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# ALTERNATE ENERGY SOURCES FOR THE FUTURE

An Interactive Qualifying Project Report
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## Abstract

This project examines the renewable alternatives of fossil fuels in view of their projected depletion. We concentrated on nuclear energy and examined its potential dangers and ways to improve its safety. Special attention was paid to protection from terrorist attacks, storage and disposal of byproduct. We conclude that nuclear energy is a viable energy source to replace fossil fuels in the near future.

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# Executive Summary

The world today has a great demand of energy. Fossil fuels are currently the biggest energy providers. Since oil and coal are eventually going to run out, the world biggest problem is formed. Searching for alternate power sources needs to be done before the world hits the oil crisis, so that we are ready for it when it comes. Thus, the purpose of this project is to shed light on the ongoing problems that this world will eventually have to face, and also to look for alternative energy sources.

This paper starts off with background research which looked into most commonly used energies of today's world. Oil is a cheap and efficient energy source, but it has some big down sides. Oil requires big drilling investments and it is not renewable. The fact that most of the major oil fields have already been discovered and are already exploited, and that the oil is produced at much higher rates in today's world raises major concerns. Natural gas is cheap and efficient, but is mainly traded at regional levels and it also requires enormous amounts of money to build pipe networks. The real obstacle is that natural gas trading requires economic and political stability, making natural gas very cumbersome. Solar power is inexhaustible and very clean, but the power generated is only around 15%, making it very inefficient as a major supplier. Wind is one of the oldest power suppliers and it is also clean, but it requires specific environments in order to become efficient. Hydro power is also very efficient, and clean, but it requires specific locations. So far hydro plants have been very efficient and had made a considerable difference. At last, nuclear power is one of the cleanest power sources, and also provides a lot of energy, most of which is electricity. The main problem with the nuclear power is

that in case of disaster a lot of radioactive material would be able to spread, making the area uninhabitable.

The paper then moves on towards nuclear power giving more details about how the Nuclear Reactors work. It explains everything from the process to rods and cooling systems, from what fuels them to the decontamination process. The paper also includes information about nuclear power plants in the country, as well as abroad. The WPI Nuclear Reactor's technical data, as well as safety measures are included, although this is strictly a research facility. Abroad, the paper discusses the French nuclear power plants, which is a very developed program, generating 87% of France's electricity, as well as development programs, fuel recycling and plans for the future.

There are a couple major nuclear accidents, the one at Chernobyl, and the one at the Three Mile Island, being examined in detail. The Chernobyl disaster was caused by many factors, like design flaws, infringements of safety regulations and staff errors. This disaster shows how unprepared the world was for nuclear power, the Russian scientists were taken by surprise by the magnitude of the catastrophe. There were some 20 countries affected, and financial losses of three billion dollars, which could have never been foreseen. The Three Mile Island incident happened mainly because of poor design and training.

The paper also talks about nuclear safety inside the facility as well as outside of it, where two concrete liners keep radioactive material from spreading. The nuclear power plants in France are designed to withstand earthquakes, flooding, small sized airplanes, as well as sabotage from outside. Another issue discussed is the terrorist threats. There are scenarios about planes crashes, land vehicles, bombings, boat landings, missile attacks or internal attacks, for which several anti-sabotage measures are being taken.

Next, nuclear waste disposal opportunities are brought up. Places like Mt Yucca Repository are ideal for depositing radioactive waste. For the last 20 years, scientists have argued over the importance of this repository. There are many issues discussed, like the location, the composition of the mountain, as well as moisture, transportation and deposit of the radioactive waste.

Finally, the paper provides a look into the future of fusion and how it works, as well as finding a safer place for a new nuclear power plant, keeping it far from inhabited places.

## Introduction

In today's world our society has an extremely high demand for energy, which primarily is made up of natural recourses. The most consumed resource is oil. Oil is the resource that we rely on more than any other. There is a world wide problem with this. Oil is now on high demand with a short supply left, and when it is gone it is gone for good. Alternative energy sources must be sot out and pursued. As much as we would like these sources to be pollution free, there are not any pollution free sources that are major energy producers. This problem has to be addressed and solved before the world runs out of oil.

# Background Research

## *Oil*

Global oil production is expected to reach its peak sometime between 2004 and 2008. This is a major problem considering it is already the year 2005. Oil is going to become nothing but more expensive. This will affect the entire world economy in every way imaginable.

Hubbert's predictions for United States oil production informed us that the peak would be sometime around the year 1970. This had caused some serious controversy in the states, until 1970 when it was realized that the production of crude oil started to decline. Hubbert was right. After this, his prediction methods were used for the world's crude oil production. This is how the years 2004-2008 came into play.

The way that Hubbert's prediction works is that oil production will start to slow down. As we become more and more dependent on it, with more products, like cars, we consume more of it. It also becomes cheaper to buy because more people are producing it. This is when it becomes almost a very logical choice for the consumer. Oil is a cheap and very efficient energy to use. It is at this point when the curve starts out slow and increases to a much steeper slope (Figure 1). The problem in this case is that the world only has a limited supply of it. So much energy from oil is demanded, that the resource becomes scarce, and is no longer the cheap logical choice for energy. Then the world has to turn to cheaper, more logical choices of energy. This is when the curve reaches its peak and starts to fall down in a similar manner as to how it went up.

Finding the oil is one of the most difficult obstacles of obtaining it. It is a big investment to have a company to drill down 10,000 feet to find nothing. That is why geologists for companies, like Shell, try to identify the most likely spots where there would be oil before commencing drilling. It is better than the old method of drilling next to grave yards. This was actually quite an observant strategy that they used in the past. Sometimes hilltops were created by a structural dome. In these domes the oil is held up by water and trapped in these domes. It is almost like a storage unit. This was known as "anticlinal theory of oil" – the fist intellectual idea in the exploration of oil.

Finding oil is getting harder and harder because almost every part of the world has already been tapped. If it has not already been tapped, then it has been determined that it is not a very likely place to have oil, or at least not a significant amount. The South China Sea is going to be one of the last, if not the absolute last, major oil field left in the world. Is it likely that it is going to be bigger than Ghawar? Ghawar is the oil field in Iraq which is currently the biggest one ever discovered. While it is not very likely, it is possible. The biggest fields are most likely to have already been found, and it is the fact that the bigger the target is the harder it is too miss. The chance that we have missed some of the biggest targets for over 100 years is not very likely.

As oil gets more expensive, everything from food to electricity will cost more to purchase. The cost of living is going to become very high, and the quality of life most likely will take a turn for the worse. Transporting products such as food will become a very difficult barrier. We eat food from all around the world daily. This will cause a big problem, for example, when a person would like to purchase a Florida orange, it can not simply be driven to Massachusetts and dispersed among the grocery stores. It will affect almost every part of our everyday lives. It is a problem that we have to think about before the time comes when oil becomes completely consumed. Especially, these oil fields are not renewable resources. We need to come up with alternatives before the crisis becomes even more imminent.

A major problem is predicting when the crisis is going to hit. Even though there are many experts in the world currently working to solve this problem, few want to admit that there is a six month supply left of oil. Some researchers claim we have another ten years to contain panic among society and help them keep their job. This is a major reason why some of the world's oil predictions are going as far as 2047. This is not going to happen unless a large reservoir of oil is found. Chances are against oil lasting this long.

There are some efficient alternate energy methods that are already in use today. Among these are windmills, solar panels, geothermal, and nuclear. There is a geothermal plant in California which is said that in its lifetime it can replace three million barrels of oil. What is ironic is the fact that the United States imports approximately six million barrels a day. This will solve the U.S. energy problem for about half a day. There is about the same amount of power per square foot in sunshine as there is in wind. The problem with this is about five square miles would have to be paved with solar panels to equal the power of one nuclear power plant. Which could be done, but that would be very expensive to build. It is not that the natural resources are not available to use and make useful solar power plants, but it takes large amounts of energy and money to make the material from the necessary ores. This is not a very logical solution.

With a hundred year supply of uranium in the world, nuclear power is a hard choice to pass up. It is a very powerful source, and along with this it puts no carbon into the air. However, it becomes necessary to properly and safely dispose of the nuclear waste. There are new methods used that have discovered how to reuse parts of the waste making it less toxic. The current plan that is practiced is burying the waste in a remote and isolated area where repercussions on the environment and human beings are minimal. Also another benefit about nuclear power is that it is not permanent. If we can come up with a solution to the radioactive waste, we can recollect it from their waste sites and eliminate it. With little other logical choice, people will have to become educated about the truths about nuclear power and how it is a safe and practical energy source or live in a major energy crisis.

### *Natural Gas*

Natural Gas has proven to be a rather more difficult and more expensive energy resource, compared to the oil or coal. The natural gas reserves are split into two categories. The unconventional gas is the natural gas extracted from reservoirs that are not exploitable by conventional recovery techniques. There are many different kinds of unconventional gases, like coalbed methane, tight formation gas, gas hydrates, and aquifer. We are not interested in these kinds of gases because our main concern is the use of gas as an energy resource. Thus, we will be looking into the conventional gases from now on.

In 1998 the proven recoverable reserves of natural gas reached an unbelievable 147 $Tm^3$, and in 2000 there were some 502.2 $Tm^3$ in proven and additional reserves. The recoverable reserves translate to 11,448 Trillion $ft^3$, which is predicted to supply us with energy for another two hundred years. The rate of growth is at 2.6% per year, and we have used some 17.1% of the US Geological Survey's estimate of conventional gas reserves given in 1995. Experts agree that the reserves consumption will not go beyond 41%, because of several factors, like regional trading, capital investments, political risks and concerns, and the take-or-pay contracts, which will be discussed below.

Natural gas is a trade developed at a regional level, because about 75% of the gas is traded through pipes. This limits the use of natural gas as an effective energy source. The pipeline transmission is 'capital-intensive', which means that it requires a lot of money for a company to build a pipe network in order to be able to supply the buyers. Those pipes are vulnerable and can get damaged easily, either from accidents or terrorist acts. Also they allow little or no flexibility of choice between buyers and sellers. With all this been said there are still sections of pipes out there that are as long as 4,000km, and many of them also cross borders, rivers or mountains. For example, North America is getting the supply from Canada; in Europe the distributors are the Soviet Union, Norway, and the Netherlands; in Asia, natural gas is being transported from Indonesia, Malaysia, Australia, Brunei, United Arab Emirates, and Qatar; and in Latin America the fortunate countries are Bolivia, and Argentina.

The natural gas industry raises a lot of questions and involves a lot of political risks, when a country decides to supply, or be supplied by another, mainly because of the big investment, that the supplier country will have to do in order to facilitate the gas refinement and transport. This raises a lot of political concerns and security problems, because during a conflict between two countries the gas supply might seize, thus leaving a lot of people without heat, or any means for cooking. Any regional disputes, disagreements among firms, accidents or sabotage will severely affect the integrity of the pipeline and the continuity of supply. Granted that this could happen with any other energy sources, like coal or oil supplies, but because of the limited ways to transport natural gas, a country will not be able to adapt and provide continuous supply to their residents, unless the country or firm in question will come to an agreement with them. Therefore countries have provided laws and funds to facilitate natural gas exchange. Also firms have agreed to a take-or-pay contract between both the seller and buyer, which states that no matter if they use the gas or not, they still have to buy it from the distributor for a period of time. Another risk involves electricity shortages due to the increasing dependence on natural gas in electricity production, which could also severely affect the energy supply for a region.

In conclusion, people already have thought of other means of transportation for natural gas, and that is in liquefied form, but this requires an even bigger investment for a refinery, but the transportation with vehicles will not be as cost effective as oil, because gas produces less energy than oil. Natural gas is also more pollutant than other energy resources. It also contributes to global warming and reduces human health, thus we need to make better stoves with higher efficiency, lower emissions, and cleaner fuels in the future.

## *Coal Fuels*

Coal fuels are the most abundant fossil fuel, with almost 1,000 billion tons of reserves, equivalent to 27,300 exajoules (WEC, 1998). Most of these reserves are evenly distributed around the world, making coal cheap. At 1998 production levels coal energy could last 220 years. Coal has a very negative effect on the environment causing acid rain. This led to reduce the use of coal today; however it is being increasingly used to compensate for the high prices of oil, especially in Asia to keep up with their modernization.

Coal deposits are found in sedimentary basins of different geological ages, where the production is in open-pit extraction or underground mining. Coal resources are estimated by drill-hole testing and geological observations. The three types of coal are: Bituminous coal which is a hard dark coal that has a high energy (about 16,500 KJ), Sub-bituminous coal, and lignite a soft brown coal that has low energy.

The world coal resources are estimated at more than 7,400 billion tons of coal or 4,470 Gtoe; about 500 Gtoe are estimated to recoverable. 85% of the resources are classified as bituminous or sub-bituminous (hard coal) the rest is lignite (soft brown) coal.

