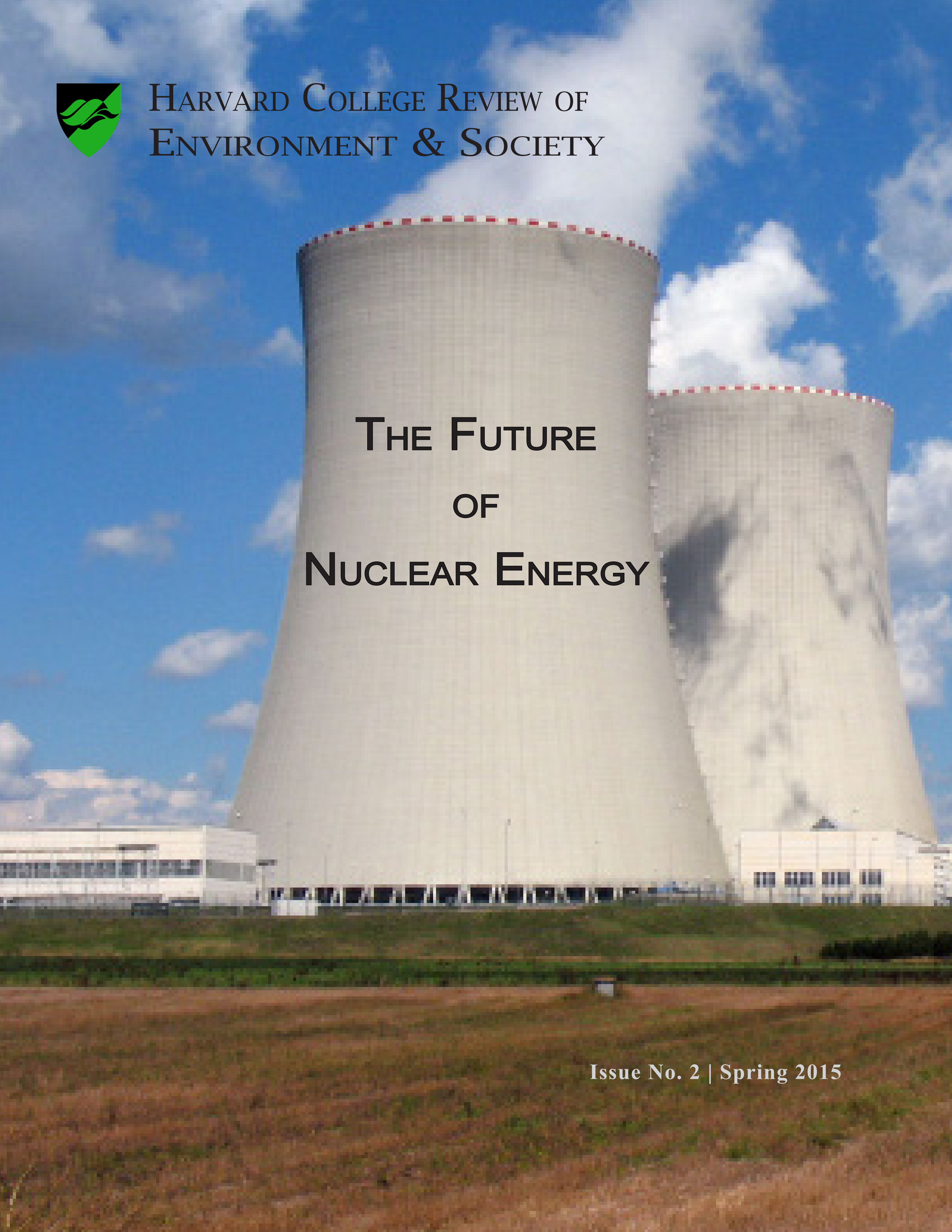
Harvard College Review of Environment & Society



The Future of Nuclear Energy

Issue No. 2 | Spring 2015

Harvard College Review of Environment & Society

Contents | Spring 2015

About the Review

A publication at Harvard University that seeks to provide a platform for connecting students, researchers, business and political leaders, and the public to enable integrative discussion that is paramount to developing successful solutions to our current environmental issues. While much of the contemporary discourse on environment and society have been focused on either one or the other, this publication provides a robust multidisciplinary discussion on the full gamut of competing pressures and interests relating to the environment.

We elucidate featured topics in our print journal and delve into more diverse issues on our website, www.hcs.harvard.edu/~res.

All questions, suggestions, and criticisms can be directed to res@hcs.harvard.edu

Submission information can be found at www.hcs.harvard. edu/~res/contribute

Introduction to the Second Issue

This publication, the second issue of the Harvard College Review of Environment & Society, focuses on the contentious subject of nuclear energy. Since the outset, nuclear energy has been a hotly-debated issue. First developed during the Second World War for anything-but peaceful purposes, the novel technology was not employed benignly for electricity production until 1951. Since then, its popularity has waxed and waned, and currently accounts for 4.8% of global energy production (as of 2012). What explains the world's use of nuclear energy? And what does the future hold for this energy source? This publication will seek answe rthese quetions.

Due to the technical nature of nuclear energy production, we begin this *Review* with a brief introduction to the science and engineering behind nuclear technology so that our readers will gain a foundation to approach the topic with a more informed and discerning eye.

In our first contributed article, Daniel Kammen discusses the potential role that nuclear energy could play in reducing greenhouse gas emissions to address the problem of climate change. While conventional energy sources, such as oil and gas, are gradually and nearly imperceptibly polluting the environment with climate-changing greenhouse gases, nuclear energy's effects on the environment can be sudden, catastrophic, and obvious. But Mikhail Chudakov, the Deputy Director General and Head of the Department of Nuclear Energy at the International Atomic Energy Agency, explains how these risks can be managed, and how nuclear energy promises to be the safe and important energy source of the future. In contrast, Daniel Thorpe argues that the infrastructure costs combined with social uncertainty make nuclear energy investments prohibitively expensive.

But there is more to the nuclear energy debate than simply technical cost-benefit analysis. Isao Hashimoto, a Japanese artist, illustrates with his own artwork the deeply emotional elements of this nuclear energy controversy.

Embraced for its low-carbon energy generation, yet spurned for its potential to create large-scale environmental catastrophes, nuclear energy has always had a complicated relationship with environmentalists. Hannah Kates examines this unique way that nuclear technology has been regarded by the environmentalist community. Finally, Danny Wilson scrutinizes the relationship between nuclear energy and culture in Japan and suggests that it is this relationship that is most instructive for understanding how nuclear power is employed now and in the future.

Bringing together this diversity of perspectives, we hope that our examination of nuclear energy expands the understandings of our readers. We hope this Review exposes the intricate and multifaceted complexities of this controversial topic, and sparks new awareness about the factors that determine what happens when you flip your light switch.

Sincerely,

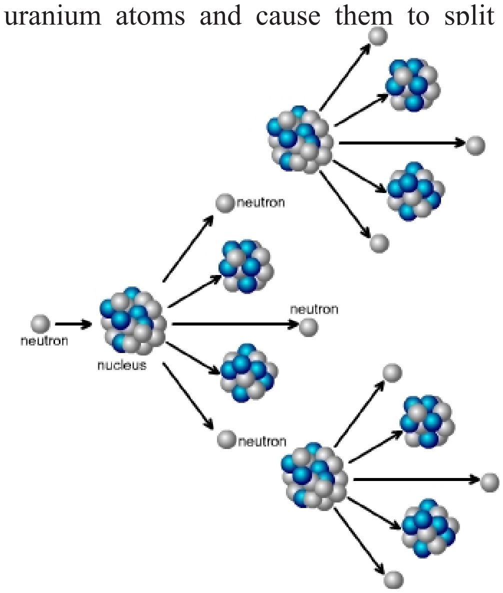
Harold Eyster, Co-Editor-in-Chief

Harvard College Review of Environment & Society

How Does Nuclear Energy Work?: A brief scientific introduction

The Editors

The basic principle at the core of most nuclear reactors is simple: pack together enough radioactive material of the right type, and you get a chain reaction in which an atom (let's say uranium) "splits" into two smaller atoms (i.e. undergoes fission), releasing some heat and also some neutrons (particles at the center of atoms); the neutrons can strike nearby uranium atoms and cause them to split as well,



leading to a chain reaction that continues to release heat along with the neutrons that sustain it [figure 1, above[1]].

