85	1073
Diablo Canyon 2	93	3/86	1087
San Onofre 2	71	8/83	1070
San Onofre 3	72	4/84	1080

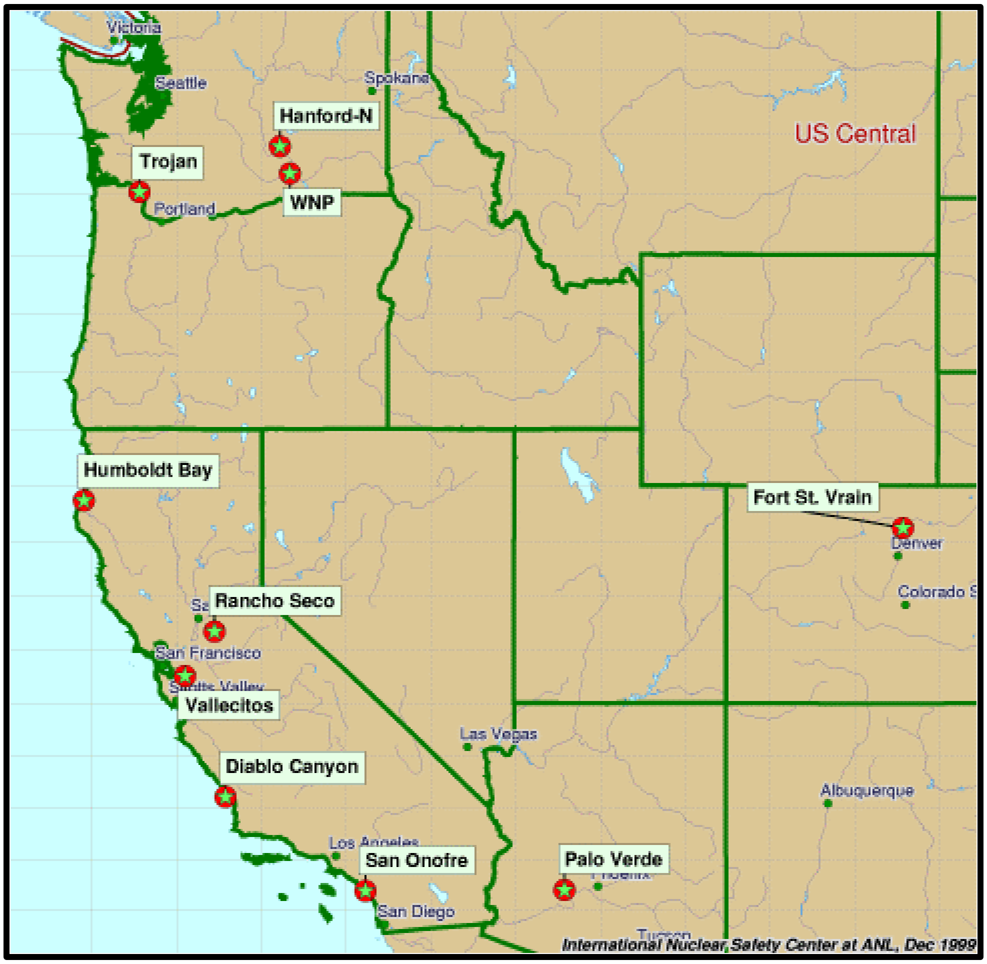
Source: Nuclear Regulatory Commission
Note: Capacity factor is the percentage of total possible output that the plant actually produces.

California's nuclear power plants have consistently operated above the national average in terms of their capacity factor.[9] Diablo Canyon and San Onofre are the two largest power plants in the state although there are two gas-powered plants that are almost as large.

The state also imports power generated at Palo Verde, a nuclear generating station in Arizona. This plant has run above 90 percent of its capacity for the last several years, topping both the nation's average and those of California's plants. Palo Verde consists of three nuclear reactors each rated at 1270 megawatts. At various point, California utilities, including Southern California Edison, had a stake in this facility.

The following map shows the nuclear power plants in the other western states. For California, the map includes the research reactor at Vallecitos, the decommissioned Rancho Seco plant, and the shut down Humboldt Bay and San Onofre 1 plants.

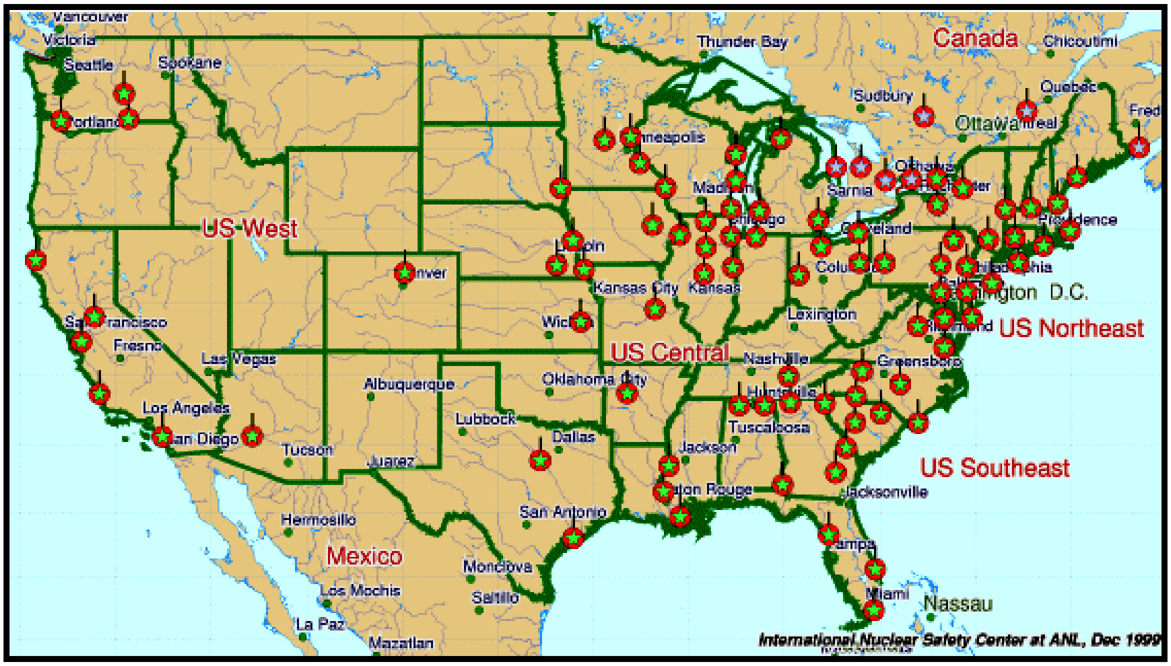
Map 1
Nuclear Reactors in the Western United States



Source: International Nuclear Safety Center

The following map shows reactors throughout the United States.

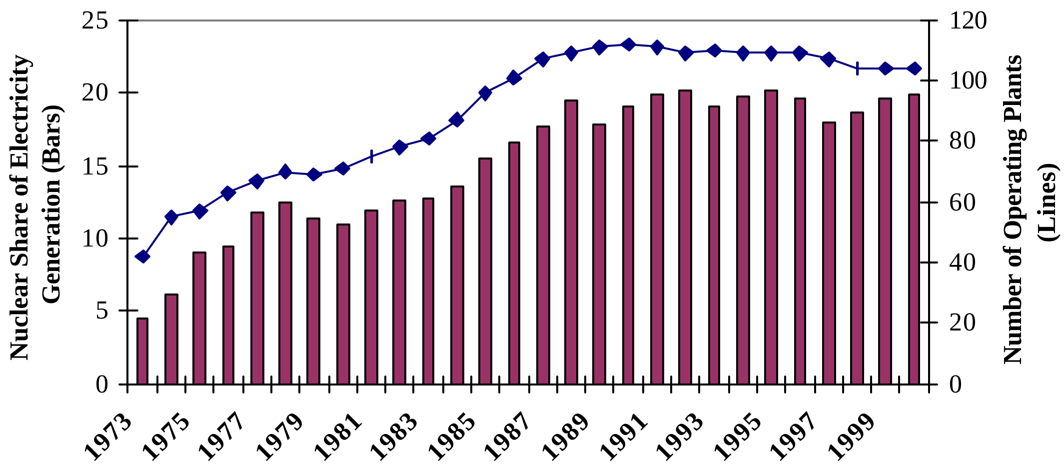
Map 2
Nuclear Reactors in the United States



Source: International Nuclear Safety Center

As the following chart shows, nuclear power has grown steadily as a source of electricity generation in the United States. The total number of power plants, the line in the chart, topped out in the early 90s as some plants subsequently closed. The proportion of all electricity produced from nuclear plants, the bars, has stayed relatively constant since the late 1980s.

Chart 2
U.S. Nuclear Electricity Generation



Source: Energy Information Agency, Department of Energy

Brief Description of a Nuclear Power Plant: Two facts are important to understand material in the rest of the report. (See Appendix A for a more detailed discussion and a diagram of a nuclear power plant.)

- Nuclear power works because a uranium atom will split in two and release a large amount of energy in the form of heat. It splits when bombarded by a neutron from a decaying radioactive element. The process is called fission.
- Radioactive uranium decays naturally, throwing off neutrons that lead to fission and additional splitting of atoms. The splitting also releases radiation.

The uranium must be processed, or enriched, to reactor grade for use in a nuclear power plant. The enriched uranium contains more of the radioactive portion of uranium. The reactor core is where fission splits the uranium, thereby generating heat, which is used to boil water and create steam. The steam then turns a turbine, generating electricity. Water surrounds the fuel and neutron-absorbing control rods and helps controls the chain reaction. The control rods are critically important as they absorb neutrons and slow down the pace of fission. The reactor vessel is also flooded with water, which acts as a coolant and a moderator, meaning it moderates the reaction by absorbing neutrons.

Although usually only uranium is loaded into the reactor we are describing here, fission soon produces plutonium. Plutonium is a man-made radioactive element. That plutonium is useful in place for fuel, about one-third of the energy produced by a nuclear reactor comes from fission of the created plutonium.

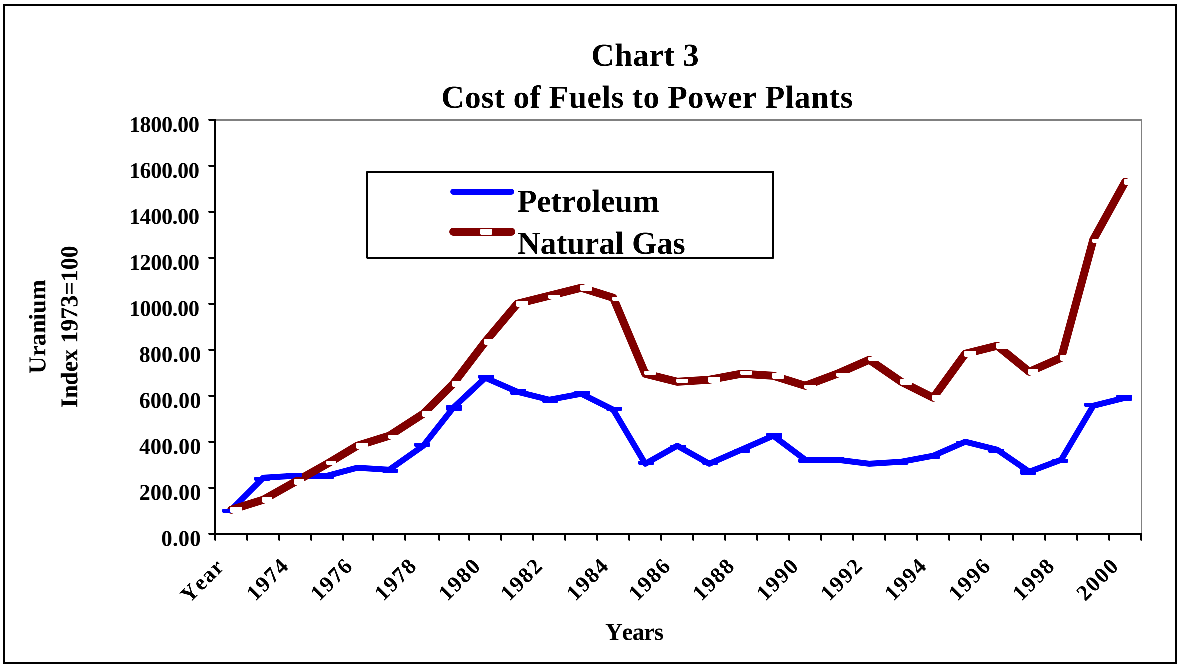
II. NUCLEAR POWER INDUSTRY

U.S. nuclear power industry is the largest in the world with 104 operating plants. The last new plant opened in 1996, twenty-six years after the utility ordered the plant. The industry is composed of many operators, although the number is shrinking with consolidations. The largest single operator in the world is Electricité de France, the French national utility with 59 plants.

Nuclear power industry officials are now optimistic about the future of nuclear power. One executive has called the current situation, a "… renaissance of nuclear power."[10] This optimism comes fast on the heels of what appeared to be a depressed time for the industry. Utilities closed six reactors since 1996, leading some industry critics to forecast the decline of the industry as a whole, especially with the advent of a competitive electricity market. Many analysts thought that nuclear power would be uncompetitive and that market forces would force plant closures.[11] Others argued that these plant closures did not reflect conditions in the overall industry, but were poor-performing plants that required significant investment.[12]

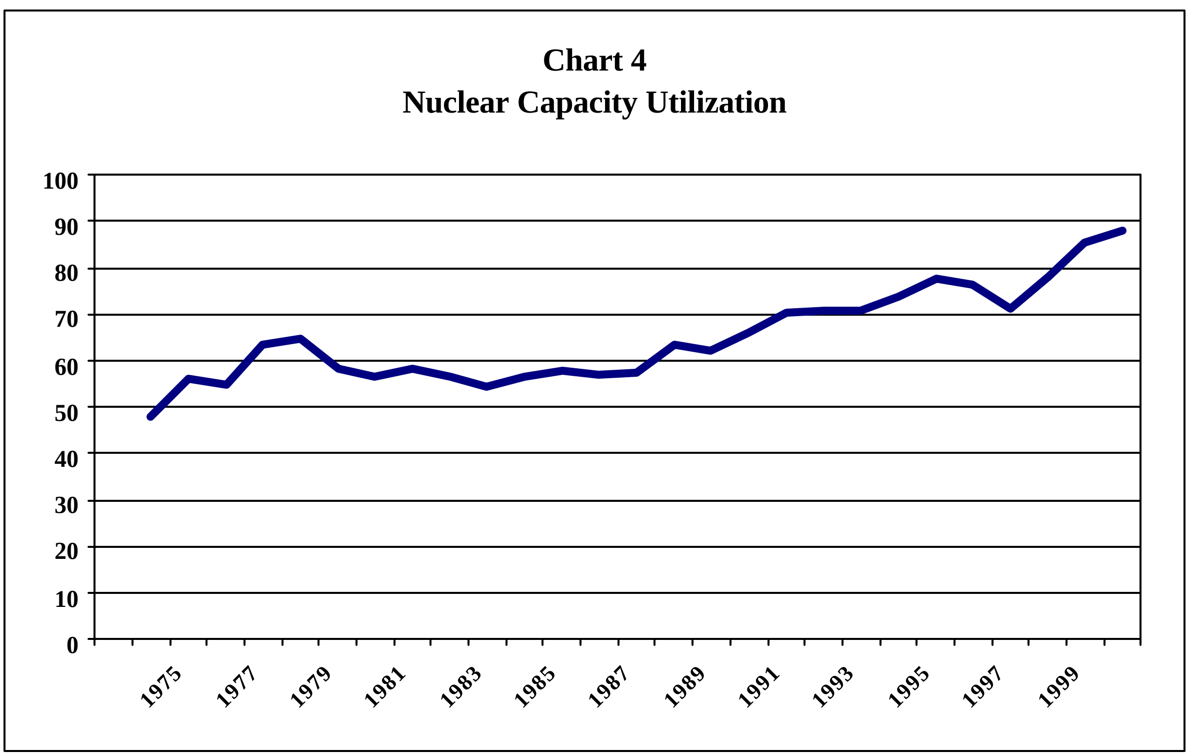
Representatives of the industry credit the optimism to these trends.[13]

- Operators have made significant improvements in the performance of these plants. The industry operating at 65 percent of capacity in the early 1980s is now at 89 percent and some operators are attaining mid-90 percent capacity rating factors.
- Nuclear power is currently the lowest priced power in the United States if only operating expenses are counted. Part of the reason for the low cost is that the nuclear fuel prices, in contrast to natural gas and petroleum has been relatively stable. Natural gas prices more than doubled in the last couple of years and have significantly affected electricity prices.
- Emissions of gases that contribute to global climate change are much lower for nuclear power than other fuels such as coal and natural gas.
- Operators have significantly increased the capacity of their plants. "Uprates" as they are called have totaled 2500 megawatts (MWs) since 1977 and over 300 MW in the first half of 2001.



