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**Swiss Nuclear Power**

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by

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**Abstract**

This report, prepared during studies at the Federal Technical University of Zurich, Switzerland (ETHZ), addresses the past, current, and future state of nuclear power in Switzerland. It provides a technical description of the nuclear power production process used in Swiss plants. It also examines political and social trends and makes predictions about how these trends effect the future of nuclear power in Switzerland.

**Acknowledgements**

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## 1. Introduction

For the time shortly after the birth of nuclear power, the discussions of its uses, effects and implications was confined to a small community of scientists. Since then, the topic has expanded its followers to include politicians, journalists, environmentalists, and, in fact, the wide majority of our society.

The discussions seem to run the gamut of sentiments. One finds fanatical support of the new and unknown, mystical predictions of unimaginable benefits or ruin, controversial political debate, and cold, boring scientific analysis. While these reports differ only slightly in the actual facts given, they can, and often do, differ tremendously in the social interpretation of these facts.

This paper does not seek to add any new or original interpretations. It attempts to convey a history and an explanation, not only of the scientific phenomenon of nuclear power itself, but also of the social interpretations and societal effects nuclear power has had on the central European country of Switzerland.

## 2. The Nuclear Power Production Process

Before jumping right in to the topic of Swiss nuclear power, it is wise to put the topic in perspective. Before we discuss the characteristics that make Swiss nuclear power unique, we will address some of the characteristics of nuclear power in general.

People have been discussing the topic of nuclear power since before the first commercial nuclear power plant was built in 1954, but what exactly is nuclear power? To some, the words conjure up notions of abundant, cheap energy – to others, the destruction of our environment, and even the apocalyptic ruin of the human race. In truth, the production of nuclear power is simply a process for obtaining usable electricity from naturally radioactive substances. Although the process is essentially simple, the complexity is in the details.

### *2.1. Generation of Electricity:*

In general, most power plants work on the same basic principles. At the very core of the process is the basic physical effect that moving a permanent magnet in the presence of a conductive wire produces a current (electricity) in the wire. So, on the larger scale, commercial power plants use many magnets and many wires, arranged geometrically so that a simple turning motion moves the magnets around the wires. This assembly is usually packaged together in what is called a generator. Generators are used to create electricity from all the various energy sources - solar, hydroelectric, nuclear, etc.

What the generator needs is motion, because when the magnets are simply at rest next to the wire, nothing happens. Only the motion of the magnets produces the electricity. Physical conservation laws state that it is impossible to make more energy out of less energy, so it is inherently inefficient to use any sort of electric motor to move the magnets. To be effective, the generator requires a mechanical turning motion. This is usually accomplished by attaching a turbine to the generator to make a turbine generator.

With windmills, the wind turns the turbines, and with hydroelectric power, jets of water turn the turbines. With most other power sources, steam is forced though thin pipes to create high-pressure steam jets, which turn the turbines. The steam simply comes from heating up water taken from a cold water source, like a lake or river. What differentiates the other power sources from each other is the method that they use to heat up the water. Conventional power sources heat water by burning some kind of fuel (wood, oil, natural gas, coal, etc.) Nuclear power plants heat water by taking advantage of the energy (heat) given off during certain sustained nuclear reactions.

### *2.2. The Nuclear Reaction – Fission:*

At the heart of any nuclear power plant is the nuclear fission reaction. In a fission reaction, a single atom of some radioactive substance decays, splitting up into two smaller atoms while also ejecting a huge amount of energy in the form of radiation. The most common nuclear fission reactions used in nuclear power reactors involve the decay of Uranium 235 (U-235), which produces its radioactive energy in the form of very fast-moving (thermal) neutrons. In fact, in a single decay of a U-235, more than just one thermal neutron is emitted.

U-235 atoms will spontaneously decay by themselves if given enough time, but they tend to decay immediately if they are excited. Fortunately, U-235 atoms can be excited by the neutrons ejected from other decaying U-235 atoms. This results in a chain reaction, where each U-235 decay causes more atoms to decay, producing more and more thermal neutrons, which in turn produce heat. The radioactive substance used in the fission reaction is called the nuclear fuel.

