Nuclear Energy

Future and Risks

Quest Club Paper

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At 2:46 pm on March 11, 2010 (one year ago this Sunday), the Tōhoku earthquake struck with an epicenter approximately 43 miles east of the Oshika Peninsula of Japan. The magnitude 9.0 undersea earthquake generated a tsunami with waves up to 133 feet high.

Traveling at a speed at times in excess of 400 miles per hour, it took just 41 minutes for the tsunami to reach Futuba, Japan, site of the Fukushima Daichi Nuclear Power Plant. The Plant consists of six nuclear reactors driving electrical generators with a combined power of 4.7 gigawatts, making the Fukushima plant one of the 25 largest nuclear power stations in the world.

Planners knew the Fukushima location could be subjected to violent earthquakes and tsunamis, so the vital fuel cooling system was designed with multiple safeguards and backup mechanisms. As planners had expected, the earthquake immediately knocked out the electrical grid serving the plant, triggering the backup diesel generators to begin.

The 33-foot seawall protecting the plant stopped the first tsunami wave, but the second wave easily topped the seawall, disabling the backup generators to four of the six nuclear reactors. At this point, a third backup system, an array of powerful batteries, began providing electricity for the cooling system. Those batteries, though, had a useful life of only eight hours, and in the chaos following the earthquake rescuers were unable to deliver fresh batteries to the plant before the cooling system failed.

Without the necessary cooling systems, within 6 hours the nuclear fuel rods heated up rapidly as the temperature inside the core reached 2,800 °C, or 5,000 F. The reactor core melted and burned a hole through the containment vessel. Today, an area the size of Connecticut lies within the evacuated exclusionary zone, which covers more than 3 percent of the landmass of Japan.

The catastrophe has led many observers to conclude that, after Three Mile Island and Chernobyl, Fukushima was the final nail on the coffin in the debate over the safety of nuclear power.

Yet one year after the Fukushima meltdown only a handful of the 443 operational nuclear power plants around the world have been shut down, while over 200 new plants are planned. Nuclear power continues to provide 14% of the world's energy needs, and economic plans for Brazil, Russia, India and China are dependent on significant new growth in nuclear power.

So today we will ask the question: What is the future of nuclear energy?

The predominant use of nuclear energy is to power the electrical grid – that vast array of power lines around the world which provide the voltage needed to turn on lights, operate appliances and keep our computers humming.

To keep that grid charged there are two important points to remember. First, the energy can't travel very far, so power plants need to be located fairly close to the end user. Second, for all practical purposes there is no such thing as storage on the grid. At any minute of the day, we must be producing almost exactly as much electricity as we are using, and using as much as we are producing.

At present, the world's population consumes about 15,000 gigawatts of power.   For those of you like me whose science knowledge comes from popular culture, the flux capacitor used to power Marty McFly's vehicle in ***Back to the Future*** required 1.21 gigawatts of power. So we will need to build about 12,000 flux capacitors to fulfill our energy needs. Unfortunately, flux capacitors have not yet been invented. To better understand what 15,000 gigawatts of power means, a typical coal-fired power plant will produce about 1 gigawatt of energy.

Furthermore, as the world's population grows and less developed countries become wealthier, energy needs from power grids will increase. By 2050, the world's power consumption is likely to have doubled to 30,000 gigawatts.

With our current technology, there are six options to power the electrical grid: Coal, natural gas, hydroelectric power, wind power, solar power and nuclear power.

As much as we would all like to use more wind, solar and hydroelectric power, those energy sources cannot help power the grid. When the wind doesn't blow or the sun doesn't shine or there is no nearby river to dam, those sources will have limited value. Even under the best of circumstances, wind, solar and hydro will never produce more than 20%-30% of the world's total electric needs.

Under the most optimistic scenarios, by 2050 wind, solar and hydro power will provide about 10,000 gigawatts of power. To produce the other 20,000 gigawatts we will need, the world has three options: coal, natural gas, and nuclear power.

