Should Anchorage generate electricity with nuclear power?

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This essay provides background for the directors of Alaska's largest electric utility and for those who wish to understand the tremendous superiority of nuclear power for electric power generation.

Sections:

Anchorage should consider generation of a substantial portion of its electric power using a nuclear reactor as the heat source.

The 30-year shutdown in U.S. nuclear power construction

Building nuclear-fueled power plants began with great promise in the 1950's. Some of you will remember the hype of the 1950's when the low fuel costs of nuclear power made some speculate that it would be too cheap to bother metering. By 1980 no new reactor construction was being started in the United States. Only a few much delayed plants were completed after that point.

The public attitude began to change in the late 60's as the newly sensitized environmental movement started lashing out in all directions. Nuclear power was an ideal target because:

- It was new
- Public experience with it was very limited
- People had only a short track record to use in evaluating the enviros' wild claims
- It also was mysterious
- It was connected to those horrendous bombs
- It invisibly could cause cancer and death

In reality more was known about the safety and health effects of nuclear power than any of the more traditional forms of electricity generation. Unfortunately specialists who had this knowledge were quickly marginalized as self-interested participants in the industry.

Even today the health of nuclear power workers and any exposed members of the general public are intensely studied.

Comparable studies into the health effects of coal generation are not nearly so comprehensive, but do show that coal is many orders of magnitude more dangerous to both workers and the general public.

The impact of nuclear fearmongers

In the late 60's and 70's those fearful of the new technology such as Helen Caldicott, and Ralph Nader used the public's ignorance of nuclear physics to sell the idea that nuclear power generation was unreasonably dangerous. These ideas persist into the current era.

Representative of the misinformation used to discourage construction of nuclear plants were:

"Plutonium 239, one of the most dangerous elements known to humans, is so toxic that one-millionth of a gram is carcinogenic." – Helen Caldicott.

Plutonium-239 has about the same toxicity as lead. It is, however, a slightly radioactive alpha emitter and, if inhaled, can damage some cells (see *Radioactive* in

Glossary) and increase the potential for future cancer. A former U.S Senator from Alaska once claimed that Plutonium was the most toxic substance known to man. I hope he has since become better informed.

"[A nuclear accident would result in] up to 100,000 deaths and the destruction of an area the size of Pennsylvania" – Ralph Nader.

Mr. Nader does not specify the type of accident he is postulating. Even a nuclear explosion (impossible for a power reactor) would not damage a major part of Pennsylvania. One would have to violate the physical laws of the universe to get a nuclear explosion using the fuel in a power plant. Anyone with even a little knowledge of the subject wonders what Nader was smoking.

"When things went awry at the Enrico Fermi reactor near Detroit, four million people went about their business in happy ignorance, while technicians tinkered with the renegade's invisible interior. They knew what the public did not – a mistake could trigger a nuclear explosion." – M.E. Gale.

The Fermi 1 plant lost coolant to 2 of its 100 fuel assembles and some fuel melted. The safety systems all worked and the plant was repaired and resumed operation. There was no danger to Detroit (or even the plant operators). No nuclear explosion was possible.

"By the end of the decade our rivers may have reached the boiling point: three decades more, and they may evaporate… One of the causes of this thermal pollution is the spread of nuclear power across the land." – Edwin Newman.

Nuclear plants produce the same amount of waste heat as a fossil fueled plant of the same size and efficiency.

There is no end to the number of inflammatory statements because they can be made up on the spur of the moment and backed with manufactured statistics. Proper replies often require significant research so keeping up is not possible. The above examples were given so you could sample the flavor.

These statements raise fears and very pointedly ignore accurate information that might destroy their emotional potential.

The nuclear fearmongers of both present and past describe any information or research that contradicts their assertions as lies. They succeeded in sowing distrust of anyone with the technical knowledge able to expose <u>their</u> lies.

Spreading fear is a great way to gain notoriety and make money, but does not lead to good public policy.

Unfortunately for public health, fear of the unknown stopped further deployment of nuclear power in the United States for over 30 years. The U.S. -- initiator, developer and onetime technology leader -- is stalled at 104 commercial plants.

Some other nations have had similar opposition to nuclear power. Austria, Australia, Italy, and New Zealand are officially nuclear-free zones and a few countries have committed to closing their nuclear plants. Most are reconsidering.

Meanwhile, deployment worldwide has continued and there are now 334 operating plants in other countries. Nuclear plant operating experience (worldwide) totaled a cumulative 12,000 reactor-years by the end of 2005. The U.S. Navy has run 254 plants (up to 190MWt) accumulating over 5400 reactor-years of experience with no accidents.

U.S. construction was stopped by a combination of:

- lawsuits
- delaying injunctions
- over-regulation
- protests
- high interest rates,
- Three Mile Island

Regulators, under pressure from those fearful of the new technology, forced changes to plant design while construction was underway. Construction costs went through the roof. The delays generated cost over-runs that bankrupted some utilities and ran capital costs up so high that nuclear power generation became impractical. As a result no new plants have been brought into operation since 1994 (a much delayed holdover of the earlier era). An old plant damaged by fire in 1975 was restarted in 2007. Nuclear generation of electricity has stalled at about 20% of the U.S. total.

Since the 70's the public has seen decades of safe nuclear plant operation. This has destroyed much of the fearmongers influence, but has not removed nagging doubts from the earlier period.

Many people genuinely concerned about the environment have reconsidered their opposition to nuclear power generation. After seeing the environment degraded by coal power generation and the vast superiority of nuclear power, many have become supporters.