This splitting happens naturally at a low rate in uranium, so if you pack the material tightly enough with the right conditions, the process can start on its own. In fact it has happened spontaneously in nature on rare occasions, for example 1.7 billion years ago in Oklo, Gabon, the right convergence of natural uranium and water led to an underground "reactor" that lasted for over 1000 years and produced about 100 kilowatts (kW) of heat on average, roughly equal to the output of 20 standard residential rooftop solar arrays in midday sun. Alhough 100 kW is small, the energy that can be released from such a process per unit of fuel is enormous - 1 metric ton of typical enriched uranium fuel can release over 1 billion kWh of thermal energy over its useful life in a reactor, as much as would be derived from 160,000 metric tons of coal.

Building a device that releases this huge store of energy is quite straightforward. Making such a device both safe and economical is the technical challenge engineers and scientists have labored over for the past 60 years. Additionally, engineers must contend with the problem of nuclear waste disposal and how to prevent undesired parties from using the same technology needed for a benign energy system to instead make a weapon. Each of these topics is complex and deserving of multiple textbooks, but here we briefly overview the technical aspects of plant design, fuel cycles, and waste as a primer for reading some of the articles in this review.

Basic Plant Design

At a high level, all a nuclear power plant is doing is carrying out the chain reaction described above in a controlled way, and then using the resultant heat to produce electricity. Typically, electricity is generated by using the heat to produce steam that turns a generator, in much the same way as in a coal plant or concentrating solar power array.

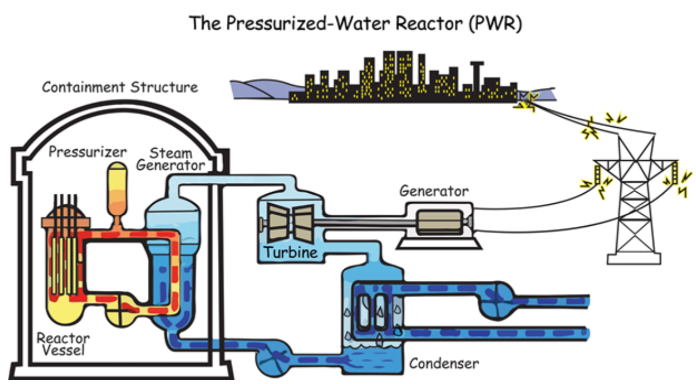


Figure 2 [above][2] shows a typical modern "Pressurized Water Reactor" (PWR), with three "loops" of water. The first loop passes through the reactor and picks up heat from the chain reaction, but is so pressurized that it does not actually boil. The water pipes carrying this hot water then pass through a steam generator, where water from a separate loop vaporizes to steam. Note that the water coming directly from the reactor core, containing radioactive elements, ideally never comes in physical contact with the water being turned to steam, it just passes its heat along and heads back to the reactor core. The hot steam then turns a turbine to generate electricity, and later comes into contact

1 Source: Intel Education Resources. http://inteleducationresources.intel.co.uk/examcentre.aspx?id=278

2 Source: US National Nuclear Regulatory Commission. http://www.nrc.gov/admin/img/art-students-reactors-1-lg.gif

with pipes from a third loop carrying cold water. The cold water cools down the steam and condenses it back into liquid water, so it can then flow back to the steam generator and be vaporized again. The cooling loop, several steps removed from the actual nuclear reactions, either passes through an iconic cooling tower (like the one displayed on the cover of this publication) or an external water source like the ocean or a river, releasing the heat into the air or water, but not releasing any physical material from the nuclear reaction.

Of course, the details are more complex, especially what is happening inside the reactor itself. All uranium is not equally useful for sustaining a chain reaction - the most abundant isotope, U238, is fairly difficult to use, while the much less common U235 is more desirable. Natural uranium found today contains around 99.3% U238 and just 0.7% U235, which under most conditions is not enough to carry out a chain reaction as neutrons released by the fissioning (splitting) of one U235 atom are not likely to collide with another U235 atom in time. To run most modern nuclear reactors, the uranium either needs to be "enriched," by increasing the fraction of U235, or needs to be immersed in a strong "moderator," a substance that makes neutrons bump into other uranium atoms at a higher rate, thus making a chain reaction more likely. Water, the typical working fluid in reactors as described above, is not a very strong moderator, meaning that the uranium has to be slightly enriched in standard plant designs, usually to 3% U235. However, other configurations are possible - Canada did not want to enrich nuclear material, so instead built the CANDU fleet of plants using deuterium oxide ("heavy water") which is a much stronger moderator than H2O, allowing even natural uranium to carry out a chain reaction. This eliminated the need for enrichment facilities to increase the fraction of U235 in fuel, but required facilities to produce heavy water instead.

Controlling A Chain Reaction, and Its After-Effects

One obvious question: if a chain reaction is happening in the reactor, releasing ever more heat and neutrons, how do we keep the reaction from "running away" and becoming so hot it melts the reactor? Modern reactors use three main strategies: 1) they are designed with a negative feedback loop, where the reactor becoming hotter slows down the reaction for reasons we will not describe here, 2) they are designed with a "negative void coefficient," meaning that the reaction slows down or stops if the pressurized water coolant is lost; thus, if the reactor starts to overheat and vaporizes the water, the reaction is slowed or halted, and 3) they use "control rods," physical rods made of some neutron-absorbing material that can be inserted amongst the fuel rods, absorbing enough neutrons to halt the process. These processes have been very reliable - there have been no major accidents at plants with the above three safety measures.

But there certainly have been accidents at nuclear power plants. They usually involve "decay heat," which is heat that is released even after the chain reaction has ceased. This heat comes from the continued breakdown of unstable atoms produced in the reaction, and can be of considerable magnitude. A full day after a reaction has been halted, a typical reactor will still be producing 10 Mega Watts (MW) of heat. This is enough to heat all of the water in the "first loop" by over 750 C per day, and would quickly start melting through the reactor vessel and/or start causing explosions if the rest of the loops were not running to draw the heat away. This was the problem at Fukushima - the reaction was halted, but without electricity, the cooling loops could not keep running and the reactor eventually overheated. Managing decay heat is thus one of the central problems addressed in new reactor designs, which brings us to the next section, a brief review of new designs being considered.

Improving Plant Design

So far we have reviewed the predominant type of reactor in the world today, the Pressurized Water Reactor using enriched uranium. There are other types, such as the CANDU reactors with heavy water mentioned before, and "boiling water reactors" that allow the first loop of water to boil rather than keeping it liquid with high pressure. But most of the basic principles are the same. To use nuclear industry parlance, all reactors of these types are usually categorized as Generation III, or III+ if they have slightly improved safety and/or performance.

Do we need to improve on this plant design? In some countries, namely China and South Korea, new Generation III and III+ plants are being built fairly economically (roughly cost-competitive with other options) and are deemed safe enough. In the West, however, most countries either deem them unsafe or struggle to build them economically, for a variety of reasons.

Especially given growing interest in low-carbon electricity, much attention is being given to new reactor and plant designs. These are too varied and detailed to treat in depth, but they usually involve some of the following three: 1) **improved safety**, 2) **reduced cost**, and 3) **reduced waste**.