A nuclear reactor is effectively a big device for boiling water. Instead of using the combustion of fossil fuel as its heat source, a nuclear power plant uses atomic fission of uranium.

THE NUCLEAR AGE began 70 years ago on a squash court in the University of Chicago, under the watchful eye of a man with an axe. A team led by Enrico Fermi had been building a nuclear "pile" for weeks, slotting pellets of uranium and bricks of graphite into a carefully planned geometry through which ran various "control rods" of cadmium. The squash court was the only convenient large space available on the university campus. On December 2nd 1942 the pile had grown large enough to allow a nuclear reaction to take off when the control rods were drawn back.

The axe man was there in case the reaction went out of control. If it did he would chop through a rope, sending the main control rod crashing back into place, absorbing the neutrons driving the reaction and restoring stability. Today every commercial power reactor has control rods poised to shut it down at a moment's notice, a procedure that is still called a scram. The name comes from the safety process in place at that squash court in 1942: "**S**afety **C**ontrol **R**od **A**xe **M**an", or SCRAM.

Current nuclear plants are technologically complex systems that are very unforgiving. They work really well within a very narrow range of conditions. When those conditions are breached by an earthquake, a tsunami, a hurricane or some other disaster, things can get out of control fast.

A nuclear power plant is susceptible to two significant risks. The first is a criticality accident, in which the nuclear chain reaction becomes uncontrolled. The second is an overheating of the reactor core. Unlike coal, which quits generating heat as soon as combustion ceases, nuclear fuel does not stop generating heat when you stop splitting atoms.

This means, then, that when a nuclear power plant breaks down, the consequences are much more severe than with a coal-fired or natural gas power plant.

There are several layers of protection that keep nuclear fuel contained within a nuclear plant. The first barrier is what is called the cladding — a zirconium cover that surrounds the fuel, keeping it in an environment that is conducive to reactor management and cooling.

The second layer of protection is the reactor vessel, a steel container that houses the reactor and its coolant.

The third layer of protection is the containment building. This is a thick, steel-reinforced concrete structure built to withstand very high heat and pressure. If the reactor vessel is breached, the job of the containment building is to withstand incredible force and contain the nuclear fuel.

Many of you may recall watching a new film starring Michael Douglas and Jane Fonda which came out the second weekend in March, 1979. The film's title, "China Syndrome" referred to the idea that molten radioactive fuel undergoing a runaway reaction might burn its way through the bottom of the reactor's pressure vessel and containment structure, and then down into the Earth. Of course the fuel would never actually reach China, but were it to breach the containment structure; the result could be a huge release of radioactivity. As a physicist is quoted as saying in that film, such an event would render "an area the size of Pennsylvania" permanently uninhabitable.

Less than two weeks after that movie was released, the world watched as a nuclear accident unfolded at the Three Mile Island nuclear plant in, of all places, Pennsylvania. In that instance, mechanical failures and operator error allowed large amounts of nuclear reactor coolant to escape, leading to the evacuation of 140,000 people.

At Three Mile Island, the pressure vessel containing the nuclear core held, and virtually no dangerous radioactive gases escaped from the plant. Although the accident nearly killed off America's nuclear-power industry, it did not harm any people.

But a few years later a truly horrific disaster occurred. In 1986 a reactor at Chernobyl in Ukraine became unstable, suffered a criticality incident, and a power surge inside the core led to two explosions that destroyed the reactor and blew its roof off. As a result, significant amounts of radioactive material escaped into the environment. About 30 emergency workers died of radiation exposure shortly after the accident. Thousands more people who lived in contaminated areas developed serious health problems, some of them fatal.

Fukushima Dai-ichi, on the other hand, did not experience a criticality incident but developed problems as a result of overheating.   Less well-known overheating also occurred at an experimental reactor in Idaho Falls, Idaho, in 1955 and at the Fermi I breeder reactor outside Detroit in 1966.

Along with the health dangers, the nuclear industry has also been unable to develop a solution to the problems of nuclear waste.

Nuclear reactors run on enriched uranium fuel. The process leaves behind waste that is no longer capable of sustaining a nuclear reaction but is still highly radioactive.