Environmentalist James Lovelock says "I am a Green, and I entreat my friends in the movement to drop their wrongheaded objection to nuclear energy."

A founding member of Greenpeace, Patrick Moore said in 1976 that nuclear power plants were "the most dangerous devices that man has ever created. Their construction and proliferation is the most irresponsible, in fact the most criminal, act ever to have taken place on this planet." He now calls for their construction as an essential part of our energy supply.

Meanwhile, improvements in operation and refueling efficiency have made individual plants a good deal more productive during their lifetimes, and the total amount of electricity produced has increased even though a few plants have been shut down.

At the same time the exceptional profitability of nuclear plants in a time of high fossil fuel costs has started a resurgence of applications for nuclear plant construction.

It appears the limiting factors in the near future will be:

- a shortage of nuclear professionals
- the skilled workforce necessary for construction
- a global shortage of high-quality components and materials.

But let's step back and review what allows these plants to produce so much power.

How does nuclear power work?

Fossil fueled plants *burn* (italicized words are further described in the Glossary) fuel to produce heat that is used

- either as a direct gas stream or
- as heat for steam production

to turn a turbine connected to a electric generator.

Nuclear stations use a nuclear *fission* reaction that produces approximately <u>2.7 million times</u> as much heat as burning coal.

This extremely concentrated form of energy is a direct consequence of utilizing natural nuclear forces (rather than molecular reactions at the atoms electron shell) to generate heat. It brings Einstein's equation: $E = mc^2$ dramatically into play. Because the speed of light (c) is 3×10^{10} cm/second, the squared term is very large. Applying his equation to the conversion of a single gram (1/454 of a pound) of matter into energy we get (after converting units) 25 million kilowatt-hours. This is approximately the electrical consumption of one million people in one day.

Since the nuclear reaction releases so much more energy, the quantity of fuel required is a great deal lower. This remarkably small fuel quantity affects:

- extraction costs
- purification

- handling
- waste disposal
- human health
- environmental health

The *fission* reaction most commonly used, splits atoms of uranium-235 into smaller atoms. These fission fragments are often *radioactive* nuclei that decay on many time scales to more stable forms.

In nature uranium-235 is only found as 0.7% of any uranium deposit. The other 99.3% is uranium-238. *Separation* of the two *isotopes* is very difficult since they have the same chemical properties and nearly the same mass.

For military purposes *enrichment* proceeds to about 90% U-235 in order to produce the dense concentration necessary to permit the rapid, self-sustaining, *fission* chain reaction in an atomic bomb. To cause this extreme effect, sufficient U-235 is brought together with explosives at a rate faster than it can heat up and force itself apart.

Enrichment for power purposes – usually to 3-5% U-235 – is sufficient to permit self-sustaining *fission*. It is not concentrated enough to be used for military purposes. Without costly further refinement it is impossible to get power reactor fuel to generate a nuclear explosion.

Viva la différence		
	Bomb	**Power Plant**
U-235 concentration	90%	3-5%
Compression	explosives	none

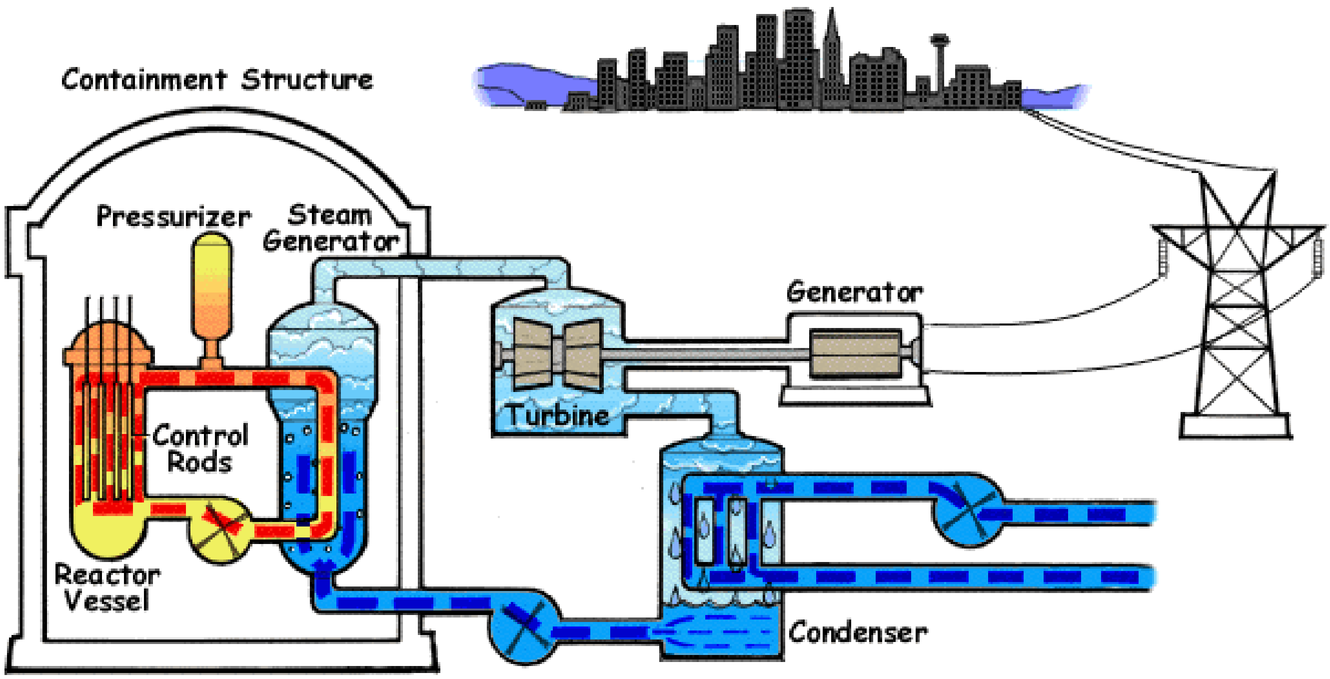
There are a number of reactor designs and new ones are being developed continually. One Canadian reactor type (CANDU) can use un-enriched uranium as fuel but requires the expensive production of deuterium oxide ("heavy water") instead.