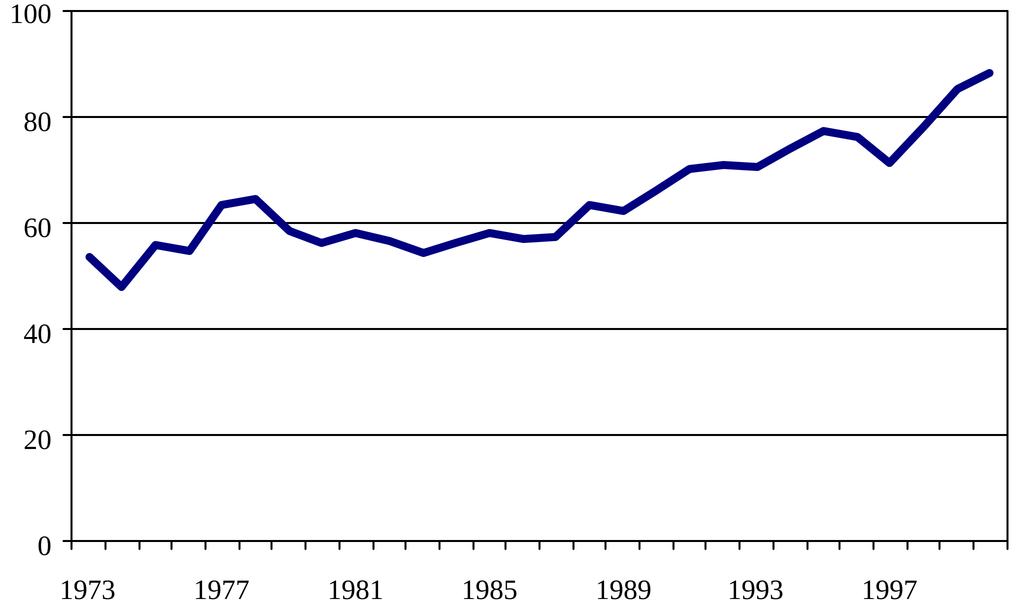
Source: Energy Information Administration, Department of Energy

The following chart showing improved capacity utilization details some of the improvements in the industry. Plant operators have been able to greatly improve plant performance and increase capacity utilization.



Source: Energy Information Administration, Department of Energy

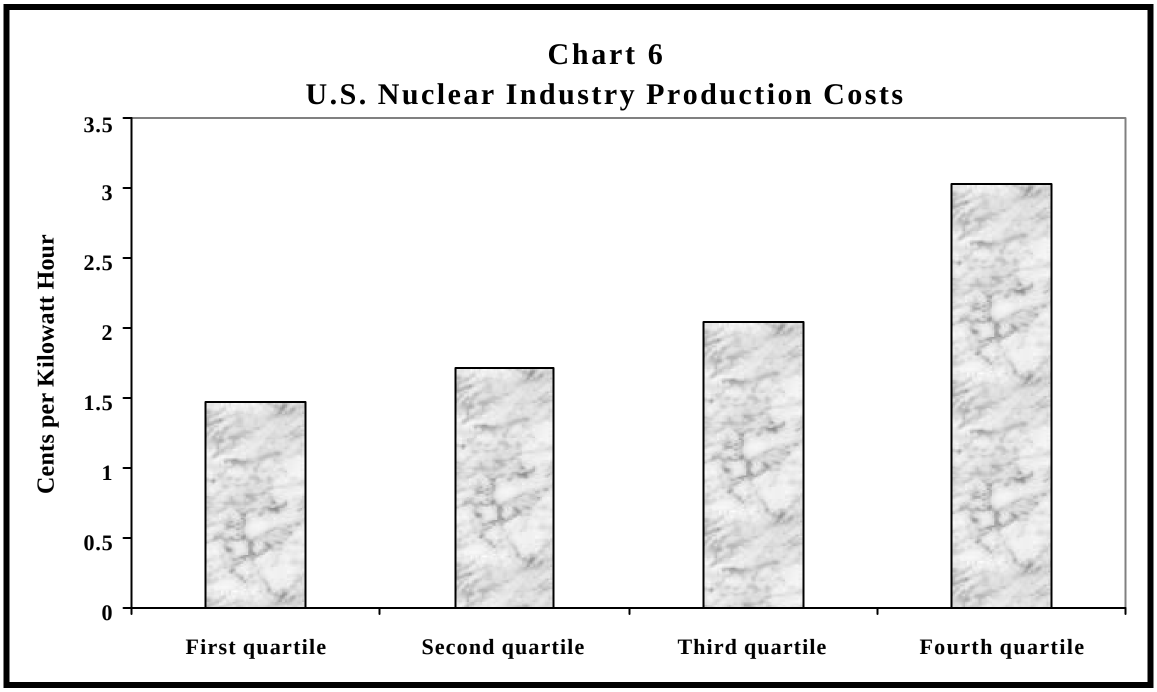
Chart 5
Capacity Utilization



Source: Energy Information Administration, U.S. Department of Energy

Industry officials also point to the decline in the number of “events” as further proof of improved operations. An event triggers any of the multitude of safety systems. The number of events has dropped from 2.37 in 1985 to .03 in 2000.[14]

Despite these overall trends of improved operation and maintenance, the industry’s performance varies significantly. The following chart divides the production costs (operation and maintenance only) among four groups of nuclear plant operators. The costs for the most expensive producers are more than twice that of the cheapest.



Source: Nuclear Energy Institute

Deregulation is changing the structure of the utility industry and the nuclear industry is changing with it. The utilities are becoming larger companies as they merge or acquire other companies. Some utilities are divesting energy-generating assets and new companies are entering the electricity market as generators. The latter generate power and sell to distributors, often the investor-owned utilities. Some of these generators own nuclear power plants.

Utilities are realizing that there are economies of scale operating in nuclear power and those companies owning one or two plants are selling them. There have been 14 sales since 1998 and the prices appear to have jumped.[‡] The most recent prices have been ten times higher than sales of just several years ago. Five years ago, 46 companies were operating the 103 nuclear plants in the country. This year the number of operators dropped to 24. With the concentration of ownership increasing, those companies owning nuclear power plants have holdings throughout the nation and even elsewhere in the world. Five operators own half the nuclear generating capacity in the United States.

Originally, federal regulators licensed nuclear power plants for 40 years. The current average plant age is about 18 years, but some plants have reached the end of their license. The Nuclear Regulatory Commission (NRC) re-licensed its first plant March 2000 and more extensions have been granted or are pending. Most industry observers predict that the NRC will extend many of these existing licenses, as plants are more durable than proponents originally envisioned.

‡ It is difficult to generalize with complete certainty as the plant quality may differ, the amount of transferred fuel varies, etc.

INTERNATIONAL DEVELOPMENTS

Thirty-two countries operate nuclear reactors. Another four nations, Egypt, Indonesia, Iran, and North Korea, are poised to join the nuclear power club once they complete reactors in the planning or construction stage. Nuclear power is doing well in third world countries, especially in Asia. The Department of Energy expects the developing world to double its nuclear generation capacity within the next 20 years.

Within the industrialized world, the outlook is different.[15] Analysts forecast that only Finland, France, Japan, and Canada will expand or even maintain their current levels of nuclear generating capacity.[16] In Europe, most countries are planning to eliminate or reduce nuclear power. These actions are a combination of the continuing concern about the affects of nuclear power combined with relatively new finds of natural gas, especially in those countries bordering the North Sea. Ironically, European countries are acting with caution at a time when the European Commission issued a report recommending European utilities build least 85 new nuclear plants to meet the Kyoto protocol.[17]

A number of countries never allowed nuclear plants or opted to shut down their industry. These include Ireland, Sweden (dismantle existing plants), Philippines (dismantle existing plant), Australia, Luxembourg, New Zealand, Denmark, Austria, and Greece.[18] Some of these countries acted in the wake of the Chernobyl accident, but others had already announced their opposition to nuclear power. For example, Austria banned nuclear power in 1978.

Following is a partial listing of important developments in nuclear power throughout the world. Appendix B contains a complete listing of the status of reactors throughout the world.

Canada: One of the world's nuclear pioneers, because of the nation's role in developing the first atomic weapon and its use of nuclear power. Canada has 14 operating plants and an additional six mothballed plants are being brought back into service.

China: The country brought its first nuclear plant on-line in 1991. The country's priority is developing hydropower with thermal power a lower priority. However, China sees a role for nuclear power in the energy-deficient coastal provinces with no domestic fossil fuels and little hydropower potential. The country is planning for as many as 50 nuclear power plants by 2020.

Finland: Unlike countries such as the United Kingdom, Norway, or the Netherlands, Finland is not one of the energy-rich countries of Europe. They are seriously planning for the construction of a new plant to augment the country's existing five plants. The government has adopted this plan as the only reasonable way the country can meet its obligations under the Kyoto Protocol carbon reduction goals.[19]

France: France has pursued a vigorous pro-nuclear policy since the mid-70s, shortly after the OPEC-induced oil price shock. The country's 59 units give France the second most nuclear power plants after the United States. Nuclear power produces a greater share of electricity than in any other major country, 76 percent.

There is a widespread debate over why nuclear power has been so successful in France. A Ministry of Industry official cited three reasons.[20]

- The traditional independence of the French and the concerns about being dependent on the unsettled Middle East for energy sources. France had fought and lost a long bitter war for Algerian independence less than 15 years before the first oil embargo. They did not view themselves as having an alternative to nuclear power if they were to increase energy independence.
- France has a tradition and culture of large centrally managed technological projects.
- French authorities have worked hard at advertising the benefits and risks of nuclear energy.

Nuclear industry critics, including Ralph Nader, put an alternative view about France's adoption of nuclear power forth. He views France as a closed society:

> "When it comes to nuclear reactors they might as well be a totalitarian society. They're as closed on nuclear power as the Soviet Union was."[21]

The French example is widely praised by industry observers cited for their standardized approach with one company responsible for all operations. That structure allowed mistakes and lessons to be quickly transmitted throughout the corporate entity. They used, with some exceptions, one basic design. France has been recycling their waste, to both get new fuel and reduce the quantities of waste requiring disposal.

Nuclear power was not universally popular in France.[22] The utility met enormous resistance when the policy was first announced. Death threats, bombings, and vandalism all occurred, although that eventually slackened. More recently, there are reports of waning popularity.[23] A recent poll showed reduced public support and the government has started talking about reducing dependence on nuclear energy, although certainly not ending their support of nuclear power. The reduced public acceptance follows several mishaps and problems, including the government's shut down of the expensive and troubled breeder reactor, the release of a study that showed higher than average leukemia rates around the fuel reprocessing plant, and the government's charging the reprocesser with illegally storing nuclear waste.

France is not planning or constructing any new units. Around 2010 the oldest plants are slated to be shut down and the government will have to decide how to replace the power they produce.

Germany: After several years of controversy and negotiation, Chancellor Schroeder has agreed to shut down the country's 19 nuclear power plants over a 20-year period. These reactors provide 35 percent of the nation's electricity.

Italy: Italian voters approved a non-nuclear policy in 1987 in the wake of the Chernobyl accident. Italy's last plant was shut down in 1990.

India:[24] They also have an ambitious civilian nuclear electricity generating industry. Their interest in nuclear has been fanned by their large geographic size and few domestic energy resources, save for hydropower and coal, both of which are geographically limited. While they have a large number of reactors, their energy policy is to have a mix of various sources including renewable and non-conventional. The country is also very interested in pursuing thorium as a reactor fuel due to their large domestic deposits. The country is pursuing nuclear power for energy security looking at both the current energy environment and to ensure that if in the future prices go up they will have the technology and infrastructure to expand their nuclear power.

India used a research reactor to join the club of nations with nuclear weapons.

Indonesia: Despite the country's large petroleum reserves, Indonesia, like some other oil producing countries, wants to maximize oil export revenues. Hence, they want alternatives to petroleum for electricity generation. They are developing their first reactor.

Japan: The country launched its ambitious nuclear program shortly after the end of World War II. They wanted to increase their energy security, an important issue for Japan as a country that started and lost one war, at least in part, because of their energy security concerns. Japan's ambitious program is third only to France and the United States with 53 reactors.

The program has been dogged by accidents lately. A fire occurred at a prototype reactor in 1995. Later, a reactor was shut down as a precaution in the wake of a strong earthquake. No damage occurred. In 1999, an accident at a reprocessing plant killed two plant workers and exposed almost 500 people, including those outside of the plant to radiation. In light of the incident, the government abandoned plans to build 16 to 20 new reactors.

Despite the recent problems, the government remains committed to nuclear power for energy security as well as concerns about global warming.[25] The government rejected increased use of renewable energy sources, chiefly solar, because of the poor economics and potentially large land impacts. As a densely populated island nation, the government finds the low volume of wastes produced by nuclear power attractive and they are trying to find a long-term disposal option. Although strongly committed to nonproliferation of nuclear weapons, Japan does use fuel-recycling technology.

Republic of Korea: This country has one of the most ambitious programs with 16 units operating, four under construction, and another eight reactors planned.

Mexico: Mexico has two nuclear power plants, both in the southern part of the country.

Netherlands: The Dutch are in the process of shutting down their two plants by 2004.

Pakistan: Like India, Pakistan has acquired nuclear weapons. Also like India, the lack of indigenous energy resources, save for hydropower, is pushing their plans for nuclear power. They have long-term plans for additional plants.

Russia:[26] Avowedly nuclear, Russia just announced plans for a second breeder reactor to be built. The country has 30 operating plants, including some of the same design as the Chernobyl plant.

Spain: This is another of the western European countries that has a moratorium on the construction of new plants. The country has plans to shut down their nine existing plants within the next ten years.

Sweden: After a referendum against nuclear power passed in 1980, the government eventually shut down its first nuclear power plant in 1999. The parliament voted to shut two units, one of which will be shut down only if it can be replaced with sufficient capacity from renewables or electricity conservation. As of June 2001, there are 11 reactors operating in the country.

Taiwan: This country continues to build plants to increase the diversity of their electricity mix.

Turkey: The country recently cancelled a plant that was under development. Instead government decided to focus on energy conservation and invest in natural gas, hydro, solar, and wind. The decision was made in part because of the country's austerity measures. There was also strong opposition to the planned plant, based in part on seismic concern.

United Kingdom: Thirty-three plants generate over 20 percent of the country's electricity requirements. However, no new plants are planned. Analysts expect the amount of generating capacity is expected to shrink significantly as older plants are decommissioned. During the last 25 years, this country has had a remarkable change in energy fortunes with the development of significant quantities of oil and natural gas in the North Sea. This country's ready access to fossil fuels has hurt the economics of nuclear power.

Ukraine: There are 13 operating plants in the country.[27] The industry is marred by unpaid bills and continued problems of forced shut downs to maintain the plants. The Ukraine has expressed willingness to close down Chernobyl, but it claims it needs help from the developed world.[§] The country plans to build two new reactors to replace the closed Chernobyl. The country's only indigenous source of energy is coal.