### *2.3. The Nuclear Energy Model – An Overview of Light Water Reactors (LWR):*

Nuclear power plants are characterized by their fuel, their moderator, and their coolant. The basic model is rather simple, and in the most common type of nuclear power plant, both the moderator and coolant are very pure ordinary water. Reactors of this type are called light water reactors (LWR). All of Switzerland's nuclear power plants are LWRs.

Instead of burning oil or coal, nuclear power plants use a radioactive substance, or fuel (typically U-235), which ejects fast-moving neutrons when it decays. This nuclear fuel is immersed in a coolant, and the ejected neutrons excite the coolant molecules, heating them up. When the coolant is sufficiently heated, it evaporates, producing steam. The steam is used by turbine generators to generate electricity in the conventional manner.

Since the coolant (water) that was in the reactor has been irradiated, some of it actually becomes radioactive, even while it is steam. Instead of simply releasing this steam into the air, it must be condensed back into liquid, so that it can be reused in a closed system. The large-scale condensation takes place inside a condenser, which requires a large supply of cold water, such as a nearby river.

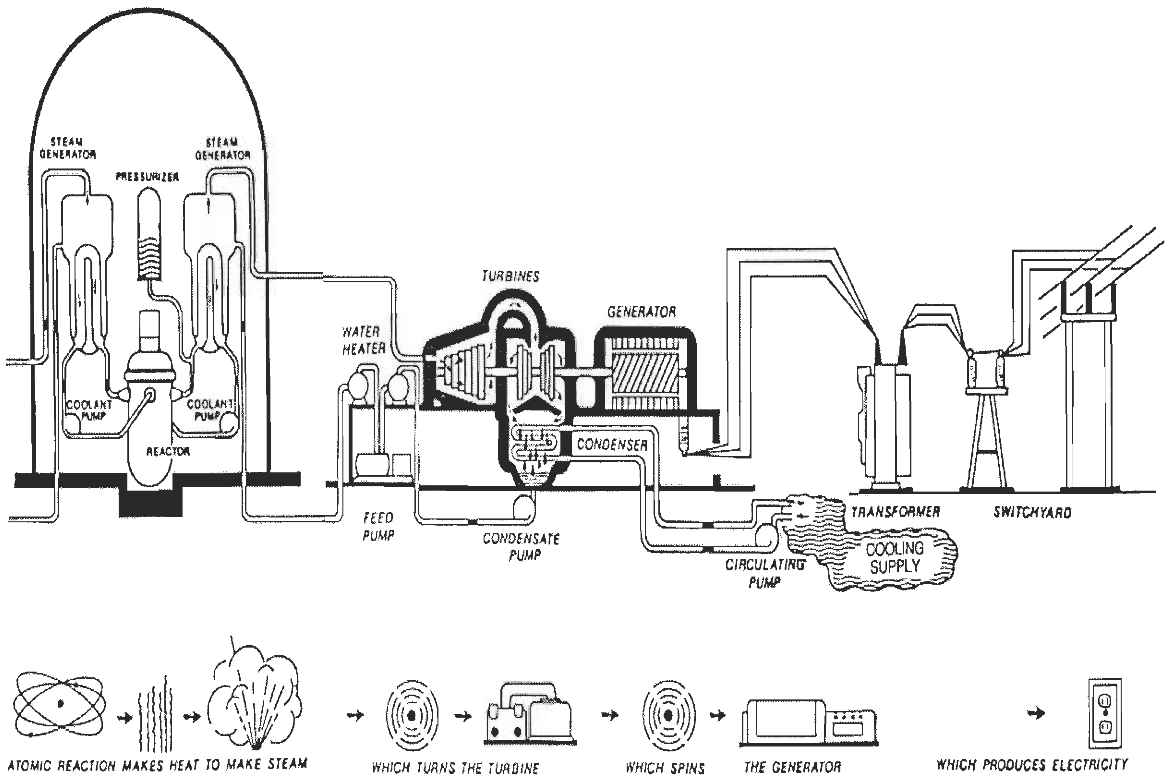
### 2.4. Moderation of the Nuclear Reaction:

Unfortunately, the fission reaction is not automatically self-sustaining. The problem is that the neutrons that are ejected during the fission reaction are moving much too fast to be easily absorbed by successive U-235 atoms. In order to achieve a sustained reaction, the neutrons have to be slowed down with a moderator.

