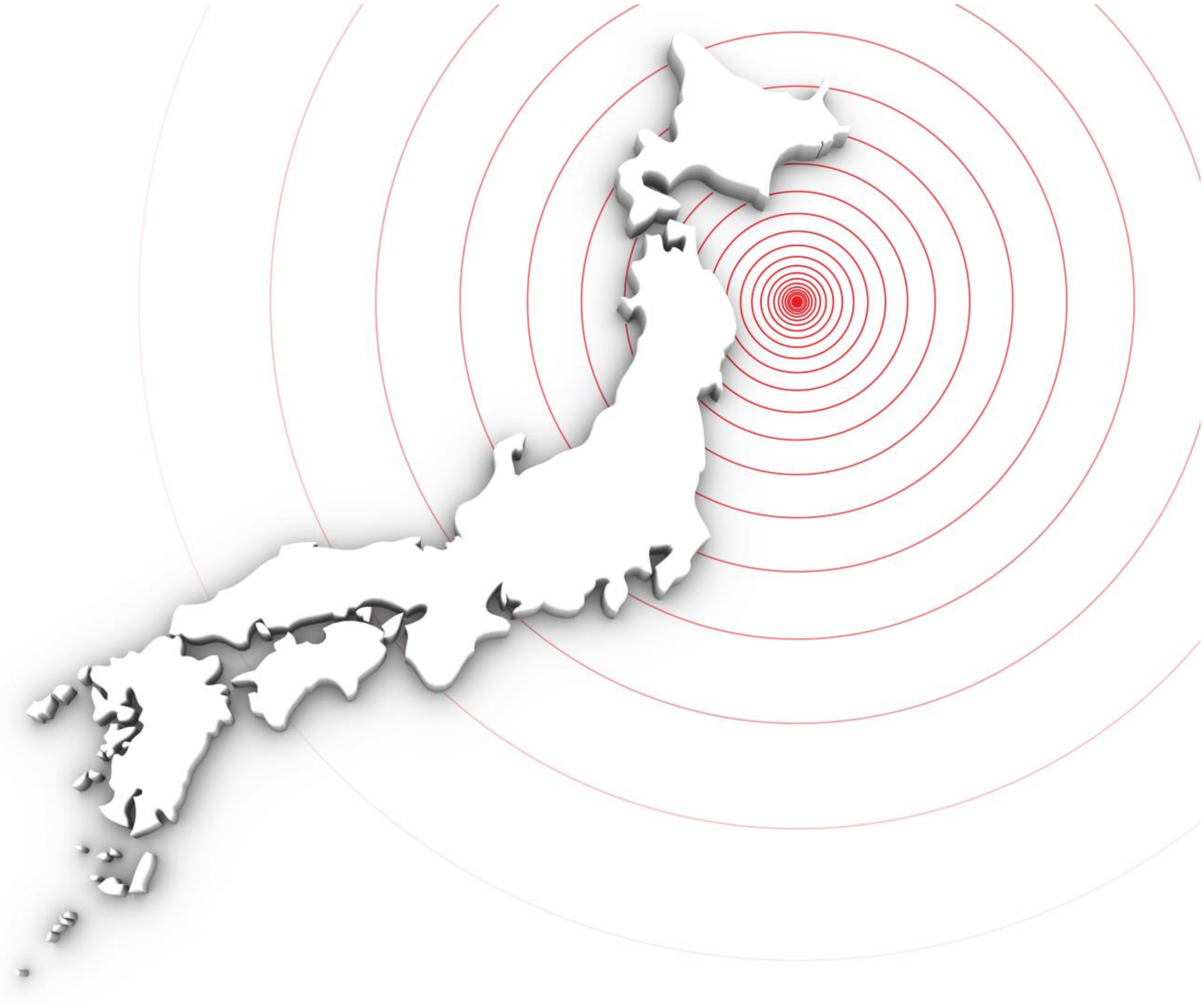
FAS Issue Brief May 2013

Regulating Japanese Nuclear Power in the Wake of the Fukushima Daiichi Accident



Charles D. Ferguson

Mark Jansson

Federation of American Scientists

FAS ISSUE BRIEF

Authors
Charles D. Ferguson, Ph.D., President, Federation of American Scientists
Mark Jansson, Special Projects Director, Federation of American Scientists

About FAS Issue Briefs
FAS Issue Briefs provide nonpartisan research and analysis for policymakers, government officials, academics, and the general public. Individual authors who may be FAS staff or acknowledged experts from outside the institution write these Issue Briefs. All statements of fact and expressions of opinion contained in this and other FAS Issue Briefs are the sole responsibility of the author or authors. This report does not necessarily represent the views of the Federation of American Scientists.

About FAS
Founded in 1945 by many of the scientists who built the first atomic bombs, the Federation of American Scientists (FAS) is devoted to the belief that scientists, engineers, and other technically trained people have the ethical obligation to ensure that the technological fruits of their intellect and labor are applied to the benefit of humankind. The founding mission was to prevent nuclear war. While nuclear security remains a major objective of FAS today, the organization has expanded its critical work to address urgent issues at the intersection of science and security.

FAS publications are produced to increase the understanding of policymakers, the public, and the press about urgent issues in science and security policy. Individual authors who may be FAS staff or acknowledged experts from outside the institution write these reports. Thus, these reports do not represent an FAS institutional position on policy issues. All statements of fact and expressions of opinion contained in this and other FAS Special Reports are the sole responsibility of the author or authors.

Acknowledgments
The authors would like to thank the IBT Corporation for its support of this project. They would also like to express their gratitude to Stephanie Lee for her very diligent and helpful research.

© 2013 by the Federation of American Scientists. All rights reserved.

Printed in the United States of America.

For more information about FAS or publications and reports, please call 1-202-546-3300, email fas@fas.org, or visit the website at www.fas.org.

Contents

Executive Summary

The accident at the Fukushima Daiichi nuclear power plant in 2011 was preventable. The Great East Japan earthquake and the tsunami that followed it were unprecedented events in recent history, but they were not altogether unforeseeable. Stronger regulation across the nuclear power industry could have prevented many of the worst outcomes at Fukushima Daiichi and will be needed to prevent future accidents. Poor planning led to the underutilization of resources and compounded the problem at Fukushima Daiichi. This report reviews some of the major problems leading up to the accident and the proposed regulatory reforms, including an overhaul of the nuclear regulatory bureaucracy and specific safety requirements that have been proposed.

Re-organizing the Nuclear Regulation Bureaucracy

The previous bureaucratic alignment facilitated "regulatory capture" by the nuclear power industry, resulting in substandard and weakly enforced rules to ensure safety. The primary agency in charge of regulation, the Nuclear and Industrial Safety Agency (NISA), was routinely overpowered by the industry interests represented in the Ministry of Economy Trade and Industry (METI) that housed it while also holding responsibility for promoting the nuclear power industry. Another problem that the Fukushima accident exposed was the poorly defined responsibilities of other agencies that had a role in developing regulation and in managing accident scenarios.

The formation of the Nuclear Regulatory Authority (NRA) within the Ministry of Environment is a vitally important step towards establishing a truly independent regulatory body that can more aggressively advance safety. Now that this step has been taken, it will be important for the Japanese government and the NRA to establish the necessary legal and policy frameworks to ensure that the agency functions effectively. To that end, we recommend the following.

- Japan should consider exempting the NRA from the practice of rotating government employees between jobs every several years and expedite the proper and entire incorporation of Japan Nuclear Energy Safety Organization (JNES) and all technical support organizations into the NRA.
- The NRA must take a leading role in working with industry to professionalize the workforce through proper training, hiring practices, and compensation. It will be incumbent on the rest of the Japanese government to fully support it in this regard.
- Japan should review and, as needed, strengthen whistleblower protections that apply to both industry and government employees. Within the NRA, it should stand up an Inspector General's office (or functional equivalent) to provide necessary oversight.

Managing the "revolving door" dilemma

Another significant problem in Japan was the potential for conflicts of interests to arise for regulators who were planning to seek employment in industry following their service as a regulator. The cultural tradition of "amakudari" (descent from heaven) in which senior bureaucrats would assume high paying jobs in industry following retirement from government service epitomized this problem. However, the "revolving door" dilemma in which personnel move between jobs in industry and in regulatory bodies affects all industry-regulator relationships, given the demand on both sides for special and technical expertise.

The proposed prohibition, with an exception for the first five years after implementation, that bans NRA personnel from returning to jobs in government agencies that promote nuclear power could help mitigate the potential for conflicts of interests to surface within government, but this is a stricter rule than government employment practices in the United States and many other countries. The fact that there is no similar ban preventing NRA personnel from assuming jobs in industry, though disappointing to some, is not inconsistent with practices in other countries. The limitations on regulatory personnel seeking jobs in industry are also consistent with practices elsewhere. Overall, complete isolation of the regulator from industry is neither practical nor necessarily desirable. A few additional recommendations to prevent individual conflicts of interests include the following.

- Consider developing more robust alternative means to industry experience for developing the technical expertise required for effective regulation so that the NRA is not populated *exclusively* by former industry workers.
- To bring even greater transparency to the matter of regulators seeking jobs in industry, Japan could consider establishing rules that require industry firms to report that they have been contacted by outside parties, e.g., consultancies, about hiring specific NRA personnel.
- Because conflicts of interests and lax oversight are more likely to become a problem in a regulatory workforce that is demoralized, the NRA should proactively seek input from other regulatory bodies such as the U.S. Nuclear Regulatory Commission on how to improve employee satisfaction.

Specific Safety Measures

A number of specific safety upgrades are under consideration to become industry-wide standards for all nuclear power plants. These include requiring nuclear power plants to install filtered vents above reactor containment vessels, to establish earthquake-resistant control centers, to build secondary control rooms to use in the event that the primary control rooms becomes unusable, and to limit reactor life to no more than forty years. We also consider the issue of restarting nuclear reactors in Japan to meet energy demands.