Three-fourths of the global reserves are located in Australia, China, India, South Africa and the United States. North America has the largest coal reserves; there are substantial reserves in the former Soviet Union and South Asia. Europe’s reserves may soon be declassified to resource.

Coal provides 22% of worlds energy and 40% of it is used for electricity. In 1997 coal production totaled 2,310 Gtoe, where 91% was hard coal (bituminous coal). China was the leading producer of coal, producing 31% followed by the United States which produced 26%. India, Australia, South Africa, each produced about 6% of coal. 90% of the world coal was used domestically. During 1997 ten of the largest coal exporters traded about 500 million tons of hard coal, the leading exporters was Australia followed by the United States.

| | **Estimated** | **Coal** | **Reserves** | |
|---|---|---|---|---|
| | (Millions of Tonnes) | (Millions of Tonnes) | (Millions of Tonnes) | (Exajoules) |
| **Region** | **Bituminous** | **Sub-Bituminous** | **Lignite** | **Total** |
| North America | 115,600 | 103,300 | 36,200 | 6,065 |
| Latin America & Caribbean | 8,700 | 13,900 | 200 | 533 |
| Western Europe | 26,300 | 600 | 47,700 | 1,178 |
| Central & Eastern Europe | 15,400 | 5,500 | 10,700 | 744 |
| Former USSR | 97,500 | 113,500 | 36,700 | 4,981 |
| Middle East & Africa | 200 | 20 | 0 | 6 |
| Sub-Sahara Africa | 61,000 | 200 | <100 | 1,465 |
| Pacific Asia | 900 | 16,000 | 5,100 | 10 |
| South Asia | 72,800 | 3,000 | 2,000 | 1,611 |
| Central Asia | 62,700 | 34,000 | 18,600 | 2,344 |
| Pacific OCED | 48,100 | 2,000 | 41,600 | 1,729 |
| **Total** | 509,200 | 227,600 | 198,900 | 20,666 |

| **Estimated** | **Coal** | **Resources** | |
|---|---|---|---|
| | (Billions of Tonnes) | (Billions of Tonnes) | (Exajoules) |
| **Region** | **Hard Coal (Bituminous)** | **Soft Coal (Lignite)** | **Total** |
| North America | 647 | 201 | 25,638 |
| Latin America & Caribbean | 37 | 2 | 1,143 |
| Western Europe | 337 | 11 | 10,196 |
| Central & Eastern Europe | 106 | 14 | 3,516 |
| Former USSR | 3,025 | 751 | 110,637 |
| Middle East & Africa | 1 | 1 | 58 |
| Sub-Sahara Africa | 181 | <1 | 5,303 |
| Pacific Asia | 7 | 5 | 352 |
| South Asia | 84 | 1 | 2,491 |
| Central Asia | 429 | 36 | 13,595 |
| Pacific OCED | 139 | 67 | 6,030 |
| **Total** | 5,021 | 1,089 | 178,959 |

## *Solar Energy*

Solar energy is one of the most environmentally safe means of producing energy today, but it is not as efficient as are some other methods. Producing energy from fossil fuels like coal and oil, are much more efficient at this time. They produce a lot more energy and are in abundance for now. Solar power on the other hand is practically inexhaustible. Unless we destroy the environment enough to create a thick cover of clouds around the globe at all times, we are pretty safe in assuming that the power generated from the sun rays does not have limitations.

The energy is generated when the sunlight hits the Photovoltaic cells (PV) and the "electrons are dislodged, creating an electrical current" (SEPA). The most widely material used for these PV cells is a semiconductor called silicon. In it are placed some impurities like boron or phosphorus in order to give the silicon the needed properties for giving up electrons when the cells get hit by photons. This energy source would be more efficient towards the equator. Even though the power output is reduced at higher temperatures, the fact that it will receive a lot more direct sunlight will severely increase the energy production.

Although the power output for a system like this is usually around the $15^{th}$ percentile, people are looking into it, because they want to develop a clean and sustainable energy source that requires no fuel, produces no noise or pollution and has no moving parts.

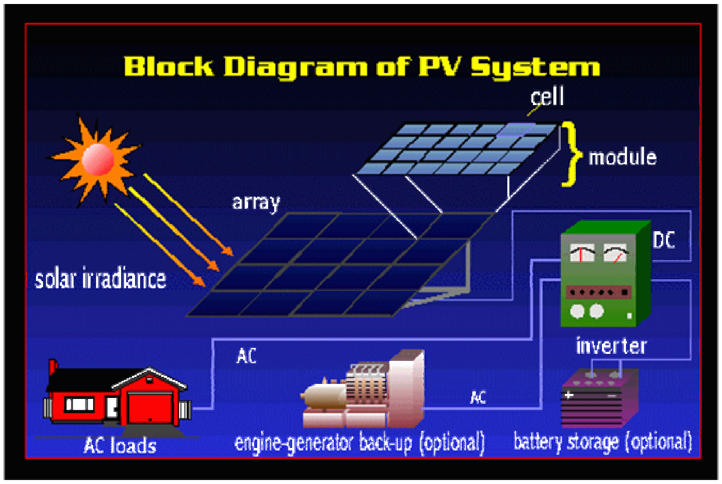



Figure 1: Block diagram of a PV system

## *Wind Power*

Wind power is one of the oldest power generating ways. To our knowledge, wind was first used to pump water for irrigation, then for sailing ships around the world, and even for grinding corn, but lately wind power has been researched and developed into a new way of producing electricity.

Wind is formed when warm air rises and cold is trying to take its place. The best place for wind farms, as they are called, is on the coast, on top of rounded hills, in open plains or in valleys between mountains. These places have strong and reliable wind drafts. In order to become a good energy resource, the wind's speed needs to be around 17 mph. The mechanism consists of four large propellers sitting on a pivot point at the top of a high tower; this allows the propellers to turn around and always face the wind outputting the maximum amount of energy (BWEA).

Although the wind is not always constant and that the propellers make a constant noise, the wind is a free energy generator. It does not require fuel to keep working, as well as it does not produce any pollution or exhaust. This makes wind power a worthy candidate for the ideal energy resources of the future.


Figure 2: Wind Farm at Novar

## *Hydropower*

The power generated by water in today's dams is considerable. There are rivers that have several dams on them. The way the power is generated is that a stream of water falls on a turbine, which converts the kinetic energy of the falling water into mechanical energy. Then, the generator is used to convert the mechanical energy from the turbine into electrical energy. However, in order to produce a considerable amount of power, a very large plant is required. For example, a "micro-hydro" can only power a few homes, or a giant dam like Hoover Dam can provide electricity for millions of people.

The components of a hydropower plant are: the dam, which is used to raise the level of the water to create falling water, the turbine, on whose blades the water falls, causing it to rotate, the generator, which is connected to the turbine by shafts and gears and is therefore spun by the former, thus creating electric power and transmission lines, that link the hydropower plant with the outside world, transporting the electricity to the consumers.

An argument for the use of hydropower plants is that they have no pollution. All they use is the law of gravity and a reusable resource – the water – to create energy. No radioactive wastes or carbon dioxide are released in the environment. It is a fully environmental-safe way of producing power. The main downside is that, in order to provide energy at the level at which is required by today's consumers, an extremely large number of plants would have to be created. Not only does this alter the natural surrounding by modifying the river trails, but it may also constitute a danger for the ecosystem. Fish usually travel along the river, from near its spring down to the place it spills itself in the ocean; by placing a dam (or more) on the river, those periodic travels are no longer possible. Fish are isolated in relatively tiny segments of the river, thus endangering the ecosystem they live in.

Hydropower plants have been used for quite a while ago, and so far they represent the most environment-friendly way of producing electricity. However, with the ever growing demand for power, thus electricity, they will not be able to face all the demand, and will have to be replaced by more efficient plants, even though this may imply that a trade-off will have to be made between the power generated and the amount of waste that is thrown in the atmosphere.

### *Nuclear Power*

Nuclear power is a source that is underestimated by the common public. People have been afraid of its potential disasters for many years. Because of that, many plants have been shut down, and yet there have been only two major disasters in its history.

Nuclear power comes from a variety of sources. It can come from uranium, thorium, plutonium, or the fusion of hydrogen into helium. As of today the most wide used source is uranium. This is because it is not as radioactive and hazardous as plutonium, and there is a large supply of it on earth.

Nuclear power is considered a more dangerous energy source than most others, but it is very effective in producing lots of power for the world's constant demands. With nuclear technology and the advances the world has made with nuclear power it has become a very safe and effective power source. To put the potential of nuclear power into perspective; the fission of one uranium atom produces approximately ten million times the energy from burning one atom of coal.

Besides the fact that the amount of power that can be produced with a nuclear reactor is so high, it is a very clean energy source, too . There are no emissions that are put into the atmosphere. The only waste that the plants produce is solid waste. There are already solutions on what will be done with the disposal of this waste, which will be discussed later.

The history of nuclear power has had its disasters, but this is to our advantage now. Engineers know what went wrong in each one of the last accidents. This allows everyone to learn from the history. The reactors that we are designing today have safety features to prevent all of what went wrong in the past. Nuclear scientists and operators know now what a serious disaster could happen, and what to do not to let it happen again.

# Analysis

## *How Nuclear Power Works*

A nuclear power plant works the same way a hydroelectric dam or a fossil fuel plant work. The plant spins turbines that are attached to a generator which produces power. While, in the dams the water flowing through the turbines is what spins them, in fossil fuel plants along with nuclear power the heat generates steam which spins the blades.

In nuclear power plants, uranium, or any other nuclear fuel, is made into ceramic pellets that are put into metal fuel rods. These metal fuel rods are put in the reactor's core. These are the rods that produce the heat. The heat is what creates the steam which will eventually spin the turbines.

The heat is created from the uranium (uranium is chosen for example because it is the most popular) going to a controlled fission process. Fission is when a neutron runs into the uranium atom. When this happens it causes the atom to split in two, giving off large amounts of heat. To keep the amount of heat under control, control rods along with borated (boric acid) water is used. The borated water can slow down, or speed up the reaction to produce more or less heat. The control rods can do the same, as well as stop the reactions all together. They are rods that can be raised in between the fuel rods to stop the chain reaction of fission.

This is a basic equation that can be helpful when determining how well and controlled the reactor is running.

$$Keff = v * F/(F+C) * (1-L)$$

F = fission rate in the medium
C = neutron capture rate
L = fraction of neutrons produced which leak from the system with out causing fission or being captured
v = average number of neutrons produced

In the nuclear reaction there are two possible states. That reaction is considered to be good or constant when Keff stays the same. This means that the power level and reaction is staying constant. When the Keff is going up or down the reaction is considered to be unstable or critical. This means that the reaction could die off, or become too fast. If the reaction becomes too fast it could be a problem, since this could cause a melt down of the core.

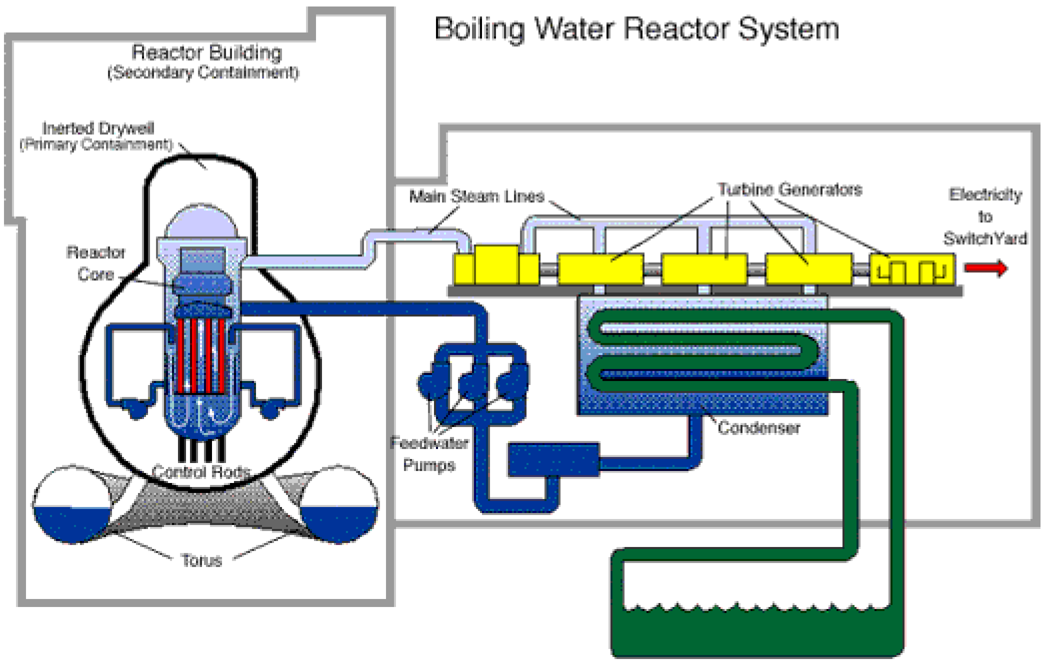
The water that is actually in contact with the fuel cells is heated to a temperature of about 300$^{o}$C. This water is kept under very high pressure to prevent it from boiling. The tubes that it travels through are then passed through steam generators. These are a second batch of water. The heat is transferred to the secondary water which boils and produces steam. This steam is then routed up through the turbines. It then spins the turbines and therefore power is produced.