The U.S. does have the world's largest number of plants – 104 reactors in 31 states producing about 20% of our electric power. These reactors were ordered prior to the 70's, before nuclear hysteria stopped construction. These plants were initially licensed for 40 years and most will probably be licensed for another 20 years.

The 438 reactors around the world include 2 in Lithuania that produce 83% of its power and 59 in France that produce 78% of its electricity. Even South Korea derives 36% of its electricity from its 16 nuclear reactors.

Features of a nuclear power station.

The pressurized water reactor (PWR) is the most common design in the U.S. (69 reactors) so I will describe its basic layout.



U.S. Nuclear Regulatory Commission

Fuel rods containing encapsulated uranium dioxide pellets are suspended in a matrix inside a heavy steel pressure vessel (usually about 6" thick). The *fission* reaction in the rods heats water to 322 degrees Centigrade at over 2000 psi. The water in this primary loop circulates through a heat exchanger (steam generator) to make steam. *Control rods* of a strong neutron absorber are suspended above a number of open fuel positions in the fuel matrix. They can be partially inserted to control power level or fully inserted to stop the reaction.

Lower pressure steam exits the steam generator (and the containment structure) to drive a turbine linked to a generator to produce electricity. The used steam is condensed and returned to the steam generator.

A very thick reinforced concrete *containment* structure surrounds the reactor and the primary loop to prevent any significant release of *radiation* in the event of a major failure.

This basic description does not mention significant redundancy – a fundamental part of reactor design to keep it in fail-safe mode.

Chernobyl.

All U.S. power reactors are *under-moderated* so any increase in reactor temperature above normal levels causes the reaction to slow down. Since temperature increases expand the moderator and decrease its density, *under-moderation* insures that the number of slow neutrons needed to sustain the chain reaction is reduced. This helps keep the reactor at the correct operating temperature. If a pipe breaks water temperature goes up and the reaction is suppressed.

The Chernobyl design had a "*positive void coefficient*" that violated the under-moderation design constraint. This allowed the reaction to continue as the heat increased until the moderator caught fire and a chemical (not a nuclear) explosion blew radioactive material into the atmosphere. (Chernobyl had no containment vessel). It is important to understand that western-style power reactors are designed to avoid a Chernobyl type accident.

Three Mile Island.

The incident at Unit 2 of Three Mile Island (an 880 MWe pressurized water reactor) was the worst nuclear power accident in U.S. history. A valve shutting in the line from the condenser to a pump in the *secondary water system* plus four consecutive operator errors caused meltdown of half the reactor's fuel. The fuel never escaped the reactor vessel and the containment building held in almost all the radioactive material. A small radiation release occurred when a tank overflowed before *containment* was shut down. The released radiation did not reach the level we experience from nature in ordinary life. No one was killed and the only danger to the public was unwarranted anxiety.

This incident shows that a significant failure followed by successive incorrect operator actions endangered neither the operators nor the public. The *fission* reaction shut down as the plant design intended and only operator errors in handling the residual heat caused plant damage. The operator information that permitted the errors has been corrected in existing plants. New designs now feature better operator information and make much better use of passive safety systems. The last thing reactor owners want is a damaged core at their plant.

A Comparison of Chernobyl & TMI Designs

	Chernobyl	TMI
Moderation	Over	Under
Effect when overheats	Fission continues	Reaction slows
Residual heat	Fuel rods melt, graphite moderator burns, chemical explosion	Fuel melts in vessel, no explosion
Radiation dispersal	Open to atmosphere	Held in containment

Three Mile Island's real damage was psychological and occurred in subsequent years. It aided the virtual shutdown of nuclear power plant construction and thus exposed the public to the far greater dangers of fossil fuel power generation.

Other reactor designs.

The PWR design discussed above is the most widely used and updated versions have been certified by the Nuclear Regulatory Commission (NRC). A boiling water design (BWR) has also been certified.

The smallest of these certified designs is a 600 MWe unit. Since this is larger than the entire generating capacity of Chugach Electric, other designs must be considered.

Many of these more modern designs promise greater operating efficiency, better fuel utilization, and lower construction cost. They do entail greater political risk however, since certification is by no means assured.

In the 165 to 325 MWe range several High Temperature Gas-cooled Reactors (HTGR) are in the pre-certification stage. One operated in the U.S. from 1974 through 1989 and another in Germany. Some more recent designs use fuel pebbles which are continually cycled in and out of the reactor to check for possible replacement. This should bypass the 20 day refueling period every 1.5 to 2 years that takes most reactors off line.