Simple, pure water makes a very good moderator, because neutrons can bounce back and forth between water molecules, exciting the water molecules. This both heats up the water and slows down the neutrons enough to make them easily absorbed by surrounding U-235 atoms.

However, a moderated nuclear reaction can quickly get out of hand if left unchecked. This is prevented by making sure that, on average, only one of the neutrons is absorbed by another U-235 atom to cause another reaction. Since the neutrons will always be absorbed by something, this is equivalent to making sure that something else, besides the nuclear fuel, absorbs the neutrons.

Controls rods are placed in-between the fuel elements inside the reactor, and are made of a substance that absorbs neutrons without heating the water or contributing to the reaction. The distance from the control rods to the fuel elements is mechanically controlled. If the control rods are placed completely into the fuel elements, then the reaction is stopped.




(Courtesy NSP)

**Figure 1: Below, the path of producing nuclear power. Above, the equipment used in each step.**

### *2.5. Cooling the Reactor:*

A controlled, moderated nuclear reaction will continuously produce energy in the form of heat. Coolant is needed to prevent the reactor from overheating, and to extract the energy in a usable form.

Swiss power plants use two different techniques for cooling the reactor. The plants in which each of these different techniques are used are called Boiling Water Reactors (BWR) and Pressurized Water Reactors (PWR).

In a BWR, some of the same water used as a moderator is allowed to boil, and evaporate into steam. The steam is then used to turn the turbines of turbine generators, generating usable electricity. One advantage of this model is simplicity and efficiency, but a disadvantage is that the generators are exposed to radioactive steam which, over many years, can erode the generators.

In a PWR, the water moderator is kept at a high enough pressure so that it does not boil. The very hot, but liquid water is then used in a heat exchanger to heat a separate water source to the point of boiling. Then the steam from the second water supply is used with the turbine generators to produce electricity. This model is more complicated and less efficient than the BWR model because of the energy lost during the heat exchange. However, since the radiation does not pass through the heat exchanger, the steam used to power the generator is not radioactive, and therefore the generators tend to require less service.

### 2.6. Completing the Cycle:

Although this is all that is required to produce electricity, environmental and economic concerns necessitate additional efforts.

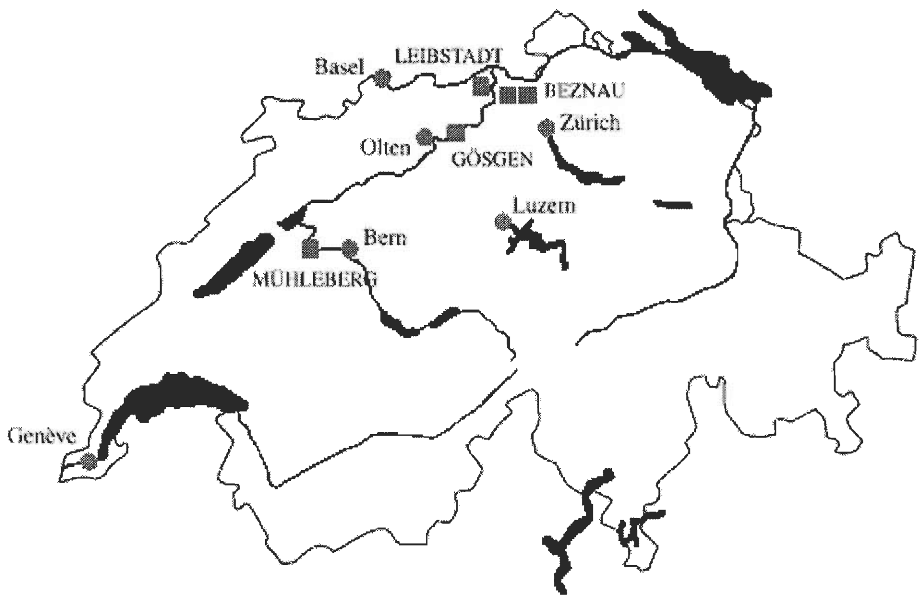
In the BWR, the radioactive steam must be contained within the reactor system. A condenser is used to cool the steam down, converting it back into liquid water before sending it back into the reaction chamber to be boiled again.