"Passively safe" is a term associated with next-generation plant designs, ideally meaning a plant design where decay heat is handled passively and does not rely on active engineering systems that could fail. A simple example would be to have the reactor resting in a huge pool of coolant all the time, so large that even in the event of indefinite power outage the coolant reservoir is able to handle the decay heat. Costs can be reduced by reducing the complexity of plant design, or by operating at higher temperatures to allow better thermal efficiency in electricity generation. Wastes can be reduced in several ways, such as by modifying the nuclear chain reaction to produce less stable radioactive byproducts, resulting in less total waste with shorter lifetimes.

Some proposed designs attempt to combine multiple improvements, for example small modular reactors (<300 MW) could be significantly safer due to their small size and easier thermal management, and could reduce costs by being easier to assemble in factories with less time for costly on-site construction. Of course, only time and experience will tell if their costs would actually be lower, or whether smaller economies of scale or other factors would make them more expensive. Most proposed designs trade off between safety, cost, or wastes, for example “fast neutron reactors” can significantly cut waste generation but are usually more costly, or supercritical water reactors that could reduce costs but may not offer much additional inherent safety. But all of these designs are very far from commercial licensing, probably on the order of a decade or longer, and significant financial investment and patience will be required to develop them further and determine with more certainty if any offer a more appealing set of traits than current Generation III reactors.

Fuel Cycle

In the final section of this brief overview, we will examine the basics of the nuclear fuel cycle as it exists in most countries with PWR’s. Natural uranium is mined and sent to a fuel enrichment and fabrication facility. There it is separated into two streams - one enriched in U235, usually to around 3%, and another very depleted in U235, which is usually discarded. Unfortunately, the same equipment used to enrich the uranium to this level for nuclear power can also be used to enrich it further, closer to 90% U235, to make weapons-grade material, leading to ambiguities over whether some countries are enriching uranium for civilian or military purposes.

The enriched fuel can then be used in PWR’s, where it serves as fuel until the level of fissionable isotopes becomes very low again. Notice that the spent fuel leaving the plant now has quite a variety of radioactive products, formed through various reactions happening inside the reactor. The diversity of these wastes adds to the challenge of waste management, as some have half-lives of only several years while others have half-lives of many thousands of years.

Also notice that the spent fuel contains a significant amount of plutonium. This plutonium could also be used as fissionable material in a reactor, so many countries choose to “reprocess” their waste by extracting the plutonium and mixing it with depleted uranium to make more reactor fuel. This process tends to reduce the volume of waste and could be advantageous if uranium were in short supply or expensive, but for now uranium seems relatively abundant and inexpensive, and the reprocessing itself has proven expensive. Pure, fissionable plutonium created through reprocessing also leads to concerns about safety, weapons proliferation, and terrorism. However, despite these concerns, most countries using nuclear energy routinely reprocess their fuel, with the US being a notable exception mostly due its policies that attempted to “lead by example” in reducing weapons proliferation in the 1970’s.

As with plant designs, there are ways to improve on the current fuel cycle. One high level improvement would be to form a “closed” rather than “open” fuel cycle by utilizing different kinds of reactors that generate as much fissionable materials as they consume. Another is to use “fast reactors,” described earlier, to reduce the amount and lifetime of wastes. There are also possible geopolitical improvements, for example a global fuel cycle where a few agreed-upon countries supply fuel and accept waste from other countries. This would allow some countries to have nuclear power plants while never enriching fuel or handling their waste, and for countries like the US to have an easier waste disposal solution. Like the new reactor designs, though, these changes would take a very long time, easily beyond a decade, so if countries or the world decide they are desirable they will require patience.

Clean Energy Futures and the Role of Nuclear Power

Daniel M. Kammen[1]

Thanks to a number of factors – natural disasters, the steady flow of increasingly clear and detailed data, and significant new political accords such as the US-China climate consensus from October 2014 – climate change is now very squarely in the public and political debate (The White House, 2014). Many of us, of course, have been arguing that this should have been the case long ago. In my case I am very pleased to have worked as a contributing and then a lead author to the Intergovernmental Panel on Climate Change since the late 1990s' (IPCC, 2000).

With the scientific consensus now clear that global emissions must be dramatically reduced, by eighty percent or more by 2050, attention is turning to two themes: 1) what is the permissible budget of fossil fuel use? and 2) What are our viable scientific, technological, economic, and political options to power the economy cleanly before mid-century?

On the first question a series of increasingly clear assessments have appeared that document the oversupply we have of carbon-based fuels. In the latest, high-profile paper, researchers Christophe McGlade and Paul Ekins (2015) make clear that Hubbert's peak – the rise and then decline in a non-renewable resource such as coal, oil or gas – is largely irrelevant to addressing the climate issue. Fossil fuel scarcity will not initiate the necessary transition.

The environmental bottom line is that to meet our climate targets, cumulative carbon dioxide emissions must be less than 870 to 1,240 gigatonnes (109 tons) between 2011 and 2050 if we are to limit global warming to 2 °C above the average global temperature of pre-industrial times. In contrast to that, however, the carbon contained in our global supply of fossil fuels is estimated to be equivalent to about 11,000 Gt of CO2, which means that the implementation of ambitious climate policies would leave large proportions of reserves unexploited.

> "Half of all the new nuclear power plants planned by 2030 worldwide are forecast to be built in China"

There have been several recent calls from people and organizations concerned about global warming to use nuclear electricity generation as part of the solution. This includes The New York Times, the Center for Climate and Energy Solutions (formerly the Pew Center on Global Climate Change), and a number of leading scientists, engineers, and politicians. These calls speak to the potential of nuclear energy technologies to deliver large amounts of low-cost energy. New advanced reactors, small-modular reactors, and fusion are all candidates for providing this energy, with knowledgeable and ardent supporters backing each of these technologies and pathways.

At the same time, there are very serious concerns with both the nuclear power industry as it has developed thus far, and with how it might evolve in the future. Alan Robock of Rutgers University summarizes these concerns in an exceptionally clear editorial piece (Robock, 2014), where he questions the ability of the nuclear power industry to meet needed standards of: 1) proliferation resistance; 2) the potential for catastrophic accidents; 3) vulnerability to terrorist attacks; 4) unsafe operations; 5) economic viability; 6) waste disposal; 7) impacts of uranium mining; and 8) life-

1 Dr. Daniel M. Kammen is a professor in the Energy and Resources Group, and in the Goldmen School of Public Policy, and in the Department of Nuclear Engineering, and is the Founding Director, Renewable and Appropriate Energy Laboratory (http://rael.berkeley.edu) at the University of California, Berkeley.

cycle greenhouse impacts relative to "renewables." Battles back and forth between proponents and detractors are sure to continue, but simply looking at #5 on this list alone – the direct costs and opportunity costs of investing in present-day nuclear power–demonstrates the scale of the challenge.

To address this, consider that of the 437 nuclear plants in operation worldwide today, most will need to be replaced in the coming three decades for nuclear power to even retain its current generation capacity, let alone to grow as a major technology path to address climate change. To examine this future, my students Gang He and Anne-Perrine Arvin (2015) and I have built a model of the entire Chinese energy economy, where nuclear power is expected to play a major role.

Today, China's power sector accounts for 50% of the country's total greenhouse gas emissions and 12.5% of total global emissions. The transition from the current fossil fuel-dominated electricity supply and delivery system to a sustainable, resource-efficient system will shape how the country, and to a large extent, the world, addresses local pollution and global climate change. While coal is the dominant energy source today, ongoing rapid technological change coupled with strategic national investments in transmission capacity and new nuclear, solar and wind generation demonstrate that China has the capacity to completely alter the trajectory.