Once the power is produced the steam is then run through a cooling system and cooled down back into water. Then it is pumped back into the steam generator to be reused and transformed back into steam.

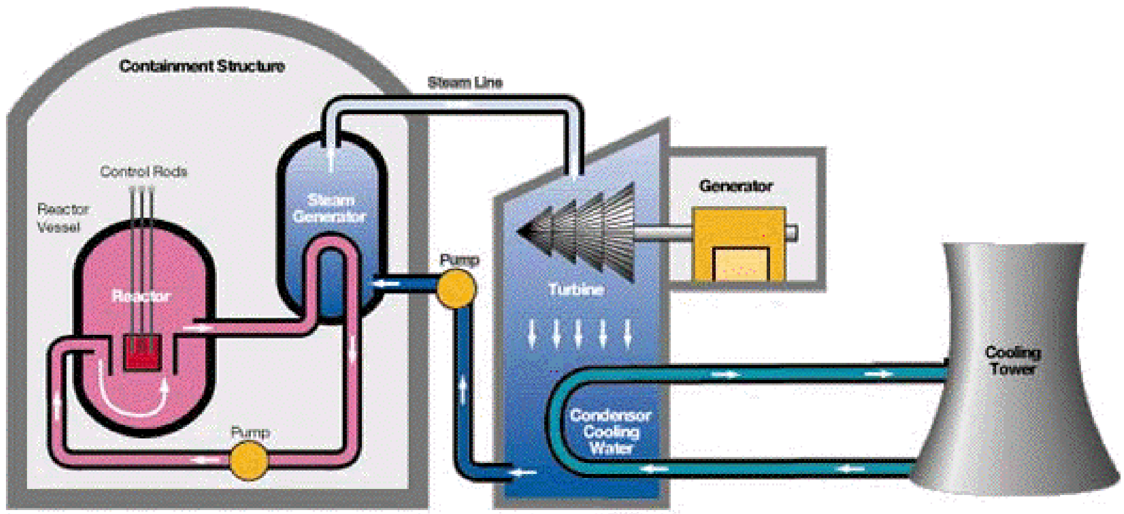
In a boiling reactor, the water that is transformed into steam is the same water as in the core, so the only difference is that there is no pressurized water that goes through and boils. It is essentially its own steam generator.

The water that cools off the reactor is kept separated from the rest of the water in the reactor. This is to assure that the water stays non-radioactive. This is done for obvious reasons such as not contaminating the river or the lake that the water is being dumped into. This water that comes out of the plant is drinkable as long as the water that went into the plant is.

This is a general reactor that runs on boiling water.




This is a general reactor that runs on pressurized water.



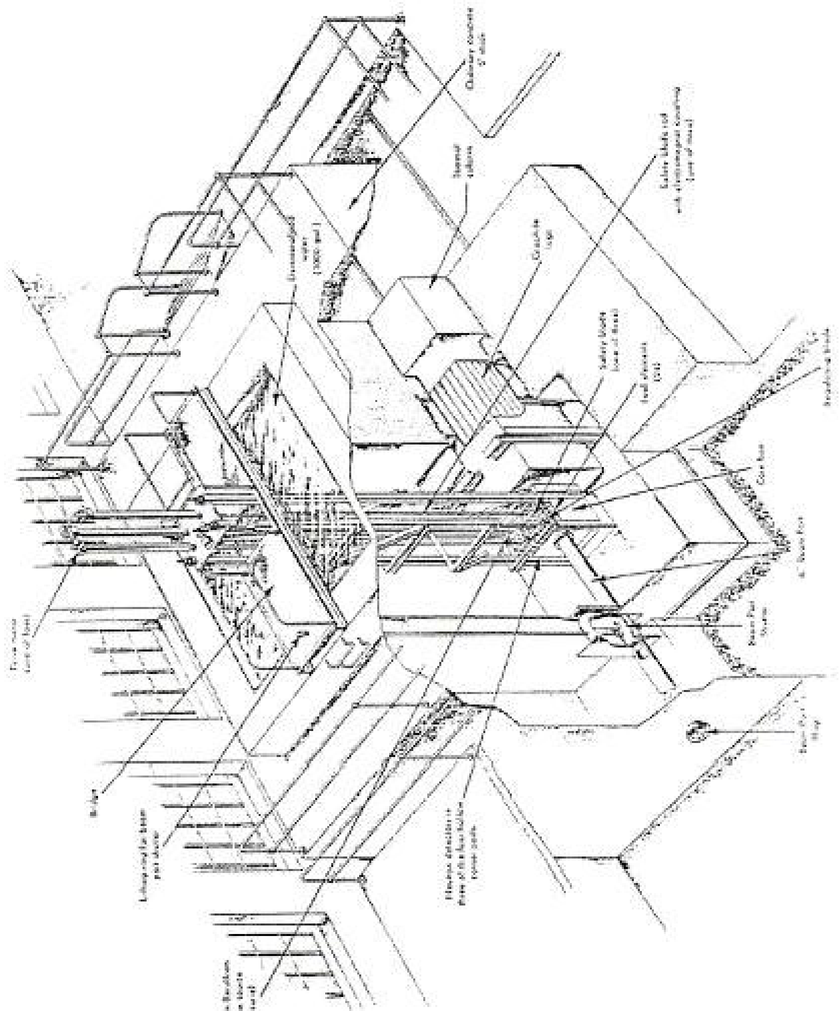

### *WPI's Nuclear Reactor Facility*

The reactor was constructed by General Energy Company for Worcester Polytechnic Institute as a 1kW reactor in 1959. It first achieved criticality in December of 1959, but the reactor got upgraded to a 10kW maximum thermal output reactor in 1967 and it now covers 4500 $ft^2$ in Washburn Laboratories. The reactor's fuel was changed from 93% to 20% enriched Uranium in 1989. The reactor is a "swimming pool" type reactor, and it sits at the bottom of an 8 x 8 x 15 foot pool of demineralized water inside a 5 foot thick aluminum wall. The reactor core consists of 21 fuel elements arranged in a 15" x 24" grid, and each fuel element consists of 18 fuel plates, which are composed of an aluminum-uranium alloy. The aluminum plates help for a better water flow to the reactor. At full power the water surrounding the reactor raises to 80º F, and because of this low power level, the fuel burnup throughout the years has been minimal. At shutdown there are .02 mm REM over the pool, and the average radiation while in critical operation mode is about 2mm REM over the pool. A worker is allowed to get 100 mm REM per week. To reduce exposure they reinforced the reactor room's walls and ceiling with lead, thus they do not have to cancel classes above the facility whenever they run the reactor at full power anymore.

The reactor is controlled by three boral safety blades and a stainless steel regulating blade, and the insertion of any of those blades will terminate the reactor's operations. In a worst case, like when the core is crushed there is very little or no exposure expected. The reactor allows experiments to be conducted through a 6" Beam Port and a graphite thermal column, and the open pool design facilitates observation and the measurement of power when core is critical. Those facilities allow neutron radiography and neutron diffusion studies, but there is also equipment provided for sample neutron irradiation and radioisotope studies. The reactor includes two germanium detectors with microchips and several scintillation detectors which allow gamma-ray spectrometry as well as gamma or beta counting.

This reactor was build for research purposes only, and it serves as a good research facility on campus. It allows students to make experiments like instrumentation analysis, critical reactor operation, critical mass determination, flux mapping, activation analysis, the creation and use of radioisotopes, neutron radiography, and shielding studies. As well as several projects using neutron activation analysis (NAA), like detection of mercury in fetal blood, riverbed contamination by industrial metals, superconductor composition and fingerprint analysis. Those are a variety of experiments and projects that have been conducted at WPI's nuclear reactor facility, but there are other areas of study like real time and still imaging using neutron radiography, radiation damage studies, and cancer therapy using boron tracers, that have been conducted here. The facility also serves as a training facility for the students interested in nuclear power plants.

There has been word of decommissioning the Nuclear Reactor Facility but there has not been a proposal made yet, but the estimates of the expenses for decommissioning the reactor fall between 1-2 million dollars. So, as a short term solution the school choose to keep it but limit its use.



WORCESTER POOL TRAINING REACTOR

## OCCUPATIONAL EXPOSURE RECORD FOR A MONITORING PERIOD

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| DOSES (in rem) | | |
|---|---|---|
| DEEP DOSE EQUIVALENT | (DDE) | 11. 0.001 |
| EYE DOSE EQUIVALENT TO THE LENS OF THE EYE | (LDE) | 12. 0.001 |
| SHALLOW DOSE EQUIVALENT, WHOLE BODY | (SDE, WB) | 13. 0.001 |
| SHALLOW DOSE EQUIVALENT, MAX EXTREMITY | (SDE, ME) | 14. ND |
| COMMITTED EFFECTIVE DOSE EQUIVALENT | (CEDE) | 15. |
| COMMITTED DOSE EQUIVALENT, MAXIMALLY EXPOSED ORGAN | (CDE) | 16. |
| TOTAL EFFECTIVE DOSE EQUIVALENT | (BLOCKS 11 + 15) (TEDE) | 17. 0.001 |
| TOTAL ORGAN DOSE EQUIVALENT, MAX ORGAN | (BLOCKS 11 + 16) (TODE) | 18. 0.001 |

19. COMMENTS

PERMANENT TO DATE (IN REM)

DDE : 0.082
LDE : 0.081
SDE,WB: 0.084
SDE,ME: 0.270
TEDE : 0.082

| 20. SIGNATURE - LICENSEE | DATE SIGNED | 21. DATE PREPARED |
|---|---|---|
| | | 05/17/04 |

- FORM5 Q N1 I 1 1 1 Q INCEPTION DATE: 10/15/98 ONLY PAGE 1

### *French Nuclear Power*

France is a country capable of heavy engineering, but with very little indigenous energy resources, which pushed its government into seeking alternative ways of providing energy for its residents. Nuclear development took place in France as early as 1945, but it wasn't until 1956 when for the first time electricity was generated from a nuclear reactor at Marcoule, in southern France.

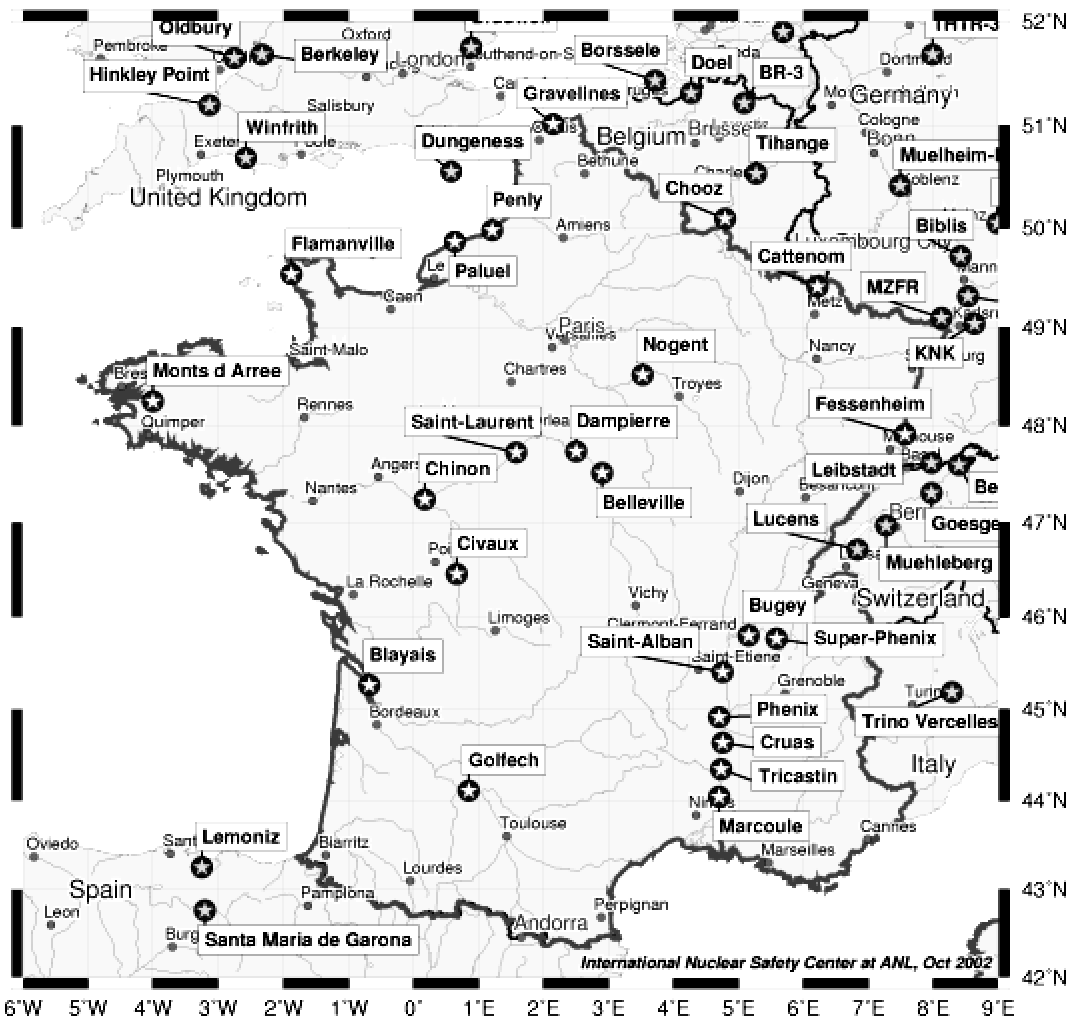



Figure 1: The locations of all the Nuclear Power Plants in France as of 2003.