[§] Although the plant involved in the Chernobyl accident is shut down there are other reactors at the site.

III. HEALTH AND SAFETY

One observer, an advocate of nuclear power, made the following observation:[28]

> "Fifteen years have passed since I first alluded to nuclear energy as a Faustian bargain: humans, in opting for nuclear energy, must pay the price of extraordinary technical vigilance for the energy they derive from nuclear fission if they are to avoid serious trouble."

Using nuclear power presents some risks. Risk can be thought of as the possibility of a consequence multiplied by the likelihood of such an incident occurring. In risk analysis, mere analysis of the consequences is misleading. Since we know that airplanes crash, why would we ever fly? The reason is that we also consider the likelihood of such an event actually occurring. Operating nuclear generating stations could lead to some potentially very severe consequences. The chances of these events occurring are low; hence the probability greatly affects the risk.

RADIATION—GENERAL

Radiation is simply defined as energy traveling through space. It is truly everywhere, as sunlight is composed of radiation. Beyond the ultraviolet radiation in sunlight, there are high-energy types of radiation to which we are regularly exposed through medical x-rays or natural sources. Much of our natural exposure can come from radon gas, which seeps from the earth's crust and mixes with the air we breath.

High-energy forms of radiation can cause damage to living tissues. There are several types of radiation with different biological effects. For example, ingesting alpha particles is quite dangerous, but unbroken skin is sufficient to protect a person from them. Large doses of certain types of radiation can cause illness and death within days. However, there are doses that can cause no immediate noticeable harmful effects, but can lead to greatly increased risks of cancers in the future. Manmade radiation is no more or less toxic than natural, but it increases the amount of radiation over the natural background level.

Radiation has two types of health effects, somatic and genetic. At high doses, the somatic injuries that occur usually occur quite quickly usually within hours, a day, or at most weeks. Chronic low-level exposure may lead to similar effects, but over many years. Acute exposure to radiation can lead to death within a few days or weeks. Smaller doses can cause burns, loss of hair, nausea, loss of fertility and pronounced changes in the blood, cancer, congenital abnormalities, and genetic defects.[29] The human body has some ability to repair itself from exposure to radiation.

The normal operation of nuclear power does release radiation. There are standards for radiation protection and exposures that are based on the standards of the International Commission of Radiological Protection. Radiation releases are a safety hazard of nuclear power plants. Radiation is released three main ways:

Routine radioactive releases during normal operations of a plant. Such releases are permitted and governed by federal regulation and internationally accepted standards of exposure. The standards allow releases, although regulated, beyond the plant boundaries.

Radioactive releases during emergency and accidental conditions. Such emissions occurred at the Three Mile Island accident and the much more catastrophic Chernobyl nuclear generating station in 1986. At Chernobyl, only four percent of the fission products escaped causing widespread significant impacts that are discussed later in this section.

Radioactive releases from storage of long-lived radioactive wastes. Some fission products are very long-lived and must be stored to ensure safety. Releases could occur into the groundwater or from rupturing of the storage area and dispersal into the atmosphere.

Although not directly associated with the plant, releases can also occur from uranium mining. Mining has a great potential of environmental damage and has caused such damage in the past. During operations, there can be radioactive releases of gas, dust, or other radioactive material. Inadequate care during mining's early days has led to heightened death rates among miners.[30]

Although nuclear power does lead to radiation releases, the amounts are small under normal operations. They are not even the largest source of manmade releases. The largest source of these is not nuclear power, but coal-fired power plants.[31] A 1000-megawatt coal plant releases about 100 times more radioactivity than a nuclear plant during its normal operation. Following is a table of exposures from various activities, all of which exceed the permissible releases from a nuclear power plant.

Table 2
Radioactive Exposures

Activity	Exposure
Sleeping with someone for 8 hours	2 mrems
Living within 50 miles of a coal plant	3 mrems
Living in a masonry home	7 mrems
Living on the Earth	200 mrems
Smoking	16,000 mrems
Air Travel	1 mrem per 1000 miles
Grand Central Station (Granite construction materials)	120 mrem for employees
Maximum allowed exposure for a nuclear power plant worker	5 mrem

Note: Mrem is defined as a unit of radiation dose equivalent to one-thousandth of a rem (which stand for Roentgen equivalent man). It measures the amount of damage to human tissue from a dose of radiation.
Source: Frontline: Nuclear Reaction,
http://www.pbs.org/wgbh/pages/frontline/shows/reaction/interact/facts.html

What is the Harm from Small Exposures? Radiation is easy to detect, even in minuscule small amounts, but it is difficult to determine the health impacts from these low doses of radiation. The impacts of low-level exposure are extrapolated from high-level exposure. The impacts of low exposures are hard to detect in the human population, as the possible impacts are difficult to observe given normal mortality from cancer and other illnesses.

The scientific community assumes that the health impacts are proportional to the radiation exposure and that all doses, even the smallest, are potentially damaging in proportion to the quantity of radiation. This linear relationship is an assumption and is increasingly being called into question.[32]

An example of the difficulty of determining the impacts from radiation exposure can be seen by examining the aftermath of an incident at the Sellafield fuel reprocessing plant in the United Kingdom. Research had shown that there was a sufficiently high rate of leukemia to warrant the area being called a cluster. Attention was focused on the plant, which in its early days had relatively high releases. However, the rates of leukemia were much higher than what would be expected given the releases. It is an open question if this was a case of a particularly vulnerable population being stricken or just a statistical anomaly. The existence of a cancer cluster alone does not mean the radioactivity from the plant is the cause. Researchers found other clusters of cancer in the United Kingdom that had no explanation and were not linked to a source of radiation.

Large statistical studies from areas surrounding nuclear power plants have shown mixed results. A major survey conducted by the National Cancer Institute and published in the Journal of the American Medical Association found no elevated risks of cancer in 107 U.S. counties located near 62 nuclear power plants.[33] Nevertheless, there have been studies of other communities, both here and in the United Kingdom that have shown elevated rates.[34] There has been continuing debate about the adequacy of these studies.[35]

NUCLEAR PROLIFERATION

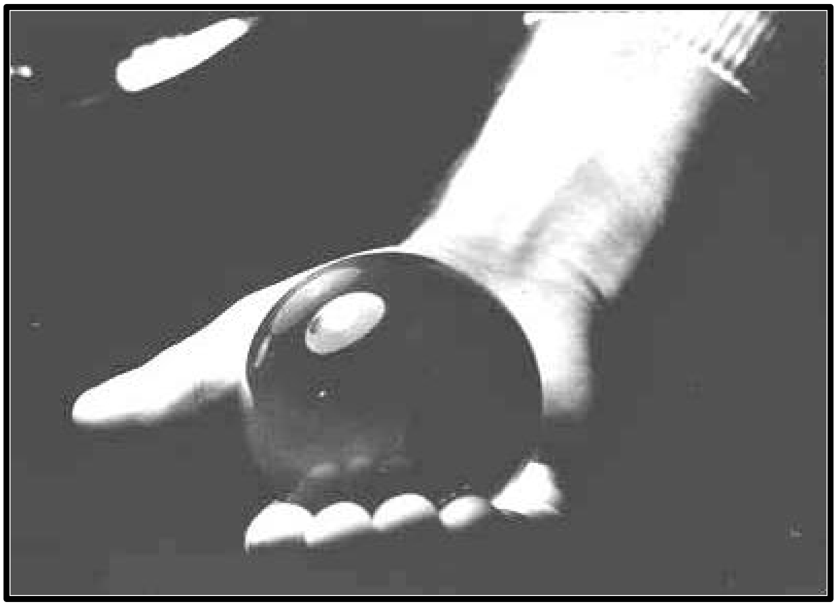
Nuclear proliferation occurs when materials used for civilian power purposes are diverted to weapons. Theft or diversion, misuse of facilities, or transferring of skills and knowledge can all constitute nuclear proliferation.

Diversion of plutonium is one of the most worrisome proliferation issues. Plutonium is a manmade element that is the primary explosive in most nuclear weapons and can be used as a fuel in nuclear reactors. A reactor fueled with uranium produces plutonium during fission. The produced plutonium becomes a portion of the high-level nuclear waste from a reactor. High-level waste is strongly radioactive, a risk to health, and remains radioactive for a very long time.

Plutonium is toxic, but it is not the most toxic element known to man, as claimed by some nuclear opponents. It is actually less toxic than many substances, but it does pose a great danger if a very small amount is inhaled.

As the following picture shows, a small amount of plutonium can produce a very powerful weapon.

Amount of Plutonium Necessary for a Nuclear Weapon



Source: Canadian Coalition for Nuclear Responsibility

The plutonium produced in civilian reactors can be separated and enriched to produce a nuclear weapon. However, this plutonium is not ideal for weapons, because it is highly radioactive, hot, and unstable.[36] There is debate regarding how significant are the barriers of using this relatively undesirable isotope for an adequate nuclear weapon. One argument is that the unstable plutonium is only capable of producing much lower-yield nuclear weapons.[37] Another argument is that although it is not ideal, the barriers to using it as a weapon are not insurmountable for a nuclear state or even a terrorist group.[38]

Most, if not all, of the countries that have acquired nuclear weapons, have done this by using facilities that are designed and optimized to produce material for nuclear weapons, not civilian nuclear power stations.[39] India developed its nuclear weapons in a research reactor not an electricity-producing reactor. Research reactors are significantly cheaper to build and use when compared to civilian generating stations and research reactors will provide the optimum type of plutonium.[40] Nuclear generating stations, however, can provide a training ground for acquiring skills and expertise that makes weapons production easier. As such, some argue that just the existence of a civilian nuclear power program carries an ambiguous threat that may lead others to attempt to develop nuclear weapons.[41]

Plutonium can be an important source of energy. The spent fuel produced by civilian reactors contains a great deal of uranium and plutonium. Reprocessing can enrich these both and allow them to be reused as fuel. Reprocessing for fuel production does not produce pure plutonium, but plutonium mixed with uranium for use as reactor fuel. Special reactors, termed "breeder reactors" are designed to maximize and optimize that production of plutonium and can create a great deal of plutonium for use as fuel. The use of breeder reactors could increase the world's supply of fuel for reactors by a factor of 60, meaning thousands of years of fuel rather than hundreds. Another source of plutonium is from nuclear disarmament.

The argument for reprocessing is that reactors create a considerable amount of plutonium, about 500 pounds per year in a 1000 mw reactor, which must be disposed of as high-level waste. Using the plutonium in a reactor destroys it, instead of leaving it in the ground with other wastes. Over time, as the plutonium decays it changes into a type of plutonium that is easier to make into weapons.

Concerns about proliferation from plutonium mean that any technology that uses or produces plutonium is controversial. These include any reactor that burns plutonium as fuel and plants that reprocess spent fuel to produce plutonium. To reduce the availability of plutonium and help stop the proliferation of nuclear weapons, President Carter stopped the breeder reactor in the United States and halted efforts to reprocess spent uranium fuel and produce plutonium for commercial uses.

Other countries disagreed with the U.S. policy and have gone ahead with breeder reactors and/or plutonium reprocessing. Among them are Britain, France, Belgium, India, and Japan. Still others are considering the breeder reactor. The United States did not attempt to end fuel reprocessing in other countries.[42]

Plutonium could be manufactured illicitly for weapons by other means. Depleted uranium, which is relatively easy to obtain, can be placed inside a civilian reactor and the subsequent neutron bombardment will produce plutonium. Although such an action would be a violation of international protocols and treaties, it is relatively easy to do. Israel was sufficiently concerned about the use of a civilian reactor for making a nuclear weapon that it destroyed the Iraqi reactor in 1981.[43] Researchers are also concerned about new, cheaper, and easier ways to make weapons grade uranium.[44]

The International Atomic Energy Agency does the bookkeeping and follows up with inspections regarding the production and storing of nuclear materials. They have not reported any anomalies that suggest that diversions have occurred.[45] However, observers acknowledge that measurement error could still allow diversion of sufficient material for weapons without notice by the agency.[46]

Proliferation concerns are not limited to nuclear power. There are sufficient radioactive isotopes in coal, so that coal ash that could be used as a source for weapons material.[47] The ash from any coal generation plant could be collected and reprocessed. The Atomic Energy Commission (AEC) at one time actually investigated that option.[48] The amount of ash produced each year from a typical coal-fired power plant contains 5.2 tons of uranium (75 pounds of U-235) and 12.8 tons of thorium.[49] Because coal-burning facilities do not have a high profile, it could represent a less obtrusive way for a country to gather the necessary radioactive material for a nuclear weapon.

SAFETY OF POWER GENERATION

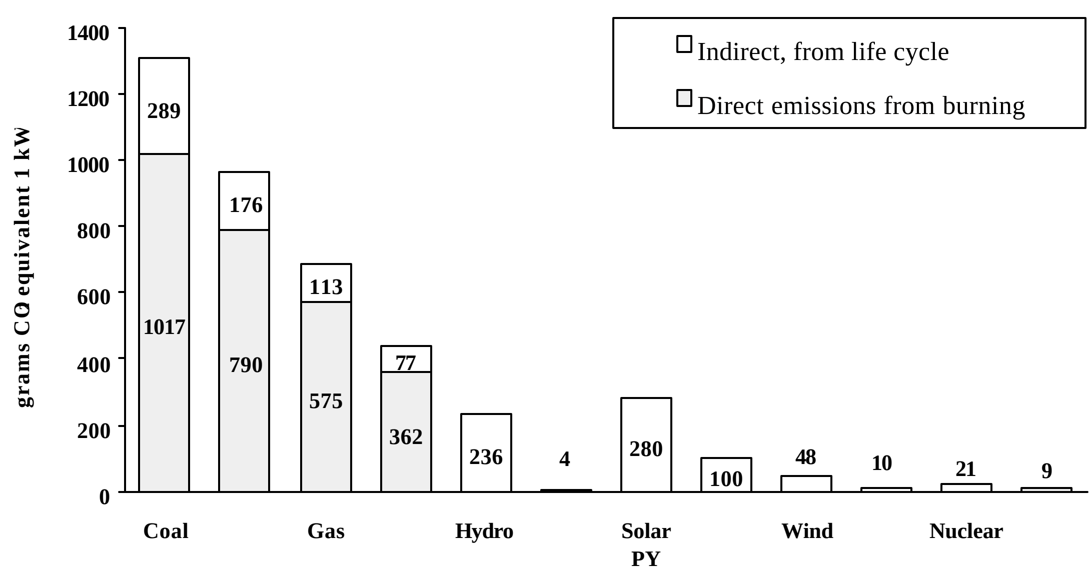
All forms of electricity generation feature risks. These risks are posed at all stages, exploration, production, transportation, and the actual operation of a plant. Research has attempted to quantify the exact frequency of accidents and the resulting number of deaths for a variety of energy sources, including nuclear power.[50] The research shows that nuclear comes out as a safer means of energy production, far safer than coal, oil, natural gas, or hydropower.[51] Appendix C contains some tables that show the relative frequency of accidents. These figures are based on the historical record of incidents, not hypothetical or possible incidents. A very large nuclear accident could dramatically change those historical frequencies.

Another approach that research has taken is to look at longer-term health impacts.[52] Based on the historical pattern, nuclear power is safer than coal and oil and approximately as safe as natural gas. Emissions from burning fossil fuels, especially coal, create a significant risk. Both of these studies are based on international data, hence they include the damage caused by the Chernobyl accident.

NUCLEAR POWER AND AIR EMISSIONS

Nuclear power is getting some increased attention because of the reduced greenhouse gas emissions. The following chart shows the greenhouse gas emissions from various power sources.

Chart 7
Greenhouse Gas Emissions From Electricity Production



Source: International Atomic Energy Agency

Surprisingly renewables do not do as well in this analysis as you might expect considering they do not have direct emissions during generation. The emissions reflect the large size of operation that is required to generate substantial amounts of electricity. It is the large size of the construction effort that leads to the increased emissions of greenhouse gases. A wind farm equivalent to a 1000 MW fuel plant would require 4,000 turbines on hundreds of square miles and would be a major construction project. Both would consume large tracts of land and require expanded gathering and transmission systems. Distributed generation technologies could ameliorate the impacts presented here.