Many designs exist for liquid-metal-cooled-fast-reactors which greatly extend fuel life. Sodium, lead, or lead-bismuth are the metals of choice. Some of these designs are to be factory built, transported to the site and installed below ground. The one proposed for Galena, Alaska will maintain an outlet coolant temperature of 510 degrees C and have a generating capacity of 10 MWe for 30 years without refueling. It also is designed to have a 50 MWe version.

Many more designs have been proposed and some prototypes built, but commercialization has been slow in an uncertain regulatory environment.

Cost comparison.

Costs for any form of power generation consist of:

1) facility construction
2) fuel price
3) operation

Over the 40 to 60 year life of a plant the ratio of these costs depend strongly on the technology used. Typically a natural gas plant is cheap to construct but the fuel is expensive. A nuclear plant is expensive to construct but has very low fuel costs.

Operations costs are modest for natural gas generation, and higher for coal plant operation. The cost of operating a nuclear plant is high, in part, because of intense government regulation. If coal plants were subject to the same sort of safety and health scrutiny none would be able to operate.

Plant costs.

Nuclear plant utilization has been continually pushed higher and is now over 90 %. This is in spite of shutdowns for refueling that take about 20 days. Shutdown frequency is currently moving from 18 months to 2 years.

Construction figures for nuclear plants in the United States are hard to come by since no plants have been built under the current economic and regulatory regime.

Under the designs and regulation prevalent in the 70's operators saw their costs soar as the anti-technologists of the day used every sort of misinformation to delay construction. The U.S. Nuclear Regulatory Commission (NRC) gave in to far too many uniformed complaints. They often approved a set of plans only to change their mind after construction had started. The operator then had to tear out part of the construction and build again. In at least one notorious case the regulators once again changed their mind mandating demolition and reconstruction in the way it had been originally constructed.

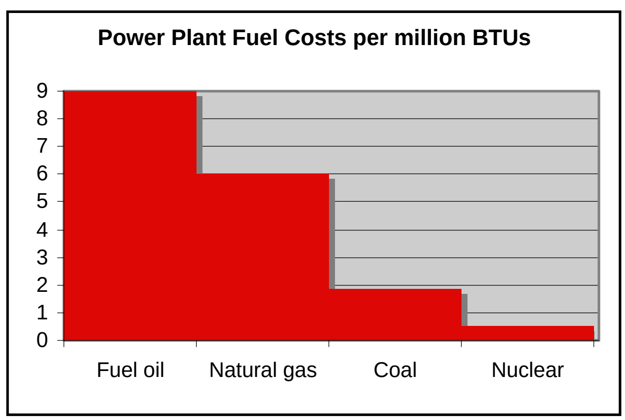
The NRC is now approving standard reactor designs and some designs can have major pieces factory built before moving to the site. Thus there is great hope that late changes and significant plan revisions can be avoided.

A 2004 estimate suggests that coal fired plants cost about $1100/*kWt* (see glossary) while a modern pressurized water plant built under U.S. regulatory control is expected to cost $1700/kWt.

Fuel costs.

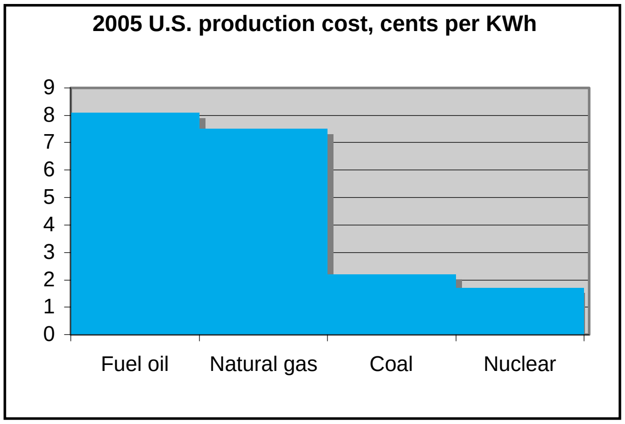
The low fuel costs for nuclear plants mean they are relatively insensitive to changes in the price of fuel. A doubling of the cost of uranium will typically raise electricity costs by 7%. Doubling natural gas prices would add 70% to electricity produced from that fuel.

In these days of rapidly increasing prices of gas and oil, nuclear plant operators across the United States are making great profit margins. Even in the 1990's the Vogtle twin reactor stations (SE of Augusta GA) were producing 15 billion kW-hours per year for 2 cents and selling it for 5 cents. Hauling away $450 million in profit each year is a nice problem for their investors.



Operating costs.

These costs vary all over the map depending on plant type, age, and regulation. Perhaps the best way to look at this uses actual production costs (fuel plus operating costs) across the U.S in 2005:



The numbers have escalated recently for fuel. The trends over time can be seen in the chart on the next page. They suggest that using oil or natural gas could be painfully expensive over the long term.

Fuel supply.

The United States has hundreds of years of coal available at nearly current costs.

Natural gas supply is a more difficult question as price has escalated over 3 times in this decade. Speculation about significant additional supplies is common. The largest methane sources such as the deep ocean, require significant new technology. However, plans for plants with a 40-60 year life must avoid speculation on potential future sources. Estimates must assume escalating costs that likely will make these plants even less competitive than they are today.

The U.S. uses uranium in a "once-through" fuel cycle. That is, we discard the 99.3% of uranium that is U-238, all of the plutonium-239, and the residual uranium-235. This limits the known high-grade supply to several hundred years.

The U.S. supply of nuclear fuel can be greatly expanded if reprocessing is permitted. Breeder reactors would produce more fuel than the U-235 they consume in generating electricity. With reprocessing the available supply could be extended to thousands of years – far in excess of the supplies of any fossil fuels.