As the map in Figure 1 shows, France now prides itself with 58 nuclear reactors, which have a total capacity of over 63 GWe, and supplying over 420 billion kWh per year of electricity. There are three main types of Pressurized Water Reactors (PWR). France has thirty-four 900 MWe, twenty 1300 MWe, and four 1450 MWe nuclear reactors. There are various systems for nuclear power plants and France uses one of the safest and most used around the world. The French nuclear power plants built by Electricité de France are pressurized water reactor systems, which are fueled by slightly enriched uranium or MOX (mixed uranium and plutonium), they have ordinary water moderator as, and pressurized ordinary water as a heat exchanger fluid (edf). These nuclear reactors produce over 75% (Figure 2) of the electricity needed in France, as reported by Electricité de France (EdF).

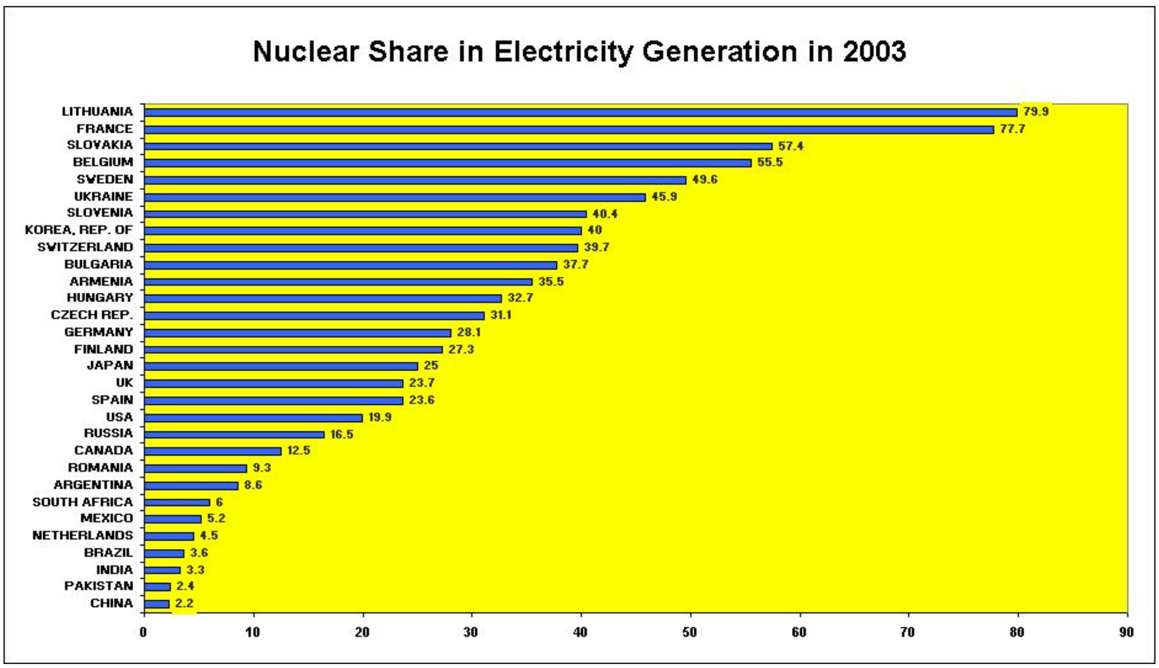



Figure 2: Nuclear power percentage in Electricity generation.

This massive power output from nuclear reactors in combination with the Hydropower, gives France the unique stature of energy independence. The energy received from both nuclear and hydro power plants, amounts to an amazing 90% of France's total energy requirements. France's exports reached 63 billion kWh in 1999, which brought an income of about 2.6 billion Euro (edf). This initiated a joint program between Framatome (France) and Siemens (Germany) of developing and improving the existing PWR. They have developed a European Pressurized Water Reactor (EPR) which has an output of about 1600 MWe, and they are trying to have it built in the near future (edf).

The development and sustainment of a nuclear program proved to be very difficult for the French government, especially when word of the potential disasters that accompany the nuclear power plants reached the citizens of France. Chernobyl's disaster and the Japan incident struck a defining blow in the midst of the nuclear program already present in France. Thus, the nuclear program already in place lost a lot of believers and supporters, among the general population. These raised more concerning issues, like if France is willing to be the sole nuclear power producer for the entire Europe, while the other countries will just import electricity, and not actually build a nuclear power plant or implement waste management programs like France's. Despite the fact that gas-fired thermal stations require only one fourth of the initial investment that a nuclear power station require, the government in France still supports nuclear power, after all it is the cleanest and the most environmentally safe (US – France Analysis). Also France instituted a program that recycles the nuclear waste from all those reactors, and it allows it to generate 30% more power from the same Uranium, after it has been enriched and prepared for the nuclear reactions (edf). This gives process not only allows more energy to be produced from the same fuel cells, but also the products from the second reaction are less radioactive and less dangerous than initially.

France has a lot of laws concerning the nuclear power program, but it also has prospects that need to be met. The government introduced a successful conservation of energy policy, but it clearly depends on the willingness of the country to invest in energy saving projects. Thus, it is still debatable if the most efficient means to meet the future energy targets is through energy conservation, or if it will be easier to just continue with the renovation and the building of new nuclear power plants. The complete renovation of France's nuclear power stations would cost approximately $ 1 trillion (US – France Analysis).

## *Nuclear Accidents*

### *Chernobyl*

#### Design issues of the RBMK Reactor

The Soviet Union nuclear program was so hushed that there were no technical design plans of any of there existing power plants in the U.S.S.R. They wanted the nuclear program to look near perfect that any reactor design flaws or infringements of safety regulations was hushed up. After the Chernobyl accident the Institute of Atomic Energy in Moscow declared that "… the main cause of the accident was a freak combination of infringements of rules and working practices on the part of the reactor staff, under which faults in the design of the reactor and it automatic control and safety systems became independent." (Chernousenko, p72) But a British group considered the mistakes of the operators as a contributing factor and the American experts blamed the reactors trip mechanism for causing the explosion. A. A. Yadrikhinskii, a safety inspector at the Kursk nuclear power station writes, "The nuclear accident- the explosion of block 4 of Chernobyl Nuclear Power Station – was the result of the infringements of the SRNPS-04-74 regulations by the chief scientist officer and chief designer." (Chernousenko, p74) Some of the SRNPS safety rules that the designers had to follow were that the reactor should have quickly shut down when: 1) power output reaches a dangerous level, 2) dangerous power surge, 3) technical faults developed which make it necessary to trip the reactor, 4) emergency button is pushed. The RBMK design had 32 infringements of the SRNPS and GSG regulations.

The RBMK reactor blocks are powered by a reactor that is a descendent of the industrial uranium-graphite reactors of the Siberian NPS-type which could deliver 0.6 million kw; however the reactor blocks of Chernobyl were running at 1.0 million kw.

The safety violations and errors committed by the staff should have caused the reactor's emergency system to shut it down, but the emergency system didn't function correctly. Since the fail-safe mechanism did not work, the last action taken by the staff was to shut down the block which eventually lead to a catastrophic growth of power ending in a meltdown due to power safety designs. Three seconds after the emergency button was pushed the power level increased from 200 MW to 520 MW and the alarms went off but the accident prevention system failed to trip the reactor. During the fifth second the reactor blew, throwing 190 tons of the reactors fuel into the environment. The reactor power level increased when the control rods entered the core because the rods had the wrong length creating a brief power surge. An IAE report said that the pressing of the emergency button when the reactor was in that state lead to an increase in reactivity and runaway of the reactor. Another safety flaw with the control rods was that they were inserted too slow in the reactor core, taking 18 to 20 seconds, while it only took five seconds for the reactor to blow. After Chernobyl, the RBMK reactor's control rods were modified to fully insert in 2 to 2.5 seconds. Yet another faulty protection system design was that the core height was 7 meters and the length of the water displacer was at 4.5 meters. The reactor was a graphite-moderated fuel reactor, where the graphite is used as a moderator to slow down the neutrons in order to ensure optimal speed for a fission reaction. Bundles of rods are inserted into pressure tubes placed in the graphite moderator block. Fission heat converts the water rising through the tubes to steam which drives the turbines and is then re-injected to exploit the remaining heat. The core is simply confined by a steel mantle that has a layer of inert gas in it.

The original drawings of the Chernobyl reactor in 1965 had control rods that would have an absorbing section and full-length displacer of 7 meters. But the 1969 technical drawing showed groups of control rods with shorten absorbers and displacers of 5 to 6 meters, with thin-film-cooling of channels, thus eliminating the positive surge and speeding up the control rids going into the core. The working drawings showed the control rods with shortened absorbers and displacers and with water-filled channels instead of the rods. They did not put the thin-film-cooling channels in because they were more expensive to construct.

No independent or external groups analyzed the RBMK plans at the design stage. However the designers did carry out a very poor analysis of the reactor mainly because of the inadequate experimental facilities, and the lack of available computer technology. Also the Soviet nuclear science program was a monopoly so the RBMK reactors were not subjected to any serious tests or trials of their durability.

## Infringements by Staff

The operational surplus reactivity (OSR) was limited to 15 rods recommended by the chief designer. This recommendation was broken by the staff since the OSR value stood at 18 to 19 rods thirty minutes after the accident. Since the OSR was violated the safety system should have shut down the reactor but the design flaws did not allow that. A second infringement was when the staff was experimentally running the reactor at low power output levels at a lot less than 700 MW, where at this state the RBMK reactor had self-accelerating properties. The reactor should not have been running at a lower than 700 MW output but the staff had no knowledge of this because no documents at this time mentioned the minimal power output limit. A third mistake the staff did was having certain few pumps during the experiment work at a rate of 8000 cubic meters per hour. All the pumps should have been running at a rate of 7000 cubic meters per hour when the input of water is less than 500 tons per hour, but running some of the main circulation pumps at higher levels did not cause the explosion. What put the reactor in danger was having a large flow of coolant when the reactor was at low power output causing conditions for a maximum stem-void effect to occur. But the staff did not know the danger of running the reactor in this state because no restrictions were put in effect when the reactor was in this state. The last infringement was when the chief chose to disconnect the emergency reactor cooling system (ECCS) completely. The ECCS system admits water to the MFCS and fuel channels when there is a large diameter rupture in the MFCS pipe preventing the emptying of fuel channels. The reasons the chief engineer shut down the ECCS was because the ECCS admits cold water into MFCS pipes which are heated 300ºC; this could lead to further rupture of the pipes. Also, the ventilation and cooling system, with its emergency cooling capacity, was in operation, and after the experiment the power plant was supposed to shut down for repairs. But if the ECCS system had been online it would not have prevented the explosion, because before the reactor exploded there were no signs of a rupture in MFCS pipes. And if there had been a rupture it would have take four to five seconds for the ECCS system to send the water to the core.

## After the Chernobyl Disaster

There are but a few people, like the staff of the nuclear facility and the firefighters, who saw the explosions from the beginning of the accident. At the time of the accident Daniil Miruzhenko, a watchmen, rushed to the window, upon hearing the first couple of explosions. He was about 300 m away from the reactor No. 4 looking through the window, when the full blast of the explosion reached him.

> Just then came the final, most terrible explosion, a thunderclap as loud as the sonic boom of a jet fighter, and a flash of light, which cast a glow into the office where he was standing. The walls shook; the windowpanes shattered, and some were blown out; the ground quaked beneath his feet. A pillar of flames, sparks, and red-hot fragments of something or other shot up into the night sky. Bits of concrete and metal structure could be seen tumbling about in the air, above the flames. (Medvedev, p.83)

There were about 270 people working on the plant on the night of the accident, and the radiation was up to 1 or 2 roentgens per hour, besides all the dust particles and all the debris that was in the atmosphere. Most workers did not assume that the explosions and the sonic boom were part of a nuclear disaster. There were also a couple of fishermen down river from the Nuclear power plant. By morning their skin was tanned, like they have just spent the last month on the beach. They found themselves on their way to the Moscow clinic later that day (Medvedev, p.87).