Nuclear power could be one way to reduce the release of greenhouse gases. As a baseline, the Department of Energy (DOE) sees carbon dioxide emissions increasing steadily. Releases in the United States will grow from 1.5 to 2.1 million metric tons by 2020.[53] This growth is moderated by what they see as higher projected nuclear generation. A recent article in *Science* laid out a scenario where carbon dioxide emissions are held constant in the face of another three billion people and additional growth in income. The scenario laid out in the article would have world nuclear generation growing ten –fold.[54] As noted earlier, the European Commission has just released a report saying that Europe will need at least 85 new plants if projected carbon dioxide releases are to be cut to allow Europe to meet the emission guidance in the Kyoto protocol.[55]

There are alternative views showing that the United States could meet the Kyoto Protocols without expanded nuclear.[56] For California, the Energy Commission has released a report showing how California could reduce its emissions of greenhouse gases.[57] For the electricity generation sector, they recommended incorporating the external environmental costs in resource planning. This would require polluting forms of generation to pay their social costs. Their options include promoting high-efficiency gas generation technologies and funding renewable resource development and commercialization until it becomes a market economy. They also recommend further integration of renewable generation technologies into the electricity system.

Besides the reduced greenhouse gas emissions, nuclear power, as well as renewables, does not release the air pollution that results from burning fossil fuels. Coal is the largest source, a 1000 mw coal-fired station consumes three million tons of coal. The plant will produce seven million tons of carbon dioxide, 120,000 tons of sulfur dioxide, 20,000 tones of nitrogen oxide and three quarters of a million tons of ash--disposed in a landfill. These emissions are not benign. Sulfur dioxide emission may promote acid rain and, nitrous oxides are precursors to smog. Particulate, especially from the burning of coal, causes lung ailments.

PLANT SAFETY AND INCIDENTS

In a 1994 study, the World Health Organization (WHO) categorized radiation incidents into two different categories and inventoried as extensively as possible all of the world's incidents.

- The first type consists of incidents that involve a large number of people. This type is very rare. The World Health Organization could find only seven such incidents.[58] In these incidents, the radioactive exposure is lower than in the second type of incidents.
- The second type of incident features very high exposures to radiation, but these incidents affect a small number of people as the affected must be very close to the source of the radiation. These occur most often in the workforce because of industrial accidents and are much more common.

Of the seven incidents in the first category where a large number of people were exposed, three of these were at reactors of which two were at civilian nuclear reactors. The accidents at reactors are:

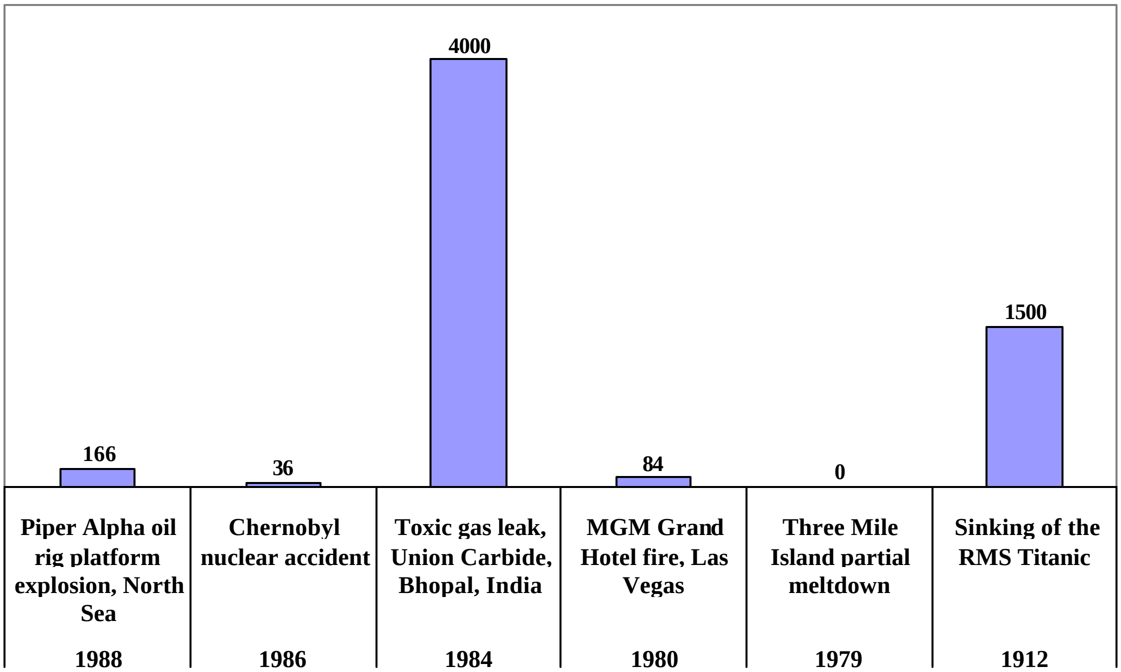
- Three Mile Island.
- Chernobyl, which happens to be in both categories, that it exposed a large number of people in a widespread area and acutely exposed those working at the plant. This is the other civilian nuclear reactor accident.
- Reactor fire in the United Kingdom (Windscale). This was a military reactor.

Chernobyl and the other four incidents that were not at civilian reactors resulted in much more serious health impacts than Three Mile Island or the Windscale reactor fire.[59]

Events that feature greatly elevated exposures to radiation have occurred only as the result of industrial and medical accidents and not from civilian nuclear power reactors, save for Chernobyl, although there was a recent event in Japan at a fuel reprocessing plant that occurred after the WHO study.[60] At least several of these elevated exposure incidents occurred in the United States. There were reactor incidents, but all at research reactors in the late 1950s and early 1960s.

The World Health Organization holds that nuclear power is, in principle, a safe technology when practiced in accordance with the well-established and very strict national and international rules and regulations.[61] The following chart shows some other industrial accidents, to place in perspective the size of the nuclear incidents that have occurred. Again, a highly improbable but very large nuclear accident could dramatically alter this chart.

Chart 8
Noted Industrial Accidents



Source Public Broadcasting System, California Research Bureau

The worst incident that can occur at a nuclear reactor is the release of fission products. A nuclear plant cannot blow up as if it was a weapon. Release of fission products could occur if the fuel melts and releases fission products, some of which could be released as dust. If there is some water left in the reactor, a reaction could start that releases hydrogen, an inflammable and potentially explosive gas. The explosion of hydrogen might rupture the containment vessel. In such an incident, the containment vessel is likely to remain intact in most of the occurrences and no deaths are expected.[62] In one out of five incidents, however, researchers calculate there would be 1,000 deaths, and in possibly one out of 100,000 incidents, there would be 50,000 deaths. While this is clearly a large number of deaths, the probability of any individual perishing from a reactor accident is still less than the risk of death from an airplane crashing into your house.[63]

Recently constructed nuclear power plants are safer than those built earlier. Part of the increased safety is a result of operational experience. There have been significant improvements since Three Mile Island.[64] A study of incidents shortly before and after Three Mile Island found over a 60-fold improvement comparing the period 1969-79 to 1980-81.[65] That study looked at events that would have caused a melt down save for operator intervention. The improvement has continued today, with the number of events dropping from 2.37 in 1985 to .03 in 2000.[66] In this study, the researchers defined events as incidents that trigger one of the many safety systems.

The increased concern over terrorism has heightened concern about the safety of nuclear reactors. The containment structure could be breached by the crash of a large jet. Any breach of the containment structure when combined with a serious reactor problem leading to a melt down could lead to widespread dispersion of radiation.

One argument made by some researchers is that the plants are already safe enough, indeed even too safe.[67] While this may sound heretical, the argument is that society has spent too much money on safety at nuclear power plants and some of those funds would have much greater results and saved more lives if spent on other, more dangerous activities.

MAJOR ACCIDENTS AT NUCLEAR POWER PLANTS

Browns Ferry, Alabama: The Tennessee Valley Authority operated this nuclear power plant. In 1975, an electrician searching for air leaks with a candle around electric cables wrapped in flammable insulation caught the insulation on fire. At the time, the reactor operator had approved of this method for finding such leaks. These cables operated the control room and safety systems of the reactor and the fire soon rendered these inoperable. Despite the loss of controls, the reactors were shut down eventually. As a result of the damage that one candle started, a new 2200 megawatt generating station was significantly damaged and shut down. There was no damage to the reactor itself and the danger of radiation release to the public was remote.[68] Many shortcomings in plant operation and planning were exposed by this incident.

Three Mile Island, Pennsylvania: The accident occurred with the plant operating at full power when a valve stuck sending primary system water into the containment structure. The secondary system was out of service. With the loss of water, the reactor was uncovered and partially melted down, resulting in irreparable damage. A meltdown is very dangerous because the molten fuel could escape through the concrete floor and contaminate ground water.[**]

There were detectable radioactive releases from the accident.[69] The radioactive releases appeared, by most accounts, to have been of no major consequence.[70] The plant released radioactive iodine but the dose to anyone drinking water was deemed to be less than .2 milirem, a permissible exposure. Radioactive gases were detected but only one-quarter of the level of permissible releases. Some soil samples contained small amounts of radiation. At the insistence of citizens, regulators placed monitors in the neighboring town, but the relatively high level of background radiation that naturally occurs in the area complicated readings.

The state, after receiving advice from the federal government, ordered evacuations of pregnant women and preschool children within five miles of the plant. Many more

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[**] The term "China syndrome" is used to describe this kind of incident. The term is accurate as to the direction the molten fuel heads, but the cooling effect of the ground and its ability to absorb neutrons, quickly slows down the reaction and then halts the melt down within a couple hundred feet of the source.

people, approximately 80,000, left voluntarily. Insurers set up a temporary office and issued emergency checks to cover hotel and meal expenses.

The 1979 mishap at Three Mile Island nuclear plant in Pennsylvania affected utilities all over the world. Several impacts were felt immediately. Any plans for additional nuclear power plants were dealt a serious, perhaps even fatal blow in the United States. Plants that were under construction faced immense modifications in response to the Nuclear Regulatory Commission. The cost for the operators skyrocketed as they faced delays and increased outlays for construction.

Not surprisingly, there was tremendous fear about the ultimate health effects. No identifiable injuries except psychological were recorded.[71] Arguably, this cannot be a final assessment because cancers may take a considerable period to develop.

Subsequent public health studies have supported the benign assessment, with some exceptions. Studies were conducted after the incident to determine if there were any increases in cancer rates or mortality. Of the five major studies that have been undertaken, all but one arrived at the conclusion that there were not any impacts on the incidence of cancer.[72]

A lawsuit against the utility brought by some residents who claimed injury was dismissed and the judge found that there was insufficient factual evidence that radioactive releases had caused harm to justify allowing the case to go forward.[††]

Regulators and the nuclear industry had to change fundamentally how they thought about safety after Three Mile Island.[73] There was a widespread culture within the NRC and the utilities that such an incident could not happen, which in turn probably stood in the way of an effective response to the incident.[74] The accident also showed that a combination of freak events could occur, that those individual events in themselves were not foreseeable and that the interaction was important and determined the risk. Prior to Three Mile Island, regulators and the industry thought about in a more isolated context, i.e. would this pipe break or not. This thinking was reflected in the design of the control area at Three Mile Island. The control room had over 600 individual alarms. These were useful in tracking the performance of individual systems and very useful if one individual system developed problems. When the incident occurred, many of the alarms went off, overwhelming the control room crew and leading to long delay before control room staff could attend to any individual alarm.

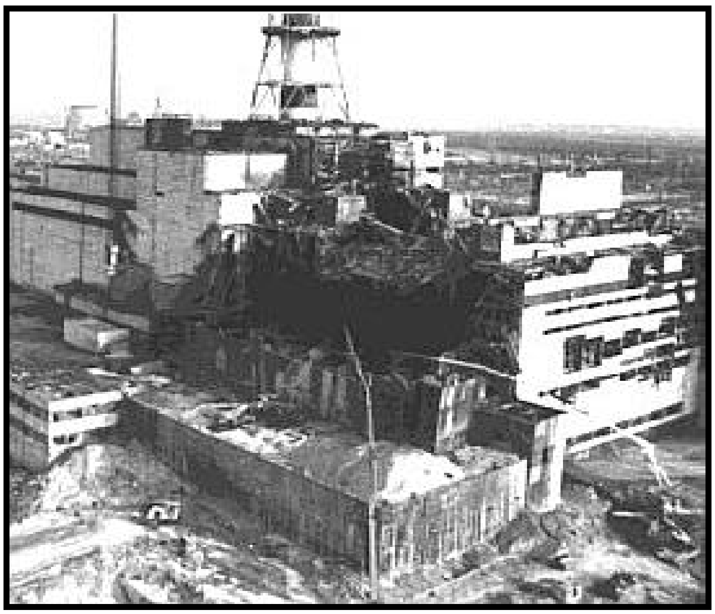
The complexity of a nuclear generating plant is not unrivaled, chemical plants are known to be quite complex. Utilities were unused to that level of complexity. Fossil-fueled plants are not as complex and if there is a problem the plant can be shut down without much chance of an incident affecting the surrounding area.

[††] The U.S. Court of Appeals and the U.S. Supreme Court upheld the decision. In a separate case, almost 2,000 people have filed claims. This case has not yet been decided.

Three Mile Island, although it appears to be ultimately benign in terms of impacts on health, provided a graphic illustration that accidents can happen and they can be potentially serious. The incident dealt a serious blow to the public's trust in the nuclear industry and its government regulation.[75] The valve that had failed had malfunctioned 11 times before at other nuclear plants, yet the NRC had not taken corrective action or issued a warning to other operators.

Chernobyl: This 1986 incident was the most catastrophic accident in the history of nuclear power. The effects of the disaster were magnified because it was a large plant and had been operating a long time so that it had a large inventory of radioactive materials when the plant exploded and caught fire.[‡‡]

Chernobyl Nuclear Plant After the Fire



Source: Nuclear Regulatory Commission

The incident occurred during a test to determine if an emergency shut down could be conducted if off-site power was lost. The test began and within a few seconds, two explosions shook the control room as the power rose to 120 times its rated capacity. The fuel rods exploded, and the cooling water flashed into steam. As the pressure from the steam mounted, it breached the reactor structure and escaped into the environment. Although Soviet reactors did not have a containment vessel, the reactor was encased in cement. The 1,000-pound slab was easily tossed aside. For the first time, the lethal radioactive contents of a large power reactor were exposed to the atmosphere. The graphite control rods caught fire and smoldered for seven days spewing out radioactive releases. It took 11 days to quench the fire and end radioactive releases.

[‡‡] It was not a nuclear explosion; rather chemical explosions resulting mainly from the interactions between steam and overheated fuel elements.

Approximately 30 workers died quickly, most who heroically fought the fire. Another several hundred had radiation sickness. Although they recovered, they are at risk for cancer. Officials ordered the evacuation of 135,000 people and parents sent their children away voluntarily. The monetary costs of the incident are also significant, probably reaching $10 billion.[76] Chernobyl contaminated approximately 50,000 square miles.[77] There were isolated incidents of high radioactivity readings in food, such as reindeer in Scandinavia, sheep in Wales, and fish in Switzerland.

Besides the plant workers, the only other easily identifiable mortality is from thyroid cancer in children. There have been 800 cases and more are expected. These cases were avoidable if the children ingested iodine tablets.[78] Although thyroid cancer is largely treatable, there have been several fatalities.

The soil in the region contains elevated levels of radioactivity. The food chain will remain contaminated for many years. An exclusion zone was created and at least some of the wildlife that inhabits it has absorbed high levels of radiation. Approximately 100,000 residents were permanently relocated.