The decision to use the once-through fuel cycle was a political one in the emotional period of the 1970's. Other countries made the opposite decision. Perhaps it is now time to try and reclaim our former leadership in this area and assure the world of adequate power into the distant future.

External costs.

Claims have been advanced that nuclear power generation imposes external costs on the public that are not captured in rate-payer charges. This is much less true in the case of nuclear power than in other forms of generation. The intense regulatory environment caused nuclear power generators to provide advance funds for many items (shutdown, waste disposal, catastrophic and health insurance) that are often deferred or foisted on the public by other power generation techniques. Under the current regulatory and tax environment nuclear ratepayers more fully finance (internalize) cost than the other generation techniques. A 2003 study by the Organization for Economic Co-operation and Development (OECD, NEA4372) concluded that although costs estimates for fossil fuels and biomass externalities are rather crude they are at least 10 times higher than for nuclear power.

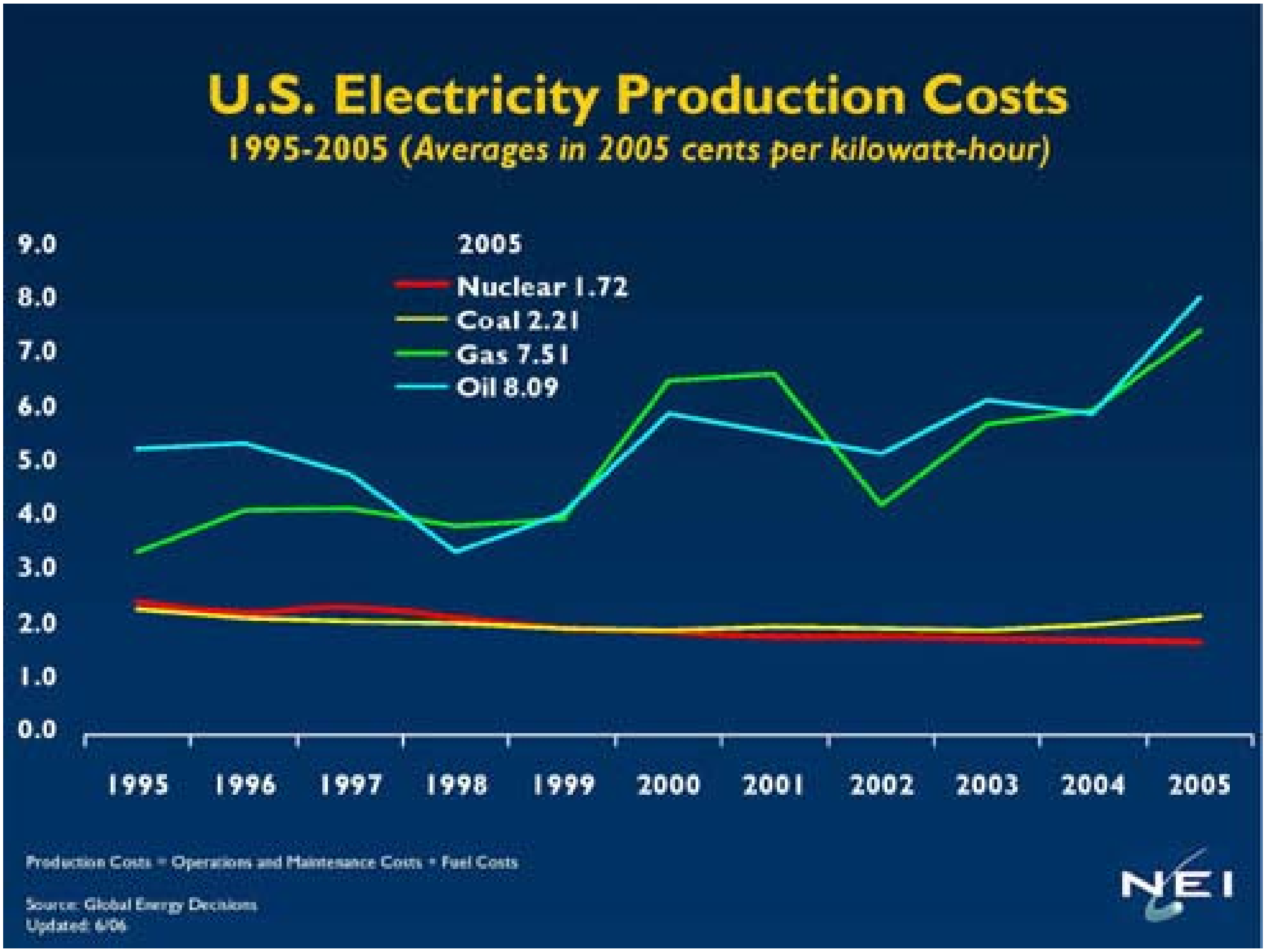
Once the health and safety concerns for fossil fuel generation are studied/regulated with the attention that nuclear has received, we can expect the internalization of these costs to add significantly to the rate-payers bill.

Overall costs.

In spite of construction cost estimating difficulties in 2005 the OECD did come up with generation cost estimates for a number of countries. For the U.S. they estimated (for 2010) overall generating costs in cents/kWh with a 40 year plant lifetime, a 85% capacity factor, and a 5% discount rate as:

Nuclear	3.01
Coal	2.71
Gas	4.67

Other sources place overall nuclear costs at or slightly below the cost of coal production. If the uncertain initial plant construction is factored out nuclear is significantly cheaper.



