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[Comments by Bent in italics and brackets]

Nuclear Power: The Possible Solution to World Energy Needs

One of the driving forces of the 21st century is the non-renewable nature of fossil fuels. With over 75% of the world's energy coming from fossil fuels, new methods of energy conversion must be found to replace reliance on these sources once they run out. Fortunately, many people want to find a replacement energy source that is also environmentally friendly and will not contribute to the already precarious conditions the human race has inflicted on the planet. One such purposed energy source is nuclear power; and while nuclear power comes with many dangers of its own, it has proven to be a fairly safe and effective method of energy conversion.

[I like your choice of the word "coversion" rather than "use," because the latter implies that energy can be "used up," which isn't the case according the principle of conservation of energy (the first law of thermodynamics), which states (see p. 18 of the text) that "in any physical process, energy may be transformed (converted) from one form to another but cannot be created or destroyed."]

To truly judge nuclear power an understanding is needed not only of the basic processes of nuclear energy, but an understanding of the general opinion of the people who, in the end, will choose the future course of the world's energy needs.

Nuclear energy is derived from the splitting of an atom, the building block of all substances on earth. All matter, whether solid, liquid, gaseous, or plasmatic in form, is composed of atoms or a combination of atoms called compounds. The atom is basically made of three smaller components of mass and/or electrical charge known as protons, electrons and neutrons. Electrons hold a negative charge but weigh practically nothing, neutrons hold no charge but help comprise the weight of an atom, and protons hold a positive charge and weigh about as much as a neutron. The protons and neutrons of an atom are located in the center of the atom, called the nucleus, while the electrons orbit in specific areas known as electron clouds. The number of protons in the nucleus determines the element of an atom and describes it's

nature. The number of neutrons in an atom differs from element to element, but each atom has a specific number of neutrons that makes it most stable. Variations on the number of neutrons in an atom are called a isotopes. Some isotopes that exist in nature are highly unstable, and so the binding force holding the nucleus together is slightly weakened (Think Quest).

These breakable forms of an element are called fissile isotopes, and the process which can break them apart is called fission. The most used fissile isotope in fission reactions is Uranium 235 (U-235). If nucleus of a U-235 atom is hit by a neutral neuron traveling at a very high velocity,

> *[Slow moving neutrons are more effective than fast ones at fissioning a nucleus (as you state on p. 3), hence the "moderator" in a reactor.]*

the force of the impact will split the U-235 atom into many different substances. The uranium itself will become a combination of different elements depending on the angle and velocity of the fired neutron. Upon impact a small amount of energy is released in the form of heat, and two neutrons fly out from the nucleus and travel until they come into contact with other U-235 nuclei. This starts a chain reaction wherein one neuron fired soon becomes 2, then 4, 16, 256 and so on. If this reaction is left unchecked, it is called a runaway nuclear reaction and the total energy released becomes enormous. Runaway reactions can only be used for atomic weapons;

as such massive amounts of energy are too destructive to function as an energy source. However, there is a way to control the pace of a fission reaction and harness this power as an energy source (Think Quest).

Before a controlled fission reaction can take place, the raw materials must first be obtained and processed. The first step is to mine uranium from the ground. Depending on the location of the ore, an open pit mine or an underground mine will be dug. Pure uranium ore must then be extracted from the rest of the ore. Using a strong acid or alkaline, the uranium can be precipitated out of a solution in a process called leaching. After this refinement the concentration of uranium in the sample increases from 1% to up to 60% (Henderson 81). Natural uranium is mostly comprised of the non-fissile isotope U-238 and contains only 0.7% U-

235 (Henderson 81). So through the enrichment process U-238 is extracted and the uranium sample can increase U-235 concentration to 4.5%.

[Separating U235 from U238 is actually a very difficult and expensive process.]

This purer U-235 is then heated and pressed into ceramic hard pellets which are arranged end to end to form a fuel rod. About 100 of these fuel rods are grouped together in assemblies. Assemblies are then placed within the core of the nuclear reactor. By shooting neutrons into the core, a fission nuclear reaction will take place. In order to prevent a runaway reaction, control rods made of the element cadmium can be moved in and out of the core. These control rods collect excess neutrons, preventing them from coming into contact with U-235 nuclei and thus enabling operators to control the speed of the nuclear reaction (Think Quest).

The energy released from the fission reaction is often collected using the Pressurized Water Reactor (PWR) method. Water is used throughout this process as a collector of heat and as an integral part in controlling the nuclear reaction itself. As the nuclear reaction takes place in the core, the speed of the resulting neutrons is often erratic. If the neurons move too quickly, they will pass through the U-235 nuclei and no reaction will take place. To prevent this, highly pressurized water is used as a modulator to help slow down the speed of neutrons. The water also acts as a coolant, carrying the heat and energy away from the reactor. However, this water carries with it many of the byproducts from the reactor core, making it radioactive. To prevent damage to the plant and its workers, many facilities push radioactive water through pipes in tanks of water, which transfers the heat into the cleaner water. This clean water is then depressurized, converting it into steam. This steam is pushed through turbines which harnesses the nuclear heat energy and converts it into electricity (Think Quest). One ton of processed and refined uranium can generate up to 40 million kilowatt-hours of electricity, as opposed to oil which requires about 80,000 barrels (Henderson 82).