Granted the Chernobyl incident was the biggest nuclear accident, but what made it a disaster, was the way in which it got handled. At first the staff was unsure about what happened. The scientists, knew of the danger from a nuclear power plant explosion, but they did not get involved until later on, when the commission assembled by the Communist Party in Moscow, showed up to the scene. The staff members knew about how the machinery operated and what they needed to do in order to ensure the smooth running of the facility. We now know that they took a big risk by shutting off all the emergency systems and regulators in order to perform the tests. The safety and emergency system's shut down was suggested repeatedly to other nuclear facilities beforehand, but none of them agreed to it, since it was left at the discretion of the crew. The new personnel hired were not expected to know the physics behind the nuclear reactor, and I was under the impression, that not even the rest of the crew or the chiefs knew them.

Another factor that contributed to the creation of a nuclear disaster was the fact that the chief engineers from the nuclear power plant did not believe that the reactor No.4 blew up, until the early hours of the morning, thus allowing massive amounts of radiation to spread throughout the air (Medvedev, p.117). They have sent the staff to find the colleagues that were not responding to the calls, and also send two members to manually push back in the gammed control rods. They did not believe that the reactor blew, not even when two staff members came and reported that there were no control rods, or even a cover on the reactor, and that the reactor was just not there anymore.

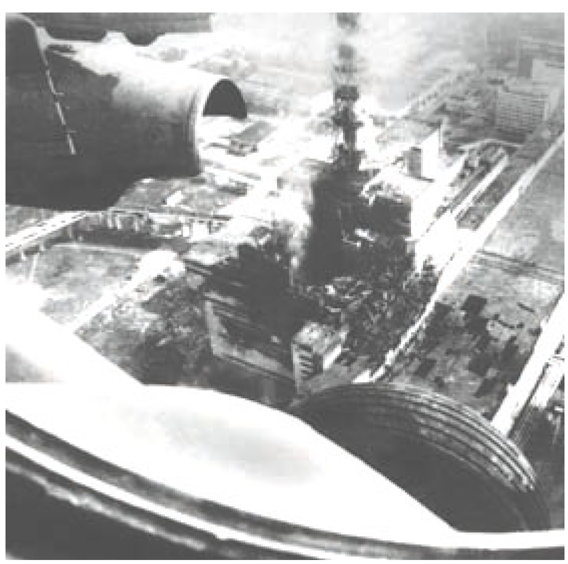


Figure 1: Reactor No. 4's explosion

The chiefs went outside towards the No. 4 generator to take a look, but all they saw, besides the radioactive materials and the parts from the reactor's cover, were nineteen fire trucks around a massive hole pouring water in order to extinguish the flames. Because of these mistakes, they were not able to make the right decisions, thus sending people to their deaths by giving them orders to approach the reactor and do various task on it. They sent also workers in search parties to find the missing people or do specific tasks without the proper gear, which was destroyed in the explosion. They also allowed water that was meant to cool down the reactor, to be pumped it in the chambers below, thus flooding the rooms underneath the reactor and adding electrical short circuits to the whole disaster, nearly shutting down all the reactors and their fail monitoring systems (Medvedev, p.108). They were also not be able to warn the firefighters and other people about the danger, as well as disregarding as "faulty equipment" what was supposed to measure the radioactivity and the amount of roentgens in the air around them. All these factors contributed to the creation of a worldwide disaster.

Figure 2: The damage of Reactor No. 4 after explosion

At first they did not have the right measuring devices, because one of the bigger scale devices was broken and the one that could go up to 1,000 roentgens was in the safe buried underneath massive amounts of concrete (Medvedev, p.101). But, when one of the engineers showed up with one that was measuring up to 250 roentgens and it went of the scale in places, they considered it faulty.

Later that day when Major General Antoshkin showed up at the site and he was horrified by the inability to repair the damage that was already done or even just to stop the radiation. His first priority was to find ways to close up the reactor, so no more radiation could go through. He called helicopters to his aid, and had some 100-150 people from the towns near by come and help them fill bags with sand and load them in the helicopters, which will later be dumped into the hot open reactor (Medvedev, p.193).

Figure 3: People helping to put out the reactor

Initially there were no measures taken to protect the people that were directly above the open reactor, where the readings indicated as much as 500 roentgens per hour (Medvedev, p.190). Later on, lead protection was provided to the passengers and the pilots of those helicopters (Medvedev, p.194). Initially the dumping of the sandbags from 350 feet in the air, made the situation worse, because the dust got propagated into the atmosphere, and the impact of the bags only served in releasing more energy, thus further feeding the radioactive things in the reactor.

When the committee was assembled, the information provided to the scientists in Moscow was wrong. Instead of being an accurate and complete description of the damage, it was grossly inaccurate approximation. They were told that the reactor is intact and that water is being pumped into it. The government also failed to inform its citizens of the disaster that occurred and to take the necessary measures in the evacuation of Pripyat, which was the nearest town. Thus, leaving a lot of people with the false hope of the return to their homes and no more than a mere three days supply (Medvedev, p.181).

Figure 4: People evacuating by train the area surrounding Chernobyl

In conclusion, the accident from Chernobyl was poorly handled, for the mere reason that the people that worked in the facility failed to understand the reactor’s physics and design, as well as its potential risk to the environment surrounding it.

## Chernobyl's Overall Effects

Chernobyl was the most serious and the most horrifying nuclear power accident. It had some “1,000 immediate injuries, 31 deaths, 135,000 people evacuated from their homes in the Ukraine, and at least $3 billion in financial losses” (Flavin, p.5), as it was reported in 1987. The researchers in the field estimated the resulting cancer deaths to be from as little as 1,000 to as much as 500,000 people. In any case there seems to be a strong correlation between the nuclear disaster at Chernobyl and the rise in the cancer rates and deaths in the region (Flavin, p.5).

Scientists were surprised by the magnitude of the disaster and the extent of the contamination area. The explosion and the graphite fire lifted the radioactive materials high into the atmosphere, where the high-speed winds circulating around the continent pushed them throughout Europe. For the first couple of days the radioactive cloud was carried northwest towards Byelorussia, Latvia, Lithuania, northern Poland, and as far as Scandinavia. From the second to the fourth day, the cloud moved west and southwest, and the radioactivity settled in Ukraine, southern Poland, Austria, Czechoslovakia, southern Germany, Switzerland, northern Italy, as well as eastern France. After which the winds carried the cloud across Romania, Bulgaria, Yugoslavia, and Greece. In the fifth day the cloud turned northwest again, hitting central Germany, the Netherlands and Great Britain. After which it finally turned northeast and headed towards Moscow and the central Soviet Union (Flavin, p.13).

The radioactive materials were deposited in some 20 countries and as far as 2,000 km from Chernobyl. But several radioisotopes, like cesium 137 with a half-life of 30 years, plutonium 239 with a half-life of 24,000 years and the iodine 131 with the half-life of eight days, which were released in the accident are of more concern than others, because of their destructive power and their long life (Flavin, p.14). The iodine 131 presents a serious health threat because it concentrates in the thyroid gland where it creates nodules, which become cancerous within couple of years. Also plutonium 239 is highly radioactive and its half-life makes it real hard to ignore. But the greatest long-term concern is presented by cesium137, which is biologically active, and it was released in very large quantities. Each country dealt with the problem of radiation differently. There are some that put major restrictions on the food supplied to its citizens, some countries only limited the supplies of some products more vulnerable to the radiation exposure, like milk or fresh fruit and vegetables, and then there are countries that did very little to prevent their citizens from getting radioactive poison into their systems (Flavin, p.16). Some of the radioactive components are dangerous because they damage or kill the internal immunity system of humans and other animals. It is very hard to determine radioactive presence and prevent poisoning, because it is not visible to human eye. When exposed to direct radiation the body functions start shutting down and the growth rate for some cells in your body merely seize to exist.

Around Chernobyl the radiation exposure was more intense. As reported on the 7$^{th}$ of May, around the nuclear power plant, the graphite was generating some 2,000 roentgens per hour, and the fuel up to 15,000 roentgens per hour, in general the radiation was some 1,200 roentgens per hour (Flavin, p.208). On the roof of the waste storage facility were around 40 roentgens per hour, and as an average in Chernobyl was some 15 milliroentgens per hour in the air, and up to 20 roentgens per hour in the ground. In Pripyat there were around 0.5-1.0 roentgens per hour in the air and 10 to 60 roentgens per hour on the roads, and asphalt. Also in Ivankov, which was 37 miles out, there were some 5 milliroentgens per hour (Medvedev, p.208).

In conclusion, the effects of the radiation emitted from the disaster at Chernobyl spread throughout the whole Europe and affected hundreds of millions of people, something that scientists failed to foresee in their calculation of the risks involved in nuclear power energy and the imminent disasters that came with it.

Left: Chernobyl's reactor after the disaster

Right: Chernobyl's Reactor No.4 sealed

### *3 Mile Island*

On Wednesday March 28, 1977 at 4:00 a.m. the main feed water system (system that supplies water to the steam generators) malfunctioned and shut off the flow of water. The cause of the malfunction is unknown but could have happened when maintenance was being performed on the condensation polishing system. After the feed failure, one hundred alarms were sounding in the control room confusing the staff. The auxiliary feed water system should have come on automatically, but did not, because the critical valves in the system were left closed due to maintenance error. This system provides an emergency source of cooling water to the steam generators. Since it did not cool the boiled water, this resulted in a rapid rise in the reactor's cooling system temperatures and pressure. So the turbine shut down automatically and then the reactor control system shut down the reactor, stopping the fission process.

Pressure and temperature rose in the reactor system and the water flowed in the pressurizer (filled about halfway with water and steam) which protects the reactor against pressure change. The pressure-regulating valve opened in order to reduce pressure in the reactor, while the steam flows from the valve through piping to the collecting tank located in the basement (the steam from the reactor could have radioactive material) After the pressure decreased from the reactor, the pressure-regulating valve did not close and was stuck open and the operators had no way to check the valve. Cooling water started to flow from the reactor through the valve to the basement. This caused the pressure in the reactor's cooling system to drop and after that the emergency core cooling system started to automatically supply water.

The operators measured the reactors water level and volume indirectly through the system's pressurizer. Since it had an increase of water in it, the operators thought the reactor system had too much water in, so they shut down one of the emergency core cooling system pumps reducing the flow of water. Coolant continued to flow on for an hour and a half, the water level in the primary cooling system dropping with the pressure (causing the coolant pumps to shake) by 5:30 am. Operators thought they had a main steam line break accident, which represented a leak in the steam system leading from the generators to large valves which isolate the steam generators from the turbines. While this was happening, water was being spilled on the floor of the containment building and pumped into the filled tanks in the auxiliary building. In the auxiliary building radioactive gases began to escape out of the building ventilation system.

The fuel rods temperature began to rise when the coolant level dropped to the top of the reactor, which could cause the rods to melt. During the next hour water levels continued to drop causing the fuel to overheat and melt, while the zirconium alloy covering the fuel rod were heating, oxidizing and eventually failing. The radioactive gases were then released from the rods making the water contaminated with radioactivity. The water was still being pumped to the auxiliary building where radiation escape into the environment, causing the radiation alarms to go off.

At 6:22 a.m. operators figured that the relief valve was open, so they closed a backup valve stopping the flow of water. At 6:55 a.m., in Three Mile Island a state of emergency was declared. At 7:24 a.m., in recognition of the extremely high levels of radiation in the containment building, teams were dispatched on the Island to check radiation level. By 8:00 a.m. the personal had concluded some fuel damage but underestimated it, and at 8:25 a.m. news of the accident began to hit the airways. After that, a team found radioactive iodine (which causes thyroid cancer) in a nearby town of Goldsboro.

At 9:00 a.m. contaminated water was found the in the auxiliary building and stopped the pumping from the containment building, slowing down the release of radioactivity. The operators finally turned on the emergency core cooling system which put cooling water in the primary system and discharged the water through a relief valve. But the relief valve continued to release hydrogen into the containment building, while the hydrogen was mixing with oxygen and finally ignited at 1:50 p.m. But the design of the containment building allowed no danger of a breach. At 8:00 p.m., the reactor system was cooled, and the coolant pumps could be turned on, in order to continue the process of heat removal.