Source: Nuclear Energy Institute

Note: the above data refer to fuel plus operation and maintenance costs only, they exclude capital, since this varies greatly among utilities and states, as well as with the age of the plant.

Summarizing the various fuels for generating electricity

We have not previously included solar and wind power in our comparisons because they are not capable of providing the continuous baseload power necessary to a modern society. People who have not done the arithmetic keep hoping that technological advances will make them effective. Such hopes founder on problems of:

- intermittency
- low energy density
- seasonality
- poor integration with existing sources
- environmental impact.

Anyone who retains such hopes should view the very informative DVD "Nobody's Fuel." Solar and wind will remain minor sources, useful where utility power is not available and battery storage can cover the many unproductive periods.

Commodity	Advantages	Disadvantages
Coal	• relatively low costs • plentiful supplies	• produces air and water pollution • produces ash requiring disposal
Hydropower	• low pollution • very low operating costs	• may cause the modification or destruction of ecosystems • most potential hydro locations are already developed
Natural Gas	• low generating costs • low capital costs	• supply and price can fluctuate • produces air pollution, though less than some other sources
Nuclear	• does not produce air or water pollution during operation • low operating costs	• produces radioactive waste requiring carefully controlled storage • high initial capital costs
Oil	• easy to use and transport	• produces air and water pollution • supply and price can fluctuate • relatively expensive
INTERMITTENT SOURCES (potential scale too small for baseload power)		
Solar	• inexhaustible supply • no pollution during operation	• large scale projects require much land • very expensive • requires operating full backup plant
Wind	• inexhaustible supply • no pollution during operation	• large scale projects require much land • wind doesn't always blow when electricity demands are high • requires operating full backup plant • extremely noisy • too small-scale for urban areas

Cameco, 29 June 2006

Safety & health while generating electricity.

Nuclear power generation has tremendous health benefits to the general public. It displaces more polluting fossil fuels for a very significant reduction in illness and death, as well as a drastic reduction in climate altering gases. Nuclear power also has safety benefits to those engaged in the whole fuel preparation and power generation cycle. This would not be apparent if one listened only to opponents who have tried to prevent use of this new advanced technology.

All power has risks although being without power is even more detrimental to one's health. Estimates differ, but in the absence of electricity and fuel-based transportation our planet would see 2/3 of the people starve and the rest live shorter disease ridden lives of constant drudgery.

Therefore any risk estimate must be a comparison between viable technologies capable of significant power production. At present these are only coal, natural gas, nuclear, and hydro.

Hydro safety.

Hydro power generation poses more of a safety problem than a health problem. When dams rupture they affect the general public considerably.

In Vaiont near Belluno, Italy a mountainside collapsed into a reservoir and caused flooding. It killed 2,000 people and made 50,000 homeless. A number of dam breaks in the U.S have each killed hundreds of people. Careful risk calculations indicate major hydro accidents are least 10,000 times more likely than major nuclear accidents.

Health problems are the most significant characteristic of the other three power generation technologies.

Coal safety.

Coal causes, at present, an estimated 24,000 to 70,000 premature deaths in the U.S. each year from air pollution. In addition there are deaths in coal mining, and waste disposal. Even coal transport kills about 100 people a year. Burning coal releases natural radioactivity directly into the biosphere far in excess of that permitted from a nuclear plant. I have seen no estimates for the dangers from the toxicity of mountains of ash produced by burning coal.

Natural gas safety.

Natural gas produces significantly less air pollution than coal but still features many of the same atmospheric pollutants at lower concentrations.

It is also a storage hazard in many cities, particularly where LNG is delivered to tanks near a city's population. Delivery pipelines have ruptured, killed people and caused spectacular fires.

Nuclear regulation mandates a much higher level of public safety than natural gas. While the nuclear regulators were insisting on plant changes that might save one life per year at a cost of 800 million dollars, no one was willing to spend the money to move natural gas storage out of population centers. The cost of this natural gas safety precaution was calculated as less than $1,000 per life saved.

Nuclear safety.

Nuclear power generation has substantially lower risks. In fact it has had to rely on calculated theoretical dangers since no one has yet been killed in U.S. power reactor operation. This exemplary record persists even though we use nuclear generation for about 20% of U.S. power. Some reactors have been operating for several decades. Other countries have not had quite as safe an operating history, but still have far surpassed the safety records amassed by other generating techniques.

Nuclear health and safety concerns revolve around the release of dangerous levels of radiation. The maximum radiation level permitted at the plant's perimeter is less than 4% of natural background radiation.

Underground uranium mining is another matter. That and other underground mining that encounters high radon levels can produce elevated lung cancer risks. Since high-grade uranium mines often have higher radon levels than the average mine, the cancer risk is also higher if ventilation is inadequate. This risk appears to be lower than the other occupational risks of underground mining, but are not stopped by ending the exposure period. This area is subject to a lot of controversy and compensation to former miners is in dispute. Almost all of this exposure occurred in the early mining for WWII and the early cold war. Meanwhile a very much larger number of coal miners developed black lung disease.

Most current uranium mining is open pit with notably lower risks. About one-quarter of world uranium mining is now done by in-situ leaching, so the risks are very much reduced. The remaining problem is potential groundwater contamination.

Estimates of radiation danger used in the industry and in the NRC are very conservative and are known to significantly overstate the problem of low-level radiation.

Canadian experiments in cell biology actually show that cell survival is <u>improved</u> with some low levels of radiation.