[I think you need a paragraph here explaining why, pound for pound, nuclear fission releases so much more energy than chemical reactions do. It's because the nuclear forces that hold neutrons and protons together in the nucleus are millions of times stronger than the chemical (electrical) forces that hold atoms together in molecules. Hence, nuclear binding energies are millions of times greater than chemical binding energies.]

Nuclear power plants do create a lot of electricity from a relatively small sample of raw material, but whether or not nuclear power is the answer to the worlds energy needs depends on a delicate balance of dangers and economic feasibility. When nuclear power was first promoted, it was optimistically promised that energy would soon become, “too cheap to meter” (Vaitheeswaran 276). But on the 28th of March 1979, the Three Mile High nuclear power plant in Middletown, Pennsylvania had an accident which struck fear in the hearts of Americans. Richard Thornburgh, the then current governor of Pennsylvania and later attorney general to George Bush Sr., explains his disillusion, “I no longer took for granted the fact that this source of electric power was as risk free as its promoters had indicated in the early years" (Vaitheeswaran 275). Today however, the Three Mile Island plant is one of the most productive, safest and profitable plant in the nation. Between 2000 and 2001 the operating costs for this facility averaged to be 1.8¢ per kW-hour. The average cost for a coal power plant in that same time period was 2.1¢ per kW-hour and a natural gas plant, 3.5¢ per hour (Vaitheeswaran 280). This advance in efficiency is linked to a recent consolidation of plant ownership across the nation and illustrates an economic advantage to nuclear power.

[Not counting the initial capital costs, the costs of operation safety, and the costs of decommissioning the reactor. I think the nuclear reactor under construction at Marble Hill, IN in the 1980s (?) was never completed for economic reasons.]

However, the current nuclear plants are all scheduled to be shut down by the year 2035 unless a resurgence of support for nuclear power occurs; and if the world were to decide on nuclear power to solve the world's energy crisis many brand new plants would have to be built. Speaking in terms of construction costs, nuclear plants have a history of underestimating the amount of money needed. According to the US Department of Energy, original estimates for the construction of 75 nuclear reactors was $45 billion, but at the end of construction the overall cost was over $145 billion (Henderson 103). This gross underestimate was publicly recognized by *Forbes* magazine, to be "the largest managerial disaster in business history" (Henderson 103). But what opponents and financial critics did not take into account was that construction can

account for up to 75% of the total cost of a nuclear plant (Vaitheeswaran 281). So with good managing of the facilities, a nuclear plant would not be as expensive to run as it was to build. However, the construction costs would still have to be taken into account when averaging the cost of electricity for the consumer. This would make nuclear electricity much more expensive than the 1.8¢ per kW hour currently available at some older facilities who's construction costs have already been paid for. But this does not mean that nuclear power could not be more efficient and cost effective with new technological developments.

Unfortunately funding for research in nuclear technologies is not necessarily forthcoming. Many people are frightened of the potential dangers of nuclear power and for much of its history, politicians, frightened of losing public opinion, were not keen on diverting funds for nuclear research. In 1986 the Ukrainian nuclear plant at Chernobyl experienced a severe accident which lead to the immediate deaths of dozens and is estimated to have caused the deaths of over 3,500 more due to radiation-induced cancer (Riter 80). But the Chernobyl plant does not represent the standards of nuclear facilities; the plant was too large, mismanaged and lacked safety technology that is standard on most other nuclear plants. The fact is that in all of nuclear history, the Chernobyl represents its only major disaster. When compared to the thousand or so lives lost yearly in accidents at conventional coal, oil or gas plants, nuclear safety looks much more secure (Riter 81). But "public perception often differs from professional judgments" (Lee 97)

[A key point that will determine the future of nuclear power in the U.S.]

and despite these statistics, not a single nuclear reactor has been built in the United States since the Three Mile High incident of 1979. Most people are just uncomfortable with nuclear power and the survival of this method of energy conversion becomes more political than technical.

One major problem people have with nuclear power is that it leaves radioactive waste behind, and the modern method of disposal is to bury it in the ground. Vijay V. Vaitheeswaran, economist and obvious opponent of nuclear power, expresses his aversion thusly:

> The best that the world's sharpest minds could come up with after 50 years of research and endless pots of money is to take this horrid stuff, bury it in a big hole in the ground, and pray that our grandchildren will be clever enough to figure out how to make it safe (Vaitheeswaran, 286).