In the PWR, the steam is not radioactive, and could simply be released into the air, but nuclear power plants do not actually adopt this practice, because they can pipe the steam to nearby factories and residences, selling heating service. The steam that is not sent away for heating condenses back into hot water. But even then, the hot water cannot simply be returned to the river from which it came because the effects of dumping warmer water into a colder river, known as thermal pollution, can take their toll on the natural ecosystem.

## 3. Swiss Nuclear Power Plants:

### *3.1. Overview and Summary*

Although there are only four nuclear power generation stations in Switzerland, there are actually five nuclear power plants, each with its own nuclear reactor. This confusion arises from the fact that two nuclear power plants (Beznau 1 and Beznau 2) operate at one site. The other three plants are located in Gösgen, Leibstadt, and Mühleberg. There are no current plans to build any new nuclear power plants in Switzerland.[1]




(Courtesy PSI)

**Figure 2: Locations of Swiss nuclear power plants**

The annual net output of Switzerland's five nuclear power plants tops 24 TWh. In total electricity production, this amounts to approximately 40% of the national total.[2] This figure is slightly above average among European countries.

| **Country** | **Nuclear Portion of total Energy Production** |
|---|---|
| Switzerland | 37% |
| Germany | 34% |
| France | 78% |
| Belgium | 59% |
| England | 26% |
| Netherlands | 5% |
| Russia | 13% |
| USA | 21% |

**Table 1: Percentage of nuclear portion of total energy production for various countries**[3]

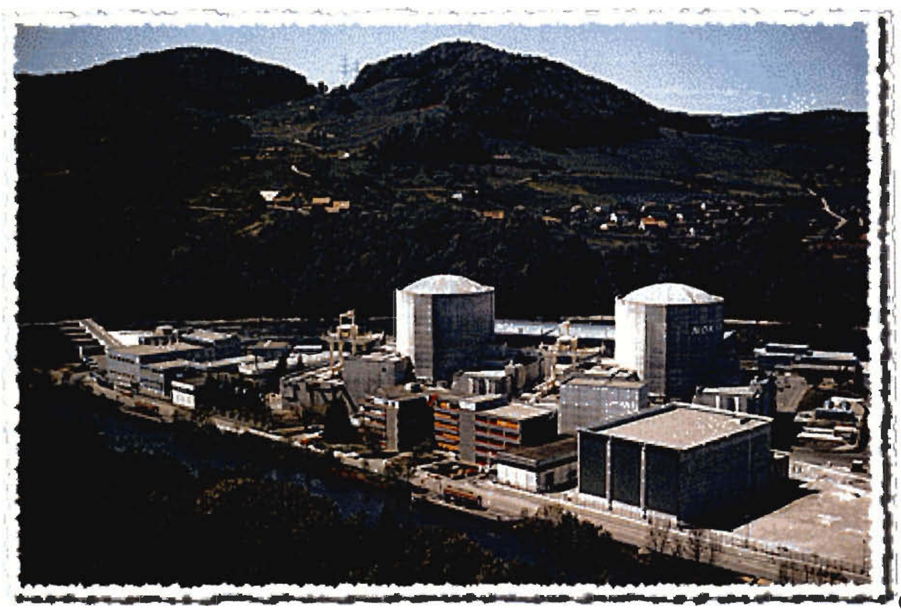
*3.1.1. Upgrades:*

An application for a power upgrade which will increase the capacity of the Leibstadt plant by 15% is under consideration by the authorities.

The 1993 steam generator exchange at Beznau 1 and subsequent improvements in turbine efficiency at the station have resulted in better overall performance of both units, without the need to improve reactor performance. The new installed capacity figures (net) as of October 1, 1996 are Beznau 1 – 365 MW (15 MW increase), and Beznau 2 – 357 MW (7 MW increase).[4]

| | Beznau 1 | Beznau 2 | Mühleberg | Gösgen | Leibstadt |
|---|---|---|---|---|---|
| **Reactor Type** | PWR | PWR | BWR | PWR | BWR |
| **Reactor Supplier** | Westing-house | Westing-house | General Electric | Kraftwerk-Union | General Electric |
| **Year Built** | 1964 | 1967 | 1967 | 1973 | 1975 |
| **Operating Since** | 1969 | 1972 | 1972 | 1979 | 1984 |
| **Nuclear Capacity** | 365 MWe | 357 MWe | 355 MWe | 970 MWe | 1030 MWe |
| **Annual production in 1996** | 2753 GWh | 2754 GWh | 2649 GWh | 7928 GWh | 7705 GWh |