The transition to a low-carbon or "circular" economy is, in fact, the official goal of the Chinese government (SI-S2). In the U.S.-China Joint Announcement on Climate Change, China is determined to peak its carbon emission by 2030 and get 20% of its primary energy from non-fossil sources by the same year. The challenge is making good on these objectives. Installed wind capacity, for example, has sustained a remarkable 80% annual growth rate since 2005, putting China far in the lead globally with over 91 gigawatts (4% of national electricity capacity) of installed capacity in 2013 compared to the next two largest deployments, namely 61 gigawatts (GW) in the United States (5% of total electricity) and 34 GW in Germany (15% of total capacity).

China's solar power installed capacity has also been growing at an unprecedented pace. Its grid-connected installed solar photovoltaic (PV) capacity has reached 19.42 GW by the end of 2013 (1.6% of total capacity), a 20-fold increase of its capacity in four years from 0.9 GW in 2010. These figures show that rapid technological deployment is possible.

Central to this discussion is the role of nuclear power, because half of all the new nuclear power plants planned by 2030 worldwide are forecast to be built in China (roughly 30 of 60 total nuclear plants anticipated to be constructed over the next 15 years).

The question remains whether this large-scale build-out of nuclear power will happen a) in China; and b) as a significant component of the energy mix in other nations, both industrialized and industrializing.

In our modeling work on both the Chinese and United States energy economies (see the program website: http://rael.berkeley.edu/switch), we find that there is a diverse range of pathways that can achieve the needed 80% emission reduction by mid-century. Some are more solar-dominated (Mileva, et al., 2013), some more wind-driven, some heavily reliant on biological carbon capture (Sanchez, et al., 2015) and so forth. A carbon price of $30 – 40 per ton of carbon dioxide is critical to drive each of these cases, and nuclear is no exception.

Returning to the list of challenges that Alan Robock poses, however, the prospects for nuclear power as a major source of energy are troublesome. This path is contingent on solving a very long and serious list of issues that most energy planners would conclude, at least at present, has not been successfully addressed.

Literature Cited: See page 20

Skepticism About a Large Nuclear Expansion in the US

The US may not be good enough at large infrastructure projects to do it well

Daniel Thorpe[1]

We are currently in the midst of protracted interest in a "nuclear renaissance," including newfound support amongst some environmentalists concerned enough about climate change to bracket fears about nuclear waste and risk and argue for a role for nuclear power. There are four modern reactors under construction in the southern US, which if completed would be a significant step forward after 20+ years of no new reactors coming on line. And government-led expansion of Generation III and III+ reactors has been rapid and relatively inexpensive in South Korea and China.

Despite this, I remain skeptical about the US significantly expanding its nuclear generating capacity as a way to mitigate climate change in the next several decades. Specifically, I think that such an expansion would require a large push of funding and leadership from the federal government that would probably have to go beyond a simple price on carbon, and I think that would be a poor investment based on the US's recent track record with nuclear power plants and other large, complex infrastructure projects.

There are many other possible reasons to think the US shouldn't make such a push, and some of them partially influence my assessment. Intergenerational ethical problems top many people's lists, as politically embattled nuclear waste that needs to be contained for thousands of years is not the kindest inheritance. Fears of catastrophic risk including terrorism and weapons proliferation are also prominent concerns, and are near the top of my list. There are also other worries that don't sway me as much but are significant parts of the public debate, including nuclear exceptionalism, the idea that nuclear contamination is a unique kind of harm to humans and the environment that cannot be traded off against other costs and risks.

These kinds of concerns are enough to make even the highly climate-motivated reluctant about nuclear power, and I think the final deciding factor is the significant uncertainty surrounding how quickly the US could really build new plants, and at what cost, especially when nuclear cost curves appear to be increasing. In fairness, much of this uncertainty comes from experiences with interminable construction delays in the 1980's that were often the result of escalating regulations during construction, or public opposition in certain parts of the country. The 2005 Energy Policy Act streamlined many of the most problematic aspects of plant licensing, and the four new reactors under construction are in Georgia and South Carolina where the public is largely supportive of nuclear energy, hopefully paving the way for easier construction.

> "The final deciding factor is the significant uncertainty surrounding how quickly the US could really build new plants, and at what cost, especially when nuclear cost curves appear to be increasing"

But even these four reactors are already experiencing significant delays and cost overruns. The two AP1000 units at Plant Vogtle began construction in 2013 and have already been delayed until at least 2019. With capital costs nearing $15 billion for 2.22 gigawatt (GW) of capacity, a basic Levelized Cost of Energy (LCOE) calculation

1 PhD candidate, Harvard School of Engineering & Applied Sciences.

suggests a break even price of around \$0.14/kWh.[1] The two AP1000 units at the VC Summer Generating Station began construction shortly before Plant Vogtle, and are also delayed from their original 2017-2018 completion time (2017 for the first unit, 2018 for the second) to 2019-2020. Costs have also escalated, from \$9.8 billion to at least \$11.2 billion. This yields an LCOE estimate around \$0.1/kWh.[2] This might also fit into a larger trend of US struggles with large infrastructure projects, including notably more expensive subway construction costs than other countries, and significantly more difficulty planning high-speed rail.[3]

Of course, much time has passed since our last construction of plants, so delays and high costs aren't totally surprising. Maybe if we committed to building many more AP1000's in a row, then costs and construction times would eventually come down and yield relatively dispatchable and inexpensive low carbon electricity. A large entity like the US government could afford to make such an investment, but it doesn't seem like a good bet to me given the alternatives. First, the size and complexity (both engineering and regulatory) of modern nuclear plants along with the long time scales for licensing and construction make learning-by-doing more difficult than for other low carbon generators. The extreme contrast is solar photovoltaics (PV): many 100 MW solar PV arrays are being rapidly installed in several months or less, and PV cells are being manufactured at a fast pace, creating greater economies of scale and allowing for more incremental advances than the nuclear plants that take years to license and at minimum 4 years to build. Furthermore, such large projects as nuclear reactors are almost certainly more likely to experience significant delays, and this is especially true of plants where regulatory scrutiny of any changes during construction is intense and time consuming. Lastly, nuclear reactors are probably the only low carbon generators that could fall completely out of public favor as the result of one discrete event – an act of terrorism, the use of a weapon, or a significant accident could all lead to irreparable reversals of trust by the public and thus the government. While the chance of this happening in any one year is small, if we imagine making a large push for learning-by-doing that could take several decades it starts to be a considerable risk.

This isn't to say that there will be no new nuclear reactors installed in the US in the future. It's quite likely that there will be at least several more, and it's possible that costs could come down significantly after this first new wave of reactors is built and spawn a large, spontaneous build-out. There seems to be a strong possibility that China will expand its nuclear fleet, likely benefiting from a strong centralized government and a track record of timely construction. But it has been a long time since the US has built reactors economically, and relative to other countries we might have a harder time executing large, high profile infrastructure projects, especially if they draw significant public interest and possible litigation. This leads me to believe significant government support would be needed to make nuclear expansion a reality, and that it would not be a wise choice even viewed strictly as a carbon-reduction strategy. Momentum matters when tackling a contentious issue like climate change, and the US might be better off putting its effort behind technologies with cost curves that are more obviously declining, and that can be built in a series of smaller victories rather than large, one-GW steps that could be contentious or frequently delayed.

Literature Cited: See page 20

1 See LCOE calculation in Literature Cited section on page 20-21

2 See LCOE calculation in Literature Cited section

3 See Lepska (2011) for comparison of per-km costs of subway construction in different cities, and Dayen (2015) for a brief review of the sources of delays and opposition to high speed rail in California.

Nuclear Power After Fukushima: IAEA Projections

Mikhail Chudakov[1]

"It is still an exciting time for nuclear power," International Atomic Energy Agency (IAEA) Director General Yukiya Amano said last January at a lecture in Singapore. Four years after the devastating accident at Japan's Fukushima Daiichi nuclear plant, what justifies such a view?

Several objective reasons do.

For many countries, nuclear power remains an important option for improving energy security and reducing the impact of volatile fossil-fuel prices. As a stable, base-load source of electricity in an era of ever-increasing global energy demand, nuclear power complements other energy sources—including renewables.