In assessing these recommendations, we drew heavily from the experience of the United States and Europe. Overall, we further recommend that the NRA embrace a dynamic approach that continually assesses risks rather than adopt a deterministic approach that may give a false impression to the public and may place undue costs on continuance of nuclear power plants that can operate safely. The NRA would best be able to work with regulatory agencies in other countries by harmonizing its regulatory approach with the risk informed and probabilistic safety assessment methodology followed in these countries' regulatory agencies. Other findings and recommendations are as follows.

- Our assessment is that the U.S. decision on whether to require filtered vents should be based on achieving safety performance goals determined by probabilistic risk assessments and risk informed regulation. These goals can be met in different ways. Regulatory bodies in other countries such as Japan can and should apply this approach to their decisions on whether to require filtered vents at various plants.
- The NRA should decide on whether or not to issue a license to operate nuclear plants beyond 40 years based on safety assessments guided by risk informed regulation. We urge that such decisions not be influenced by political considerations. Nonetheless, we understand that utilities may decide to not operate a nuclear plant, even if that plant receives a license extension, because of other economic considerations. In particular, the cost of safety upgrades may be too prohibitive to permit economically competitive operation of a plant.
- We recommend that Japan and the United States work together to investigate strengthening plant safety with an eye to determining whether various plants can operate beyond 60 years.
- We recommend that any decision to restart nuclear reactors in Japan not be unduly influenced by political decisions. In particular, the NRA should follow a risk informed approach when examining each individual plant. A defense-in-depth safety approach should be the overarching philosophy. While each defensive layer is individually imperfect, the combined functioning of the layers together should be designed to meet safety performance objectives to keep the risk to the public to an acceptably low level.

Introduction

The Great East Japan Earthquake and the tsunami it generated were absolutely devastating. Given the magnitude of the earthquake and the massive force of the tsunami, it is not surprising that the defenses at the nearby Fukushima Daiichi nuclear power plant failed. The resulting accident at the plant – in which three of its six reactors experienced a core meltdown and significant amounts of radiation was released into the environment – was one of the worst nuclear accidents on record. The fact that things went so badly at Fukushima Daiichi sent shockwaves around the world and triggered a great deal of investigation, introspection, and soul-searching by both the producers and consumers of nuclear power.

No deaths so far have been directly attributed to radiation released by the Fukushima Daiichi accident. However, because radiation effects are variable and sometimes take years if not decades to manifest, we will not know whether or not any lives were ultimately cut short by radiation exposure for quite some time. Predictions vary but it appears that the overall public health effects of radiation release from Fukushima are likely to be small.[1] In the eyes of some, the larger public health concern is likely to be the psychological effects of the trauma.[2] No matter what the outcomes of scientific study of the radiation effects turn out to be, they will not put a stop to the anxiety about nuclear power that will last a lifetime for many people, particularly those who had first-hand experience with the earthquake, the tsunami, and the resulting accident at Fukushima Daiichi.

Despite the severity of the natural disaster that precipitated the nuclear one, investigation into the incident at Fukushima Daiichi found that the accident was largely man-made. Several studies, most notably the National Diet of Japan, pointed to the unsettling conclusion that many of the problems experienced at Fukushima Daiichi could have been prevented. Some problems could have possibly been avoided in the first place; others could have been responded to more effectively. These failures pointed to systemic problems in how Japan's nuclear power industry was operated, managed, and regulated. In the pages that follow, we will review some of the regulatory problems that the Fukushima experience brought to light and some of the proposed changes, including those that apply to how the regulatory agency is structured, proposed rules that will apply to regulators, and proposed technical requirements that will apply to nuclear power plant operators.

Before proceeding, two points must be made upfront. The first is that nuclear power in Japan has a long history that spans several decades and includes several phases, turning points, and political decisions that led to the reality that existed prior to the Fukushima accident. It would be impossible to account for the entirety of this history in this paper. So, we will focus on what appear to be the key issues while recognizing that they represent just pieces of a much larger historical record that can be viewed from different perspectives that may lead others to different conclusions than ours. The second point is that, just as it remains difficult to write authoritatively about the past in only a relatively short report, it is also difficult to account for all of the different factors that are, or may, influence Japan's nuclear future. Disaster recovery and industry reform are ongoing processes that may produce new developments, investigative findings, or other information that is relevant to the following analysis, which has been produced at a specific point in time.

Any discussion of the regulatory successes and failures brought to light by the Fukushima Daiichi accident must begin with an acknowledgment that the plant was in the path of an unfolding natural disaster. No nuclear power facility has ever had to weather an onslaught as powerfully destructive as the tsunami that hit the plant after the Great East Japan Earthquake. The conditions in the area and at the plant must also be taken into account when considering the response by the nuclear plant operator, Tokyo Electric Power Company (TEPCO), and the government in the aftermath of the devastation. While reflecting soberly on whatever mistakes were made, it is important to remain mindful of the many things that were done well and the countless of acts of heroism by individuals in the Fukushima prefecture to help one another cope with the tragedy. With this in mind, we write from the perspective that the best way to honor those efforts is to dedicate as much effort as possible to minimizing the chances that an accident like the one at Fukushima Daiichi ever occurs again. That effort begins with a review of where and how improved regulation could have made a difference and how it can be made better in the future.

Past Problems with Japan's Regulatory System

A Captured Regulator within the "Nuclear Village"

It was well-known long before the Fukushima Daiichi accident that regulation of Japan's nuclear power industry needed to be improved. For over a decade, several accidents and recurring problems with corporate misconduct among utility companies accentuated public unease about whether nuclear energy in Japan was, or could be made to be, safe enough. Among the many reasons for concern was a core dilemma that faces every country that uses nuclear power: the risk of regulatory capture. In short, regulatory capture occurs when private industry succeeds in defanging government regulators who oversee their activities. Regulatory capture can refer narrowly to the specific ways in which regulated companies manipulate or defang government regulators. More broadly, it can also refer to the ways that industry and other special interest groups influence the formulation and enforcement of laws governing their activities.[3] In the worst cases, instead of aggressively working to protect the public good by enforcing rules, a "captured" regulator ends up serving the interests of industry by tailoring regulation to serve companies' business interests and by weak enforcement of whatever rules are on the books.

The need for regulators to possess specialized knowledge of the sector they regulate creates a major risk factor for regulatory capture in many industries, especially the nuclear power industry. Even in a well-developed country like Japan, which has the world's third highest percentages of residents with a college degree, the number of individuals with the expertise necessary to understand nuclear power technology and plant operations well-enough to serve as a regulator is relatively limited.[4] As we have seen in other contexts, the specialization requirement leads to the regulator workforce and private industry workforce becoming essentially one in the same. In Japan, it helped power the growth of what became known as the "nuclear village" – a community of businessmen from the nuclear industry, the government regulators and bureaucrats who oversaw it, and a few academics and technical experts that advised it.

Within the village, there were several governmental bodies and organizations that were assigned a role in enforcing safety standards. The main regulating body was the Nuclear and Industrial Safety Agency (NISA), a semi-autonomous organization under the Agency for Natural Resources and Energy (ANRE) within the Ministry of Economy Trade and Industry (METI). NISA relied on the Japan Nuclear Energy Safety Organization (JNES), formed in 2003, to carry out on-site safety inspections and assessments. The Ministry of Education, Culture, Sports, Science and Technology (MEXT) is responsible for environmental radiation monitoring, promotion of nuclear energy, and nuclear safety regulation for research reactors. The Nuclear Safety Commission (NSC) was established as an independent agency under the cabinet office to develop and promulgate safety regulations as well as to monitor the work of NISA and MEXT. Additionally, the Japan Nuclear Technology Institute (JANTI) was established by nuclear power operators to share information and best practices on safety issues while the Federation of Electric Power Companies (FEPC) served as the lobbying arm of the nuclear industry.

There were several problems with this arrangement that effectively facilitated the capture of NISA by industry. The first, and most glaring, was NISA's institutional address within METI, the ministry charged with promoting nuclear power in Japan. Although NISA was established as a "special agency" purported to be independent of METI, the reality in practice was one of NISA being routinely overpowered by industry interests when it came to promoting more rigorous safety standards and enforcing those already in place. The problem was at its worst at the top of the organizational hierarchy within METI, as a practice known as "amakudari" – or "descent from heaven" – in which senior officials from METI commonly assumed lofty, high-paying positions in industry following their retirement from government service. This created a stark conflict of interest for those in charge of regulating Japan's nuclear power industry, as insisting on stricter standards and imposing penalties on non-compliant utilities could have hurt the chances of METI's senior officials to descend from government into high-paying jobs in the private sector.[5]

Another problem stemmed from the confusing and in some ways overlapping structure of Japan's regulatory apparatus. The NSC, in particular, had responsibility for crafting and promoting new safety regulations to be monitored and enforced by NISA. However, because the NSC was established as merely an advisory body under law and remained so during the restructuring of the government in 2001, it had little power to ensure that NISA swiftly incorporated its recommendations into new regulations or to ensure that those regulations were enforced. Instead, it fell into a role of essentially double-checking NISA's work in investigating everything from major accidents to rashes of industry data falsification and cover-ups in reporting on safety issues. As problems mounted, both NISA and the NSC became so consumed with investigating past incidents that neither was able to devote sufficient resources to actively promoting new safety regulations based on new scientific data or best practices from around the world.

Lastly, policies governing personnel undermined NISA's ability to perform at a high level. Its staff was comprised of two fairly distinct categories: ministry generalists from METI known as "policy makers" and technically-trained "experts" hired from industry vendors. A government-wide requirement governing all staff stipulated that individuals change jobs every two-to-three years. Many of the policy makers on rotation from NISA from different parts of METI lacked specific expertise in nuclear technology, power plant operation, or other technical areas of relevance to ensuring nuclear safety. The brevity of their rotation in and out of NISA prevented them from acquiring such expertise. For the experts, NISA managed this problem by rotating them within the agency. However, in a similar way to the policy experts, the continued movement of staff, especially at the higher levels within NISA, prevented them from developing the kind of comprehensive expertise of operations that they needed to promote a proper safety culture among and within plants.