To many people this may seem extraordinarily dangerous, to have radioactive materials simply buried in the ground. But the actual volume of nuclear waste is quite small, only about 4,500 tons of waste per year. The amount of greenhouse gases expelled by conventional fossil facilities is billions of tons a year and escapes directly into the atmosphere (Riter 82). Nuclear waste can be controlled and stored safely. There is currently no permanent storage facility for nuclear wastes, but one is being purposed by navy contractors (DOE), the Environmental Protection Agency, and the Nuclear Regulatory Commission at the Yucca Mountain site in Nevada. The site is removed from population and has a long history of seismic and volcanic inactivity. The storage area is intended to be located 1,000 feet underground and 1,000 feet above the groundwater source. In an area with very little rainfall there is little chance that the rain will permeate 2,000 feet to the ground water, so the waste stored there should be safe (Henderson 90). The facility will also be surrounded with materials, like lead, which do not allow radioactive radiation to escape to the surface or the groundwater below. It is possible that in the future a way will be discovered in which nuclear waste products can be recycled or reused for more energy.

[Might add a paragraph here explaining where spent reactor fuel elements are being stored now – in pools of water at the reactor sites, which are very vulnerable to sabotage.]

There is a precedent for recycling used nuclear materials that has helped reduce the amount of radioactive wastes produced by nuclear reactors. The method of plutonium repossessing can be applied multiple times to an already spent fuel rod to recycle the fissile materials and reuse them in a fission process. Spent fuel rods still contain 5% of the fissile materials Plutonium 239 (P-239) and U-235 along with the non-fissile waste products. By separating the P-239, oxidizing it, and combining it with the excess U-235, a MOX fuel is produced and the fission process can begin again (Henderson, 83). Unfortunately this process was largely abandoned in the early years of nuclear power because the spent fuel rods contain weapons grade plutonium and it was feared the rods could be stolen or targeted by enemies. With the end of the Cold War and the break up of the Soviet Union, the reprocessing method is used much more frequently than it was in the past, showing an encouraging trend of nuclear plants producing far less waste than before.

[But many people think the weapons-grade plutonium-239 problem is greater now than it was during the cold war, because of the increased likelihood of P-239 falling into the hands of terrorists.]

The world is still undecided on the nuclear issue, but with diminishing fossil fuel resources and growing concerns of global warming, nuclear power may be on the rise. Unlike fossil fuels, nuclear driven power facilities do not release carbon dioxide, and much of the world has a vested interest worldwide CO_2 levels. In 1997 the Kyoto protocol was signed in Japan, and signers promised to lower the level of carbon dioxide in the atmosphere to pre 1990 levels by the year 2012. Nearly all the members of the European Union signed the document and many believe that the only way to adhere to this protocol is to turn to nuclear power. Loyola de Palacio, a top official at the European Commission says, “I don’t have a particular fondness for nuclear energy…[but] Europe cannot do without nuclear energy unless it abandons the objectives of Kyoto” (Vaitheeswaran 277). Even the United States, which did not sign the Kyoto protocol but has a voluntary reporting program for pollution control, is starting to lean in favor of developing new nuclear technologies for the future.

[The absence of CO2 production is the main argument for nuclear power.]

Despite much public opinion opposed to further developments in nuclear power, the federal government has been looking to support its development. The Clinton administration gave nuclear power a boost when former Vice President Al Gore endorsed it at a

conference at the Chernobyl museum in 1998 by saying, “nuclear power, designed well, regulated properly, cared for meticulously, has a place in the world’s energy supply” (Hill 76). Support has also come from some environmentally aware politicians like Sen. Bob Graham in Florida, who cosponsored a bill to expand the use of nuclear energy and research into new technologies to help reduce nuclear wastes. Leaders in Alaskan government are also very interested in pushing any alternative energy methods that would prevent further oil and gas drilling in the Alaskan wilderness. While very little specific help has been given, the Bush administration and Republican supporters see nuclear power as a way to reduce the country’s dependence on foreign nations for energy needs (Hill 77).

The issue of the continuation and expansion of nuclear power is one that is highly charged and complicated. The fact that nuclear power is efficient and dependable enough to replace fossil fuels makes it impossible to ignore. Other methods of renewable energy like solar and wind power are not as dependable and have a long way to develop before they become secure enough to offer a real solution to the world’s energy needs. On the other hand, nuclear power still relies on a mined mineral from the earth, and is therefore not technically renewable. Uranium is much more common than oil or coal,

[Not by weight – by far!]

but it will not last forever. Nuclear power still produces dangerous waste materials. It is possible that these materials could be recycled in the future; but this would be placing a bet on the scientific advances of our descendants. Now is the time to find an energy source that will have the fewest consequences to the environment and the future of human culture. With so many people against nuclear power, so many little dangers and inconveniences, is nuclear power the right solution, or is it simply another temporary fix?

[For how long? Nuclear power plants are expensive to build, and they have a lifetime of 30-40 years. So, once built they are likely to be run for their full lifetimes in order to recover their capital costs.]

Nuclear power will continued to be debated on and as new scientific and political situations arise, perhaps a clearer cut answer will be found.

Works Sited

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General Comment

A fine, well-balanced paper. The informal presentation in class, without notes, showed that the author understood what she had written about. Page numbering (which I've added) is a good thing.