**Table 2: Technical data for the five Swiss nuclear power plants[5] [6]**



(Courtesy HSK)

**Figure 3: Beznau I and II**

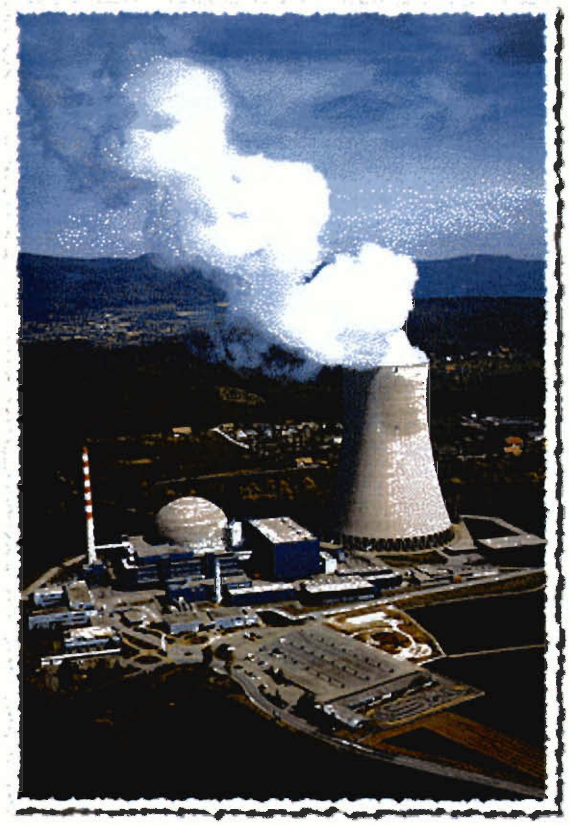


**Figure 4: Gösgen**

(Courtesy HSK)

**Figure 5: Mühleberg**

(Courtesy HSK)

**Figure 6: Leibstadt**

(Courtesy HSK)

### *3.2. Economic Issues:*

Compared to the U.S., Switzerland has relatively little conventional raw fuel for producing energy. In the U.S., the building of nuclear power plants and the use of nuclear power was prompted by business motives. Early nuclear power plants in the U.S. were basically entrepreneurial endeavors. In Switzerland, on the other hand, the introduction of nuclear power was not only a question of business economics, but also a supply politics necessity. Switzerland simply needed nuclear power.

The introduction of nuclear energy into Europe was accelerated in 1973 when the price of oil drastically increased. Most European countries became quite uncomfortable with the realization that they would soon become dependent on foreign sources of expensive oil. This effect was especially pronounced in Switzerland, where the independent Swiss mindset viewed foreign dependence as an even greater evil than most other European countries did. At about this time, politicians began speaking about the "diversification of energy sources," and they set some goals to reduce the portion of energy from oil down to 30% before 1990.[7] Although coal and natural gas made up for reduction to some degree, nuclear energy sources also became more common. At the same time, Switzerland was exploring other non-conventional energy sources such as hydroelectric, solar, and geothermal energy, but these sources did not provide a significant amount of energy.

Today, nuclear energy has eased Switzerland's foreign dependence problems. Even though the nuclear fuel, uranium, must still be imported, there are not as many difficulties with transportation and supply, since uranium is an extremely compact fuel, and there are many uranium exporters. Another effect of the increase of nuclear power in

Switzerland has been a strong reduction in pollution emissions, due simply to the reduction in the amount of oil and coal being burned.

### 3.3. Controversy:

The opposition to nuclear power in Switzerland is certainly vocal. Although the nuclear power issue is complicated and quite interrelated, it is possible to identify the main areas of controversy.

#### *3.3.1. The Waste Problem:*

The question of what to do with the spent nuclear fuel is essentially a political one. Technically, the issue is clear. The used fuel remains radioactive long after it is useful. Nuclear power opponents cite this problem as "unsolved".