And because nuclear power, together with hydropower and wind energy, has the lowest life cycle greenhouse gas emissions among all power generation sources, it is crucially linked to mitigating the effects of climate change.

A clear correlation links energy poverty and real poverty. Energy is the engine of development. In his vision for Sustainable Energy for All, UN Secretary General Ban Ki-moon says that "all energy sources and technologies have roles to play in achieving universal access in an economically, socially and environmentally sustainable fashion." Simply put, to provide energy access to everyone, all forms of energy are needed.

Today, 1.3 billion people have no access to modern forms of energy. One billion people lack proper health care due to energy poverty. And 2.6 billion people, more than a third of the world population, still burn biomass for basic energy needs.

Projections

Coupled with concern about securing energy supply and carbon emissions, we get to the current situation: Four years after Fukushima, 30 countries still use nuclear power. About 11% of the world's electricity comes from 440 operational nuclear reactors. And there are 68 more under construction, with the trend growing.

Speaking of trends: The IAEA's latest projections from August 2014 show that the world's nuclear power generating capacity will grow between 8 and 88 % by 2030 (IAEA, 2012). Fukushima may have slowed the growth in nuclear power, but it didn't stop or reverse it. In short, we expect to see continued expansion in the global use of atomic energy over the next 20 years, especially in Asia, where two-thirds of the reactors currently under construction are being built.

Of the 30 countries that operate nuclear power plants, 13 are either constructing new units or are completing previously suspended construction projects. A further 12 are actively planning to build new units (IAEA, 2014a].

Newcomers

In addition to the 30 established users of nuclear power, about the same number of countries is interested in adding nuclear to its energy mix—the so-called "newcomers." One thing must be clear: it is the sovereign decision of every country whether to launch a nuclear power program. The IAEA does not try to influence that decision. But when a Member State decides to go that route, the IAEA is there to help (IAEA, 2014a).

The newcomers are at different stages of development: although the majority are currently at the "consideration" stage and have not yet made a national decision, the United Arab Emirates and Belarus are already constructing their first nuclear power plants.

Energy Planning

The future of nuclear power is linked to the future of energy. A country's energy mix changes over time. Resources that become depleted, too expensive, or environmentally detrimental are replaced by new technologies and

1 IAEA Deputy Director General, Head of the Department of Nuclear Energy

energy sources. Hence, energy planning is vital to meeting future capacity needs in ways that are economic, clean, and socially and environmentally responsible.

The IAEA's energy planning models and tools are used by 130 Member States and by more than 20 regional and international organizations. They assist countries in making informed decisions on future plans, irrespective of their interest in nuclear power.

Fukushima Lessons

Any nuclear power program is a major undertaking. It requires careful planning, preparation and a major investment of time and human resources. Of course, safety, as the Fukushima accident reminded us, is vital to the future development of nuclear power. IAEA Member States responded quickly to the accident by unanimously adopting the *IAEA Action Plan on Nuclear Safety* (IAEA, 2011) in an effort to look critically at several technical issues in nuclear power production. From severe accident management to communication, from emergency preparedness and response to enhanced research and development, Member States are focusing on lessons learned from the accident to improve nuclear safety in a holistic way.

Innovations

In addition to post-Fukushima safety upgrades in existing reactors, technological advances are also under way to make nuclear power safer and more efficient. Nuclear fusion, fast reactors and closed fuel cycles can extend the use of our resources to thousands of years. Small and medium-sized reactors (SMR) can respond to issues involving the electricity grid and major capital requirements. There are about 45 innovative SMR concepts, with Argentina, China, India and Russia already building theirs (IAEA, 2014).

The Agency assists its Member States, both newcomers as well as experienced users, in establishing the appropriate legal and regulatory framework, and offers know-how on the construction, commissioning, start-up and safe operation of nuclear reactors. The IAEA also establishes nuclear safety standards and security guidance. Its expert peer review missions help Member States in a wide range of areas, including uranium mining, plant safety, secure nuclear facilities, decommissioning and waste management.

The IAEA, in conclusion, helps nations gain or extend access to nuclear power—one of the great applications of atomic energy. By doing so, the Agency fulfills the mandate it adopted six decades ago: to "seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world."[1]

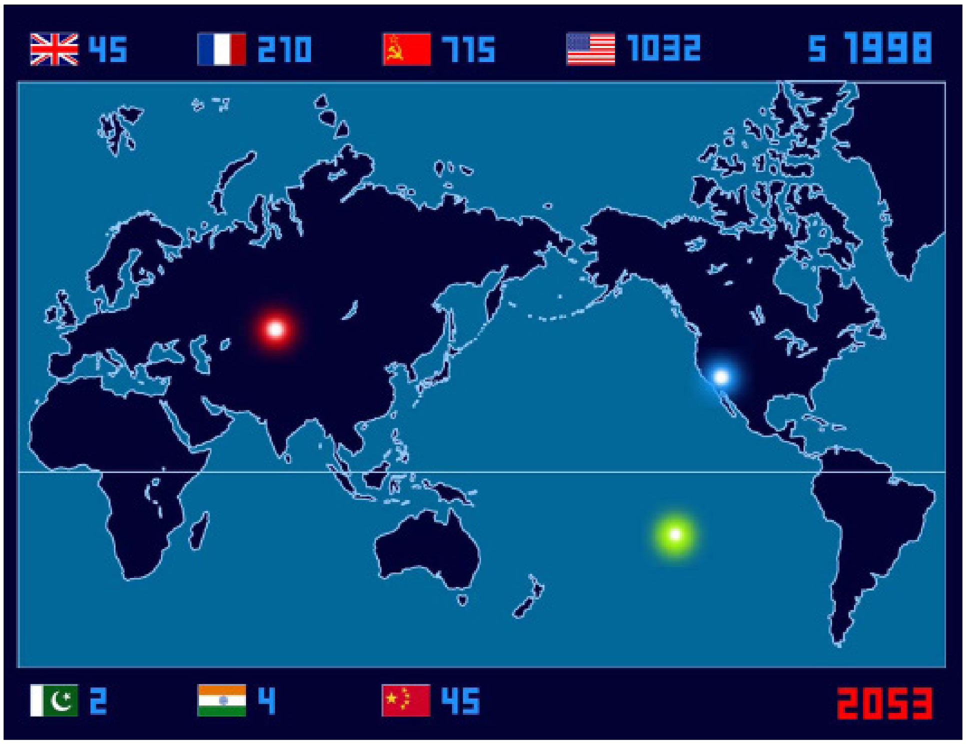
Literature Cited: See page 21

1 Article 2 of the IAEA's statute

Artwork as the Interface Between People and Problems

Isao Hashimoto[1]

Figure 1. “1945-1998”



Motivated by the tragedy of September 11, 2001, I created three artworks on atomic testing, hoping that they could contribute to world peace. After the nuclear accident in Fukushima in 2011, they were introduced and exhibited in many places around the world,[2] they were particularly influential in Germany, where the government announced the shutdown of all its nuclear power plants by the year 2022.

Before going into the details of my artworks, I would like to first summarize the history of nuclear tests.

Since the first nuclear test in 1945, followed by the actual usage of the bombs in Hiroshima and Nagasaki, more than 2000 nuclear tests have been conducted in various parts of the world. Until the early 1960’s, most of the tests were carried out in the atmosphere, causing massive radioactive contamination. In 1963, the United States, the Soviet Union and Great Britain signed “Partial Test Ban Treaty” to move testing underground, but France and China continued to conduct tests aboveground.