The majority of the country's nuclear waste is stored in pools of water known as spent-fuel pools. Circulating water is used to cool the hot radioactive fuel rods.

At the Fukushima Daiichi nuclear plant, water levels in at least one of the plant's spent-fuel pools dropped to dangerous levels, allowing radiation to escape.

The country's 104 nuclear reactors generate about 2,000 metric tons of waste a year. In all, there are some 65,000 metric tons of this waste in the U.S., almost all of it stored at current or former reactor sites.

When the first commercial nuclear reactors were built in the 1960s, the federal government expected to reprocess the spent fuel so it could be used again. But reprocessing creates plutonium, which can be used in nuclear weapons, leading to fears the material could go astray.

Instead, in 1982, Congress decided to create a permanent underground storage facility for the nation's used-up nuclear fuel, with utilities covering the costs. Five years later, Congress chose Yucca Mountain in Nevada, 80 miles northwest of Las Vegas, as the site of the permanent facility.

The facility was never built. Nevada politicians, including Senate Majority Leader Harry Reid, fought the location, saying the state's residents wouldn't be adequately protected. After years of lawsuits and political battles and billions of dollars in spending, the Energy Department last year dropped plans for the Yucca Mountain site.

After the decision to abandon the Yucca Mountain site, President Barack Obama created the Blue Ribbon Commission on America's Nuclear Future to provide recommendations for developing a safe, long-term solution to managing the nation's spent nuclear fuel. The commission released its final report in January 2012. While the recommendations of the commission make sense, the bottom line is that no one wants a nuclear waste storage facility anywhere near their backyard. Instead, the waste will continue to pile up in sites scattered throughout the world, making those sites subject not only to health issues but also to theft by people with far more sinister motives. That waste nuclear fuel can be part of the raw materials needed by a terrorist to create a nuclear weapon.

Acquiring nuclear weapons requires three elements: nuclear material (such as highly enriched uranium, called plutonium), a delivery system and a warhead. The problem with the spread of nuclear power is that some countries might claim to be acquiring and processing uranium for peaceful uses, when in fact they are masking a nuclear weapons program.

So far, only ten countries – the United States, Russia, Britain, France, China, India, Pakistan, North Korea, Israel, and South Africa – are known to have successfully created a nuclear bomb. But at least 20 other countries have tried to develop their own bomb.

Last week, President Obama and Israeli Prime Minister Benjamin Netanyahu met at the white house, and they almost certainly discussed the possibility that the Israelis will launch an attack on Iranian installations suspected of developing nuclear weapons. It’s also likely that Netanyahu asked Obama for advanced "bunker-buster" bombs and refueling planes that could improve its ability to attack Iran's underground nuclear sites.

The threat of an Israeli military strike is not an idle one. The only reason Saddam Hussein did not develop a nuclear weapon is because the Israeli’s bombed Iraq’s Osirak reactor in 1981. In 2007 they also bombed a suspected Syrian nuclear reactor under construction.

Much has been made of the nuclear Non-Proliferation Treaty signed by the world’s leaders. But the spread of nuclear power throughout the world, and the availability of spent nuclear fuel in hundreds of locations, can only lead to more possibilities for nuclear terrorism.

Given what we have just discussed, why would any country undertake the risks of nuclear energy? Despite the problems for health & safety, of the disposal of nuclear waste, and of the spread of nuclear terrorism, nuclear energy has two important arguments in its favor: Economic and environmental.

Nuclear power plants are expensive to build but cheap to operate. They are so cheap to operate, in fact, that in 1954 the head of America's Atomic Energy Commission declared that one day nuclear power would be “too cheap to meter”. Also, of course, much of the nuclear industry's raw material – uranium -- is conveniently located in politically friendly countries such as Australia and Canada.

It’s generally true that nuclear power is the cheapest power to produce when measured by cost per kilowatt-hour, followed by coal and then natural gas. I’ll have more on these relative costs later.