Within the nuclear village, regulators were consistently overpowered by industry interests when it came to improving safety standards and overwhelmed when it came to investigating the rash of accidents and endemic industry non-compliance that inevitably surfaced. Weak oversight became self-perpetuating as the growth of problems outpaced the regulatory capacity to deal with them. Instead of aggressively pursuing measures to reduce risks, the nuclear village aggressively promoted a "safety myth" that the country's nuclear power reactors were already one-hundred percent safe. Over time, overconfidence in the existing technology actually led to what one expert described as a "kind of mind-set that rejected progress through the introduction of new technology."[6]

Outdated Regulation and the Growth of Safety Problems across Japan's Nuclear Power Industry

Recent history of Japan's nuclear power industry is one of weak regulation and, at times, cavalier disregard for public and environmental health. The lack of respect for NISA was brought into the public spotlight by the falsification scandals in which utility companies across the country systematically distorted, concealed, or omitted important information in their communications. In 2002, an inquiry triggered two years prior about the handling of inspection records led Tokyo Electric Power Company (TEPCO) to reveal that it had falsified its reporting to NISA on numerous occasions, including sixteen particular episodes that TEPCO's president, Tsunehisa Katsumata, later admitted were "serious cases of inappropriate conduct." These cases included failure to report cracks in pipes and pumps that are important for water circulation and reactor cooling; cracks in stainless steel shrouds that surround fuel assemblies; secretly injecting compressed air into a reactor primary containment vessel to slow its leakage rate during inspections; and ordering destruction of records of damage to neutron measuring equipment. In other cases, TEPCO workers altered seawater temperature measuring equipment so that their readings would cloak ecosystem-threatening changes resulting from dumping hot water from the plant into the Sea of Japan.[7]

It was only after NISA requested in 2007 that utilities double-check their records and come clean about inaccuracies that these incidents came into the public spotlight. And it was only due to this reporting that it became aware of one particularly alarming incident in 1999 at the Shika Nuclear Power Station Unit I, which resulted in the reactor core reaching criticality – an uncontrolled, self-sustaining process of nuclear fission – that could have severely damaged the facility and possibly resulted in a core melt incident (also known as a "meltdown" or "partial meltdown"). Criticality incidents like these are extremely dangerous. Nevertheless, the plant operators, concerned about blowback from the public that would impede the construction of the Shika Unit II reactor, decided to cover-up the incident by lying to management at Hokuriku Nuclear Power Company. Despite the disinformation from the plant director, the follow up investigation by NISA in 2007 revealed that, with the data provided by neutron flux detectors that generated a shutdown signal, Hokuriku Electric Power Company "could realize that a criticality incident had occurred" and should have reported the incident to the government, as required by law.[8] The report also found that there had been as many as ten similar incidents involving control rod removal during reactor shutdown going back to 1978, including one incident at Fukushima Daiichi Unit 3 in which the reactor core went critical.[9]

NISA was informed about other severe accidents in a timelier manner. These include as the criticality accident at the Tokai-mura uranium reconversion facility that killed two workers in 1999, a steam pipe explosion at a Kansai Electric plant in 2004 that killed five workers, the fire that broke out at the Monju fast breeder reactor in 1995, and the leakage of 1,200 liters of radioactive wastewater into the Sea of Japan after the Kashiwazaki-Kariwa plant suffered damage from an earthquake. But industry critics argue compellingly that utility companies only admit to problems when the accidents are so severe that they cannot be ignored or when the news media uncover the story. While the circumstances surrounding each cover-up and accident may be unique, it is clear from the overall pattern of deception and recurring safety problems at plants that the relationship between NISA and the country's utility companies was improper and dysfunctional.

In addition to lax oversight to ensure that equipment was in good working condition and plant operators were following best safety practices, another major problem with the regulatory system was the glacial pace at which NISA updated its safety requirements in response to newly acquired technical information. In particular, Japan lagged behind other countries in using probabilistic safety assessment (PSA) methods to inform regulatory requirements and improve accident management plans in preparation for "beyond design basis" events – that is, severe conditions that are more extreme than what nuclear power plants were built to endure. Probabilistic methods for assessing risk differ from deterministic approaches in that they take into account the possible occurrence of rare events that, though not necessarily a part of any historical record, are still within a specified realm of probability and therefore create some level of risk. Deterministic approaches to safety, by contrast, are derived from specific assumptions about known events and their causes, and seek to establish adequate safety margins so that those particular events do not result in severe accidents. Both methods need to be applied in an integrated fashion to improve plant safety as part of what the IAEA calls a "risk-informed" approach.[10] More rigorous application of PSA-based safety standards for "external events" such as earthquakes, tsunamis, or man-made accidents would have led to changes at the Fukushima Daiichi plant that would have made it more resilient to the tsunami that struck it in March 2011.

As the final report of an Investigation Committee established by the Japanese government explains in detail, NISA and the NSC had been looking into the incorporation of PSAs into regulatory requirements since the early 1990s, but progress in doing so was extremely slow.[11] The foot-dragging in translating PSA methodologies into clear regulator guidance should have been disconcerting for both regulators and operators in an earthquake-prone country like Japan. It was not until 2003 that the NSC published its Basic Policy on Risk Informed Regulation.[12] And it was not until 2006 that it called on operators to use "quantitative evaluation of residual risks" as a "preparatory approach to the future full practice of PSA in safety regulation."[13] The following year, the Atomic Energy Society of Japan (AESJ) published guidelines for applying external event PSAs in their report, "Implementation Standards for Probabilistic Safety Analysis for Events Induced by Earthquakes at Nuclear Power Stations." That year, an International Atomic Energy Agency (IAEA) visit to Japan to review its regulatory practices through its Integrated Regulatory Review Service (IRRS) praised Japan for its progress in promoting the use of PSAs as a complement to deterministic assessments, stating that "the basic policy of utilization of risk information in nuclear regulation is sound." However, the report also noted that the publication of guidelines was just the beginning, a "necessary pre-requisite for the increased use of risk informed regulation."[14]

Unfortunately, the NSC and NISA did not take the appropriate follow-on steps of crafting concrete regulatory requirements using PSAs and holding utilities accountable for meeting those standards. At the time of the Fukushima Daiichi accident, tsunami risks were still assessed through a strictly deterministic approach rooted in historical “tsunami folklore.”[15] (The seismic design basis for the Fukushima Daiichi plant was based on the 1938 Shioyazaki offshore earthquake.[16]) Up to that point, industry continually objected to making PSA adherence to regulatory requirements on the grounds that it would be “using a methodology of technical uncertainties,” and relied on that argument to delay reform even though it meant falling behind the best practices of other countries and promulgated by the IAEA.[17] As an IAEA document presciently noted in response to skepticism about applying PSA methods, there is “a great danger in spending too much time and effort on the analysis rather than on practical measures that will affect safety . . . even a low quality PSA may provide some insights when integrated with other factors.”[18] But the problem with applying PSAs in Japan was merely a symptom of a larger problem. It was no accident that PSAs remained an undertaking by utility companies that were required merely to report their results as opposed to being legally obligated to adhere to more rigorous safety requirements demanded by properly utilized PSAs; industry preferred it that way. And industry getting what it wanted meant weak regulation and plant-specific safety standards that fell substantially below those promoted by the IAEA in important respects.[19]

An appropriate use of PSAs for earthquakes and tsunamis would have led to changes at Fukushima that could have prevented the disaster. For instance, both TEPCO and NISA were aware of studies that pointed to the high near-term probability of a powerful earthquake and that such an earthquake was likely to generate a tsunami exceeding the design basis at Fukushima. However, this information did not lead to any regulatory requirement that NISA imposed on TEPCO. Rather, TEPCO, like all other utility companies, was left to its own devices in incorporating new information into accident management plans and taking countermeasures at its leisure. After the new guidelines were issued in 2006 by NISA to assess earthquake-related risks, TEPCO was allowed to unilaterally announce in 2009 that it would not be reporting on its progress in conducting seismic “backchecks” or taking appropriate countermeasures that year (as requested by NISA) – and, in fact, would not do so until 2016.[20]

In order for a risk-informed safety approach to work, all parties concerned – and nuclear plant operators especially – must accept the basic premise that probabilistic risk assessment is an appropriate and important part of safety planning. Furthermore, both regulators and regulated companies must actively seek out and listen to the opinions of outside experts who have carried out research relevant to risks. In addition, there needs to be a fluid and agreed upon process for the timely updating of safety regulations when new scientific information concerning risk probability comes to light. Regulators must also have the capacity to ensure that operators are adhering to revised guidelines and willingness to punish them if and when they are not. Virtually none of these conditions were met in Japan prior to the Fukushima accident. Instead, the process of assessing risk and improving safety became an adversarial one that lead to protracted legal battles. When outside experts would present findings from scientific studies about the potential for earthquakes of a magnitude that exceeded the design basis of nuclear power plants, those close to or inside the nuclear village would present their own scientific analyses refuting the findings.[21]

Also troubling was the fact that utilities were under no specific obligations to prepare adequate countermeasures in the event of an accident; everything was voluntary. In its report to the IAEA, Japan frankly acknowledged that ". . . accident management measures are basically regarded as voluntary efforts by operators, not legal requirements, and so the development of these measures lacked strictness. The guideline for accident management has not been reviewed since its development in 1992, and has not been strengthened or improved."[22] Given that Japan has experienced multiple criticality accidents since that time and is vulnerable to earthquakes, tsunamis, and other natural disasters, there was no excuse for not reviewing these guidelines in nearly twenty years or for making them regulatory requirements. The outcome at Fukushima was a plant that was horrendously under-prepared for a severe accident; its disaster response plans called for only one stretcher, a satellite phone, and fifty protective suits.[23]