Despite the detailed knowledge of the radioactive fallout, the health effects cannot be exactly determined. Considerable non-radiation health-related impacts related to anxiety and stress have been documented by researchers.[79]

Researchers expect higher than normal deaths from cancer for years to come. There were not elevated levels of leukemia when a 1993 follow up was conducted.[80] Researchers found this surprising because after Hiroshima and Nagasaki leukemia was the earliest sign of long-term radiation effects. Various studies contain estimates of 5,000, 14,000, 600,000, or even one million additional deaths from cancer.[81] The most common range is around 10,000-50,000. Thirty-five thousand cases would mean an increase in cancer rate of about one-half percent.[82] The smaller estimates are not as large as the expected number of cancers from coal and or the probability of dying in a car accident.

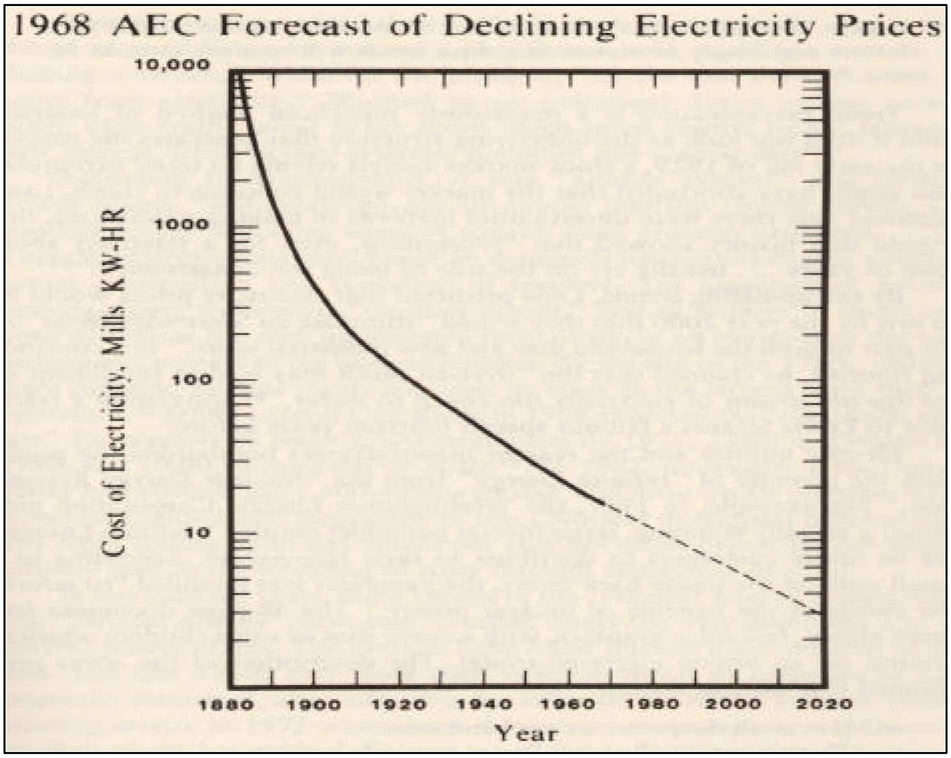
Statistically this elevated mortality level will be very difficult to monitor. The affected areas are large, containing over four billion people, of whom 700-800 million are likely to die of cancer even absent Chernobyl.[83]

The ignorance about the results of exposure to very low levels of radiation leads to this uncertainty about the impacts. Except for very near the plant, the dose was lower than the background dose. The World Health Organization calculated the dosage from Chernobyl at .01 mrem for the world and .1mrem for those in Eastern Europe.

An incident such as this raises the question of could such an event happen in the United States. Most analysts would not compare Chernobyl with an American plant or any other commercial plant outside of Eastern Europe.[84] The main differences are the lack of containment structure, the unstable reactor design, faults in the reactor design, and the non-routine operation during the test.

IV. ECONOMICS

The basic economics of nuclear power were once unbelievably bright. Nuclear power was supposed to become too cheap to meter according to Atomic Energy Commission (AEC) Chairman Lewis Strauss.§§[85]



Source: Nukespeak[86]

Chairman Strauss' remarks were appealing but were wishful thinking, unsupported by scholarly work. At the time, there were a variety of studies that raised some questions about nuclear power, not that it wouldn't work, but about the cost and whether it could compete with fossil fuels.[87]

Nuclear power never lived up to its promise. In fact, the nuclear industry became what Forbes Magazine called in 1985, "... the largest managerial disaster in business history."[88]

Today nuclear power seems to rest between those two pronouncements. Currently it is producing electricity very cheaply, although that cost ignores the construction costs of a plant. If the high construction costs are included, nuclear-produced electricity is not economic. Nuclear power has been especially valuable during the last 18 months in California where it has been a reliable and inexpensive source of electricity.

§§ The forecast contained in this logarithmic graph is for electricity prices of approximately five mills per kilowatt-hour or .5 cents in the period 2000 to 2020. For the year 2000, California utilities earned a little less than 11 cents per kilowatt-hour or slightly over 100 mills. Inflation adjustment does little to bridge the gap between the forecast and the actual recorded prices.

Nuclear power plants require a significant capital investment, more so than other electrical generating stations. To illustrate the complexity, a Vice President of Duke offered the following: "These are more complex plants. In a big coal plant, you would have no more than 200 critical pipe hangers.[***] In a nuclear plant you need 30,000."[89]

Utilities were not deterred by the large capital costs. With traditional rate of return regulation of utilities, they had an incentive to favor projects with large capital costs. Utilities earned a rate of return on invested capital and not on labor and materials. They were not overly concerned with the financial risks as their experience was that they would be able to put nearly all of the construction costs into the rate base. That ability to pass the costs onto ratepayers began to change after 1974, when electricity costs in general and nuclear reactor construction costs in particular began to escalate.[90] Public Utilities Commissions (PUCs) were reluctant to approve actions that would dramatically increase consumer electricity rates.

Cost overruns actually began before the 1970s, although they grew dramatically during that period. Cost overruns led to plants costing 6-8 times more than planned and many times more than plants that had already been constructed. A reactor built in the early 1970s cost approximately $170 million. By 1983, the plant probably would have cost $1.7 billion, if the utility was lucky. When adjusted for inflation in today's dollars, the cost is about $3 billion. Later plants were costing well over $6 billion (in 2002 $). Those involved in the debate point to the following reasons for the cost escalation:

- Utility mismanagement. This factor seems to get the lion's share of the blame from nuclear power's friends and foes alike.[91]
- Anti-nuclear opposition, which slowed licensing and approvals.
- Beginning construction with incomplete designs, which in some instances were changed radically before the plant was completed.
- The changes that were brought about by the meltdown at Three Mile Island. Significant changes were made in the designs of power plants that were then under construction. A plant could have been 70-percent complete and then after some regulatory changes, it became a 30-percent complete plant.

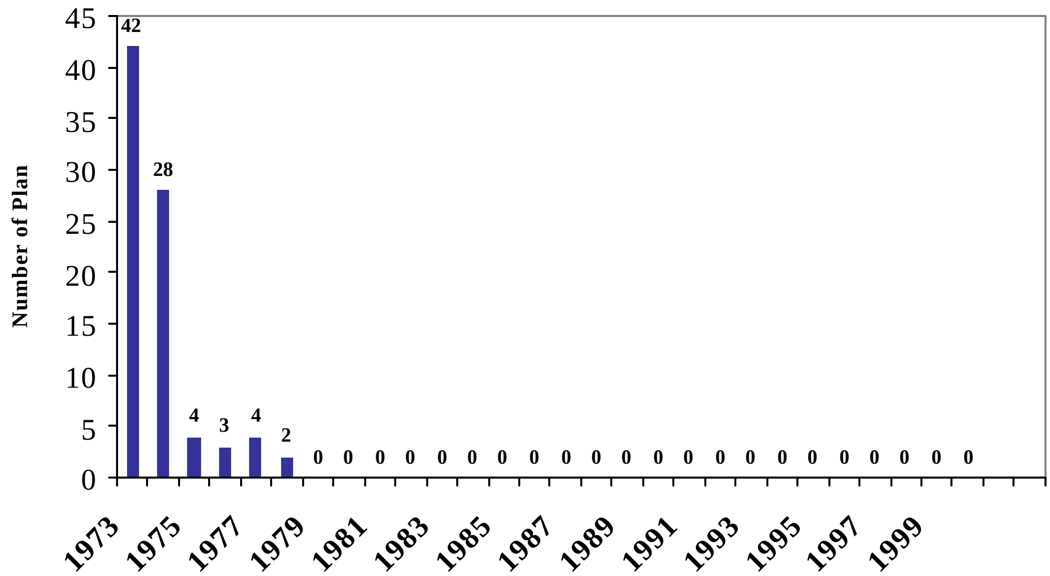
More specifically, Forbes Magazine maintained in a 1985 article that nuclear power was killed, like the antagonist in *Murder on the Orient Express*, by many. Forbes lays the chief blame, not on the enemies of nuclear power, but its friends:[92]

- The federal government and NRC, which botched the day-to-day management and also failed to consider how its regulations would impact costs.
- Equipment manufacturers who did not take safety considerations and public concerns seriously enough. They sold the plants as if nuclear generation was a mature technology when in fact it was rapidly evolving.

[***] A pipe hanger is simply a bracket, clip, ring, or loop used to suspend pipes on ceilings or beams.

- Contractors who demanded cost plus contracts and did not question the impacts of design changes. Contractors also rigged bids and intimidated quality control inspectors.
- Utility executives who ignored costs believing that public utility commissions would bail them out.
- State Public Utility Commissions (PUCs) whose "grossly inadequate oversight of the schemes, ambitions and monstrous expenditures for nuclear projects made it easier for all of the above to betray consumers and investors alike."[93]

Chart 9
Nuclear Power Plant Orders



Source: Energy Information Agency, Department of Energy.

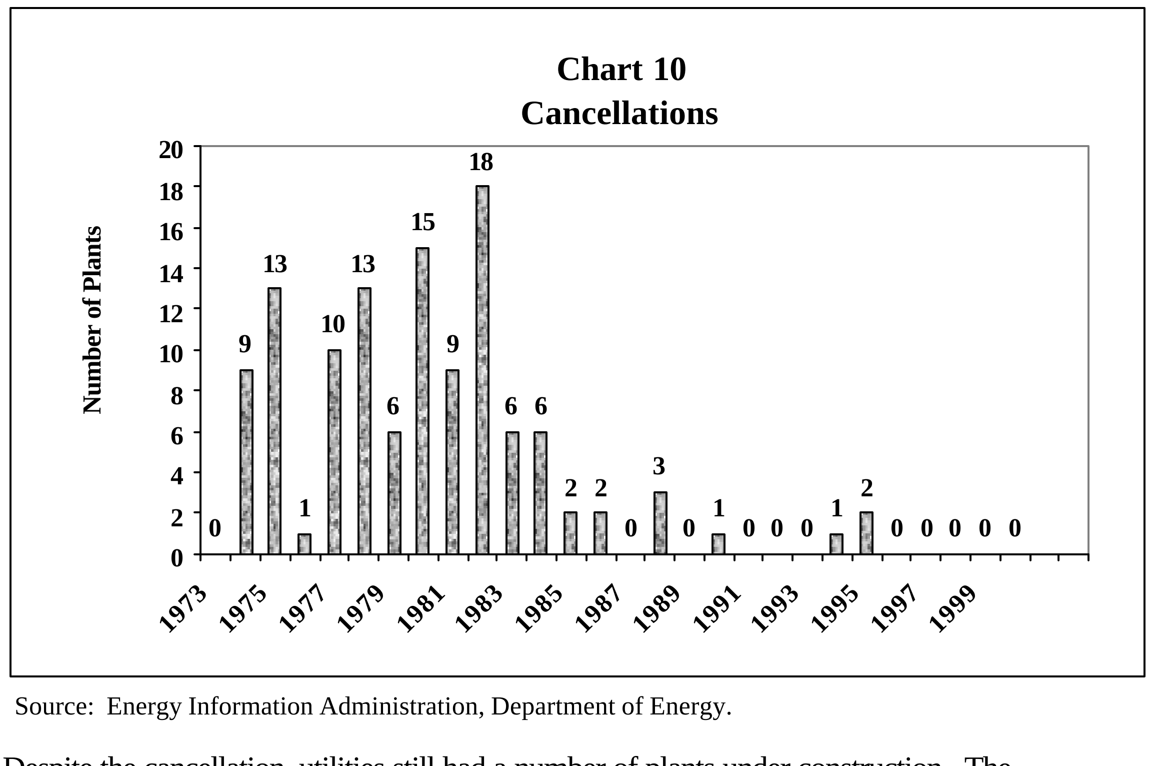
While examples of construction mismanagement abound, a notable one is from California.[94]

- Construction began on Diablo Canyon in 1968 when the project was estimated at $320 million ($1.5 billion adjusted for inflation to 2002) with a completion date of 1976.
- In 1976, the completion cost had grown to $1 billion ($3 billion in $2002).
- The Nuclear Regulatory Commission then ordered a re-design to take into account the Hosgri earthquake fault; the project then became a $2 billion reactor.
- Costs ballooned more with the discovery of a number of design errors and inaccurate reading of plans. Upon completion, that plant cost approximately $5.5 billion ($9.9 billion in $2002) when the plant was completed in the mid 1980s. It is among the most expensive nuclear generating stations ever constructed.

Because of large capital costs, constructing a nuclear power plant is tremendously sensitive to interest rates. In addition, inflation significantly affects the cost both through cost increases when the plant is being built and the effect of inflation on the interest rates. If a plant costs $1 billion to construct that cost can increase markedly with any delays. If regulators delay licensing the plant for two years, the $1 billion plant can become a $1.2 billion plant because of interest costs alone.[†††]

Another economic factor, and an important one, that affected the plans of nuclear plant operators was the slowing of electricity demand growth. The nuclear plants were being planned and constructed at a time when the rapid increase in electricity prices and the slowing economy was playing havoc with demand. Electricity consumption had been increasing at a seven percent annual growth rate, meaning it doubled every ten years. As it slowed to an annual rate of as small as one percent, it means that consumption doubles every 70 years.

The combination of cost escalation and slowing growth mortally wounded nuclear power, at least until recently. The industry's fate was sealed when fossil fuel prices began to decline. Demand growth did not pick up but the economics of fossil-fueled plants had improved markedly. These factors forced utilities throughout the world to cancel plants because of slowing demand growth for electricity and declining fossil-fuel prices.[95]



Source: Energy Information Administration, Department of Energy.

Despite the cancellation, utilities still had a number of plants under construction. The rising costs were beginning to impact ratepayers. Under the rate of return regulation that

[†††] An interest rate of ten percent was used in this simple example.

dominated at that time, state PUCs approved the projects and committed the ratepayers to paying the costs of construction. This regulatory scheme protected the utilities from some of the investment risk. The utilities, of course, were subject to reviews examining whether the costs incurred were prudent. As the costs of nuclear power soared, these prudency reviews became more important and PUCs began disallowing some of the costs from being passed onto ratepayers. Utilities' investment risk grew as shareholders had to pay when costs were excluded from rates.

While the PUCs disallowed significant amounts for the investor-owned utilities, the costs that went into a rate base became a problem for ratepayers and public utilities commissions. As these large costs went into the rate base, electricity prices increased. When states, including California, reduced regulation in the electricity market, these so-called "stranded costs" became a thorny problem. Stranded costs were the costs incorporated into the rate base from building what had become uneconomic facilities. Nationwide, nuclear power comprised about one-third of the $200 billion in stranded costs.[96]

Utilities must also plan for decommissioning costs. Utilities must decommission a nuclear plant when the plant reaches the end of its useful life. Those opposed to nuclear power point out the high decommissioning costs and claim, that "It may cost as much to decommission a plant as build one."[97]

Decommissioning, as with any other large obligation or debt that a publicly traded company has, must be funded over the life of the asset. Regulated utilities accumulate funds to pay the decommissioning costs over the economic life of the plant. Utilities have decommissioned several plants in the United States. The Fort St. Vrain Nuclear Generating Station in Colorado was the first commercial plant a utility decommissioned. Decommissioning of this unit began in 1990 and ended in 1996 at a cost of $188 million.[98] Many more have been decommissioned around the world. Costs are now estimated at $325 million per reactor.[99]

Decommissioning requires all equipment and buildings be removed or decontaminated. Eventually, the regulations require that the site's radioactivity cannot exceed the natural level. The goal of the regulators is have the site so clean that entry does not have to be monitored. The amount of time necessary for the various stages of decommissioning can vary.