However, proponents of nuclear power have proposed several solutions. One solution is simply to store the spent fuel away from people for up to 500 years. This involves long-term storage facilities, which are usually deep holes embedded in granite or some other stable rock formation.

This solution is technically attractive, but it suffers from the prevailing "Fine, but not in my backyard" mentality. The scientific community has demonstrated that long-term storage facilities do not pose any health risk to the surrounding areas since they simply do not allow dangerous levels of radiation to escape. However, politicians still oppose the construction of these facilities in their own cantons. Two of the most common concerns they mention are the uncertainty of how these facilities would withstand natural geological changes, such as earthquakes, and the fear that the facilities would be forgotten and then stumbled upon by people in the distant future.

### *3.3.2. Connection with Nuclear Weapons:*

Nuclear power opponents and even the population in general tend to consider nuclear power plants as intimately connected with nuclear weapons. In fact, nuclear weapons and nuclear power have the same connection that water guns and hydro-electric power have. The very same water which powers a hydro-electric power plant can be used in a water gun. Admittedly, nuclear weapons are infinitely more destructive than water guns.

Another solution to the waste disposal issue demonstrates this relatively incidental connection. This solution is to reprocess the fuel so that it becomes suitable for use as fuel in another type of nuclear reactor. Technically, this is very attractive because it increases the efficiency of the entire nuclear fuel cycle. Politically, this provides nuclear power opponents with a logical connection with nuclear weapons. The reprocessing process involves some materials which could be converted into weapons-grade plutonium. Therefore, these reprocessing plants are high-security areas and are protected against terrorist theft. Nevertheless, to many people, these plants pose an unacceptable risk of nuclear weapon proliferation.

### *3.3.3. Risks Involved in Transportation of Nuclear Materials:*

Nuclear power opponents cite two types of risks concerning the transportation of nuclear materials. First, they say that nuclear material could be hijacked by terrorists during transport, and then used to make a weapon. This is an unreasonable concern. Even the enriched nuclear fuel is not sufficiently enriched to make a nuclear weapon, and anyone who has access to the facilities that can enrich nuclear fuel certainly has no need to steal fuel-grade nuclear materials.

Second, there is a risk that an accident during transportation would expose people to unhealthy radiation. This concern is valid, but the task of safely transporting equally hazardous material is well understood and routinely performed.

*3.3.4. Risks of Nuclear Power Plant Accidents:*

Critics refer to accidents at Chernobyl and Three Mile Island to point out the risks of nuclear power plant accidents. There is much misunderstanding about these events.

A nuclear power plant could never explode like a nuclear weapon. This is due to the fundamental speed at which fission neutrons travel and has nothing to do with the way reactors are designed. The explosion at the Chernobyl plant was only indirectly nuclear. The reactor was poorly operated and poorly designed, and the reactor overheated, turning its water into high pressure steam. This high pressure steam then blew the plant apart. This is nothing like what happens with a nuclear bomb.

Thirty-one people were killed in the explosion. Often, hundreds of people are killed in a single cave-in in a large coal mine. The land within about 3 miles of the plant became uninhabitable for quite a while. Radioactive fallout probably increased the incidence of cancer all over Europe, but to such a small degree that it has not yet been possible to measure it. Estimates of the total number of deaths due to the Chernobyl accident range from about 50 to a few thousand.[8] Even the largest estimates would make Chernobyl a disaster on par with the Bhopal chemical plant or the Texas City explosion of a shipload of ammonium nitrate, but small compared to the number who die in a major earthquake in countries using adobe or sod houses.

At Three Mile Island, an accident destroyed the reactor, but safety features functioned as they were designed to do and there was no harm to the public. In general, at the end of 1998 there were 9012 civilian power reactor years of experience throughout the world,[9] but Chernobyl is the only nuclear power plant accident harming the public.

## 3.4. Political Issues:

### *3.4.1. Moratorium:*

On September 23, 1990, two important public initiatives went before the entire Swiss nation for a popular vote. The Swiss rejected the initiative 'For a gradual abandonment of nuclear energy.' They accepted the second initiative, which declared a ten-year moratorium on nuclear energy. The purpose of the moratorium was to give Switzerland time to find a better solution to the energy policy problem. During the past 10 years, economic recession has resulted in rather low growth rates in energy consumption, so the current supply of energy should be sufficient for a while yet. However, recently Switzerland has been forced to import energy from other countries during the winter, when demand is higher.