Then, as the anti-nuclear movements gained

1 Isao Hashimoto is an artist and Curator of the Lalique Museum, Hakone, Japan.

2 The artwork “1945-1998”(2003) was uploaded on the front page of website of CTBTO (Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization). And it is now exhibited in the gallery of CTBTO headquarters in Vienna as a permanent installation.

more strength, the Non-Proliferation Treaty (NPT) was finally put into effect in 1970. It is an intergovernmental agreement that seeks to reduce the possibility of nuclear war by preventing new countries from possessing nuclear weapons. Following this, in 1996 the "Comprehensive Nuclear Test Ban Treaty" was adopted, and by 1998 all nuclear tests accompanied by nuclear explosions were banned. However, the United States and Russia, ignoring criticism by the international community, are continuing to conduct sub-critical nuclear experiments that do not cause nuclear explosions.[1]

My first artwork (see figure 1), "1945-1998" (2003) gives the audience a bird's eye view of the history of nuclear testing over 50 years within 14 minutes by scaling down a month time into one second.[2] The blinking light, the sound and the numbers on the world map show when, where and how many tests each country has conducted. I avoided using any words so that everyone could appreciate the video, regardless of what language they speak, and used familiar mediums such as a world map and national flags to make it easy to understand.

The second artwork (see figure 2), is titled "Overkilled" (2005). This piece of work aims to make the audience experience the number of nuclear bombs that exist in the world (as of January 2005) through both audio and visual.

The first two drops of toy bullets onto a tin plate represent the bombs dropped in Hiroshima and Nagasaki, these two bombs alone have already killed thousands of people. Next, many more bullets are dropped, each one representing a nuclear bomb that exist in the world now, the total of which is more than 13 times the number of explosive nuclear tests conducted so far. The whole video lasts less than two minutes, but the sheer number and the sound of

Figure 2. "Overkilled"

1 Despite the global effort to stop atomic tests, North Korea executed atomic tests with actual explosions in October 2006, May 2009 and February 2013.

2 The full video can be viewed here: http://www.ctbto.org/specials/1945-1998-by-isao-hashimoto/

the toy bullets is an astonishing experience to audiences.[1]

The last piece of artwork that I created (see figure 3) is "The Names of the Experiments" (2006). This piece of work projects sequentially the code names of the nuclear tests, using "Kanon" by Johan Pachelbel as the background music. A Kanon is a style of music that repeats and develops a particular theme in rounds. The repetition of the theme symbolizes how the nuclear tests have been repeated over the last half-century. The audience of this film will see the thoughtlessness and irreverence that nuclear scientists displayed in naming each bomb. There are silly names in the list such as "Bravo" and "Fatman," the names of colors, wine, cheese, vegetables, stars, etc. There were some tests that were named after famous scientists such as "Newton" and "Pascal." These great scientist must have been the heroes for the little children who were dreaming of an affluent society with highly advanced technology and science. And when they had grown to be in charge of the atomic tests, they name the tests after those legendary scientists. This seems to suggest that the tests were executed with thoughts of grandeur and dignity, not guilt.

When ordinary people obey orders without critical evaluation of the consequences of their actions, they can cause irreparable disasters. This phenomenon is explained by the phrase "Banality of Evil" coined by Hannah Arendt (philosopher, 1906-1975). We must overcome this instinct or temptation of unquestioning obedience if we want to solve the problem of atomic bombs.

In "1945-1998," I did not use any blasting sound for the explosions of each test, but instead used electronic beeps. I tried to be as "cool" and "neutral" as possible to deliver the severity of the problem, especially to the people of the younger generation who are so used to the exciting scenes created by computer graphics. I aimed to quietly bring the audiences into the world of my artworks, and to let them think deeply, and to finally guide them through the momentum of these nuclear explosions.

My artworks may not be the perfect solution to convey to audiences the seriousness of nuclear problems, but I sincerely hope they are of some guidance in some way. As an artist, I will continue to create artwork that builds an interface between uninformed people and the extremely grave and current issues of the world.

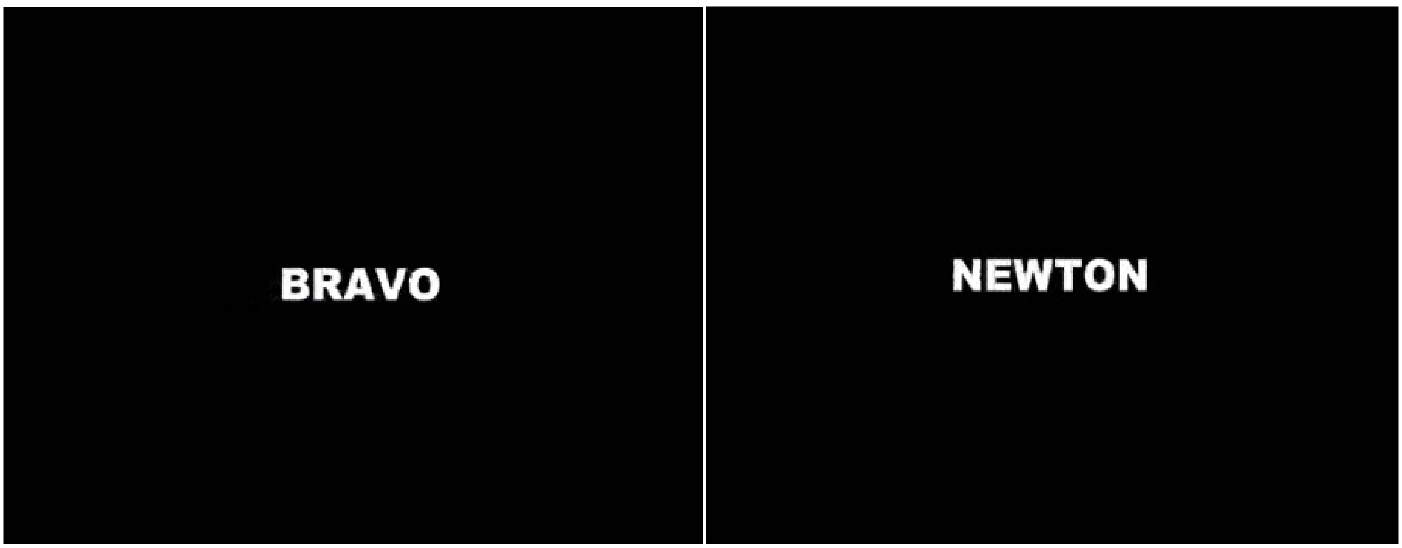


Figure 3. "The Names of the Experiments"

1 According to the Newsletter of "Bulletin of the Atomic Scientists" dated October 31 2013, the total number of atomic warheads has been dismantled down to 17,200 from 20,590 of 2005 (The peak of the stockpile used to be 125,000). If I am to revise my artwork to reflect the current figure, I will need to shorten the length of the film by 20 percent, although the overall situation of overkilled remain unchanged.

Nuclear Energy's Tangled Past

Reviewing forty years of activism

Hannah Kates[1]

"The environmental movement," reported the 1991 issue of *Society and Natural Resources*, "is not only alive and well after two decades but… may be stronger than ever." The future of environmentalism, which at that point had survived three tumultuous decades, seemed rosy. "Few social movements achieve such widespread acceptance," the publication lauded, "and fewer still are able to celebrate a twentieth anniversary." Indeed, more than two decades after that issue's release, environmentalism is alive and well. Yet we rarely speak of "environmentalism" these days, for it no longer refers to a code of uniform views on environmental policy. Nowhere is this more clear than in the case of public response to nuclear power.