While the nuclear industry labors under the disadvantage of high capital costs, they enjoy an advantage in operating costs. While the capital costs of a nuclear plant are large compared to a fossil-fueled plant, fuel cost for the nuclear plant is lower. The operating costs, as a result, are low as long as the plant is working well. Unlike fossil-fueled plants, a nuclear power plant's electricity production costs do not vary significantly with fuel prices.

Uranium ores are widespread so that producers don't enjoy significant market power. The following table shows that reserves of uranium are widespread. This reduces the chance of a seller's oligopoly that influences prices, like that of the Organization of Petroleum Exporting Countries (OPEC) for crude oil.

A government interested in reducing further the vulnerability of uranium to supply disruptions could easily establish a strategic reserve. Pound for pound, uranium fuel produces 130,000 times more energy than coal. Given its energy intensity and ease of storage, government or industry could establish a reserve that would last many years relatively cheaply and simply.

The United States supplies almost 40 percent of its own fuel. The remainder is purchased abroad. The quantity demanded by U.S. reactor operators is projected to remain steady through this decade.[100]

The estimated reserves in the following table represent approximately 50 years of supply at current price levels.[101] Another industry organization, the World Energy Congress has a similar estimate of supply.[102] Higher prices, further exploration, and technological change will, as with other nonrenewable resources, increase the supply. At this point, energy analysts estimate that the world's supply of uranium appears to be on the order of fossil fuels.[103] Speculating about the supply over a very long period is difficult between the uncertainty of increased demand, liquidation of military stockpiles, and the economics of both reprocessing and the breeder reactor. The breeder reactor could increase the fuel supply by 40 or 50 times, meaning thousands of years of fuel would be available at current consumption.

Table 3
Known Recoverable Resources* of Uranium

Country	Tons U_3O_8	Percentage of World
Australia	889,000	27%
Kazakhstan	558,000	17%
Canada	511,000	15%
South Africa	354,000	11%
Namibia	256,000	8%
Brazil	232,000	7%
Russian Fed.	157,000	5%
USA	125,000	4%
Uzbekistan	125,000	4%
World total	3,340,000	

Source: OECD NEA and IAEA.
Note: * Reasonably Assured Resources plus Estimated Additional Resources - category 1, to US$ 80/kg U, 1/1/99. Brazil, Kazakhstan, and Russian figures above are 75% of in situ totals.

The industry originally had trouble obtaining insurance. Insurance companies were understandably reluctant to underwrite insurance for nuclear power plants. They did not have any history with nuclear power, so they did not have information for underwriting purposes. The nature and extent of personal injuries would probably not be known for many years after an incident, complicating the paying of claims. The small number of plants meant that there were few available to pay the premiums and little ability to reduce risk with a large pool of insured. Insurers faced a situation where the potential losses in an accident, however unlikely the accident might be, exceeded the exposure they wanted to any type of hazard. The insurers' concerns were exacerbated when the federal report released a report saying that liability claims could reach $7 billion after an accident.[104] (This was during the 1950s). The lack of insurance led utilities to threaten abandoning their projects.[105]

The Federal government responded by passing the Price-Anderson Act in 1957. The Price-Anderson Act creates funding, currently approximately $9 billion, which is available to pay claims. The funds are available from a combination of sources. The individual plant operator must provide a primary lay of insurance of financial security of $200 million. For damages exceeding that there is an industry pool funded by a premium of approximately $80 million paid by each plant operator.[‡‡‡] In short, the federal government would go to each utility after an accident and demand funds to pay for any damages. The amount of total insurance available varies by the number of licensed reactors. These premiums are retrospective and the plant operator must provide insurance to cover those premiums should paying them be necessary. Utilities have no additional financial liability.

Covered damages include death, personal injury, and loss of or damage to property. The insurance will pay the costs of damages caused by a precautionary evacuation and the response costs of local governments. Insurance paid about $25 million for evacuation at Three Mile Island.

The Price-Anderson Act has been amended several times since its passage.[106] The act is scheduled for reauthorization before August 1, 2002. Regardless, existing plants would continue to operate under the current Price-Anderson system.

The insurance mechanism does not cover all possible damages. The President is authorized to provide to Congress a plan should damages exceed the amount of the insurance and pool. Congress may then authorize payment for any additional damages, the costs of which would be borne by taxpayers.

The insurance shortfall from possible damages is not unusual for large industrial ventures. Most large industrial enterprises simply cannot obtain adequate insurance to cover all possibilities. For example, the Exxon Valdez oil spill led to damages on the order of $3-4 billion. Exxon had insurance, but it did not have adequate pollution insurance to cover these damages and such a policy simply was not available. Exxon had the financial ability to pay the damages, but a larger and/or more expensive spill would have exhausted even Exxon's immense resources. Many shipping companies simply do not have anywhere near the resources of Exxon and state and federal funds would have to be used in the event of such a large spill.

[‡‡‡] The premiums are adjusted every five years to reflect the changes in the consumer price index.

Opponents of nuclear power argue that this liability cap protects the industry from the consequences of the most severe possible accidents. Arguably, that is true, but it is not a situation that is unique to the nuclear power industry.

There is widespread disagreement on the possible external costs and benefits (externalities) of nuclear power. External costs and benefits are costs or benefits that the producer of electricity from nuclear power does not have to pay, but society as a whole does pay. An example of a cost would be any harmful effects from radiation discharges that are borne by the individual with no compensation or penalties being paid by the emitter of the radiation. The external costs would include any environmental impacts.

One view is that the external costs are relatively small, especially when compared to fossil fuels. This was the finding in a recent study done by the Nuclear Energy Agency of the Organization of Economic Cooperation and Development (OECD).[107] The study found a nuclear plant poses only a minimal threat to public safety and that there are large external costs from fossil fuel emissions, especially those from coal. The report found that the social costs of nuclear power were less than for fossil fuels and were certainly a very small part of the direct generation costs. Even for coal and petroleum, the social costs were a small part of generation costs.

The report does acknowledge that there is the possibility of a major accident and that could entail a larger social cost.[108] They discounted this in their economic analysis as being too remote to even consider, for example, they assumed that a core melt down would occur about once every million to ten million reactor years. Even with an assumption that the probabilities were significantly larger, the overall costs were still small. They assumed that a melt down would occur once in 100,000 reactor years and such a melt down led to a Chernobyl-size accident occurring. They estimated that cost of such an incident at about $200 billion. However, when this large total is amortized over all reactors and all of the operating period, the costs are only about $2 million per year per reactor. That total amounts to about one percent of the electricity cost, leaving social costs still small.[109]

An alternative view is that the social costs are much higher.[110] One crucial difference in these arguments is the assignment of probabilities and impacts of a nuclear disaster. Social costs can be increased if a sufficiently large incident is analyzed, but the question remains as to the probability of that incident. Another difference is how sunk costs are treated. The cited analysis that argues for higher costs does include sunk costs, which aren't economically relevant any longer. These sunk costs include research and development and various other government subsidies that have already been paid to the nuclear industry.

One item that critics frequently point to as a social cost of subsidy is the waste disposal. Currently, industry (and through them ratepayers) are paying the costs of disposal. The federal government has collected over $18 billion to pay for the costs of a permanent waste disposal program.

V. NUCLEAR WASTE DISPOSAL

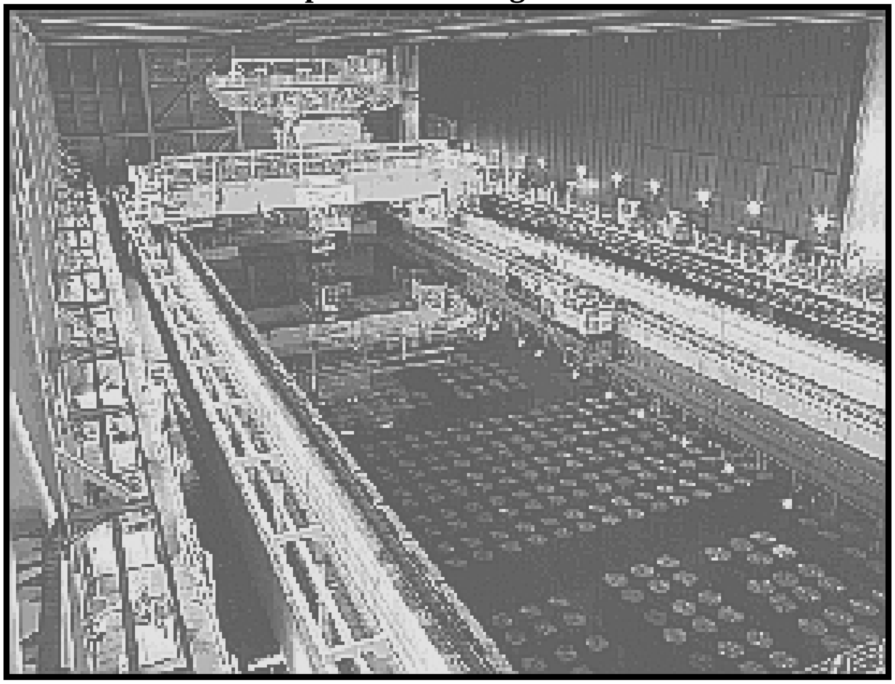
Nuclear wastes are radioactive and so long-lived that very special arrangements must be made for disposal. Concern about their proper disposal is one of the most controversial aspects of nuclear power. The focus and controversy are about high-level wastes, which are the minority of waste from a reactor but comprises the majority of the radioactivity.[111]

The waste is generated when utilities remove the spent fuel. The spent fuel rods are very hot and contain both remaining radioactive fuel and other highly radioactive fission products. The plant operator must shield the rods with water by placing them in tanks or ponds at the reactor sites. Industry has to maintain control and is responsible for storage until the final disposal site can be arranged. In the United States, utilities store all spent fuel temporarily at reactor sites. No permanent depository for high-level wastes exists. Industry argues that the management of wastes has been very successful. They report that there have not been any releases that have had adverse impacts and the costs are internalized.[112] Despite their claims of success, their remains significant concerns of long-term disposal.

The disposed material will be radioactive for a very long period, with some isotopes having half-lives of thousands of years.[§§§] Other isotopes, those that are the most highly radioactive, have shorter half-lives. Despite the long half-lives of some isotopes, the overall radiation intensity of nuclear waste declines more quickly. Ninety-nine percent of its radioactive intensity is lost in 600 years, after 1,000 years, the waste is no more radioactive than naturally occurring uranium ore. Proponents of nuclear power argue that taking care of waste for this period, is not an unprecedented activity in the realm of human experience. They point to the continuing custody and maintenance of such buildings as the Pantheon or Notre Dame.

[§§§] A half-life is the period required for the radiation intensity to decline by half. If an isotope has a half-life of five years, after five years the intensity has declined by 50 percent. After ten years, two half lives, the radioactive intensity is now one-fourth of its initial level. After ten half lives, the radiation level is reduced to one-thousandth of its original level.

Spent Fuel Storage Pond



Source: Uranium Information Centre

The volume of waste is relatively modest, about three cubic meters per year after "vitrification." That represents about 25-30 tons of spent fuel for the standard 1,000-megawatt reactor. Vitrification is the drying of the waste, which is then processed into glass. The processor then pours the glass into special stainless steel canisters. These in turn are stored to reduce the radioactivity before final disposal probably some tens of years after being removed from the reactor.

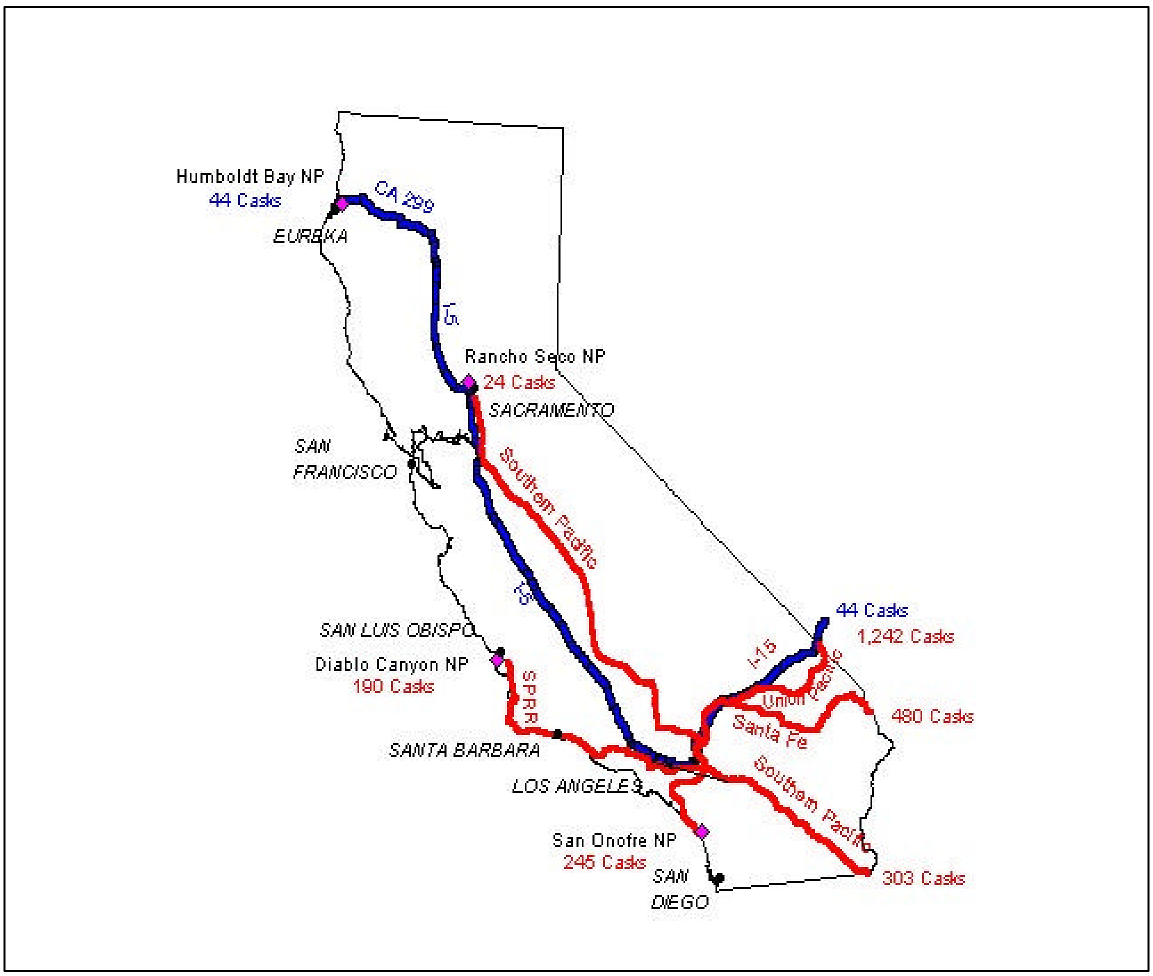
Although the volumes of waste are relatively small, they have been building for years. There are approximately 41,000 metric tons awaiting disposal in the United States and that figure grows by about 2,000 metric tons per year. Operators store this in temporary facilities.

The United States and many other countries are examining geologic disposal as the long-term solution to the disposal of high-level nuclear waste. Geologic disposal sequesters the waste where it cannot travel and where water cannot enter the site. Obviously, society needs a high degree of assurance that this will not require oversight, but will still be a permanent solution. Before such disposal, the waste must be in a stable form. Once the waste is stabilized, it needs to be placed in corrosion resistance canisters of stainless steel or copper to make it ready for geological isolation. The canisters will corrode over time slowly releasing the contents. Ideally, the release will occur itself over a long enough period so that radioactivity has declined. Since the canisters will eventually release their contents, long-term disposal requires a stable geologic site.