An apartment complex in Taiwan was mistakenly built with radioactively contaminated reinforcing rod. The many 20-year residents showed abnormally high <u>resistance</u> to cancer.

Survivors of intense radiation at Hiroshima and Nagasaki have been followed for two generations to look for excess deaths or abnormalities in subsequent generations. The numbers were <u>not changed</u> by the radiation.

Nuclear waste disposal has received a lot of political hype. Unfortunately the government is involved and they have been charging fees to provide a facility for long-term storage. It has become a political football even though the technology is comparatively easy. Industry has paid many times the cost of the storage facility at this point. Meanwhile plants are storing waste fuel assemblies in water pools or in steel and concrete casks. Both protect the public very well but water storage requires some care and the casks will need renewal after a few thousand years.

The big problem is space since land on which some plants were built assumed they could store the waste off-site after 10 or 20 years.

The exceptional safety and health benefits of nuclear plants are a result of the extremely concentrated nature of the fuel. This means that the very little bit that is used can have exceptional care taken in its preparation, use, and disposal.

Alaska’s chance for getting nuclear power.

Alaska and particularly Anchorage have a good opportunity to use cheap and plentiful nuclear power for the following reasons:

1) We have a politically powerful congressional delegation that can assist in expediting the path through the onerous federal regulatory requirements.
2) Anchorage citizens have a one of the highest educational levels of major cities across the United States. They are more open to newer technology. These features should reduce the resistance to new technology.

Chugach currently has 499 megawatts of natural gas fired capacity and 66 megawatts of hydro generation. The smallest plant fully certified by the NRC is a 650-megawatt facility. Plants of 180, 360 megawatts are in pre-certification phase and designs have been announced for plants at the 10, and 50 megawatt size. The last three are called nuclear batteries since they are manufactured and sealed with no re-fueling or maintenance for their 30-40 year life. The larger units would require cooperation among all the South-central electric utilities, but do produce the cheapest power.

Recommendations to Chugach Electric:

1) Engage a competent nuclear engineering firm to study the potential for using nuclear generation of electricity to serve south-central utilities.
2) Hold discussions with other utilities about their future power requirements.
3) Start discussions with our Congressional delegation about federal regulatory issues.
4) Investigate the potential for nuclear plants of a size appropriate to the Alaska bush.

Should anyone ask why consider nuclear power generation you can say with full justification –

> **"Nuclear generation is the safest and cheapest way to provide significant long-term power."**

Dr. Anderson is an Anchorage, Alaska businessman and physical chemist. He wishes to thanks Ed Johnson of Sunnyvale, California for his technical fact checking and editorial suggestions and Dana G. Anderson of Anchorage for her many formatting and readability suggestions. He claims ownership of any remaining errors.

Glossary

Burn – An exothermic chemical reaction that rapidly oxidizes fuel to produce both heat and various oxides. Since the fuel is impure it also produces unwanted by-products. As a chemical reaction involving only non-nuclear forces it also produces modest amounts of heat per reaction and so requires a large volume of fuel to generate practical amounts of electricity.

Containment – U.S. reactors are built inside an extremely strong reinforced concrete building that houses the reactor vessel, a steam generator (if any) and much of the safety piping necessary to remove the residual heat in a reactor once it is shut down. The number of openings are kept to a minimum and can be blocked to isolate the reaction vessel and nearly all radiation in case of a major failure.

Control rods – Rods that may be inserted into a reactor to slow or nearly stop the fission process by absorbing neutrons. Boron is often used since it absorbs rather than slows neutrons.

Enrichment – The process of increasing the percentage of U-235 in natural uranium (which is a mixture of 0.7% U-235 and 99.3% U-238).

For light water reactors uranium-235 is increased to 3–5 % or 4 to 7 times.

For military applications the enrichment is carried to about 90% U-235.

Fission – Most atoms ignore or absorb free neutrons that come their way, however the uranium-235 nucleus splits instead. The ensuing nuclear reaction breaks a uranium-235, uranium-233 or plutonium-239 into 2 lighter mass fragments generally in the mass range 72 to 160. It also produces on average about 2.4 free neutrons (from U-235) of which one is needed to initiate the next fission.

All fragments possess tremendous kinetic energy. This kinetic energy is absorbed and converted to heat (about 2.7 million times that from chemical burning).

Isotopes – Atoms with the same number of protons, but different numbers of neutrons.

At the first level of subdivision atoms are composed of protons, neutrons and electrons. In a neutral atom the number of protons equals the number of electrons.

The number of protons gives the atom its chemical properties and its atomic number.

Neutrons have no charge and their number varies but usually increases significantly for atoms with large atomic numbers. For example the most common form of hydrogen (1 proton = atomic number 1, $^{1}H_{1}$) has no neutrons. Its less common isotope - deuterium adds one neutron ($^{2}H_{1}$). The most common form of uranium (atomic number 92) has 146 neutrons for a mass number of 238 (92 protons + 146 neutrons, electrons are too light to count).

Seven tenths of one percent of natural uranium has only 143 neutrons and so this isotope is called uranium 235 ($^{235}U_{92}$). While having the same chemical properties as uranium-238, uranium-235 has different nuclear properties and a slightly lighter nucleus. When reacted with fluorine to form UF_6 for separation, the mass difference is less than 1%!

Isotope separation – Since enrichment of natural uranium is needed for most reactor designs several methods of separation have been developed, which depend on the difference in the mass of U-235 and U-238.