On Thursday March 29, the situation appeared to have stabilized, radiation levels were low around the plant and no iodine was detected. At 2:10 p.m. a burst of radiation came out of the plant’s vent, but there was no concern among officials. At 7:56 on Friday morning, the radiation was released from the storage tank in the plant due to workers relieving the pressure in the tank. A helicopter monitored the radiation levels which were many times above normal levels (1,200 millirem per hour) at 130 feet above the plant, which was no danger to the population. But officials though it was a ground-level recording and had pregnant women and children evacuate with in 5 miles form the plant. In about sixteen hours after the accident stable cooling had been achieved, but hydrogen had collected in a bubble in top of the reactor vessel. Some experts believed this hydrogen bubble could explode, but the amount of oxygen in the system was to low to cause an explosion. Eventually, on April 4th the reactor was stabilized.

There was extensive damage to the reactor core, most of the fuel rods were damaged and much of the fuel melted. The melted fuel formed a molten mass which burned through the lower core support, almost filling the head of the vessel. If the molten mass had been allowed to burn 20 minutes longer it could have caused an uncontrollable release of radiation in the environment.

There were about 34-curies iodine and 10 million curies of noble gas radiation released in the environment. Most of the iodine was contained in the primary system. The radiation material was released in an aqueous environment making it insignificant. Large amounts of radioisotopes of cesium and strontium were discovered in the primary system, the containment building and the tanks in the auxiliary building, but no amounts were found outside the plant.

The Kemeny Commission and Rogovin reports on the Three Mile Island concluded that the accident resulted from poor training; inadequate equipment design, poor control room design and a mind set that reactor are accident proof. The cleanup lasted ten years and cost about one billion dollars.

# Nuclear Safety

## *Overview*

Once outside of a nuclear power plant there is very little difference between a it and a fossil fuel plant. It is very safe. There is a concrete liner around the plant which acts as a radiation shield. Outside of this there is a much bigger steel containment vessel. This vessel is made to prevent any leaks or vapors from escaping. This part contains the core, as well as any hardware needed to repair or to replace the rods in the plant. Outside of this, there is another concrete layer that contains the whole thing. It is strong enough to resist very big impacts, even as large as or larger than an airliner crash. These secondary containments are necessary to prevent radioactive materials such as steam from being released in the atmosphere. If Chernobyl had had containment vessels such as this it would not have been nearly as bad, if bad at all. It would have only affected the people inside, and no one out of the vessel (much like Three Mile island).

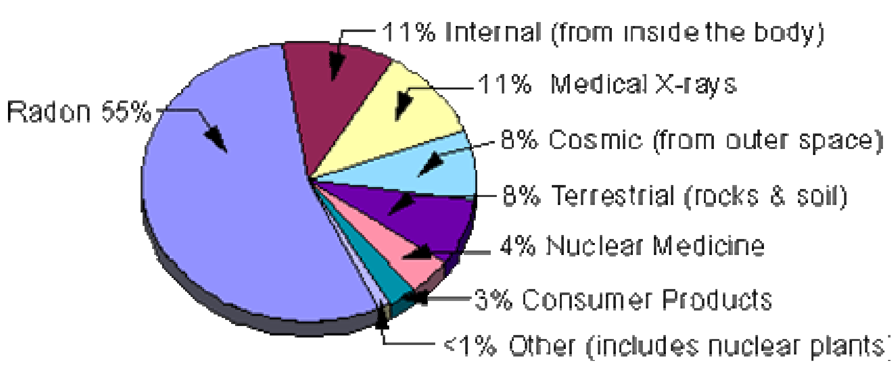


**Figure 1: Energy Source and number of deaths**

| **Fuel** | **Immediate fatalities 1970-92** | **Who?** | **Normalized to deaths per TWy* electricity** |
|---|---|---|---|
| Coal | 6400 | workers | 342 |
| Natural gas | 1200 | workers & public | 85 |
| Hydro | 4000 | public | 883 |
| Nuclear | 31 | workers | 8 |

## *Serious reactor accidents*

| **Reactor** | Date | **Immediate Deaths** | **Environmental effect** | **Follow-up action** |
|---|---|---|---|---|
| NRX, Canada (experimental, 40 MWt) | 1952 | Nil | Nil | Repaired (new core) closed 1992 |
| Windscale-1, UK (military plutonium-producing pile) | 1957 | Nil | Widespread contamination. Farms affected (c 1.5 x $10^{15}$ Bq released) | Entombed (filled with concrete) Being demolished. |
| SL-1, USA (experimental, military, 3 MWt) | 1961 | Three operators | Very minor radioactive release | Decommissioned |
| Fermi-1 USA (experimental breeder, 66 MWe) | 1966 | Nil | Nil | Repaired, restarted 1972 |
| Lucens, Switzerland (experimental, 7.5 MWe) | 1969 | Nil | Very minor radioactive release | Decommissioned |
| Browns Ferry, USA (commercial, 2 x 1080 MWe) | 1975 | Nil | Nil | Repaired |
| Three-Mile Island-2, USA (commercial, 880 MWe) | 1979 | Nil | Minor short-term radiation dose (within ICRP limits) to public, delayed release of 2 x $10^{14}$ Bq of Kr-85 | Clean-up program complete, in monitored storage stage of decommissioning |
| Saint Laurent-A2, France (commercial, 450 MWe) | 1980 | Nil | Minor radiation release (8 x $10^{10}$ Bq) | Repaired, (Decomm. 1992) |
| Chernobyl-4, Ukraine (commercial, 950 MWe) | 1986 | 31 staff and firefighters | Major radiation release across E.Europe and Scandinavia (11 x $10^{18}$ Bq) | Entombed |
| | | | | |

***Some energy-related accidents since 1977***

| Place | year | number killed | comments |
|---|---|---|---|
| Machhu II, India | 1979 | 2500 | hydro-electric dam failure |
| Hirakud, India | 1980 | 1000 | hydro-electric dam failure |
| Ortuella, Spain | 1980 | 70 | gas explosion |
| Donbass, Ukraine | 1980 | 68 | coal mine methane explosion |
| Israel | 1982 | 89 | gas explosion |
| Guavio, Colombia | 1983 | 160 | hydro-electric dam failure |
| Nile R, Egypt | 1983 | 317 | LPG explosion |
| Cubatao, Brazil | 1984 | 508 | oil fire |
| Mexico City | 1984 | 498 | LPG explosion |
| Tbilisi, Russia | 1984 | 100 | gas explosion |
| northern Taiwan | 1984 | 314 | 3 coal mine accidents |
| Chernobyl, Ukraine | 1986 | 31+ | nuclear reactor accident |
| Piper Alpha, North Sea | 1988 | 167 | explosion of offshore oil platform |
| Asha-ufa, Siberia | 1989 | 600 | LPG pipeline leak and fire |
| Dobrnja, Yugoslavia | 1990 | 178 | coal mine |
| Hongton, Shanxi, China | 1991 | 147 | coal mine |
| Belci, Romania | 1991 | 116 | hydro-electric dam failure |
| Kozlu, Turkey | 1992 | 272 | coal mine methane explosion |
| Cuenca, Equador | 1993 | 200 | coal mine |
| Durunkha, Egypt | 1994 | 580 | fuel depot hit by lightning |
| Seoul, S.Korea | 1994 | 500 | oil fire |
| Minanao, Philippines | 1994 | 90 | coal mine |
| Dhanbad, India | 1995 | 70 | coal mine |
| Taegu, S.Korea | 1995 | 100 | oil & gas explosion |
| Spitsbergen, Russia | 1996 | 141 | coal mine |
| Henan, China | 1996 | 84 | coal mine methane explosion |
| Datong, China | 1996 | 114 | coal mine methane explosion |
| Henan, China | 1997 | 89 | coal mine methane explosion |
| Fushun, China | 1997 | 68 | coal mine methane explosion |
| Kuzbass, Russia/Siberia | 1997 | 67 | coal mine methane explosion |
| Huainan, China | 1997 | 89 | coal mine methane explosion |
| Huainan, China | 1997 | 45 | coal mine methane explosion |

| | | | |
|---|---|---|---|
| Guizhou, China | 1997 | 43 | coal mine methane explosion |
| Donbass, Ukraine | 1998 | 63 | coal mine methane explosion |
| Liaoning, China | 1998 | 71 | coal mine methane explosion |
| Warri, Nigeria | 1998 | 500+ | oil pipeline leak and fire |
| Donbass, Ukraine | 1999 | 50+ | coal mine methane explosion |
| Donbass, Ukraine | 2000 | 80 | coal mine methane explosion |
| Shanxi, China | 2000 | 40 | coal mine methane explosion |
| Guizhou, China | 2000 | 150 | coal mine methane explosion |
| Shanxi, China | 2001 | 38 | coal mine methane explosion |
| Sichuan, China | 2002 | 23 | coal mine methane explosion |
| Jixi, China | 2002 | 115 | coal mine methane explosion |
| Gaoqiao, SW China | 2003 | 234 | gas well blowout with H2S |
| Kuzbass, Russia | 2004 | 44 | coal mine methane explosion |

LPG and oil accidents with less than 300 fatalities, and coal mine accidents with less than 100 fatalities are generally not shown unless recent.

Deaths per million tons of coal mined range from 0.1 per year in Australia and USA to 119 in Turkey. China's total death toll from coal mining averages well over 1000 per year (official figures give 5300 in 2000 and 5670 in 2001); Ukraine's is over two hundred per year (eg. 1999: 274, 1998: 360, 1995: 339, 1992: 459).

In Australia, 281 coal miners have been killed in 18 major disasters since 1902, and there have been 112 deaths in NSW mines since 1979, though the Australian coal mining industry is considered the safest in the world.

## *Nuclear Safety in France*

Nuclear safety covers all the conditions required for operating a nuclear facility in a safe environment. This ensures that a nuclear power plant does not have a harmful effect on the health of people and of the environment. Three basic technical rules are the prevention of the spread of radioactive products, the control of the chain reaction and the power to stop it at any time, and the removal or safe dispersion of the heat generated in the reactor core.

Safety starts at the design stage, where they make a list with all possible situations and plan the protective devices and equipment to deal with them. Thus there are four main situations, like normal operation, moderate frequency incidents, low frequency accidents, or low-probability serious accidents. Each situation has a radioactivity limit, and they are designed to stay within those limits. But the risks of external forces, such as earthquakes, flooding, airplane accidents and sabotage are also taken into account when the facility is designed. The architecture of the reactor is design to protect the reactor from ever spilling any radioactive waste on the outside. It has a metal enclosure which contains the nuclear fuel, a steel vessel which protects the reactor core, and the containment building which surrounds the whole reactor.

Safety in operations is also important. It prevents against abnormal, and requires the crew to take actions to return to a safe state, like through triggering of the back-up systems. Also the power plant control, supervision and maintenance are ensured according to precisely defined procedures.

Because of all the regulations a power plant accident is extremely unlikely. In the control room the actions to be carried out in all possible accidental hypotheses are laid out and followed closely. Also the French organization can alert, in less than one hour, a national crisis team consisting of experts in nuclear safety. They analyze the situation and propose actions to control the accident from their offices at the Technical Crisis Centre. They have two plans, the Internal Emergency Plan which limits the consequences of the accident and ensures the protection of the people working on the site, and the Special Action Plan which gets implemented only if the accident is liable to have an effect outside the site. This plan includes the assistance, the measures to be taken, and the conditions for informing the public through the media.

Nuclear Power Plant's safety also depends on the readiness and knowledge of the personnel, the quality of the equipment, the feedback from operations, and the international cooperation. The power plant operators regularly follow training courses to reinforce their theoretical and practical knowledge, after which they submit to simulation sessions which take place each year. The courses last between 4 to 6 weeks per year and have become more and more customized, which helped it develop into a culture of safety within the company.

### *Potential Terrorist Attacks*

There are 103 nuclear power plants in 31 states that generate 20% of the nation's power and 14 decommissioned plants that still hold radioactive material. If these areas were attacked by terrorist causing a reactor accident, tens of thousand could be killed and nearby land become uninhabitable for decades. Now government agencies, like the Nuclear Regulatory Commission, are racing to make the nuclear facilities more prepared against a terrorist attack.

One of the most effective ways a terrorist can attack a nuclear power plant is by crashing a plane into it. In 1982 the Argonne National Laboratory (a part of the Department of Energy) did a study on the effects a jetliner crash could inflict on the concrete walls of a nuclear reactor. They found if 1% of the jet fuel ignited in the reactor after impact, it would be equivalent to 1,000 lbs. of dynamite exploding in the reactor building which would lead to a release of radioactive material. After Sept. 11 2001, the NRC corrected itself and stated that nuclear power plants cannot withstand an impact from a large commercial jet that is loaded with fuel. An NRC spokesman stated that "it was never considered that suicidal terrorist would hijack a large commercial airliner and deliberately crash into a nuclear power plant. And he is right; during the 1960's when power plants were designed to prevent natural disasters like hurricanes and earthquakes and the possibility of a small airplane crash. But designers did not consider a fully fueled commercial airline or missile attack. Nuclear power plants are not even well equipped to prevent severe fires. Such fires would cause various safety systems to fail simultaneously, leading to coolant loss that could cause a meltdown.