### *3.4.2. The Energy Law:*

Yet another referendum that was passed on September 23, 1990 was the Energy Use Decree, which expired at the end of 1998. Its purpose was to make saving energy, and more economical use of energy a top priority in Switzerland. As a result, the more and more efficient use of energy in Switzerland has been another factor influencing the small rates of growth for energy consumption.

In 1997, the federal government took two initiatives relating to nuclear energy. First, a draft energy law was sent to Parliament which maintained the nuclear energy option for the future and contained fewer proposals for state intervention than earlier drafts.

In a second, related decision, the government recommended that two public initiatives – moves to put issues to a nationwide vote – should be rejected. Both initiatives proposed levying additional taxes on non-renewable energy sources, including nuclear power.

During the 1997 summer session of the National Council, there was much debate about replacing the Energy Use Decree with a new article, the Energy Law. Three distinct groups emerged from this debate. The center-right wanted fewer restrictions and regulations, allowing free market forces to dictate the direction of future energy supplies. The "green" bloc wanted more environmental regulations and stricter restrictions on atomic energy, with a redoubling of efforts on the savings front. The "red", left bloc, which has also historically been hostile toward nuclear energy, also voted for more restrictions and regulations.

Bienne Liberal Democrat National Councilor Marc Sutter proposed a new energy tax, included in the Energy Law, which would raise one billion Swiss francs ($800 million) per year. The tax was designed to be used to promote renewable energy sources and rational use of energy, and was enthusiastically accepted by the red-green camp. The exact value of the tax was 0.6 centimes (.5 cents) per kilowatt hour, levied on energy produced from any fossil fuel or uranium. The Energy Law was only barely accepted, with 76 votes for, and 60 votes against.

*3.4.3. "Energy 2000":*

As a follow-up to the September 1990 referendums, the Federal Council proposed an action program called "Energy 2000." The main purposes of this program were to promote energy-saving measures, and to set a direction for Swiss energy policy through the year 2000. However, energy-savings can only be taken so far while remaining economically reasonable, and the progressive Swiss have already made outstanding progress in this area, so the room for improvement is quickly diminishing.

The "Energy 2000" action program contains provisions designed to encourage the use of renewable energy sources, and to stabilize energy consumption. It also contains provisions for a 10% increase in the capacity of the five existing nuclear power plants in Switzerland. However, the opponents of nuclear energy in the Federal Council are very actively resisting the implementation of the specific provisions of the action program regarding upgrading existing nuclear power plants.

Furthermore, the ten-year moratorium will end in 2000, and even the opponents of nuclear energy admit that no valid alternative to nuclear energy has been discovered yet. Switzerland remains dependant on nuclear energy.

*3.4.4. Waste Disposal:*

The issue of waste disposal is chiefly a political one. Technically, what is needed is clear. The used fuel remains radioactive long after it is useful. It needs to be stored away from people for up to 500 years.

On August 21, 1996, the federal Swiss government authorized the construction of a central interim storage facility for all types of radioactive waste (including vitrified low level waste resulting from reprocessing, as well as spent fuel elements from nuclear power plants) near Würenlingen. Operation of the storage halls of the facility was also authorized, but operation of the waste conditioning and incineration sections, including a new high-tech plasma incinerating facility, were subject to a separate licensing procedure at a later stage. The Zwilag company started excavation work for the SFr. 500 million project five days later. The construction of this facility is still underway, and is currently the largest construction site in north-western Switzerland. The storage section of the facility is currently used, but the request for the operating license for the waste conditioning and incineration sections of the facility was submitted in December 1997, and is still pending.

The Swiss nuclear safety authority recently stated its findings that there is no technical (safety or radiological) reason why a general permit for a final repository of low and medium level waste in Wellenberg should not be granted. However, in 1995, voters in the canton of Nidwalden, where the Wellenberg site is located, narrowly rejected plans to build the repository there.[10]

Currently, NAGRA is investigating the possibility of using different geological formations in Switzerland for final disposal of high level radioactive waste.[11] Two promising possibilities include crystalline bedrock in northern Switzerland and clay formations in north-eastern Switzerland.