Fuel is not the only source of high-level waste. The structural materials in the core of an operating reactor become radioactive over time and when the reactor is decommissioned it must be dismantled and disposed of properly.

The federal government's current plan is to ship high-level waste from over 100 reactors all over the country to a single repository. Plant operators will ship the wastes in specially designed casks to minimize the possibility of spillage. The Department of Energy conducted a 1996 survey that listed some 72 transportation incidents involving spent nuclear fuel.[113] The report did not list any radiation-related injuries or deaths. Some accidents have resulted in small leaks of radiation. According to industry sources, there has not been any radiation-related injuries or death.[114] Since nearly all of the radioactive material is solid, the chances of a catastrophic release are reduced, although certainly not eliminated. A nuclear reactor produces about five tractor-trailer truckloads during a year. Following is a map showing likely transportation routes and the associated volumes within California.

Map 3
Nuclear Waste Transportation Routes



Source: Nuclear Waste Projects Office, State of Nevada

The potential problems that must be surmounted in waste storage are significant. Critics of geologic disposal doubt that these can ever be successfully met for the required period. Following are some concerns:

- The waste could start a nuclear chain reaction. This would lead to a low-power explosion sufficient to potentially spread radioactive material.
- The wastes themselves are contaminated with other non-radioactive toxic wastes; hence any release poses additional health and safety impacts beyond the release of radiation.
- Since a small amount of the waste products could be used for constructing a nuclear weapon, geological disposal is creating a future mine for weapons.
- Nuclear waste requires a great deal of special handling. Besides its radioactivity, it creates an immense amount of heat and some isotopes will burst spontaneously into flames when exposed to air.
- These concerns are especially significant given high-level waste will be transported from all over the country to a single repository.

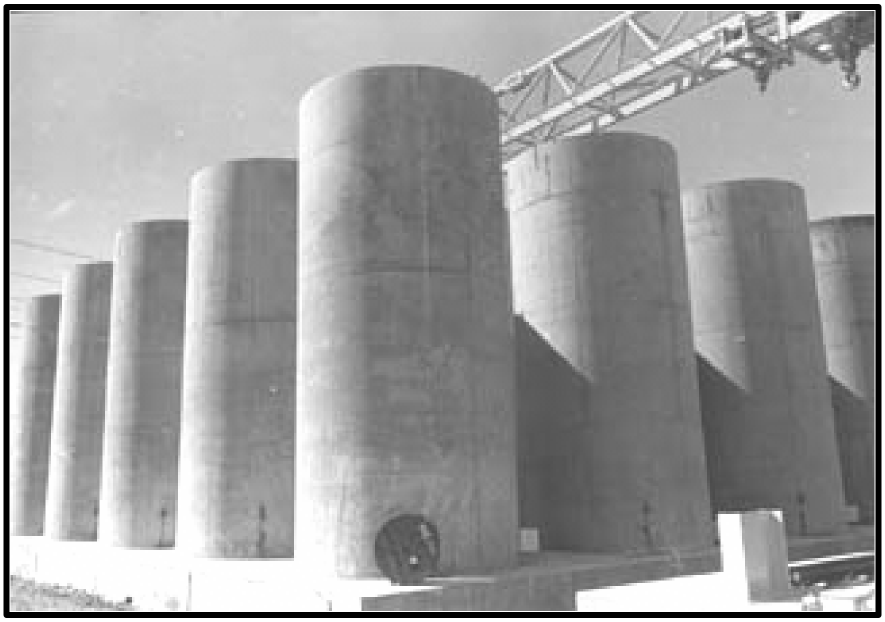
The National Research Council just completed a report on disposition of high-level waste and spent nuclear fuel.[115] Their main findings on this issue are:[116]

- The growing volume of high-level waste requires attention. They point out that the volumes are exceeding the interim storage facilities.
- There are two safe and feasible options; monitored storage on or near the earth's surface or geological disposition. Their caveat about this finding is that those responsible must be willing and able to devote adequate resources to maintain the storage facilities and that it is uncertain if future generations will be willing or able to.
- They do not believe there are scientific or technical obstacles to geological disposal. The National Research Council believes that these facilities are much less hazardous and less complex than others built and maintained by our society.

Reprocessing reduces waste to about 3 percent of what it could be. If the fuel is reprocessed, the radioactivity declines to that of coal ash in 400 years.[117] Although a long period, this is a shorter time frame than without reprocessing. The United Kingdom, Germany, Japan, and France all reprocess spent fuel. The United States does not reprocess therefore, it treats the whole fuel assembly as waste creating a substantially larger volume. Because reprocessing creates plutonium, although not of a type optimal for weapons, the United States eliminated reprocessing for reasons of nonproliferation (see the health and safety section). The slow progress on waste disposal and the continued debate is reported to have increased Congressional support for reprocessing.[118]

Nuclear power plant operations also create low-level waste. The large volume of low level waste produced by nuclear power is much easier to handle and does require more care than household garbage. Besides the nuclear power industry, low-level wastes come from hospitals, universities, and industry. It may be incinerated or buried.

High-Level Waste Storage Tanks



Waste Disposal in the United States

Congress enacted the Nuclear Waste Policy Act of 1982. The law directs that those who produce the waste should pay for its proper disposal. Since the legislation's enactment, utilities, and through them ratepayers, have paid a waste fee with every unit of nuclear power that is generated.

The law dictated that a site in a western state be selected for permanent geologic disposal. After several years of searching and growing concern and resistance among the states that contained candidate sites, further legislation was enacted in 1987 limiting the search to Yucca Mountain in Nevada. The legislation also required of a monitored retrievable storage facility. The project is behind its legislatively mandated time schedule. The 1987 amendments required the Secretary of Energy begin accepting and disposing of spent nuclear fuel no later than January 31, 1998.

Industry has paid Department of Energy (DOE) approximately $18 billion, including interest, for taking possession of the waste and storing it. At least one congressional witness estimated that DOE could not be accepting waste until 2015.[119] By legislation, the industry was required to sign an agreement with DOE and DOE agreed to take the waste by 1998.

Utilities have filed ten cases, seeking damages totaling $8.5 billion with the estimated liability climbing to as much as $40 to $80 billion.[120] The utilities are forced to store the waste at their own expense and simultaneously pay DOE. Because reactors were all designed assuming waste would be stored for short periods before being moved off-site, the storage facilities are small. Expanding them can be somewhat costly although the larger risk is public opposition and resulting regulatory delays or even lack of approval, which could lead to plant shutdown. Since these temporary sites were not designed for long-term storage, the risks of an accident, not to mention sabotage, increase with time and volume.

One option is interim storage at Yucca Mountain or elsewhere. This position was opposed by President Clinton's administration.[121] Environmental organizations and Nevada politicians remain adamantly opposed to this option just as they are opposed to the permanent solution. The opponents argue that it increases risk by increasing transportation and interim could become permanent, so nobody wants to host an interim site.

Yucca Mountain

Source: U.S. Department of Energy

The Skull Valley Band of Goshutes in Utah is in negotiation over a possible temporary centralized storage facility.[122] Because of their sovereign status, they argue that they do not need state approval. However, the State of Utah has threatened litigation if this project receives regulatory approval.

DOE has been working solely on the Yucca Mountain alternative since the 1987 amendments. The Environmental Protection Agency released public health and environmental radiation protection standards in June 2001. The DOE must meet these standards as they design and operate the Yucca Mountain facility.

The Secretary of Energy has recommended Yucca Mountain to the President as the repository site for highly radioactive materials. The President agreed with this choice and recommended the site to Congress. According to the Nuclear Waste Policy Act, the state of Nevada then has 60 days to submit a notice of disapproval to Congress, which the state has done. The disapproval can be reversed if Congress passes a joint resolution for repository siting approval. If the president signs this joint resolution into law, the site is approved.

The current prospects for congressional approval are not good. Majority Leader Tom Daschle told reporters in Las Vegas that, with respect to the Yucca Mountain project: "As long as we're in the majority, it's dead." Former Senate Energy and Natural Resources Committee chairman (now ranking member) Frank Murkowski (R-AK) expressed similar sentiments.[123]

Other countries are wrestling with the same waste disposal problems. Canada is establishing an organization composed of all operators. Their objective is deep geological disposal.

Despite the widespread public acceptance of nuclear power, waste disposal has been very controversial in France. There was widespread opposition to long-term waste disposal. Eventually the government changed their approach. They abandoned long-term disposal and moved to stocking centers. According to officials the name and the policy implies a commitment that they are not trying to bury and forget the waste, but that authorities will continue to be responsible.[124] Germany has identified a site for long-term geologic disposal. Other countries are evaluating different options for geological disposal.

VI. REGULATION OF NUCLEAR POWER

The regulation of nuclear power has undergone a dramatic change since its inception. After World War II, the United States wanted to maintain the world leadership in nuclear technology and demonstrate the benefit of peaceful atomic energy. The original regulatory agency, the Atomic Energy Commission (AEC), began as an advocate for nuclear power. The cold war and the country's desire to maintain technology superiority added urgency to the program.[125] If the AEC was perceived as moving too slowly the Joint Committee on Atomic Energy did not hesitate to apply pressure.

In the early days, the AEC approached safety much differently than it is approached today.[126] The AEC approved a safe design, based on its judgment, but they had not attempted to research or quantify fully the possibilities and probabilities of accidents at nuclear power plants. Over time, safety became a larger and larger concern of nuclear power regulation.

The AEC came under criticism over its dual role as advocate and regulator.[127] The result was the passage in 1974 of the Energy Reorganization Act with the research and development functions being placed in the Energy Research and Development Administration, later to be part of the Department of Energy. The regulatory functions were placed in a new agency, the Nuclear Regulatory Commission (NRC).

The Three Mile Island (TMI) reactor accident exposed many flaws in the operation and regulation of nuclear power. The NRC began placing greater importance on the human factor in plant performance.[128] The NRC adapted many of the techniques of a successful nuclear power entity, the United States Navy. It developed new requirements for operator training, testing, and licensing and shift scheduling and overtime. It promoted the increased use of simulators and the assessment of control rooms and instruments and beefed up its own resident inspector program to at least two at each site. The NRC also tightened their radiation standards.

TMI increased the NRC's and the industry's concerns for safety. NRC's goal is that nuclear power plant operation should not lead to any individual bearing significant additional risk to life and health, including both operators and members of the public.[129] In particular, nuclear power should not be any more risky than other sources of electricity.

TMI gave emergency planning a major boost. Prior to TMI, emergency planning was a lower priority.[130] Not that the regulators did not consider safety considerations such as siting plants in a low-population zone, but most of the effort was in adopting safety operation and procedures that would prevent an accident from ever happening. After TMI, Congress enacted legislation to place more importance on emergency planning (1980 NRC Authorization Act (PL 96-295)). The Federal Emergency Management Agency (FEMA) was established shortly after TMI and was directed to support NRC. FEMA is responsible for ensuring that state and local communities develop emergency preparedness plans to address the off-site impacts of a nuclear emergency.

Since 1980 each utility that owns a commercial nuclear power plant has been required to have both on-site and off-site emergency response plans. These must be approved by the NRC and coordinated with FEMA. Cooperation with state and local government officials is required. The plant must identify evacuation routes and reception centers for those seeking monitoring and the location of temporary lodging. Enhanced planning is done for residents within ten miles of a plant although the planning must address a radius of 50 miles from the plants.

The NRC sees itself as moving from a traditional regulatory approach. NRC now monitors performance indicators at nuclear power plants, rather than the more specific details of plant operation. Industry had complained that regulation was inflexible. Under the new approach, the NRC still has resident inspectors. The NRC is conducting studies to identify important risk factors that bear oversight. The Union of Concerned Scientists, a watchdog group, does not believe these studies are adequate, however.[131]

Industry argues their long-standing concerns need to be resolved if nuclear is to remain competitive. The first is approval of a standardized design. In addition, industry wants a predictable licensing process that resolves design, safety, and siting issues before a substantial investment is made. Specifically industry did not want to have mid-construction design changes. In addition, they wanted the approval process streamlined, with the issuance of only one license. Historically, licensing has been a two-stage process, one for construction and one for operation. The Energy Policy Act of 1992 largely implemented the industry's licensing goals, although the proof will be in the implementation. Industry is also concerned by the NRC budget itself since it is supported by user charges.[132] This is a concern shared by the Union of Concerned Scientists (UCS), although they believe that the NRC needs additional resources.[133]

In an attempt to ease licensing, the NRC has looked at a variety of new technologies and licensed three. These plants are approved in general and can be licensed anywhere in the United States. Under federal law, all safety issues have been resolved and will not be open to challenge during the licensing of any particular plant. A single license will be issued to construct and operate the plant. The NRC grants 40 years with a possible 20-year extension.

The NRC receives ample criticism. The Union of Concern Scientists and General Accounting offices both have many reports that list what they see as regulatory failures. Some of the topics that critics claim are not adequately addressed include:

- The safety probability studies do not take into consideration all of the possible mishaps that can occur.[134]
- NRC may now or may soon lack adequate staff to ensure that the main safety goals of operators are met.[135] The NRC has a significant cohort of skilled technical people who are at retirement age.
- The NRC has not adequately addressed overtime and staffing problems in the commercial nuclear power industry. The argument of the Union of Concern

Scientists is that increased competition in the industry has led to elevated patterns of overtime and that is threatening safety at nuclear reactors.[136]

- The NRC used to have more stringent security testing measures,[****] but has since relaxed those.[137] Critics raised the specter of a terrorist driving a truck bomb into the plant.
- The NRC is not taking the possibility of accidents serious enough. Critics acknowledge that there has been significant improvement in reactor safety, especially with regards to emergency response and training. Nevertheless, they warn of complacency.[138]
- Inadequate attention is paid to plants, especially those with safety problems. The GAO looked at three plants that were closed down by their operators because of safety violations.[139] Restarting the plants would have required NRC approval and the operators decided restarting was too expensive. GAO's main finding was that NRC knew about the great majority of the safety violations for a long period prior to the shutting down of the plants. They raised the question of why these plants were allowed to continue operating.

One of the NRC's major regulatory activities is re-licensing of existing plants. NRC re-licensed the first plant in March 2000 and has granted more extensions and some are pending. Again, the Union of Concerned Scientists have raised concerns.[140] They do not believe that the NRC is putting enough resources into ensuring that the "aging management" programs of operators are adequate. These aging management programs are necessary because of the increased vulnerability of certain systems as reactors age.

The Environmental Protection Agency has a role in nuclear regulation. They must promulgate standards for environmental protection from radiation releases. NRC and DOE regulate to meet these standards for waste management, disposal, and containment.

California and the Federal government have clashed over their respective roles. The Atomic Energy Act of 1954 established, and later amendments have confirmed this, that the federal government possesses preemptive authority to regulate radiation hazards associated with the development and use of atomic energy. Although the federal preemption is not in dispute, the question is how much and what residual authority is left to the states. This dispute ended up in the Supreme Court, which held that there is a strong federal preemption over safety, but the state was left with economic regulation.

California ended up in the Supreme Court because of several statutes enacted by the Legislature. These laws were enacted in the middle of the campaign over the anti-nuclear initiative, Proposition 15 of 1976. California enacted three laws governing nuclear power. These statutes prevent the California Energy Commission from approving the siting and construction of a nuclear power plant until these specified conditions are met:

[****] This critique was written prior to the September 11 terrorist attack and almost certainly that will lead to changes in security procedures.

- The Commission must find that the U.S. has a demonstrated means or technology for the disposal of high-level nuclear waste and report its findings to the Legislature. It is an approval of a technology, not a facility.[141]
- The Commission must find that there is a facility and a technology that will reprocess nuclear fuel rods.[142] Offsite storage can be a substitute. The goal is to prevent a situation where a facility is built and must store its own fuel rods and run the risk of having to shut down or reduce operations because of inadequate storage.
- The Energy Commission completes a study on the under grounding and berm containment of reactors.[143] The Commission completed the study and the section was subsequently repealed.