Another potential target at a nuclear facility is the spent fuel pool. Most commercial plants store spent fuel in water pools; only a handful store the spent fuel in dry-cast which is much safer. In the pools there are some 40,000 tons of highly radioactive spent fuel in about 137,000 spent fuel rods, causing the pools to be 5 times more radioactive than the reactor core. The pools were never meant to hold this much waste, so the NRC had operators install complicated equipment to maintain water chemistry and temperature. The spent fuel pools are encased in a steel superstructure called a corrugated building that is not as protective as a primary containment structure design to protect the reactor core. This makes the corrugated building more vulnerable to a small plane crash or a ground missile attack. If the pool and equipment are damaged by an attack that causes a leak, the fuel would undergo an exothermic reaction causing a fire when the water level drops half-way (exposing the rods).

After the 1993 World Trade Center bombing, the Nuclear Regulatory Commission started considering a ground attack on a nuclear power plant, so they put in place new security regulations to protect reactors from an attack scenario using land vehicles filled with explosives or an internal attack. The nuclear power plant security personal received advanced training, anti-sabotage procedures were implemented, and new plant monitoring devices installed. When the NRC tested the new security improvements by mock terrorist attacks they found that 47% of the time the security at the nuclear power plant failed to repel the attacks. Since nuclear facilities are located near large bodies of water, they are vulnerable to a possible boat landing, or missile shot from a ship. Currently the coast guards have set patrols around water ways near nuclear power plants due to the September 11 attacks.

Since September 11, the Nuclear Regulatory Commission has been trying to increase security at nuclear power plants in the neighborhood by increasing patrols, adding security posts, installing physical barriers, having vehicle checks at greater stand off distances, enhancing coordination law enforcement and military authorities, and by increasing background checks of employees. But all these security improvements are going to take time to work right and the NRC believes they have enough time to make these changes.

The idea of moving the spent fuel to the Mt. Yucca repository will greatly increase the safety of these nuclear power plants by reducing the radioactivity in that area and making fewer targets for the terrorist to strike at.  There are many security improvements that should be added to a nuclear power plant. First the fire safety should be improved in order to prevent a major fire from destroying safety and cooling systems in a plant. Stronger security should be installed around the perimeter of the plant to prevent dangerous vehicles from entering. There also should be a no-fly zone over a nuclear power plant. Local health centers near the area of a nuclear power plant should hold stock piles of potassium iodide which is believed to help prevent thyroid cancer due to radiation. The best security for 103 nuclear power plants is government agencies protecting planes from being hijacked and keeping tabs on believed terrorist.

### *Safety Progression against Terrorists*

In the last decade or so extensive security measures have been implemented in order to protect U.S. nuclear plants from sabotage. The U.S. Nuclear Regulatory Commission (NRC) regulations require nuclear power plants to take adequate measures and protect the public and the environment from the possibility of exposure to radiation which has been released by means of sabotage. NRC list of measures includes things like the design and construction of the containment building for the reactor, background checks for all personnel, security procedures and surveillance equipment.

For radiation to be released, several layers of protection must be penetrated, including the containment structure. The reactor containment buildings, in which the reactors are located, are designed to be resistant to catastrophes. The containment building typically has about 1.2 meters of reinforced concrete with a steel liner, and the reactor has about 150mm of protection which is made of steel. The reinforced concrete containment structures, multiple safety systems have been designed to withstand the impact of hurricanes, tornadoes, floods, and airborne objects up to a certain force.

Every nuclear plant has armed security guards on the facility's grounds which are present around the clock. Besides the active, and highly trained, security personnel, sophisticated electronic surveillance is scanning the area surrounding the power plants.

Federal regulations require the industry to demonstrate that it can protect itself from terrorist threats. These threats usually consist of well-trained paramilitary force with the intent of entering and committing sabotage. The terrorist threats known to be armed with automatic weapons and explosives, and sometimes have the assistance of an "insider", who could give information that, will aid the attackers. Thus the drills, which are conducted under NRC supervision and evaluation, are run accordingly. The presumed terrorists are provided with all the information necessary for sabotage, including the location of vital equipment, the paths to those spots, as well as the way to disable them, just as if they had been previously informed by an insider. The NRC evaluates the efficiency of the plant's security measures, and any necessary enhancements are implemented. As well as penalizing if the drills are not sufficiently rigorous, the company would be cited for a violation of NRC regulations.

Personnel threats are just as feasible, thus all nuclear power plants have programs that protect against the potential threat from personnel. New employees and contractor employees must pass severe background checks regarding employment, education, and criminal histories as well as drug and alcohol screening tests and psychological evaluations. The NRC requires energy companies to conduct random drug and alcohol tests of at least 50 percent of all employees annually. Also any personnel appearing to be under the influence of drugs or alcohol, or exhibiting erratic behavior, will be immediately removed from the work area for evaluation.

## Nuclear Waste Disposal

The problem with a nuclear plant is the solid waste that is produced. This is going to be less and less of a problem. There are actually plants now that recycle the nuclear waste. The waste will not last as long the second time as it did the first time, but for example it will be useable for one year instead of three. Nuclear power is now very feasible. Also, the waste will have lost most of its radioactivity by the time it is determined unusable. If the waste were highly radioactive then it would still be in use in the plant, because this is what makes it create heat. If the waste is placed in a secluded area over about 500 years the solid, the waste is less radioactive than its original product that was mined. Blocking off a 20 square miles for nuclear storage is not a problem in today's world considering how much land is taken up for landfills full of trash. It is considered a small sacrifice.

An issue the world has is getting the nuclear waste transported to where it is going to rest for 500 years. Transporting nuclear waste is another big concern that people have with nuclear power. It is perfectly safe. For example, since 1965 government and industry programs have transported more than 10,000 spent fuel assemblies in more than 2,700 shipments by train and by truck. There have been 4 accidents (two train, two highway), but there was not damage to the containers and there was absolutely no radioactive leakage. The containers were not even penetrated trough the first of many layers.

The steel and lead flasks that they are transported in are put to more than reasonable tests to ensure that they will not break or leak any radiation what so ever. There was an example of a 140 ton train going at 100 miles per hour. The train was destroyed. The flask was fine; it did not leak any radiation or waste. This is only one third of the impact tests done at the building facilities.

The containers must be able to withstand all of the tests in the given order:

- A drop from 30 feet onto an unyielding surface (a surface so hard and resistant that it absorbs essentially none of the energy, causing the damaging energy to be absorbed by the cask itself at its weakest point). The forces that a cask experiences from this drop test are equivalent to hitting a bridge abutment at 120 m.p.h., followed by
- A drop down from 40 inches onto a shaft 6 inches in diameter, followed by
- A fully engulfing fire at 1475 $^{o}$F for 30 minutes, followed by
- Immersion in 3 feet of water

There have been more severe tests and it has passed every one of them. This is why it is considered to be safe when it is transported in the U.S.A, as well as the rest of the world. Even though transporting nuclear waste though one point is considered dangerous, has become a task that can be done with little worries.

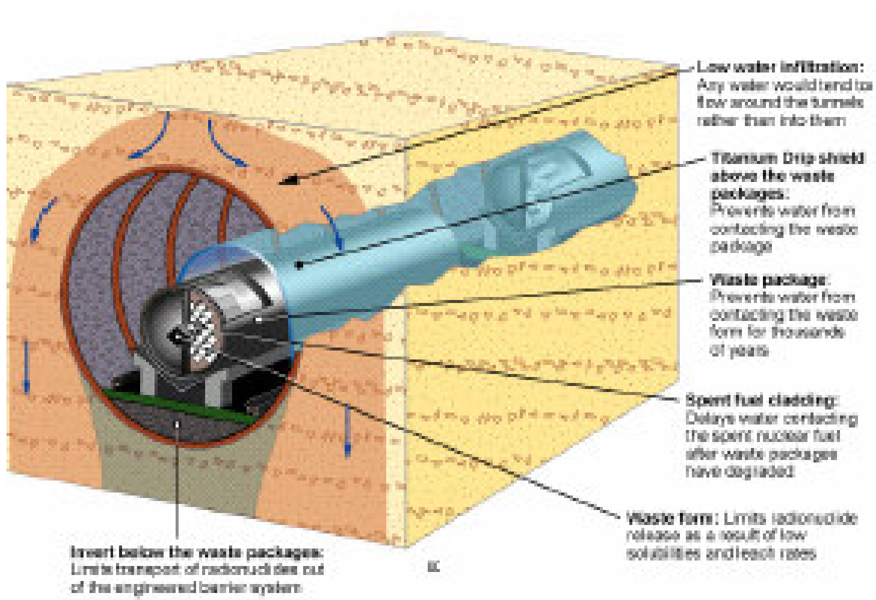
## *Mt. Yucca Repository*

### Introduction

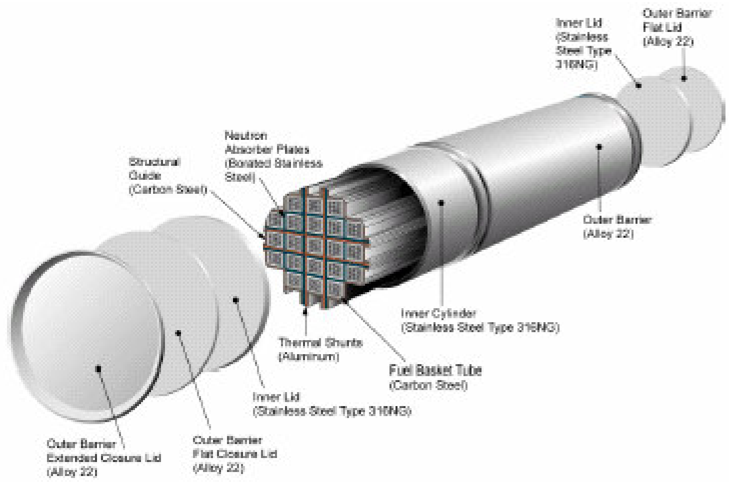
Mt Yucca has been studied for more than 20 years by the Department of Energy, who wanted to develop the Mountain into the nation's first geological repository for radioactive waste. Initial construction should begin between 2008 and 2010. Waste is expected to be arriving at the site in 2010 and 2110 is the earliest date the repository could close. Yucca Mountain is an ideal place for a repository because of its desert climate, deep water tables and the composition of the rocks. The design for the repository (which is 1,000 feet underground) will have tunnels to house the waste packages, structure support system that holds the waste packages and the waste packages with the waste in them. The surface facilities is where the radioactive waste will be received and packaged.  The subsurface facilities will be located 1,000 feet above the water table and away from major geological faults. They will have main tunnels for access, alcoves for monitoring, and tunnels for placement of the waste packages.

### Preventions of Moisture

Moisture moving through the ground is the main cause for radioactive material to escape a repository.   Since Mt. Yucca is in the Nevada desert the climate is arid, the precipitation is averaging 7.5 inches per year. Little of this precipitation seeps into the mountain; 95% of the precipitation runs off, picked up plants or lost to evaporation. The mountain has alternating layers of welded tuff[1] and non-welded tuff[2]. There is a layer of welded tuff located at the surface and the repository level, in between is a layer of non-welded tuff which contains few fractures. If water were to penetrate the top layer of the weld tuff the non-welded layer of tuff would delay the downward flow of water. Moisture would stay in the fracture and stay there in the non-welded tuff layer rather than go into the tunnels. If water were to leak in the repository and make a corrosive environment the drip shield and waste package would still have a long life time. The drip shield would be made out of titanium grade 7 that is very corrosion-resistant with general corrosion penetrating only about 0.08 inches in 10,000 years. The waste package has a nickel based alloy (Alloy 22) outer barrier that is corrosion-resistant with general corrosion penetrating only about 0.03 inches in 10,000 year.




[1] Welded tuff is volcanic ash that was laid down when it was very hot and welded itself into a solid mass of rock.
[2] Non-welded tuff is volcanic ash that was laid down when it was cool and became a cohesive mass when compressed by overlaying rock.




Waste packages use multiple layers of highly corrosion-resistant Alloy 22 and stainless steel, along with multiple welded lids, to provide confidence that water will be kept away from the solid waste forms contained inside. By way of comparison, waste package walls are about 20 times thicker than a propane tank wall.