Poor planning led to the underutilization of resources that compounded the problem at Fukushima. It was not even clear where responsibility lied and which organization was primarily responsible for protecting the public in the event of an emergency. As the report of the Japanese government to the IAEA explains, "NISA of METI is responsible for safety regulation as a primary regulatory body, while the Nuclear Safety Commission of the Cabinet Office is responsible for regulation monitoring of the primary governmental body, and relevant local governments and ministries are in charge of emergency environmental monitoring. This is why it was not clear where the primary responsibility lies in ensuring citizens' safety in an emergency."[24] Consequently, the resources that were established to help respond to emergencies – such as MEXT's System for Prediction of Environment Emergency Dose Information (SPEEDI), NISA's Emergency Response Center, the Prime Minister's Nuclear Emergency Response Headquarters, the NISA Secretariat of the Nuclear Emergency Response Headquarters, and the Regional Nuclear Emergency Response team – weren't used appropriately. The Diet report concluded soberly that "none of these organizations functioned as planned."[25]

At times, the complacency about regulation and accident management preparation went hand-in-hand with outright collusion between NISA and industry to deceive the public and perpetuate the safety myth. One example was NISA encouraging Shikoku Electric Power Company to bias a community gathering about the planned use of mixed oxide (MOX) fuel at the Ikata Nuclear Power Plant by deliberately placing those who would be in favor in the audience and encouraging them to voice their views. A former NISA official admitted that he had encouraged other power companies to do the same on two other occasions.[26] Some regulators that did not play by the rules of collusion were punished. In one instance, the identity of a General Electric technician who reported safety problems at the Fukushima Daiichi plant was leaked to TEPCO, resulting in him losing his job and being blackballed from the industry.[27] The lack of protection – and, in fact, the outright punishment – of those who bring safety concerns to light is unacceptable.

As the National Diet report explained, the regulatory situation was driven by a "mutual interest" within the nuclear village to keep nuclear power plants running by keeping the safety myth alive, despite the accidents, incidents, and the near certainty of more in the future.

> Because the regulators and operators have consistently and loudly maintained that "the safety of nuclear power is guaranteed," they had a mutual interest in averting the risk of existing reactors being shut down due to safety issues, or of lawsuits filed by anti-nuclear activists. They repeatedly avoided, compromised or postponed any course of action, and any regulation or finding that threatened the continued operation of nuclear reactors. The FEPC

> has been the main organization through which this intransigent position was maintained among the regulatory agencies and in the academic world.[28]

It is hard to know whether the public messaging imperative was a contributor to NISA's loss of autonomy or a result of it. Either way, the problem was clear: a regulator that staked its public credibility on preventing reactor shutdowns when it should have staked it on ensuring safety.

Japan's Response after the Fukushima Daiichi Accident

Japan has responded with a concerted effort to address matters at the heart of the Fukushima Daiichi incident by instituting reforms intended to improve safety and accident preparedness across the country's nuclear power sector. The severity of the Fukushima Daiichi accident makes it imperative that reforms go beyond patching specific nuclear safety gaps or merely make relative improvements in areas where Japan could be raising the bar of safety standards globally. In that spirit, this assessment endeavors to be critical yet constructive.

The following review of the steps that the Japanese government and other governments have taken in response to the Fukushima Daiichi accident is guided by the proposition that safety issues cannot be "solved" permanently. As Constance Perin describes it, the idea of "safety" implies an absolute condition, but in the real world where there are inescapable trade-offs between production and protection the goal is one of "*reducing* and *handling* risk."[29] From this it follows that the safety level that obtains at nuclear power plants is actually a negotiated outcome reached through a competition of interests within and among the nuclear power industry, industry regulators, and other stakeholders. And as Richard Meserve, President of the Carnegie Institution for Science and Chairman of the International Nuclear safety Group, reminds us, ". . . there is no way to eliminate all risk entirely . . . despite all the design improvements that we conceive, systems still fail; despite all the training and lessons learned in exercises that are conducted, human beings will still make mistakes, particularly when confronted with once-in-a-lifetime events."[30] It is always possible to do more to improve safety, but it is not always practical. However, understanding safety as a negotiated and inherently imperfect outcome does not mean that there is no objective basis for assessing the quality of that outcome or the manner in which it is achieved.

The following sections begin with a review of the reforms to regulatory governance and personnel policies to prevent the "capture" of the regulatory agency in the future. It then reviews some specific technical upgrades to safety features at nuclear power plants such as installing hardened, reliable, and filtered vents on reactors' containments, renewing the licenses of nuclear plants beyond forty years, and making upgrades to protection against earthquakes and flooding. We will pay particular attention to the lessons learned and current and future practices for the United States and Europe. The report later assesses the safety benefits of nation-wide reactor shutdown following major nuclear accidents and the criteria of stress tests to allow for nuclear plants to continue operating.

Regulatory Reforms

Japan is instituting a number of significant reforms to improve regulator independence and effectiveness. At a minimum, the reforms must protect the integrity of government regulation so that it does not again become beholden to industry interests. To that end, the reforms are aimed at changing the regulatory process on both the institutional level and the individual level. Some of the key reforms include:

- Reorganizing the bureaucracy by establishing an independent Nuclear Regulation Authority (NRA) as an extra-ministerial commission of the Ministry of Environment; and
- Curtailing *amakudari* by instituting a "no-return" rule that forbids senior-level regulators from the NRA to assume jobs in METI or MEXT after their service as regulators.
- Placing limitations on regulators seeking employment in for-profit corporations, including forbidding individuals currently employed as regulators from job-seeking activity and forbidding regulators from recommending to industry that they hire government officials; and
- Centralizing the management of re-employment by requiring that management-level regulators notify the Cabinet if they are offered re-employment in private industry and requiring the Cabinet to disclose each year a summary of re-employments.

Assessing the extent to which these reforms will be effective in guarding against regulatory capture comes down to defining regulatory capture, identifying its causes, and determining how well the reforms address those causes. Regulatory capture can refer narrowly to extreme cases where industry turns government regulators into mere representatives of industry interests or, more broadly, to the various ways that industry and other special interest groups exert influence on the formulation and enforcement of regulations.[31] This distinction between broad and narrow interpretations is important for defining goals for regulatory reform and measuring success. In short, industry governance should be structured in a way that reduces the likelihood of regulator manipulation and minimizes incentives for reckless industry-regulator collusion; however, completely isolating industry and regulators from one another is not possible and may not be desirable even if it could be achieved.

De-conflicting Institutional Interests through Bureaucratic Realignment

The formation of the Nuclear Regulation Authority within the Ministry of Environment (apart from METI) is a vitally important step that will bring Japan up-to-par with other countries possessing advanced nuclear power programs and with IAEA recommendations. IAEA milestones for establishing a nuclear power program assert that "complete separation" of regulatory bodies from industry, promotional organizations, and the political process is best for ensuring the credibility of safety-related information.[32] Indeed, the re-location of regulatory authority within the government bureaucracy will enable it to more effectively balance the claims and interests of METI and the nuclear power industry. It shows that Japan has learned one of the essential lessons that other countries have already learned: regulatory responsibilities must be separated from promotional responsibilities within the government.

The United States finally recognized this in 1975 when it finally separated its Nuclear Regulatory Commission (NRC) from the Department of Energy (DoE) to make sure that its safety recommendations would be "less susceptible to being overridden by developmental priorities."[33](Though, it is important to remember that this came only after years of incremental steps to help increase the NRC's functional independence within the DoE and, before that, within the Atomic Energy Commission.) However, being independent from the DoE has not insulated the NRC from criticism that it was regulating under the influence of industry, nor should it. In the wake of the Fukushima Daiichi accident, experts in the United States have raised concerns that a similar disaster could happen in the United States because the NRC remains "too timid" in demanding safety upgrades that may cost operators money.[34]

Similar critiques should be expected in Japan. Some have already asserted that the Ministry of the Environment may not be the most suitable institutional address for the NRA given the ministry's support for nuclear power as a way to curb carbon emissions and slow global warming.[35] This is an understandable concern, especially if the movement of personnel between METI and the MOE remains permissible even if movement in and out of the NRA specifically is highly restricted. Nevertheless, the current arrangement will likely not create the same direct conflict of interest that promoting the business interests of the nuclear power industry created in the past. Other countries have delegated nuclear power industry regulation to environment ministries or other government agencies that have a stake in mitigating global warming.[36] Experience has shown that this does not automatically make them susceptible to the same kind of manipulation that NISA suffered within METI. Moreover, the NRA being established as an Article 3 Authority under Japan's National Government Organization Law will allow it to operate independently without the control of senior officials within the MOE.[37] Establishing the NRA as an Article 3 Authority also means that the agency will be placed outside the system in which government employees are rotated from agency to agency within a ministry, as was the case with NISA within METI.[38] Indeed, this was an important improvement to earlier proposals to establish the NRA as an Article 8 organization, which would have made it a weaker, extra-ministerial bureau with less independence. For a time, it was believed that making the NRA an Article 8 organization would allow it to be more responsive during an emergency because it would not have to wait for direction from high-level bureaucrats within the MOE before acting on behalf of public safety.[39] But the solution of establishing the NRA as a stronger, more independent organization under Article 3 and granting the chairman the authority to make decisions independently during emergencies should allow the regulator to act more confidently and efficiently in the event of an accident.