Although environmentalists have always had to fight hard for their collective successes, they were unified throughout much of their first two decades; their responses to nuclear power, though of course unprecedented, was not shocking in the context of the movement's greater fragmentation. Environmentalists as a whole champion alternative energy sources almost by definition, yet nuclear power seems to occupy a distinct role in their consideration as not only an alternative energy source but as a danger to ecosystems and human communities. It has gained some notoriety because of its nominal affiliation with nuclear weaponry: "From the dawn of the nuclear age," intones the campaign website of Greenpeace, a well-known international organization, "it has been recognized that nuclear power and nuclear weapons are inextricably linked." The spread of nuclear technology amounts to the spread of nuclear arms, the page's writers imply, which "undermines our national security and the security of the planet." However, "taking nuclear power off the table," asserts a 2003 MIT study, "will prevent the global community from achieving long-term gains in the control of carbon dioxide emissions" (Deutsch and Moniz, 2003). Although the proponents of and main arguments over nuclear power have changed almost constantly since 1945, these opposing arguments encapsulate much of what is debated about nuclear energy. Nuclear power was the first truly divisive issue for American environmentalists in many respects, and as a result it has not enjoyed many of the benefits of large-scale advocacy.

In a 2013 Gallup poll, 76% of respondents thought that the US should place "more emphasis" on solar power, and 71% said the same of wind. Only 37%, though, agreed when the source in question was nuclear (http://www.pollingreport.com/energy.html). Reservations have historically stemmed from the difficulties of nuclear waste disposal, the danger of explosions, and the economic costs associated with nuclear power plants. Several major accidents in the 1970s and 80s accelerated nascent doubt about the safety and sustainability of nuclear power plants - most memorably, the meltdowns at Three Mile Island, Pennsylvania, in 1979, and at Chernobyl, USSR, in 1986. Civilians fled another major meltdown in March 2011: cooling systems in the Fukushima Daiichi plant in Fukushima prefecture, Japan, were shut down by a 9.0 earthquake, and radioactive elements were released into the surrounding area. Many opponents' reservations, though, stem from not only memories of these accidents, but from fears (some based in reality) of potential danger - fears of nuclear proliferation, of the spread of poisonous waste, and of other giant and deadly explosions. It is worth noting that even as recently as 2001, "no nation has developed nuclear weapons using plutonium from spent power reactor fuel" (Rhodes, 2001). And, surprisingly, a majority (51%) of respondents to a 2011 ABC News/Washington Post poll said that their confidence in the safety of nuclear power plants was "not affected" by the incident at Fukushima Daiichi earlier that year, indicating that the American public may understand the incredible rarity of such an accident in an otherwise modern and reliable industry. As for the issue of waste, it is worth considering Richard Rhodes' argument in the 2001 article "Nuclear Power's New Day": "the risk of radioactive waste's seeping past multiple barriers would be small compared to health risks posed by air pollution from burning fossil fuels, which the World Health Organization estimates causes three million deaths a year… substituting small, sequestered volumes of nuclear waste for vast, dispersed volumes of toxic wastes from fossil fuels could provide an enormous improvement in public health."

This constant ebb and flow of public approval of sustainable energy reflects a lack of urgency in the public debate about nuclear energy. Given the U.S.'s current situation - a large number of inactive plants need to either be destroyed or revived - it is critical that we reach a decision somehow. And while nuclear power has never enjoyed uniform support, among available alternatives to coal, gas, and oil, nuclear power it has clear merits; it is only as long as our energy needs are satisfied by fossil fuels that we can continue to discuss abstract, far-fetched reservations about nuclear power.

1 Hannah Kates is an undergraduate at Harvard.

Literature Cited: See page 21

Culture & Catastrophe: understanding the 2011 Fukushima disaster

Daniel Wilson[1]

Every night, a small number of elderly protesters gather amidst the staid, monolithic cabinet ministries in Tokyo. They carry bright, almost cartoonish flyers. Upon inspection, the handbills reveal an unexpected gravity: the specter of nuclear power, post-Fukushima, has reared its head, and the coterie of protesters fears for the health of their island nation.

The explosion at Fukushima Daiichi in March of 2011, precipitated by a magnitude 9.0 earthquake followed closely by a tsunami, shook Japan to its core. The damage at the boiling water reactor plant, operated by the Tokyo Electric Power Company (TEPCO) and responsible for nearly 30,000 gigawatt-hours (GWh) of power generation annually, propelled an unprecedented national crisis. While the earthquake and subsequent tsunami were violent and unpredictable natural acts, they exposed fundamental weaknesses of Japan's supposedly impenetrable infrastructure.

To construe any natural disaster as just that – stripped of any connection to human endeavor – is foolish. Human environments are largely of our own creation, or, rather, the result of extraordinary attempts to prosper given natural constraints. The inherent social disruption triggered by natural disasters, particularly their effects on manmade systems, has spurned a growing body of academic literature (Mayer et al., 2014). The term "socio-technical disaster" captures the cascading effects of natural acts on the form and function of societal order.

Japan's experience after Fukushima serves as a potent site to examine the global paradoxes of nuclear power. In his magisterial profile of modern Japan, the former Financial Times writer David Pilling carefully excises the contradictions of Japanese culture without further perpetuating the mysticism that surrounds the archipelago. After the devastation of World War II, nuclear power became central to Japan's phoenix-like resurgence. So, too did nuclear safety. Pilling writes, "Once nuclear power became a national imperative, it was almost an article of faith that it be safe. How else to justify building fifty-four nuclear reactors, roughly one in ten of the world's total, in the most seismically unstable country on earth? (Pilling, 2014). Pilling continues, "That imperative bred a culture of denial, arrogance, and cover-up that was breathtaking."

> "Concomitant with Japan's newfound energy independence, however, was the political power the nuclear industry held over its regulators"

Over the course of the past half-century, nuclear power had indeed facilitated, if not outright enabled, Japan's economic rise. Concomitant with Japan's newfound energy independence, however, was the political power the nuclear industry held over its regulators. This "nuclear village," as Pilling calls it, gave rise to a pernicious "safety myth" – the illusion that the country's nuclear infrastructure was truly immune to significant threat, especially from earthquakes. Jonathan Soble, a Tokyo-based correspondent for the New York Times, called the safety myth the "only way to bring the national psyche into line with what were, in an energy-poor country, powerful political and economic incentives" (Soble, 2014).

Thus, the Fukushima disaster penetrated the Japanese

1 Daniel Wilson graduated from Harvard College in 2014 and currently works in consulting.

imagination so deeply that many commentators, including Pilling, see it as an irrevocable juncture in the arc of Japanese history. Any monumental juncture necessarily strikes at the fabric of national self-consciousness; in Japan, Fukushima shook the “article of faith” in nuclear safety. But it did something that goes deeper than the atom: it challenged the idea that energy independence could, too, be an article of faith.

In her work with Sang-Hyun Kim and others, the Harvard scholar Sheila Jasanoff introduces the term “sociotechnical imaginaries” to capture how “nuclear power and nationhood are imagined together” in different places (Jasanoff & Kim, 2009). In the United States, according to Jasanoff and Kim, the state construed itself as a “responsible regulator” committed to containment – not just of the nuclear power of enemy nations but of its own civilian capacity. These imaginaries, in Jasanoff’s approximation, trigger “very different responses to nuclear shocks and challenges.”

The Japanese imaginary, then, was first one of energy, and then geopolitical, independence. The emphasis on independence superseded the threats from poor oversight. The allure of independence, particularly from strained reliance on its East Asian neighbors, infused the response to nuclear challenges on a national level before Fukushima. The safety myth did not exist in a vacuum, and did not wait until after Fukushima to emerge. Instead, it was the result of a long history of collusion mixed with willful ignorance, fueled by a desire not to subvert the centrality of nuclear power to Japanese autonomy.

The largely silent, elderly protestors in Tokyo are often “out of touch with the media techniques of modern NGOs” – witness their child-like flyers dispensed in an area of Tokyo dormant at night (B. T., 2014). Their protests come as Japan’s Prime Minister, Shinzo Abe, works to bring some of Japan’s 54 dormant power plants back online. Even though Abe’s plan is deeply unpopular, the popular response to nuclear power there has been far less potent than it was in places like Germany, where protests erupted after the disaster in Japan. Shortly thereafter, German Chancellor Angela Merkel announced that nuclear power would be phased out by 2022, before any other atomic nation (Drozdiak & Busche, 2015). The German experience – protest in response to a disaster that befell another country– is indicative of more than just attitudes about nuclear power. It reflects their own nuclear imaginary, one less tied up in Germany’s own independence and sense of power and influence.