If the water were to penetrate the waste package most of the water would evaporate before it could transport radionuclides because of the warm environment inside the repository. Also the engineered barrier system under the waste package and support pallet would contain crushed tuff that would delay the decent of any water carrying radionuclides. When the small amounts of contaminated water are able to flow out of the repository and into fractures or the pores of the rock matrix, the radionuclides would be affected in two ways. First, the radionuclides would come into contact with zeolites minerals contained in the rock; these minerals would cause the radoinuclides to stick to them slowing down the movement of radioactive material. Second, a dispersive process that occurs during transportation would throw the rock dilutes and reduces radionuclide concentration in the groundwater. When the radionuclies reach the deep water table (1,000 feet below the repository) the radioactive material would flow south towards the Amargosa Desert and the Death Valley, so the flow of the water is located in a closed hydrologic basin (Water does not flow into any rivers or oceans).

## Natural Disasters and Sabotage

The most feared natural disaster that could affect the repository located in Mt. Yucca is earthquakes and chance of volcanic activity. There are very few, if any, earthquakes in Nevada, where there are over forty year old tunnels still around in the Mt. Yucca area. An earthquake should not affect the Repository because it would be located 1,000 feet underground in a stable solid rock keeping the repository safe from any big impacts. Since the repository is underground there is less vibratory ground motion compared to the surface. The repository should be built to withstand earthquake because it is required by the Nuclear Regulatory Commission. The last small eruption in the in the Mt. Yucca Region was about 80,000 year ago, and volcanic activity has been waning since then. The DOE estimated the chance of volcanic activity in the first 10,000 years after the repository closure to be 1 in 70 million (a chance of 0.0000014% a year). It is very unlikely that the repository could come under attack by terrorist because it is a 1,000 feet underground keeping it safe from a ground attack. Also Mt. Yucca is surrounded by federal land and is more than 90 miles away from any major population center.

## Safety and Health

Scientist believes that a repository at Mt. Yucca would likely protect the health and safety of the public for at least 10,000 years. After 10,000 years the potential exposure of radiation to the public from the repository is less than 1 percent of the dose limit allowed by government regulations (1/10 of a millirem, an average person receives about 360 millirem from both natural and man made sources). Eventually when the repository is closed it would still be monitored for the health and safety of the public.

### Political Problems

There were many political issues and problems that made Mt. Yucca the National storage area for nuclear waste. In 1987, Congress was unhappy with the high cost of choosing a site for nuclear waste storage, so they ordered that only Mt. Yucca be considered. Washington State and Texas also had sites being looked at for nuclear waste storage, but critics say Nevada lost out because it didn't have political clout to block its section. The Bush administration has pushed hard for the Mt. Yucca Repository, leading to a rush in development of the nuclear storage facility. The Bush administration wants the Repository developed quickly because it wants to expand use of nuclear power which provides 20% of nation's electricity. The industry wants to build 50 new nuclear power plants by 2020 at the existing sites, but they need to move the waste to make space for new plants. While the site was being studied, the DoE had to change its rules for the site suitability guidelines because the estimated groundwater travel time from Mt. Yucca was fast enough to be disqualifying conditions in the original rules. Then on January, 2002 the Nuclear Waste Technical Review Board stated, "…The board's view is that the technical basis for the DOE's repository performance estimate is weak to moderate at this time."

## Geological and Waste Storage Problems

Ground water is one of the main geological problems with Mt. Yucca, since it is the main way the nuclear waste can escape the Mountain. The repository that contains the nuclear waste will be 500 feet above a pristine aquifer, vital to many desert communities including the state's largest dairy farm. This dairy farm is 12 miles away from the repository; it provides milk to about 30 million people in the Southwestern U.S. The State of Nevada had an independent contract studies which found that water could infiltrate the repository and can move radioactive material to drinking water in 100 to 500 years. Nevada is also worried about a loss in tourism in Las Vegas since the city is 90 miles Northwest of Mt. Yucca. Scientists are not even sure how long the caste that holds the nuclear waste can survive. According to Thomas Pigfor (Nuclear engineering professor at the University of California, Berkeley) "No solid experiments or theory confirm the predictions that casks can survive without corrosive penetration for 10,000 years, let alone several hundred thousand years, when the most severe ground water contamination is expected."

## Transportation Problems

The repository is supposed to hold 77,000 tons of highly radioactive waste, which has to be transported form commercial and military sites through 43 states to Mt. Yucca. Fifty million people live within one-half mile of the transportation routes for the about 53,000 trucks shipments or the 10,700 mostly rail shipments. This will increase nuclear waste shipments yearly by 35 times. The Department of Energy's Final Environmental Impact Statement found that people near transportation corridors may receive regular radiation exposures from 6 to 960 millirem annually depending on distance from the routes, and number of shipments. Also, the people's properties near the transportation corridors will probably decrease in value. If a severe accident were to inure in an urban area, it would cause latent cancer fatalities and cost between $63 to $108 billion dollars.

## Glimpse of the Future

### *Fusion*

Fusion is the process that powers the sun and the stars in our universe. Fusion is the reaction that occurs when two hydrogen atoms combine (fuse), to form a helium atom. In this process some of the mass is converted into energy.

The easiest way to make this reaction happen is to use deuterium with tritium. When these combine they make helium, a neutron, and energy. Using deuterium and tritium is nice, because deuterium is found in water, and tritium can be produced from the abundant metal lithium. This makes the energy source very abundant.

Fusion is presently the best possible energy source that the world's technology can produce. The effect of even the most unlikely fusion accident would be very limited in its effect, and would not require any sort of public evacuation. Also, the wastes from a fusion power plant would not require isolation from the environment for a prolonged time span, such as nuclear power. It could be easily marketable to the public because its safety is more readily demonstrable to the general public, because the public acceptance is one of the major problems with nuclear power. Like nuclear power there is no contribution to greenhouse gases or acidic emissions.

There is a major problem with such a good power source. To make fusion happen it requires pretty extreme circumstances. The atoms of hydrogen must be heated to temperatures around 100 million degrees Celsius. Along with this the atoms have to be held together long enough for fusion to happen. This is not so bad for the sun or the stars, because they are very hot, and they are so big that they can rely on gravity to hold the atoms together. On earth, at the current time, the most practical approach is to hold the ionized atoms together with a strong magnetic field, while they are heated by microwaves or some other energy source. Another method which is quite practical is a tiny frozen pellet of hydrogen is that compressed and heated by an intense energy beam, like a laser, so quickly that the atoms fuse before they have time to separate.

Another major problem with fusion is that it takes energy to get the atoms up to 100 million degrees Celsius. The methods of creating fusion now are not very efficient. The fusion plants barely produce more power than they use to create the fusion reaction. This means that it is not very economical to use this power source unless it is producing a big percentage over the amount used to create the reaction. Once this hurtle is accomplished will the use of fusion power be a big part of the solution to the world's energy crisis.

Scientists have been trying to make this work for over 40 years. If they are successful the world will have an energy source that is virtually inexhaustible. One gallon of water can produce the same amount of energy as 300 gallons of gasoline. In addition to this it is very safe and environmentally friendly.

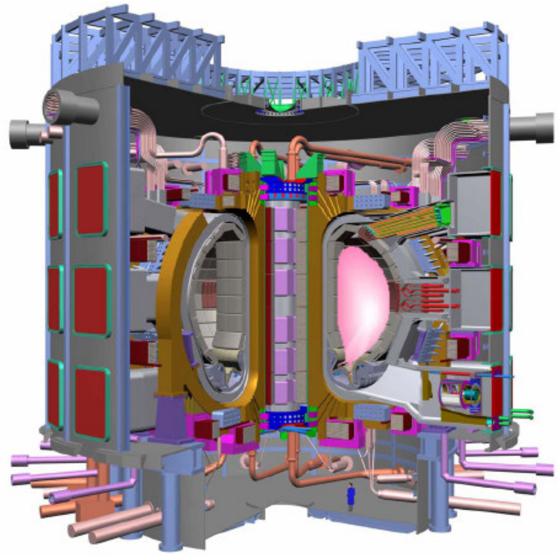


*Figure 1.3 The ITER design. The scale is indicated by the human figure at the bottom.*

The earliest expected time for fusion to come out in commercial plants is 2040. There are some major scientific hurtles that have to be accomplished before this power source is going to be main stream. Fusion is a good long term power source, but we will need something to take place of oil between now and fusion, and the most realistic major power source would be nuclear power. While fusion will be the answer, it does not appear to be the current answer. It is the answer for the future of energy.

## *Island for Power Plant*

One constant battle with nuclear power plants is how to make the plant as safe as possible. One way to make a plant as safe as possible is to get it away from the public in case something goes wrong with the plant.

The solution that was chosen is an Appledore Island off of Maine to host the nuclear power plant. This island was chosen for many reasons. One is it is far enough away from land to not harm people on the shore if something were to go wrong. Also the island is on the east coast in the jet stream. Also if it is on an island it is harder to gain access to the plant and hence being more protected from terrorists.

The jet stream plays an important role with the placement choice of the plant. The jet stream moves towards the Atlantic Ocean. This will help carry the radioactive material out to sea in case the plant has an accident or a meltdown. This is very important because the radioactive material will not all be directed onto people.

An island is also safer from terrorist attacks as well. The only way to gain access to the plant is on a boat. The plant can be as strict as they want when they are giving people access to the plant. This would allow for superior protection to a land plant.

The island is approximately 320 acres. This is more than one third of 3 Mile Island. There are three large reactors on Three Mile Island showing that this island is sufficient size to hold one large reactor, or maybe even two depending on how the plans for building come together.

An island is a smart place to put a nuclear power plant, and once again this extra safety of having the plant on an island should be taken advantage of. This is also another way to show the public what can be done to make plants safer and further gain approval.

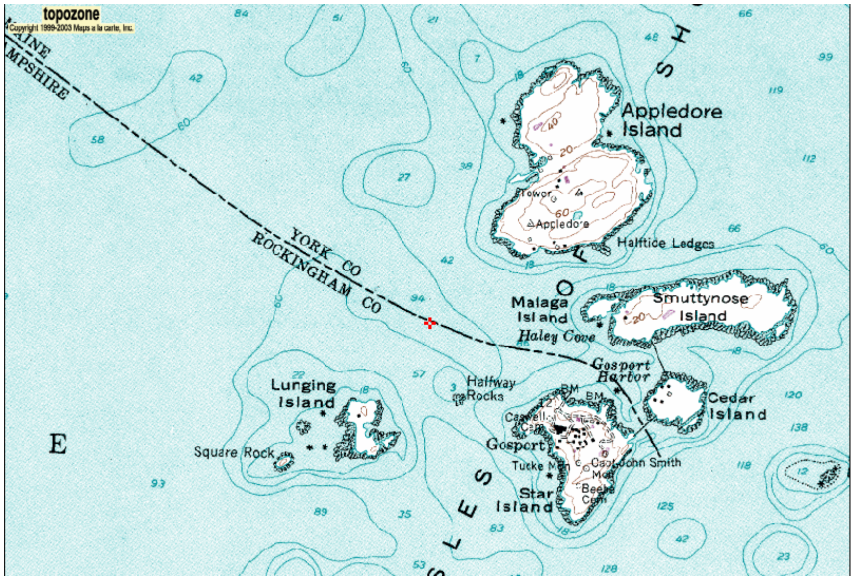



Figure 1: Map of the Appledore Island.

## Conclusions

In the last century there had been a growing concern about the exhaustion of fossil fuels. There are only limited amounts of oil, coal, and natural gas left to harvest on earth. Fossil fuels are the main source of energy worldwide, and they are predicted to run out in the near future.

An alternate power source must be sought out in order to help solve the upcoming energy source. Alternate power sources that were researched are wind power, solar power, geothermal power and nuclear power. Wind power cannot supply enough consistent energy, and takes up too much usable land. Windmills will only work successfully in certain areas where wind is prevalent in order to be a reliable source of energy for the future. Solar power has similar problems to wind power. About five square miles would have to be paved with solar panels in order to equal the power of just one nuclear power plant. This is not acceptable to power a country because it would take huge amounts of land throughout. Nuclear power is now in the picture to do the massive demand for energy in today's society.

Nuclear power is a reliable power source for the future because of the massive supply of uranium in the earth, the amount of energy a power plant puts out, and the low amount of air pollution produced. There is enough uranium to supply the world with power for at least a hundred years. Nuclear power plants put out massive amounts of energy; for example fission of one atom of uranium produces approximately ten million times the energy from burning one atom of coal. Also nuclear power plants put out very low air pollution because there is no combustion. The only emissions that come out of the plant is the steam.

In the past there have been accidents with nuclear power plants, such as the ones at Chernobyl and at Three Mile Island. The main reason why Chernobyl melted down was that the Russians ran the power plant harder than it was made to be run. Also the reason Three Mile Island almost had a melt down was because there was a coolant leak and no way to detect the leak in the system. The reactor did not melt down because the reaction was stopped before it overheated. The reactor is still in use today.

Nuclear plants have problems with approval from the public because of these past accidents, even though it is safer and used more often than most people know. There are 104 nuclear power plants in use in North America today, and there have not been any significant accidents that affected the public from any of these reactors. The past has shown that nuclear power is safe enough to be used as a major power source for the future.

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