Even though the NRA will have significant autonomy from the MOE in its day-to-day operations and accident management procedures, it will not be completely shielded from the possibility of industry influence. Its budget will be managed by the Environment Minister and the commission members who oversee the NRA's work will be appointed by the Prime Minister with the approval of the National Diet. Thus, there are other forms of indirect influence that must be accounted for in assessing the degree of regulator autonomy, which is never absolute.[40] The IAEA International Nuclear Safeguards Advisory Group (INSAG) guidance recognizes that regulators "cannot be absolutely independent in all respects of the rest of government: it must function within a national system of laws and under budget constraints, just as other governmental organizations do."[41] In other words, the NRA, like regulatory bodies elsewhere, will neither exist on an island nor have unlimited resources at its disposal. It will need to make decisions regarding its approach and allocation of resources, and these decisions will not be carried out in a vacuum without consideration by the NRA or the Diet of other government priorities. That is why INSAG goes beyond talking about independence in terms of degree of separation and describes observable actions that represent "key features" of independence such as: (1) having mechanisms for dialogue with others that do not render the agency vulnerable to external pressure; (2) science-based decision-making and providing clear explanations for decisions; (3) maintaining consistency and predictability in following established legal guidelines; and (4) being transparent and traceable in regulator operations.[42] Beyond re-locating the regulatory agency, Japan should make a priority out of continuing efforts to make the above features permanent aspects of its regulatory process. All of these features should be taken into consideration by independent organizations within Japan and by international organizations with a vested interest in continuously improving nuclear regulator effectiveness and overall nuclear safety.

Apart from independence, another major issue that the Fukushima Daiichi accident revealed is the importance of formulating clear, specific, and appropriate institutional responsibilities when it comes to ensuring safety. The chaos surrounding the Fukushima Daiichi accident proved that Japan must improve in accident management preparation and coordination. As the shortcomings of the NSC and NISA also suggest, a lack of clarity in job descriptions and organizational roles hindered the modernization of safety regulations and the cultivation of a safety culture within the industry. It is noteworthy that the first recommendation of the IRRS report on Japan was that "the role of NISA as the regulatory body and that of NSC, especially in producing safety guides, should be clarified."[43] In response, the NSC acknowledged that "this point has been brought up on other occasions" and the NSC needed to "elaborate the scope of its responsibilities . . . in a more clearly understandable way" to differentiate them from NISA's.[44] Although the NSC tended to have a pro-industry view, it was nonetheless effectively independent from METI. Had it been given a different role in developing more rigorous safety standards, NISA's independence (or lack thereof), though still undeniably problematic, might have been less costly. None of this diminishes the value of relocating regulatory authority to the NRA and MOE, it only adds that clear and appropriate differentiation of nuclear safety roles and responsibilities across the various government agencies is also needed.

Looking ahead, the NRA has dissolved the NSC and integrated its functions. Since one of the major problems with NISA and METI was the failure to incorporate lessons learned from abroad and best practices established by the IAEA, the NRA should assign a body specifically to this task. Rather than doing the continuous double-checking as the former NSC did, it would make sense if the NRA dedicated more of its time to translating best practices from abroad into regulatory requirements called for in the NRA and industry-wide standards for Japanese nuclear power companies. The sooner this work begins, the better. The numerous delegations and advisory panels that the NRA established are already providing Japan with good advice.[45] It would be unfortunate if these recommendations were lost or forgotten as the NRA finds its footing.

The loss of Japanese public confidence in the nuclear power industry is yet another reason why a high-level body committed to the aggregation and application of international best practices is important. By demonstrating that the new standards and practices adopted by the NRA have been successful elsewhere in improving safety, the government would be able to make a stronger case to the people that nuclear safety in Japan is improving and will continue to do so as international best practices evolve.

It shouldn't be necessary for each country with a nuclear power program to repeat the mistakes of others before they are learned. That is why other countries have carried out "stress tests" and "walkdowns" to re-assess plant resilience to earthquakes and floods following the Fukushima Daiichi accident.[46] In the United States, testimony by NRC officials following the Fukushima accident repeatedly stressed the importance of the approach to safety as an ongoing process of never-ending improvement. As NRC executive director for operations, William Borchardt, succinctly put it, the NRC "never stopped making improvements to our regulatory framework as we learn from operating experience."[47] Of course, continual improvement of this kind will require adequate investment in the human resources necessary to proactively identify changes to both safety standards and the regulatory process in general.

Human Resources and Professionalism

One of the biggest challenges facing Japan is the development of a cadre of professionals who are qualified to serve as regulators. In the United States, the NRC has the advantage of being able to recruit a substantial portion of its employees from the military by drawing heavily from the Navy's nuclear propulsion program.[48] Although Japan does not have the same option, it can replicate other programs that have been successful in the United States and other countries to meet their human resources needs in both operation and regulation.[49] To that end, the proposal to establish an International Nuclear Safety Training Academy should be pursued as a means to build up a cadre of technically-trained professionals to serve in the NRA and provide them with ongoing training during their professional employment. A strong emphasis should be placed on training for regulators, operators, and other nuclear power plant personnel.

The NRA must take the lead in professionalizing the nuclear industry workforce by setting high standards for education and training for the industry's workforce. According to data provided to *The Los Angeles Times* by NISA, 88 percent of the 83,000 workers at Japan's nuclear power plants are contract workers as opposed to full-time employees of the utility companies that own the plants.[50] Industry-wide, the pay for nuclear plant operators and technicians employed by utility companies averages about ¥6 million ($62,000) per year.[51] That compares reasonably well with pay scales in the United States for similar work. However, contract workers – many of whom are reportedly hired with minimal training – are not put on a career track wherein they can receive training and flourish as professionals who are continually improving their skills. According to one report, the week before the accident, the Fukushima Daiichi plant was paying full-time maintenance workers $11 per hour (¥1,056) – the same as a McDonald's employee in Tokyo.[52] Of course, not every maintenance worker needs to be career-tracked to become a plant manager or paid enough to live richly, but it is obvious that compensation should reflect an acknowledgment that servicing equipment at a nuclear power plant is a decidedly weightier undertaking than operating a deep fryer at McDonald's.

Looking at the NRA specifically, Japan will need to expand its size substantially beyond the roughly 460 it will employ over the near term after borrowing most of those staff from NISA. Specifically, it should devote substantial efforts to overcoming bureaucratic barriers that are standing in the way of incorporating JNES's 490 staff members into the NRA and increasing the NRA's budget accordingly. The NRA's current budget of approximately $573 million (~¥55 billion) will also need to be increased accordingly.[53] The total of about 950 personnel would still be less than one-quarter of the size of the U.S. NRC while Japan's 54 reactors at 18 power plants represents slightly more than half of the 104 reactors that the United States has at 65 nuclear power plants. Japan does not need to match the United States in spending on nuclear power regulation or even spend half as much since it has roughly half the reactors. However, if the government is truly committed to ensuring the highest degree of safety possible, it will need to back up that commitment by investing in the NRA.

For its part, the NRA needs to be able to get the most out of every employee and to be able to improve its competence in areas that can only be improved over time. To ensure that it does, Japan should consider exempting the NRA from government policies that require employees to rotate jobs every two-to-three years. Doing so would help senior staff achieve a greater depth of expertise and foster greater long-term continuity in regulator-industry interaction and more regulator accountability for safety outcomes. The IAEA's mission observed that the rotations were hurting the ability of senior staff to "enhance its knowledge management and effectiveness of nuclear safety regulation of strategic and operational issues."[54] Greater experience with these issues could help the NRA develop improved quality systems management guidelines for plant licensees and enforce regulations that take into account the entirety of plant operations from a probabilistic risk perspective. At a minimum, it would allow agency employees to develop a more detailed understanding of operations at nuclear power plants, thus making them better equipped to detect problems.

For this work, the NRA will also need the support of a legal framework that includes robust protection for whistleblowers from within the NRA and across the nuclear power industry. Otherwise, the industry will be prone to scandal and regulatory knowledge deficits, including blind spots to problems that could lead to severe accidents. Providing legal protection to those who bring safety concerns to the fore is essential to establishing an industry-wide culture at each plant. Likewise, the NRA should ensure the same protection for its own employees by standing up an office of an Inspector General (or functional equivalent) to investigate reports of misconduct and cover-ups within the ranks of the authority.

For example, in the United States, nuclear regulators are protected from retribution by the NRC for disclosing safety problems, reporting violations of procedures, participating in efforts to detect tampering or improper calibration of instruments, challenging superiors, and other activities that draw attention to problems. An internal Office of the Inspector General (OIG) at the NRC carries out audits and investigations to "prevent and detect fraud, waste, abuse, and mismanagement."[55] Legislation establishing the office was passed in 1978 and revised in 2008 to create an interagency group consisting of inspector generals from across government that can work together to address issues related to their independence and ability to function effectively. Despite these layered efforts to ensure accountability across government, problems can still occur. Recently, a manager within the NRC has come under fire for creating a hostile work environment for regulators and instituting salary bonus structures that created financial risks for those who exposed problems. The U.S. Congress then exerted pressure on the NRC to investigate and report on the matter.[56] Similarly, it could be said that the responsibility to improve safety across the nuclear power industry extends to Japan's National Diet, which must do its part to hold the NRA to high standards of human resource management, including whistleblower protection.

Overall, the re-organization of nuclear industry oversight in Japan bodes well for improved regulatory effectiveness and accident risk reduction in the future. However, the progress in resolving the institutional conflict of interests that afflicted NISA and METI does not obviate the need to address individual conflicts of interest that affect people responsible for developing and enforcing regulations. The next section discusses some of the decisions and incentives facing individuals involved in the regulatory process.

Recommendations:

- Japan should consider exempting the NRA from the practice of rotating government employees between jobs every several years in order to develop and preserve greater organizational competence. Expediting the proper and entire incorporation of JNES into the NRA and increasing its budget and staff accordingly should be made a priority in order to hasten the completion of bureaucratic reorganization.
- The NRA must take a leading role in working with industry to professionalize the workforce through proper training, hiring practices, and compensation. It will be incumbent on the rest of the Japanese government to support it in this regard by resourcing it appropriately and facilitating cooperation among regulators, utility companies, academia, civil society groups, and other stakeholders.
- Japan should review and, as needed, strengthen whistleblower protections that apply to both industry and government employees. Within the NRA, it should stand up an Inspector General's office (or functional equivalent).