It is important to note, though, that coal and natural gas would be much more expensive if the United States adopts either an emissions trading system for greenhouse gases or a carbon tax on fossil fuels. Emissions trading (also known as Cap and Trade) is a market-based approach used to control pollution by providing economic incentives for achieving reductions in the emissions of pollutants. While the European Union has implemented an emissions trading program for greenhouse gases, the United States has no plans to adopt either Cap and Trade or a carbon tax.

Even in the absence of Cap and Trade or carbon taxes, a strong environmental argument can be made in favor of nuclear power.

- A power plant which uses coal for fuel produces about a ton of greenhouse gases (mainly carbon dioxide) every hour
- A plant which uses cleaner-burning natural gas still produces about a half a ton of greenhouse gases every hour.
- A nuclear power plant produces no greenhouse gases.

In 2009 the world produced about 50 billion tons of greenhouse gases, mainly carbon dioxide. The United Nations has estimated that for the world to have a reasonable chance of limiting global warming to less than 2°C, carbon-dioxide emissions should be reduced to 44 billion tons, a reduction of six billion tons a year. Robert Socolow of Princeton University has calculated that if the world were to replace all of our current coal-fired power plants with nuclear power plants, it would reduce annual emissions of carbon dioxide by nearly 4 billion tons.

As a result, there is an unlikely alliance between the nuclear industry and many environmentalists, as a growing number of environmental activists have come to believe that nuclear energy is the best way to reduce carbon emissions. James Lovelock, a founder of Greenpeace, has gone even further, stating: “Only nuclear power can halt global warming.”

Some possible global warming solutions will only put more pressure on the electrical grid. One of the best ways to reduce carbon emissions is through increased use of electric cars. Yet a household that must recharge an electric car uses three times as much electricity as other households.

There's one more item to be mentioned in the case for nuclear power. While the result of a criticality incident or a reactor overheating can be horrendous, the fact is that thousands of people die each year from the consequences of using fossil fuels such as coal and natural gas.

According to the Brookings Institution, in 2010, there were more than 23,000 premature deaths, and 20 times that many cases of illness, caused by the soot from coal-fired power stations. A 2007 study found that, in the European Union, air pollution from coal power plants killed almost 25,000 people each year.

Even mining fossil fuels is dangerous, as each year in China alone 2,000 to 4,000 people die in coal mining accidents.

The point is that the production and use of any fossil fuel is dangerous. Victims of pollutants from a coal-fired power plant may not be as newsworthy as victims of nuclear accidents, but policymakers need to understand that fossil fuels are not necessarily a safe alternative to nuclear power.

While the use of nuclear energy is dependent on a variety of economic, environmental and health & safety factors, ultimately the decision to use nuclear is made in the political arena.

Sixty nuclear reactors are currently under construction around the world, with 163 more on order or planned. That is up slightly from a year ago—a month before Fukushima—showing 62 reactors under construction and 156 on order or planned. Yet some feel that the future of nuclear energy will be one of decline, not of growth. Today's issue of the Economist features a special report on the future of nuclear energy, calling it "The Dream that Failed". I do want to thank the editors of the Economist for publishing this report. I only wish that you had published it four weeks ago, and not today!

As might be expected, Japan has made the decision to significantly reduce its nuclear energy program, and perhaps end it entirely. Japan is the world's third largest consumer of electricity, behind China and the United States. It will replace its 54 nuclear reactors with coal- and gas-fired plants – fuels that will need to be purchased from other countries. In addition, in the 1997 Kyoto protocol, Japan agreed to cut its emissions of greenhouse gases by 6% by next year. Instead, Japan's emissions of greenhouse gases will exceed their goal by 210 million metric tons or 16% over the target.

In Europe, Italy and Switzerland have committed to scaling back or ending their nuclear programs. Germany has also decided to shut down its 17 nuclear power plants in the next ten years, leaving it with a 20,000 megawatt gap to fill. While some of this can be made up with renewables, most energy will come from coal and gas and it will also miss the targets set in the Kyoto protocol by a wide margin. It's also important to note that even though Germany is eliminating its nuclear program, much of their shortfall will be made up by importing power from the nuclear plants in France.