Almost immediately, PG&E filed a lawsuit arguing that the state actions were preempted by the Atomic Energy Act of 1954.[144] The case eventually found itself at the Supreme Court of the United States.[145] The court affirmed the federal preemption over all safety issues and said specifically that the state cannot reject a plant because it thinks it isn't safe. However, the court upheld these statutes as applying to those areas that the states are traditionally involved in, land use, economics, need, and reliability, that is the traditional areas of ratemaking that is the prerogative of the state. The court held that the Atomic Energy Act left these concerns with the state just as the state has similar power over any other generating plants. As such these laws are designed to protect ratepayers from the economics of nuclear power, they are not safety issues per se. The lack of a means for waste disposal could threaten the economic viability of a nuclear power plant.

The court's decision effectively granted the state authority to stop nuclear development. Other states including at least Alaska, Connecticut, Hawaii, Maine, Massachusetts, Montana, Oregon, Rhode Island, and Vermont all have enacted similar laws that effectively block nuclear power.

Decision was based, in part, that a regulated utility is by nature a different entity and is subject to a state regulatory scheme. The court found that the state could exercise their traditional authority over economic questions such as ratemaking and plant-need questions."[146] If the court was content to leave the decision to the state regulatory commission, presumably because of the need to protect ratepayers, would they arrive at a similar decision when a non-regulating generating company owned the nuclear power plant and then the shareholders, rather than ratepayers would be on the hook for losses? The rationale for the legislature was a "clearly expressed desire to protect the rate-paying consumer from a possible overly-expensive energy generation alternative."[147] De-regulation has weakened California's authority over such projects. Under rate regulation the state could look at the rates, how much capital should be invested, the appropriate return, and if operating expenses may be recovered from ratepayers.

In other areas of the code, there is strong support for nuclear energy. Section 800 of the Public Resources Code has a legislative declaration of policy to encourage the use of nuclear energy, geothermal resources, and such other energy sources as are currently under development. The purpose is to promote clean air and conserve fossil fuels.

CONCLUSION

This report has attempted to lay out the risks and benefits that are involved in nuclear power. It is clear that nuclear offers some benefits and risks. Technology and the operating abilities have advanced nuclear power so there is a reasonable possibility that the plethora of mistakes that have hobbled it would not be repeated. It is also clear that some will read the report and conclude that nuclear power plants should not be built in the future and others will conclude the opposite.

A crucial part of this debate is one's views on the economics of renewables. Some argue that solar is cost-competitive in the long-term and that is a desired energy path for reducing global warming.[148] Other arguments against nuclear are that it is actually much less efficient in displacing carbon dioxide on a dollar for dollar basis than investments in energy efficiency.[149] Specifically this argument is that a dollar invested in energy efficiency saves seven times as much carbon dioxide as that invested in nuclear power. The arguments point out that although nuclear power releases much less carbon dioxide than other thermal power plants, the mining, construction, fuel enrichment and manufacturing process all release carbon dioxide.

A word of caution is in order about such calculations and assumptions about energy efficiency and conservation.

- It is one thing to suggest a given level of efficiency is economical but individual economic decision makers actually make those decisions. What seems economical in the analyst's office may not be to the individual firm or consumer. Researchers make assumptions about energy consumers' reaction to energy prices, forecasts of future energy prices, interest rates, and uncertainty. An example of this is fluorescent light bulbs. They are much cheaper to operate although more expensive to purchase. Energy conservation advocates argue they are economical and should be used more. Nevertheless, incandescent bulbs remain much more popular.
- Much of the conservation and efficiency that took place in the late 1970s and into the 1980s was spurred by higher prices and the forecast of still higher prices. To match that level of conservation and increased efficiency would be best stimulated by a very significant increase in energy prices. If those were to occur, through either market events or tax policies, they would have a tremendous impact on the economy.
- Critics of nuclear power point to the high costs of constructing nuclear power plants. If they are correct that new plants would cost the same amount, then it is highly unlikely that a nuclear power plant would ever again be built in this country, especially given the de-regulation that has occurred in the generation of electricity. No operator would ever intend to build another plant at that high price especially when they would have to bear the burden as opposed to ratepayers.
- Another cautionary note is that these analyses don't seem to take into account the historic rebound from conservation. For example, after the fleet economy

standards were adopted and more fuel-efficient cars became widespread, driving, hence energy use, began to grow. With a fuel-efficient car, driving is less expensive, so more will be done.

- The arguments against nuclear power tend to be rather absolute. For example, nuclear power can't reverse carbon dioxide emissions alone. That does not mean that it could not help, when combined with conservation.

In summary, it is not clear if nuclear power is necessary to reduce carbon dioxide emissions. However, it is clear that one way to meet reduction standards is to penalize fossil-fueled power plants to improve the economics of plants that do not emit as much carbon dioxide, whether those are nuclear power plants or renewables.

One attempt to determine the level of that impact of carbon dioxide emissions was to roughly estimate the social costs of carbon emissions. These prices were based on the cost of achieving reductions in emissions in general and are hypothetical but illustrative of what might constitute a reasonable scheme. They are based on developed country averages for prices. The amounts are certainly enough to affect the competitive position of coal versus nuclear and possibly nuclear versus natural gas.

Table 4
Social Costs of Carbon Emissions

Fuel	Cost $
Steam coal	36
Heavy fuel oil	12
Natural gas	11
Light fuel oil	6
Gasoline	3

Note: these are based on the carbon content for a standardized energy amount.
Source: International Energy Agency

APPENDIX A

OVERVIEW OF NUCLEAR POWER MECHANICS

Quite simply, nuclear power starts with uranium. Uranium is a naturally occurring radioactive metal and is widely distributed throughout the earth's crust. Its principal uses are nuclear electricity generation and nuclear weapons. Because it is dense, even more than lead, it is also used as a material for weapons and armor for tanks. It is the only naturally occurring material that can be used for thermal fission. When bombarded by a subatomic particle called a neutron, uranium will split in two and release a large amount of energy in the form of heat. Large means large, fission releases millions of times more heat than burning a comparable amount of fossil fuels. The size of the release means that very little fuel is used. The splitting of the atom is literal, meaning that the uranium atom is split and forms two other elements. Many different elements can be formed and these, in turn, split and form other elements. The heat that is released can be used to produce electricity.

Although uranium is distributed throughout the crust, it must be mined from concentrations. Although Canada was the first source of mined uranium, it is found and mined in commercial quantities throughout the world including the United States. A variety of techniques are used including surface mining and underground mining. The recovered product is uranium oxide, which after extraction requires several steps to purify and concentrate the uranium for use as fuel. Approximately 200 tons of uranium oxide is converted into about 25 tons of enriched uranium fuel.

The concentration of uranium is required to gain the right composition for nuclear fission. Uranium comes in two important forms, or "isotopes." U-238 is the most common, but it is not useful for weapons or electricity generation by itself.[††††] The much rarer U-235 must be concentrated, or "enriched," before the uranium can be used for either purpose. U-235 normally comprises about .7 percent of uranium. For use in electricity generation, it usually must be enriched to about 3.5 percent. A much greater enrichment, over 90 percent, is required for nuclear weapons. To enrich uranium, the uranium oxide is first converted to gas and then concentrated. The United States has several facilities that are involved in conversion to gas and enriching uranium for production of nuclear fuel. None of these are in California.[‡‡‡‡]

The uranium, enriched to reactor grade, is placed into fuel assemblies before going into the reactor core. A typical reactor will have several hundred-fuel assemblies, containing about 75 tons of uranium. The fuel is replaced regularly, with about one-third being replaced every three years. The reactor core is where the U-235 isotope is split in the fission process and heat is generated. This heat is used to create steam, which then turns a turbine, generating electricity. The chain reaction is controlled by the water, which

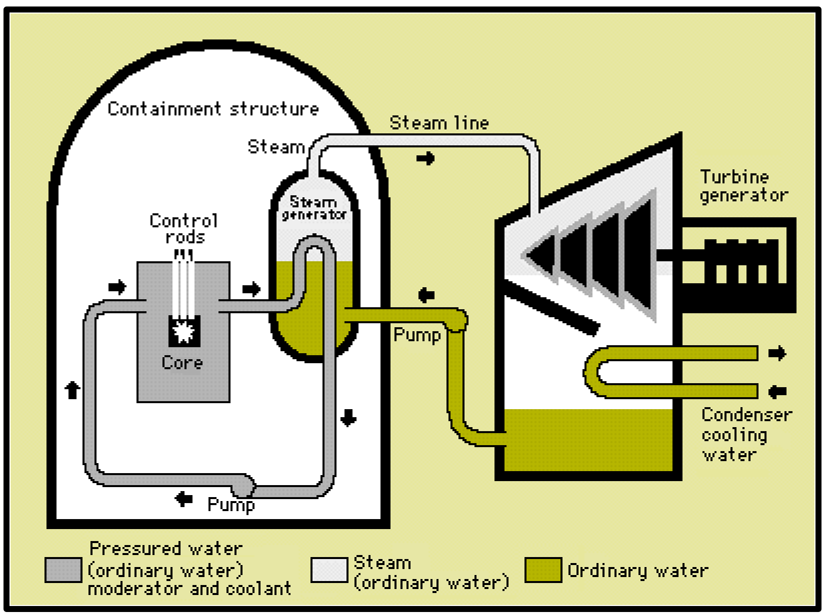
[††††] The number after the isotope is derived from combining Uranium's 92 protons (also its atomic number) plus the number of neutrons. Hence U-235 has 143 neutrons and U-238 146.

[‡‡‡‡] A small number of reactors (Canada and Britain) do not require enrichment of uranium. Although that may sound more desirable, they have other operating requirements that offset that advantage.

surrounds the fuel and neutron absorbing control rods. The control rods are critically important as they absorb neutrons and slow down the pace of fission. The reactor vessel is also flooded with water, which acts as a coolant and a moderator meaning it absorbs neutrons.

The pressurized water that circulates through the reactor core also runs through another vessel that is also filled with water. The water inside that latter vessel, which is separated from the pressurized water, is heated to produce steam, which turns a turbine, and then generates electricity. There are several other reactor designs, but this is most common both in the United States and throughout the world.

Nuclear Reactor Diagram



Source: Uranium Information Centre

Although only uranium is loaded into the reactor we are describing here, the reactor soon contains plutonium. Plutonium is a radioactive element that is man-made and the fission of uranium soon creates plutonium. That plutonium is useful in place for fuel, about one-third of the energy produced by a nuclear reactor comes from fission of the created plutonium. Plutonium and the issues it presents are discussed more in Chapter III on Health and Safety.

When the fuel assemblies are removed, the spent fuel assemblies are radioactive and very hot. They must be cooled in ponds, usually at the reactor site for approximately ten years. The water cools the fuel and absorbs neutrons, slowing the reaction. After about ten years, the spent fuel can be removed from the water and stored dry.

Like a nuclear reactor, nuclear weapons depend on fission. This does not mean that a nuclear reactor can explode like a nuclear weapon, in fact it cannot. There are two main factors that prevent the explosion of a nuclear reactor. The reactor uses fuel that is considerably less enriched than a weapon and the control rods and water serve to moderate the fission process within a reactor preventing the uncontrolled reaction that is characteristic of a nuclear weapon. The other safety systems within a nuclear reactor also serve to control the fission process.

APPENDIX B

WORLD NUCLEAR POWER REACTORS 1999-2001

and Uranium Requirements

COUNTRY	NUCLEAR ELECTRICITY GENERATION 2000		REACTORS OPERATING June 2001		REACTORS CONSTRUCTION June 2001		ON ORDER or PLANNED June 2001		URANIUM REQUIRED 2000
	Billion kWh	%	No.	MWe	No.	MWe	No.	MWe	tonnes U
Argentina	5.7	7.3	2	935	1	692	0	0	146
Armenia	1.8	33	1	376	0	0	0	0	67
Belgium	45	57	7	5728	0	0	0	0	1020
Brazil	5.6	1.5	2	1855	0	0	0	0	292
Bulgaria	18	45	6	3538	0	0	0	0	615
Canada*	69	12	14	9998	6*	3598	0	0	1326
China	16	1.2	3	2167	8	6370	2	1800	418
Czech Republic	14	19	5	2560	1	912	0	0	349
Egypt	0	0	0	0	0	0	1	600	0
Finland	21	32	4	2656	0	0	1	1000	558
France	395	76	59	63203	0	0	0	0	10513
Germany	160	31	19	21141	0	0	0	0	3707
Hungary	15	42	4	1755	0	0	0	0	354
India	14	3.1	14	2548	2	900	11	4980	312
Indonesia	0	0	0	0	0	0	1	600	0
Iran	0	0	0	0	1	950	1	950	0
Japan	305	34	53	43505	4	4492	12	15858	7334
Korea DPR (N)	0	0	0	0	0	0	2	1900	0
Korea RO (S)	104	41	16	12970	4	3800	8	9200	2480
Lithuania	8.4	74	2	2370	0	0	0	0	359
Mexico	7.9	3.9	2	1364	0	0	0	0	231
Netherlands	3.7	4	1	452	0	0	0	0	105
Pakistan	1.1	1.7	2	425	0	0	0	0	56
Romania	5.1	11	1	655	1	620	0	0	90
Russia	120	15	30	20793	3	2625	5	4050	3213
Slovak Rep.	16	53	6	2472	2	840	0	0	531
Slovenia	4.5	3.7	1	679	0	0	0	0	132
South Africa	13	6.7	2	1842	0	0	0	0	366
Spain	59	28	9	7345	0	0	0	0	1538
Sweden	55	39	11	9460	0	0	0	0	1539
Switzerland	24	36	5	3170	0	0	0	0	602
Taiwan	37	24	6	4884	2	2600	0	0	971
Ukraine	72	47	13	11195	2	1900	0	0	1878
United Kingdom	78	22	33	12528	0	0	0	0	2578
USA	754	20	104	98060	0	0	0	0	17496
WORLD	2447	16	437	352,629	37	30,299	44	40,938	61,176

Sources: Uranium Information Centre Reactor data, http://www.uic.com.au/reactors.htm

Notes:
Reactor data: based on information to June 2001

*In Canada, construction data is for four laid-up Pickering a reactors expected to re-enter service by 2003, plus two Bruce a units very likely to do so later.

IAEA- for electricity production.

Uranium Institute 2000: Global Nuclear Fuel Market (reference scenario) - for U

Operating = Connected to the grid
Building/Construction = first concrete poured
Planned = Relatively firm plans
TWh = Terawatt-hours (billion kilowatt-hours), MWe = Megawatt net (electrical as distinct from thermal), kWh = kilowatt-hour

APPENDIX C

Table 5
Summary of Accidental Deaths from Various Sources of Electricity

Energy Option	Number & type		Installation	Per event	Average
Coal	62		Mines	10-434	200
Oil	6	Capsizing	Platforms	6-123	
	15	Fire & Explosion	Refineries	5-145	90
	42	Transportation Accident	Transportation	5-500	80
Natural Gas	24		Various	6-452	200
Water	8		Dams	11--2500	
Nuclear Power	1		Chernobyl	31	

Source: Organization for Economic Cooperation and Development, Nuclear Energy Agency

Table 6
Details of Accidental Deaths from Various Sources of Electricity

Fuel	Occupational Immediate	Delayed	Public Immediate	Delayed
Coal	.16-3.2	.02-1.1	.1-1.0	2.0-6.0
Oil	.20-1.35		.001-.01	2.0-6.0
Natural Gas	.1-1.0		.2	.004-.02
Nuclear	.07-.5	.07-.37	.001-.01	.005-.02

Note: The variation occurs because of different risks, i.e. underground versus surface mining. The measurements are standardized for a constant amount of energy.
Source: Organization for Economic Cooperation and Development, Nuclear Energy Agency

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