The Revolving Door Dilemma

No matter what legal or institutional arrangements are settled on to shield the NRA from excessive industry influence, the actual oversight of Japan's utilities will be carried out by human beings. Reform of the regulatory process in Japan must therefore account for the "human factor" – specifically, those issues that can influence the decisions made by individuals working within the regulatory agency as well as the industry. A key challenge brought to the fore by the Japanese experience is the effect of the "revolving door": the movement of personnel back and forth between regulatory organizations and what are usually higher-paying jobs in industry and organizations charged with promoting industry.

The individuals who work at regulatory organizations can be biased by industry employment in two ways depending on the sequencing of their industry and regulatory service. Those who held prior industry employment may prove to be more sympathetic to industry interests as a result of them having been "socialized" to the industry's perspective. Alternatively, those who are eyeing industry employment after their work for a regulatory authority may seek to ingratiate themselves to their prospective future employers by being lenient in enforcing rules. The latter problem appeared to be particularly acute in Japan due to the practice of *amakudari* in which retired officials from NISA and METI would commonly assume high-paying jobs in the nuclear industry they were previously regulating. Although the situation was worse in Japan because amakudari has deep cultural roots and is commonplace, similar problems face regulators elsewhere. One recent case at the NRC involved a former commissioner who took a job at a private company not long after voting on a number of regulatory issues that affected that company.[57] Proper oversight – of both regulated companies and the regulator – is needed to ensure that safety regulation is not subordinated to personal interests. The "revolving door" that separates industry and regulators needs to be watched.

To that end, it is being considered that NRA personnel be forbidden from transferring back to a job within METI or MEXT (the ministries in charge of promoting nuclear power) and place restrictions on them being able to actively seek employment at private firms that they are currently regulating. The ban on returning to ministries that promote nuclear power will be delayed for five years to allow for a "settling-in" period. Additionally, restrictions on NRA staff from assisting others with job-seeking by making recommendations to industry for re-employment are also being considered. (Similar proposals to this have been developed in the past but have failed to take hold.[58]) However, because NRA will employ many of the same people who worked previously with NISA and who may seek industry employment in the future, there are concerns that the same pattern of industry-regulator interaction that resulted in lax oversight in the past will resurface in the future.[59] Some have argued that the policy that disallows senior officials within the NRA to transfer to jobs in METI should be expanded to include the entirety of the NRA's staff. It appears that, to the chagrin of many observers, the much-maligned tradition of *amakudari* may endure, albeit more openly.

We believe that isolation is not the answer. It is neither practical nor desirable to build a complete wall of separation between industry and regulators that bans movement back and forth between the two over the course of a person's entire career. Although regulators and the regulated work extensively together over time and can develop close interpersonal and organizational relationships, it does not necessarily follow that all regulation will inevitably become what Phillip White of the Citizens Nuclear Information Center described as the "amiable fiction" that obtained in Japan. That being said, this is a difficult challenge for nuclear power because the number of people who possess the scientific knowledge needed to understand the technology and the business knowledge to understand the industry built around it is limited, even in a highly educated country like Japan. Industry expert John Large has commented that "virtually every regulator in the world has a cozy relationship with the nuclear industry . . . where the regulator and the operator and the manufacturer are all drawn from the same pool of fish."[60] This partly explains what gave Japan's "nuclear village" so much cohesion. Does this make it impossible to regulate nuclear power industries effectively? Not necessarily.

Industry experience can and typically does help regulators be more effective in their jobs. As some academic research has shown, the mere possibility of obtaining a more lucrative job in industry may sometimes actually inspire regulators to be *more* aggressive as a way of signaling their technical competence, work ethic, and professionalism. This is especially true for early- to mid-career regulators or other instances where a regulator's technical qualifications may not be immediately apparent to the industry.[61] Other studies have suggested that keeping the revolving door open a little bit can encourage regulators to place more of a stake in cultivating personal reputations for quality job performance over the course of their careers.[62]

In response to criticism of the NRC's hiring of personnel with backgrounds in the nuclear power industry, Nuclear Energy Institute president, Marvin Fertel, remarked, "It's only a problem if you think getting good expertise is a problem."[63] While it is certainly true that "good expertise" can be found in industry, this does not mean that it cannot be found anywhere else. One way to mitigate the potential adverse effects of having regulatory bodies populated largely by people with backgrounds in industry is to invest in building up a separate track through which people can gain the technical training they need to serve in the NRA. This again underscores the importance of Japan investing in human resource development and bringing its recruitment and training standards up to par with the most rigorous in the world.

Although the amakaduri issue with senior bureaucrats can be a major contributor to the deterioration of regulation, attention must be paid to the early- to mid-career inspectors are still learning the ins and outs of the regulatory process and building professional rapports with licensees. While they do have incentives to demonstrate their competence and integrity by being thorough (as mentioned above), they also have incentives to be flexible. For example, an inspector may want to reduce on-the-job stress by showing flexibility with plant operators that they will need to work with on a regular basis. Low morale due to being overworked or underpaid may dissuade regulators from going the "extra mile" to address potential safety issues. The NRA will need to think through all of the factors that could lead an individual regulator to be overly lenient with operators while developing personnel policies that are relevant to every stage of a regulator's career – from recruiting the right kind of people to curtailing amakudari.

Among federal agencies in the United States, the NRC consistently ranks best in terms of employee job satisfaction.[64] Of course, even the NRC can improve. Additionally, sorting out the fundamental problems that weakened regulation in the past will go a long way for the NRA. The point is simply that, as Japan looks abroad to incorporate best practices, it should expand the scope of its cooperation with other regulatory bodies such as the NRC to devise human resources and personnel policies that contribute to job satisfaction and a healthy work environment.

Recommendations:

- Although the "revolving door" between industry and the NRA will most likely remain open for personnel, Japan should consider developing more robust alternative means to industry experience for developing the technical expertise required for effective regulation so that the NRA is not populated *exclusively* by former industry workers.
- The NRA should consider establishing rules that require industry firms to report that they have been contacted by outside parties (beyond the NRA) to hire NRA personnel in violation of standing rules pertaining to government employees seeking industry employment.
- Conflicts of interests and lax oversight are more likely to become a problem in a regulatory workforce that is demoralized. The NRA should proactively seek input from other regulatory bodies on how to improve employee satisfaction and incorporate practices from abroad and from the IAEA as appropriate.

Dealing with Amakudari

The convergence of industry and regulatory incentives to exchange personnel does not always pay dividends for public safety. Close relationships can become too close. And even with a surfeit of technically-qualified people who could conceivably work at the NRA there will always be a market demand for industry-specific insight. Likewise, there will always be a market demand within industry for people who have a deep and sophisticated understanding of regulatory requirements. Economic theorist Yeon-Koo Che describes this as an "inescapable consequence of the regulatory agency's need for specialized knowledge and industry-specific expertise."[65] This is essentially the standing business-conscious justification for *amakudari* that remains: that having former senior-level regulators on staff will facilitate communication with the regulatory body and thereby help companies prepare to comply with the rules.[66]

Research has questioned whether regulators who desire jobs in industry will automatically show favoritism through leniency towards the regulated company. As historian and economist George Hilton succinctly put it long ago, those "who are hostile to regulation do not accept positions on [regulatory] commissions."[67] Though there is some truth to this, the facts surrounding the abysmal regulatory environment and the perpetuation of the "safety myth" in Japan speak for themselves. Yet there does not appear to be any attempt at this time to vanquish *amakudari* from nuclear power regulation, only to bring more transparency to the process by requiring that government officials notify the Prime Minister of their job offers and that the Cabinet office make a list of former regulators who have been re-employed in industry.

From a policy standpoint, it is difficult to know where to draw the line on the re-employment of senior-level bureaucrats by industry. If regulators are most vulnerable to manipulation by industry or likely to have their judgment colored by the prospect of industry employment during their last years of service on a commission, then it would seem that the duration of the "no return" clause would need to be at least long enough to eliminate quick quid-pro-quo deals related to their policy recommendations or response to specific safety issues. The regulator's ineligibility period should be long enough to minimize perceptions – by either the regulator or the industry – that there is a "deal" to be made on any particular issue. For now, what can be said is that the general guidelines being considered to manage this dilemma are in-sync with those in the United States and elsewhere.

There will always be concern that whatever regulatory body oversees Japan's nuclear power industry will be vulnerable to capture and manipulation. Therefore, to build public confidence that the NRA is truly doing its job, Japan should seek to maximize the use of external validators – from both inside and outside the country – to provide an independent check on the industry's activities. Establishing mechanisms whereby the opinions of experts from outside the "nuclear village" can influence both industry practice and regulatory behavior can help restore public confidence that nuclear power – whether they believe it to be adequately safe or not – is at least under control. In a sense, this is a way of applying the "defense-in-depth" concept to the regulatory process as a whole.

To whatever extent it is believed that the NRA's relationship with industry is still too cozy and regulators will be too reticent to take a firm stance on safety issues or mete out punishment, it may behoove Japan to consider incorporating greater automaticity into the decision-making process. Remembering that regulation is carried out by human beings, clearer guidelines about what to do can help reduce uncertainty for regulators when it comes to reporting or responding to potential problems. Reducing this uncertainty closes the "window of opportunity" for industry to influence the individuals making regulatory decisions. However, this carries a substantial risk of backfiring, which brings up an important point that needs to be made before closing this discussion on the regulatory framework and process.