France has long been the world leader in nuclear energy. Thirty years ago their policymakers concluded that their country had "no oil, no gas, no coal and no choice" but to embrace nuclear power and today about 80% of its electricity is generated by 59 nuclear plants across the country. However, the front-runner in this May's presidential election has vowed to reduce that country's reliance on nuclear power by one-third.

China, the world's most aggressive builder of reactors, put all atomic approvals on hold following Japan's nuclear crisis. But it is expected that China will soon once again be the world leader in building nuclear power plants. Their government has established a goal of 70 gigawatts of nuclear capacity by 2020, a sevenfold increase from 2010.

In the United States, I agree with the prediction made by Questor Alan Grinsfelder in his paper on the future of nuclear energy that he delivered in 2008: it's likely we will see only modest growth in America's use of nuclear power in the coming years, due to a variety of factors.

The most important recent development impacting America's energy market is the vast expansion of the production of shale oil and gas. As late as 2000, shale gas was just 1% of American natural-gas supplies. Today, it is about 25% and could rise to 50% within two decades. Estimates of the entire natural-gas resources in the United States, taking shale gas into account, are now as high as 2,500 trillion cubic feet. That amounts to a more than 100-year supply of natural gas.

For those of us who remember the Arab oil embargoes of the 1970s, the growth in shale gas has led to an even more remarkable result: The United States was a net exporter of petroleum products in 2011 for the first time in 62 years. This doesn't mean that the United States has eliminated its energy independence problem. We still import nine billion barrels of crude oil every day. But the widespread availability of natural gas, and the resulting drop in the price of natural gas, will mean that it will become the fuel of choice in the development of new power plants.

There is another development effecting energy sources used to power the electrical grid, as well.

A short drive on US 30 east of Fort Wayne will bring you to the Northwest Ohio Wind Energy Project, a system of 60 wind turbines each of which is 500 feet high (that's 200 feet taller than the Lincoln Tower). When completed, that project will produce 300 megawatts of power, enough to provide energy for 80,000 homes.

The project was incentivized by a Renewable Portfolio Standard Bill signed by the Ohio governor in 2008. The bill requires Ohio to procure at least 25% of its electricity from alternative energy sources by 2025. In addition, 31 other states have passed renewable portfolio standard legislation, which will lead to increases in the use of alternative energy sources such as wind and solar power.

Because of the availability of cheap natural gas, and aggressive growth in wind and solar power, it is unlikely that the nuclear industry will expand much in the United States in the coming decade.

In conclusion, the world will need to generate much more electrical power in the coming decades. When it comes to the decision between coal, natural gas, and nuclear power, there is no such thing as a right decision. We cannot eliminate risk. No matter what we choose, someone will get hurt.

Nuclear power can be safe if power plants use the latest technology, are well-managed, and if the nation can develop a strategy that makes sense for the safe storage of nuclear waste. If the industry is allowed to expand in a thoughtful and careful manner, nuclear power can help the world meet its energy needs while protecting the environment, as well.

Not far from Fukushima, in the Japanese hamlet of Aneyoshi, a stone marker sits a short way up a hill not far from the coast at the precise point to indicate the high-water mark of previous tsunamis. Aneyoshi had been destroyed by tsunamis in both 1896 and 1933. After the 1933 devastation, the stone marker was placed on the hillside which read:

Houses built on hills will bring peace to the children and grandchildren
With the thought of devastation of the great tsunami,
Remember never to build houses below this marker
No matter how many years may pass, do not forget this warning.

When the Tuhoku tsunami struck Aneyoshi last March, homes built on higher ground than the stone marker were spared, but everything below the marker was destroyed.

Three Mile Island, Chernobyl and now Fukushima serve as reminders of the dangers of nuclear energy. But the message they give is not to give up nuclear energy forever, but to always be mindful of safety and the unexpected when nuclear energy is used. No matter how many years may pass, do not forget this warning.

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