Starting in WWII the U.S. used gaseous diffusion to enrich the fraction of U-235. This requires vast plants since each stage only achieves a very slight increase in the percentage of U-235. Since the capital investment has been made, the U.S. continues to use this capability although it will likely be phased out because of high operating costs.

With the development of stronger materials and superior bearings, most other nations use about 3,000 very-high-speed, cascaded, centrifuges to separate the isotopes. Most countries use this technology and the U.S. now has a demonstration plant and will build a full-scale centrifuge separation facility by 2012.

kWt – Kilowatt thermal. In our discussion it is the highest power rating of the heat source. It should be distinguished from kWe which is the power rating of a plant in terms of its highest possible electrical output. It is not possible to convert heat to electricity with 100% efficiency. Conversion efficiencies of 30% or more are considered good. The energy difference is usually dissipated as waste heat. Some plants use the heat directly or a portion of it (such as nuclear submarines), so the kWe term does not describe the entire potential of a electrical generating plant. However, if all possible heat is used for generating electricity the kWe term offers a comparison that incorporates plant efficiency.

Moderator – Since slow moving neutrons are more likely to cause the next fission event rather than escaping the reaction vessel a speed reducer (moderator) is used which slows down the neutrons without absorbing them. Water is such a moderator and is used in many reactor designs. U-238 also assists as a moderator.

Positive void coefficient – Some older Soviet power reactors and some research reactors are designed with a positive void coefficient. In these reactors the reactivity increases if the moderator which is often also the coolant decreases in density or "voids." For a description of a how one achieves a "negative void coefficient" see *under-moderated*.

Radioactive – Many isotopes are not stable and emit radiation in the process of moving toward a stable nucleus. Elements above bismuth (atomic number 81) have no known stable isotopes although the rate at which they decay varies a great deal.

In reactor processes we are concerned with 4 types of radiation:

1) Alpha particles are the nucleus of a helium atom (2 protons and 2 neutrons). The mass of the remaining nucleus is 4 units smaller and its atomic number is lower by 2 units. Alphas are very active and interact with everything so they do not go very far. If you hold an alpha source in your hand the dead layer of skin or a single sheet of paper will stop all alpha particles. They are a health hazard only if ingested or inhaled.

2) Beta particles are high-energy electrons emitted by the nucleus as it converts a neutron to a proton. They penetrate better than the alphas and do mess up the electrical nature of atoms, but have so much smaller mass that they don't knock things around like alphas.

3) Gamma rays are at the high end of the electromagnetic spectrum and carry a lot of energy. They are sufficiently penetrating that they can look through steel to find cracks or voids. They can easily knock an electron out of an atom and create a charged ion. This is great for killing bacteria but has the same effect on human cells. Too much gamma radiation will kill you.

4) Neutron radiation features a neutral particle, so they don't grab electrons. As emitted from a fission reaction they travel at very high speeds and do bump into anything in their path, transferring their kinetic energy to the target. Neutron bombardment can change the properties of materials in unfortunate ways such as making them more brittle. Therefore, careful material selection for reactors is important. Zirconium metal has shown remarkable durability in a high neutron environment. When a neutron is absorbed into an isotope it becomes an isotope with one higher mass number.

Now look at nuclei that produce radiation or are formed by it.

One half life indicates the period in which half the nuclei in a sample will emit radiation and decay to another element or isotope. Nuclei with short half-lives are very radioactive, but are gone in short order so we must deal with their products. Nuclei with long half-lives will be around a long time, but are only weakly radioactive.

For example: Uranium-238 has a half-life of 4.47 billion years, which accounts for its weak radioactivity as well as its continued presence on our planet long after its formation. On the other hand U-239 has a half-life of 23.5 minutes, so the only reason we ever have it is because it is formed routinely from U-238 when that isotope absorbs a neutron. On the other hand U-239 gives off a beta particle leaving behind an additional proton and becoming Neptunium-239. Neptunium-239 is not stable either and has a half-life of 2.35 days. It then does another beta emission gaining the proton needed to become plutonium-239. With a half-life of 24,100 years it's going to be around for a long time unless we put it in a reactor. Plutonium-239 fissions as well as U-235. Plutonium-239 from most power reactors is contaminated by Plutonium-240 making it less suitable for a bomb.

Since many of these fuel elements and products of the fission reactor are unstable and emit radiation, it is important to shield surroundings from the more intense sources. Unlike toxic chemicals, which can often be changed to benign forms via chemical reaction, radiation is a nuclear property and remains, regardless of the chemical compound in which the atom is bound.

Secondary water system – In pressurized water reactors there are two types of water circulation loops. The primary water system circulates the high-pressure water through the reactor and the steam generator. The secondary water system circulates the steam/water from the steam generator through the turbine and condenser and back to the steam generator. Both loops are served by redundant piping.

Under-moderated – As a control and safety feature all U.S. power reactors (and almost all around the world except some old Soviet designs) are designed so an increase in power beyond the optimum is met with negative feedback.

One feedback mechanism is to limit the amount of moderator allowed adjacent to the fuel elements. Since heating a limited moderator (usually water) decreases its density, it also decreases its ability to slow neutrons enough to allow fission. The amount of moderator in the reaction vessel is carefully computed for the desired operating temperature and helps maintain that temperature without any external inputs.

Rupture of a primary pipe also decreases the water slowing the reaction. Of course other provisions are necessary to deal with the residual heat if the primary loop is non-operative since the water is also the heat transfer agent.