Making regulatory requirements more demanding, responses to problems more automatic, and penalties more severe carries the risk of increasing industry incentives to cover-up its problems and be uncooperative with regulators. This problem lies at the opposite end of the spectrum from where Japan was before, where industry operated with virtual impunity and covered-up problems simply because it could. A balance must be struck. In a statement following the exposure of TEPCO's falsified reporting to NISA, the company's new president, Tsunehisa Katsumata, explained how the fear of public exposure led to conservatism in reporting that eventually became outright mendacity by over-confident engineers:

> . . . because the Japanese news media tends to run major stories about problems at nuclear facilities, no matter how trivial these may be, the engineers got into the habit of being defensive whenever any minor incident occurred. In addition, the engineers were so confident of their knowledge of nuclear power that they came to hold the erroneous belief that they would not have to report problems to the national government as long as safety was maintained. . . Engineers who were reluctant to report problems, therefore eventually came to believe that they would be allowed not to report faults if the faults did not pose an immediate threat to safety and, as a result, they went as far as to delete factual data and falsify inspection and repair records.[68]

This may seem like finger-pointing by TEPCO. However, it is important to remember that nuclear technology is a "peopled technology" and that plant operators regularly make decisions and take actions based on common (and sometimes undocumented) knowledge specific to their plants. They will make mistakes, as will regulators. They will need to work together continuously to define and to meet ever-improving performance goals for safety.

Recommendations:

- Japan should seek to maximize its use of outside expertise as a check on regulatory structure and performance as well as on specific technical issues pertaining to safety at nuclear power facilities.
- Japan could consider building greater automaticity into the decision-making process at the NRA in order to establish clear expectations among operators about the implications of safety lapses.

Specific Safety Measures

Having discussed the regulatory framework and process, we now to turn to a technical analysis of specific safety requirements being considered in Japan. This analysis will draw extensively from the experience of the United States with some of the technical issues at-hand and the evolution of the requirements put in place to improve safety.

Installation of Vents Equipped with Filters on Reactors' Containments

All safety improvements to nuclear plants have costs: both real and perceived. If a designer of a plant wants to increase the number and types of safety systems, he typically increases the cost of construction of the plant. If the cost of a plant increases too much, it could become uncompetitive financially compared to other electricity generation sources. On the other hand, if not enough money is spent on safety systems, the risk of an accident causing severe costs to the public and environment goes up. Risk is intentionally used here, not just probability or consequences alone. Recall that risk is probability multiplied by the consequences. Lack of enough safety systems can raise both the probability of an accident and the consequences if an accident occurs. This is real risk with the potential for serious costs and losses.

Perceived risk also depends on the number and types of safety systems. If the public perceives that a nuclear plant has many layers of safety, it is more likely willing to accept and even strongly support operation of the plant. However, if the public learns that a new safety mechanism is available but not used, it may react unfavorably toward operation of the plant. Importantly, the public tends to be more attuned to losses rather than costs.[69] Specifically, the public would want to avoid losses or damages such as radioactive contamination caused by an accident, whereas people are not as aware of the particular extra costs to install safety systems.

For this report, we pay particular attention to containment of radioactive materials in the event of an accident. Specifically, the three Fukushima Daiichi reactors that experienced core meltdowns released substantial amounts of radioactive materials to the environment outside of the plant. This contamination has displaced tens of thousands of people and has had substantial social and economic costs. The question is whether different design choices and safety features could have mitigated or even prevented this contamination.

The choice of the containment structure and associated safety systems of a nuclear plant significantly affects the cost of the plant and the ability to prevent or mitigate an accident. The commercial reactors in Japan and the United States are light water reactors of either the boiling water reactor (BWR) or pressurized water reactor (PWR) designs. There are variations on the designs of BWRs and PWRs, but in general, BWRs have smaller containment volumes than PWRs; this is especially true of the older "Generation II" BWRs in operation. The oldest BWR designs are designated as Mark I; the next oldest are designated as Mark II; the design after that is known as Mark III. The reactors at Fukushima Daiichi that experienced the accidents were of the oldest Mark I BWR containment designs.

Because the containment's volume of a Mark I or even a Mark II BWR is relatively small compared to a PWR's containment, the BWR containment can become overpressurized with steam much faster than a PWR containment. Steam is not normally present outside the reactor vessel and its associated piping and equipment. Only in the event of an accident that results in a leak or more seriously rupture of the piping that contains high temperature water would steam start to fill the containment.

While containments vary in design, the general principle is a hardened concrete structure often reinforced with high strength steel. Making the containment structure bigger and using more concrete and reinforced steel adds cost to the plant. In the 1960s, General Electric (GE) began building Mark I BWRs and marketed them as cheaper than its competitor's (Westinghouse's) PWRs. One of the main ways to lower cost of the BWRs was to build smaller containment structures. But a smaller containment could reduce safety in the absence of other systems that would reduce the likelihood of having the containment overpressurize in the event of an accident. These extra safety systems were designed to suppress the pressure buildup by absorbing much of the energy of the steam in order to condense the steam into liquid water. By making the steam bubble through liquid water or ice, these systems can allow for pressure suppression. But there has to be sufficient volume of liquid water or ice in the containment. If there is a major accident resulting in a huge generation of steam, these systems could become overwhelmed.

In the event of a loss of coolant accident, the reactor core can become uncovered, thereby exposing hot fuel cladding. The cladding material is typically made from zirconium because of this metal's favorable heat transfer properties and low probability to absorb neutrons during the nuclear chain reaction among neutrons and fissile atoms of uranium and plutonium. But zirconium has the disadvantageous property of reacting with steam and disassociating it into hydrogen and oxygen. Hydrogen, as a flammable gas, poses a serious hazard if it builds up and ignites. A powerful enough hydrogen explosion can rupture a containment structure. This type of explosion occurred at Fukushima Daiichi.

Concerns about the design and potential safety problems of the Mark I BWR were raised in the early years of these plants' deployment. In 1972, Stephen H. Hanauer, then an official at the U.S. Atomic Energy Commission, argued for discontinuing use of this design because his analysis led him to believe that "the disadvantages are preponderant."[70] In response to Hanauer's recommendation, Joseph Hendrie, an official who would later become the Chairman of the U.S. Nuclear Regulatory Commission, wrote that banning these types of containments is "attractive in some ways" but he went on to state: "Reversal of this hallowed policy, particularly at this time, could well be the end of nuclear power."[71] Soon after the Fukushima accident, David Lochbaum, a nuclear engineer who had worked at BWR plants and a safety specialist at the Union of Concerned Scientists, said, "Not banning them might be the end of nuclear power."[72] Similar concerns were raised by a top nuclear regulatory official in the mid-1980s, when Harold Denton of the U.S. NRC warned that BWR Mark I reactors had a 90 percent probability of bursting their containments in the event of the fuel rods becoming uncovered and melting. Industry officials contested this estimate and believed that the chance of this type of failure was at most 10 percent.[73] However, because of the disclosure in the late 1980s that GE's documents from the mid-1970s indicated that the containments were insufficiently tested, several utilities threatened to sue GE.

While it is easy to look back in hindsight at what could have been done, it is clear that relatively soon after these plants were built, senior U.S. officials at the Atomic Energy Commission knew of the potential danger and increased risk. Nonetheless, many of these types of reactors were built. In the United States, there are presently 23 BWR Mark I reactors (about 22 percent of the total reactor fleet) and worldwide there are 32 of these reactors. Given that the decision to ban these plants was not taken, what else could be done to improve the safety of these plants and mitigate the consequences of an accident at these plants?

Around the time that utilities were threatening legal action against GE, the NRC staff issued a plan in December 1987 to resolve the issues concerning Mark I containments. Regarding possible solutions, "the following six areas were evaluated to determine potential benefits in terms of reducing the core-melt frequency, containment failure probability, and offsite consequences: (1) hydrogen control; (2) alternative water supply for reactor vessel injection and containment drywell sprays; (3) containment pressure relief capability (venting); (4) enhanced RPV [reactor pressure vessel] depressurization system reliability; (5) core debris controls; and (6) emergency procedures and training."[74]

One of the ways to prevent buildup of hydrogen inside the containment is inerting the atmosphere with nitrogen, a nonflammable gas, by filling the containment with this gas. But if the atmosphere inside the containment is "deinerted," hydrogen could buildup in the event of an accident. Nonetheless, the NRC staff assessed, "Reactor pressure is anticipated to increase during a severe accident, releasing steam and non-condensable gases into containment. This will increase containment pressure, preventing ingress of air. Therefore, the containment atmosphere would not become deinerted for an extended period of time. Since offsite supplies of nitrogen could be readily obtained during this period, an onsite backup supply would not significantly reduce risk." However, the severe damage to the surrounding areas offsite to Fukushima Daiichi significantly restricted the capability to deliver outside supplies such as nitrogen gas canisters as well as alternative supplies of electrical power. Frank von Hippel, an independent scientist and nuclear safety analyst, has pointed out, "The hydrogen didn't explode in the containments because they had been 'inerted' by being filled with pure nitrogen (i.e., no oxygen) but, when the hydrogen was vented into the outer containment buildings, it mixed with the air there and exploded, blowing the roofs off the outer buildings."[75] These roofs were not nearly as strong as the inner containment.

The NRC staff's evaluation also considered employing "a backup or alternate supply of water and a pumping capability independent of normal and emergency AC power. By connecting this source to the low-pressure residual heat removal systems as well as to the existing drywell sprays, water could be delivered either into the reactor vessel or to the drywell by use of an appropriate valve arrangement. An alternate source of water injection into the reactor vessel would reduce the likelihood of core-melt due to station blackout or loss of long-term decay heat removal, as well as provide significant accident management capability. … A review of some Mark I facilities indicated that most plants have one or more diesel-driven pumps which could be used to provide alternative water supply. The flow rate using this backup water system may be significantly less than the design flow rate for the drywell sprays. The potential benefits of modifying the spray headers to ensure a spray were compared to having the water run out of the spray nozzles. The result of this comparison was that removal of airborne fission products in the small crowded volume in which the sprays would be effective did not change sufficiently to warrant modifications to the spray nozzles." As the Fukushima Daiichi accident showed, sustained loss of electrical power occurred and could occur again at other plants worldwide.