Germany’s swift move away from nuclear power remains one of the more durably intriguing consequences of the Fukushima disaster. Germany’s longstanding appetite for renewable energy – encapsulated by energiewende, a word that literally means “energy shift” – was strong before Fukushima. Abandoning nuclear, which as of last year still constituted over 15% of Germany’s power generation mix, is a wrenching decision for that country. But Germany’s own conception of how it can affect an energy transition is tied up in its own energy imaginary, claims to the continued efficacy, safety, and benefits of nuclear power there notwithstanding.

Herein lies an obvious but oft-forgotten lesson of the debate on nuclear energy: culture matters. Arguments for or against nuclear power are often made within the confines of a supposed rationality, one that treats the GWh as the ultimate arbiter of a technology’s merits. The successes and failures of nuclear power – or any efforts to transition to or away from it – lie now and will remain in the future within the confines of individual nations and their imagined relationship to energy. Global, sweeping arguments in favor of nuclear power, as strong as they may be, will fail if they elide this ineluctable fact.

Literature Cited: see page 21

Literature Cited

Kammen, Daniel

Buchner B, Herve-Mignucci M, Trabacchi C, Wilkinson J, Stadelmann M, Boyd R, Mazza F, Falconer A, Micale V. (2013). The Global Landscape Of Climate Finance 2013. *Climate Policy Initiative*.

Intergovernmental Panel on Climate Change Working Groups II and III. (2000). *Methodological and Technological Issues in Technology Transfer* (Cambridge University Press: New York, Cambridge UK and New York, NY). Coordinating Lead Author. ISBN 0-521-80494-9.

He, G., Avrin, A.-P., and Kammen, D. (2015). "Peaking Carbon in 2030? A Systems Approach to the Transition to a Sustainable Power System in China," in press.

Hultman, N., Koomey, J. G., and Kammen. (2007). What can history teach us about costs of future nuclear power? *Environmental Science & Technology (ES&T)*. 40, 2088 – 2093

McGlade, C. and Ekins, P. (2015). The geographical distribution of fossil fuels unused when limiting global warming to 2°C. *Nature*, 517, 187 – 191.

Mileva, A., Nelson, J. H., Johnston, J., and Kammen, D. M. (2013). SunShot Solar Power Reduces Costs and Uncertainty in Future Low-Carbon Electricity Systems. *Environmental Science & Technology*, 47 (16), 9053 – 9060.

Robock, A. (2014). Nuclear Energy Is Not a Solution for Global Warming. http://www.huffingtonpost.com/alan-robock/nuclear-energy-is-not-a-solution_b_5305594.html

Sanchez, D. L., Nelson, J. H., Johnston, J., Mileva, A., and Kammen, D. M. (2015) Biomass Enables the Transition to a Carbon-negative Power System Across Western North America. *Nature Climate Change*, in press. DOI: 10.1038/NCLIMATE2488

The White House (2014), U.S.-China Joint Announcement on Climate Change (2014), (available at http://www.whitehouse.gov/the-press-office/2014/11/11/us-china-joint-announcement-climate-change).

Thorpe, Daniel

Dayen, D. (2015, Jan 6). America's most ambitious infrastructure project of the century: Why today's high speed rail launch is miraculous. Salon.com. http://www.salon.com/2015/01/06/americas_most_ambitious_infrastructure_project_of_the_century_why_todays_high_speed_rail_launch_is_miraculous/

EIA. (2013). Updated capital cost estimates for utility-scale electricity generating plants. http://www.eia.gov/forecasts/capitalcost/pdf/updated_capcost.pdf

Lepska, D. (2011, Nov 11). Why $1 billion doesn't buy much transit infrastructure anymore. *The Atlantic: Citylab*. http://www.citylab.com/commute/2011/11/1-billion-doesnt-buy-much-transit-infrastructure-anymore/456/

Explanation of LCOE calculations:

Formulas used:

LCOE = Yearly Fixed Cost / (Utilization * Hours/Year) + Variable Cost

Fixed Cost = Capital Charge Factor * Capital Cost + Fixed O&M

Variable Cost = Fuel/(Thermal Efficiency) + Variable O&M

Assumptions:

Fuel costs $2,500,000 / ton, with a burnup of 50 GW-days/ton = $.002/kWh of thermal energy

Efficiency = 35%.

Fixed O&M $100/kW-yr, Variable O&M $.002/kWh (EIA 2013)

Utilization 85%, Capital Charge Factor 0.12 (probably generous)

VC Summer Cost = $5.5 billion each for 1.11 GW plant (http://www.world-nuclear-news.org/NN-Cost-of-Summer-AP1000s-increases-0310144.html)

LCOE = (.12*$4950/kW + $100/kW-yr) / (.85 * 8766) + $.002/

kWh_th/.35 + $.002/kWh

= $.1/kWh

Vogtle $7.5+ billion each for 1.11 GW plants (http://www.bizjournals.com/charlotte/blog/energy/2015/03/utility-says-latest-delays-to-georgia-nuclear.html?page=all)

LCOE = (.12*$7500/kW + $100/kW-yr) / (.85 * 8766) + $.002/kWh_th/.35 + $.002/kWh

= $.14/kWh

Chudakov, Mikhail

IAEA. (2012). Energy, Electricity and Nuclear Power Estimates for the Period up to 2050. http://www-pub.iaea.org/books/IAEABooks/10358/Energy-Electricity-and-Nuclear-Power-Estimates-for-the-Period-up-to-2050-2012-Edition

IAEA (2014a). International Status and Prospects for Nuclear Power 2014. http://www.iaea.org/About/Policy/GC/GC58/GC58InfDocuments/English/gc58inf-6_en.pdf

IAEA. (2014b). Nuclear Technology Review. http://www.iaea.org/sites/default/files/ntr2014.pdf

IAEA (2011). IAEA Action Plan on Nuclear Safety. https://www.iaea.org/newscenter/focus/nuclear-safety-action-plan

Kates, Hannah

Deutch, J., Moniz, E, Beckjord, E. S., Ansolabehere, S., Driscoll, M., Gray, P. E., Holdren, J. P., ... & Todreas, N. E. (2003). The future of nuclear power: An interdisciplinary MIT study. Boston, Massachusetts Institute of Technology (MIT).

Dunlap, R. E., & Mertig, A. G. (1991). The evolution of the US environmental movement from 1970 to 1990: An overview. Society & Natural Resources, 4(3), 209-218.

Rhodes, R. (2001, May 7). Nuclear power's new day. The New York Times.

Wilson, Daniel

B.T. (2014, August 3). Where's the protest? *The Economist*

Drozdiak, N., and Busche, J. (2015, March 22). Germany's Nuclear Costs Trigger Fears. *Wall Street Journal*

Mayer, B., Bergstrand, K., and Running, K. 2014. Science as Comfort: The strategic use of science in post-disaster settings. In Routledge Handbook of Science and Technology Studies, edited by Daniel Lee Kleinman and Kelly Moore. London: Routledge.

Pillings, D. 2014. Bending Adversity: Japan and the art of survival. London : Allen Lane.

Soble, J. (2014, July 23). Beware the safety myth returning to Japan's nuclear debate. *Financial Times.*

Acknowledgments

The Editors would like to thank the Harvard University Center for the Environment for underwriting the printing of this journal.

Harvard College Review of
Environment & Society

Box # 215
59 Shepard Street
Cambridge, MA 02138

res@hcs.harvard.edu

www.hcs.harvard.edu/~res