## 4. Summary

### *4.1. So Many Opinions:*

Why do people have so many different opinions about nuclear power?

Admittedly, two people will have different opinions about any issue simply because they are different people. But the diversity and adamancy of public opinion regarding the issue of nuclear power seems much greater than that of, say, nuclear weapons, or solar power.

Two factors especially contribute to the controversy of the nuclear power issue. The first factor is simple ignorance of the issue. Nuclear power's modernity and inherent complexity prevent the general public from gaining as intimate an understanding of nuclear power as of its predecessors. The second, more resistant, factor is the overwhelming abundance of misunderstood and misused symbols which are associated with nuclear power.[12]

People still tend to group all things nuclear together with nuclear weapons. In the wake of the Cold War, the memory of nuclear weapons of destruction looming over the world is still fresh. While most people agree that nuclear weapons are certainly unpleasant and undesirable, they are not necessarily rigorous in their evaluation of how this relates to nuclear power. Nuclear weapons are quickly associated with symbols of mass destruction, and genetically deformed people. Unfortunately, these symbols become just as attached to the "nuclear" part of nuclear weapons as to the "weapon" part of nuclear weapons. Therefore, when many people think of nuclear power, they recall these same symbols.

Although Switzerland did not participate in the Cold War, the proliferation of misused symbols occurred world-wide. Just like the people of any other country, the Swiss people struggle to dissociate the connotations of nuclear weapons from nuclear power.

Furthermore, the industry is gun-shy about nuclear energy right now. Even after the moratorium expires, it is unlikely that there will be any widespread endeavors to build any new nuclear power facilities in the near future.

Even the nuclear energy proponents still have the defeats of Kaiseraugst and Graben fresh in their minds. In both of these cities, projects to build nuclear power plants were abandoned due to anti-nuclear resistance. The economic losses were heavy. Investors lost SFr. 350 million in Kaiseraugst, and SFr. 227 million in Graben.

### *4.2. Conclusions*

Nuclear power is not a topic to be flippantly addressed. Its technical complexity and confusing association with various symbols make a clear, direct treatment challenging.

Switzerland has done an excellent job of educating its citizenry on the details of nuclear power. The general public has an acute awareness of both the obstacles and benefits of nuclear power.

Economic and political necessity drove Switzerland to introduce nuclear power in the 1960's. One thing is certain – the issue will not go away anytime soon. The conflict between the pragmatic necessity of nuclear power and the concerns of the environmentally-aware citizens will continue. Fortunately, the exact same skeptical nature and deep understanding of nuclear power's limitations and drawbacks that has caused Switzerland's nuclear power program to progress with the rate of extreme caution will help Switzerland to find even better implementations of nuclear power production in the future.

## Appendix A: Swiss Organizations Involved in Nuclear Power

*NAGRA - National Cooperative for the Disposal of Radioactive Waste:*

Nagra instituted a “come and see” program in 1995. It encourages people to visit nuclear power plants and to learn more about nuclear power. They have also run national television advertisements promoting nuclear power.

*Swiss Federal Nuclear Safety Inspectorate (HSK), Swiss Federal Nuclear Safety Commission (KSA):*

The Ordinance of Mar. 14, 1983 gives the HSK the power to regulate Swiss nuclear installations. It also requires that the KSA reviews any applications for a General License, Construction Permit or Operating Permit, and that the KSA further advises the HSK, and Federal Council regarding the qualifications of the applicant.

*SVA - Association Suisse pour l’Energie Atomique (ASPEA):*

The Swiss Association for Atomic Energy (Schweizerische Vereinigung für Atomenergie (SVA)) was founded in 1958 as a non-profit organization for the promotion of peaceful uses of atomic energy in Switzerland. They organize seminars and conferences, and offer post-graduate courses in nuclear engineering. They also publish brochures promoting public relations between the nuclear community and the public. Specifically, they publish the SVA-Bulletin (Bulletin ASPEA) and Kernpunkte (Flash nucléaire) in German and French.

*PSI – Paul Scherrer Institute:*

The Paul Scherrer Institute (PSI) performs research in the fields of nuclear and particle physics, the biological sciences, solid-state physics and energy. They also manage the development and operation of large, complex research installations for the benefit of national and international research associations.[13]

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