One of the most important recommended improvements to the safety of Mark I BWRs was improved venting to provide for pressure relief of the containment. "The [NRC] staff concluded that venting, if properly implemented, could have a significant benefit on plant risk. However, venting via a sheet metal ductwork path, as currently [as of the late 1980s] implemented at some Mark I plants, would be likely to greatly hamper or complicate post-accident recovery activities, and was therefore viewed by the staff as yielding reduced improvements in safety. … Controlled venting can prevent the failure of ECCS [emergency core cooling system] pumps… A hard pipe vent and vent valves capable of withstanding the anticipated severe accident pressure loadings would eliminate the problems with operating the vent system during a severe accident. The vent isolation valves should be remotely operable from the control room and should be provided with a power supply independent of normal or emergency AC power. … Given a core-melt accident, venting of the wetwell would provide a scrubbed vent path to reduce release of particulate fission products to the environment. Venting has been estimated to reduce the likelihood of late containment overpressure failure and to reduce offsite consequences for severe accident scenarios in which the containment shell does not fail for other reasons. … Inadvertent venting could result in the release of normal coolant radioactivity to the environment even when core degradation is averted or vessel integrity maintained."

This NRC staff analysis from the late 1980s is very illustrative of the concerns and tradeoffs of having the capability to vent the containments. Having a venting capability is useful for allowing the operator to prevent overpressurization and potential rupture of the containment. But the nature of the vent is very important. If the vent pathway uses "sheet metal," there are concerns that it would not be reliable. Thus, the staff assessed that hardened vents would provide a needed improvement. But another concern was raised about the operability of the vent. Its operation should not have to depend on normal or emergency AC power. The staff called attention to the need for an independent power supply. But as the Fukushima Daiichi accident illustrated, there can be an extended period of complete loss of electrical power. Consequently, having a means of operation of the vents without electrical power appears justified. The NRC staff's evaluation also raised the concern about reducing the amount of particulate radioactive fission products released into the environment. Their analysis indicated that venting via the wetwell (containing a reservoir of water) could mitigate the release of radioactive materials. Interestingly, this staff analysis did not mention installing filters on the vents. But the staff did mention the concern that the venting may be inadvertently operated during normal operations and thus result in possible release of normal coolant radioactivity, which would most likely be a very small amount of radioactivity released. But plant operators who are trying to reduce any releases of radioactivity would have to think extra hard before opening a vent.

The staff recommended that licensees with Mark I containments consider alternate water supplies for pressure reduction and that the NRC "would approve hardened vents for Mark I licensees who proposed to install them."[76] On September 1, 1989, the U.S. NRC issued Generic Letter 89-16 to all holders of operating licenses for nuclear power reactors with Mark I containments regarding "Installation of a hardened wetwell vent." This letter did not require that the plants' owners install these vents; instead, it said that the NRC would approve installation "for licensees, who on their own initiative, elect to incorporate this plant improvement." The letter also did not require a standardized approach or specific equipment for this installation. However, it did mention that the staff found the "analysis acceptable" of the installed system at the Pilgrim Nuclear Power Station and owned by Boston Edison Company. The letter enclosed a copy of Boston Edison Company's description of its system.

The apparent good news was that all Mark I BWRs in the United States did install some type of hardened wetwell vent, but they were not all of the same type. But in light of the Fukushima Daiichi accident, renewed concerns were raised that the lack of uniformity and standardization of these vents could lower the real and perceived ability of these systems. The *Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident* recommended a regulatory requirement to install hardened, reliable vents on the Mark I containments and with each vent meeting a rigorous standard.[77] This task force also recommended a reevaluation of the need for hardened vents for other containment designs. Two other containment designs that have been the focus of additional safety improvements are the about one dozen Mark II and Mark III BWRs and the ice-condenser system used in nine PWRs.

Even during the NRC staff review in 1987, consideration was given to hardened vents on the Mark II and Mark III BWRs. The NRC staff, however, "did identify any generic improvements that would be applicable to all Mark II containments." But the staff requested that each licensee consider any insights learned from individual plant evaluations. Mark II containments are somewhat bigger in volume than Mark I containments and like the Mark I, Mark II containments are inerted with nitrogen. Mark II containments are even bigger in volume with approximately five times the volume of the Mark I containment and about 65 to 85 percent of the volume of a large, dry PWR containment. Similar to Mark II containments, the NRC staff did not identify any generic improvements for the class of Mark III containments (which are not inerted) but did encourage lessons to be learned from individual plant evaluations. For ice-condenser PWR containments, concerns have been raised about certain accident sequences that could overpressurize the relatively small containment volume; specifically, studies by Sandia National Laboratories have identified these sequences.[78] The NRC staff evaluation pointed out that ice-condenser containment failure "resulting from uncontrolled H_2 burns or detonations is a potentially important failure mode … This could occur in station blackout events if power to the H_2 igniter system is lost, high concentrations of H_2 are produced as a result of core degradation, and power is then restored at a later time." But here again, the NRC staff did not have any generic improvements for ice-condenser containments but encouraged licensees to learn from insights from individual plant evaluations. Finally, for most PWRs, the containments are large and dry. The NRC staff's assessment from more than 20 years ago is that "H_2 combustion on a global basis is not believed to be a significant threat to large, dry containments. However, less firm conclusions have been reached for the smaller subatmospheric containments. It may be possible for detonable mixtures of H_2 to buildup in localized compartments of both types of dry containments and damage equipment. Therefore, the potential and effects of local H_2 burns should be evaluated on a plant-specific basis."

Fast-forward two decades later to just a few months after the Fukushima Daiichi accident, the U.S. NRC commissioners received the Near Term Task Force report as mentioned above. The NRC staff also reached out to the public and industry to obtain their views. Based on these recommendations and assessments, the Commission decided less than one year after the accident to move forward with issuing an order that is applicable to all licensees with Mark I and II containments.[79] In September 2012, NRC staff provided interim guidance to BWR licensees that includes this rationale:

1. Order EA-12-050 requires that licensees of BWR facilities with Mark I and Mark II containment designs shall ensure that these facilities have a containment venting system that meets certain requirements relating to reliable and dependable operation in order to be able to implement strategies relating to the prevention of core damage.
2. The installed venting system must meet prescribed quality standards. Generally, the system must be of a 'seismically rugged design' and meet the plant's existing design basis if more stringent requirements are necessary.
3. The Order requires that licensees develop the necessary procedures and conduct appropriate training of personnel who may be required to operate the system.[80]

Since this interim guidance was just issued in September 2012, much more work needs to be done to actually determine what vents to install that are seismically rugged and reliable, then install the vents, and develop and implement training procedures to operate this system. NRC staff have had discussions with the BWR Industry Group to obtain their views and have held open public sessions in order to demonstrate to the public in a transparent way the proper process for developing reliable, hardened vents.

Segments of the public as well as nuclear safety watchdogs have raised concern that these reliable, hardened vents are not sufficient. Specifically, they have called for filtered vents. The filters would be designed to trap more than 99 percent of the radioactive contamination so that there would not be massive contamination of the environment in the event of an accident. Calling for filtered vents is not new. As Frank von Hippel reminded the readers of the *Bulletin of the Atomic Scientists*, a group of nuclear engineers in 1977 at the University of California "suggested that a robust filtration system be installed in reactors to remove the radioactivity from the vented gases. Some countries picked up the idea. Sweden installed a filtered vent system at the Barseback reactors (subsequently shutdown) across the strait from Copenhagen and France installed vent systems at all of its reactors. … The unspoken argument against requiring the US nuclear power plants be retrofitted with filtered vents was that the industry thought that they were already safe enough and that the expense would be wasteful. And, as today, the commission did not want to force the industry to do more than it was willing to do."[81]

The *Bulletin of Atomic Scientists* on March 16, 2011, reprinted an article from 1982 by von Hippel and Jan Beyea in which they argued, "It would be relatively easy to add such a system onto an already completed containment building because the filter system could be installed in a separate building outside the existing containment building and connected to it through a large valve and underground pipe. The installed cost of these systems has been estimated to be between $1 million and $20 million per reactor, an amount which is small in comparison with the more than $1 billion total cost of a modern nuclear power plant."[82] Indeed, the cost of the Barseback filtration system was about 15 million dollars (1985 U.S. dollars).[83] By 1988, Sweden had installed filtered vents on all of its reactors, and the OECD Nuclear Energy Agency estimated that the per reactor cost was about $5 million.

Given that these are relatively low cost systems, could there be reasons other than minimizing costs for industry to resist installing filtered vents? One rationale is that operators might decide to vent too soon if they know that there are filters in place and thus release radioactive noble gases to the environment. There would then be some, but arguably very little, radioactivity released. But if a filter is not in place, the operator might decide to wait too long to vent because even more radioactive materials could be released. Another concern about earlier filter designs was that "the pressure inside containment during severe accidents might be higher than the design pressure of the ducting to and from the filter system. If so, venting the containment could over-pressurize the filter system causing it to break open. Highly radioactive gases released from ruptured ductwork could in turn cause safety equipment to fail and impede efforts by plant workers responding to the accident."[84] Hardened vents are therefore required to prevent such ruptures.

Dr. Kristine Svinicki, one of the NRC Commissioners, stated in March 2012 at a regulatory conference open to public interest groups that the sequence of things that must happen to need a filter is so long that it would never occur at a U.S. plant. But as Dave Lochbaum argued "if that risk is not high enough to require filtered venting, then it is also not high enough to require unfiltered venting." He pointed out that under normal operating conditions BWRs "would process gaseous releases through high-energy particulate air (HEPA) filters and charcoal filters… During design-basis accidents, gaseous releases from BWRs are processed through another system with HEPA and charcoal filters that significantly reduce radioactivity levels being discharged. … But during severe, or beyond-design-basis accidents, gases released via the BWR reliable hardened containment vents do not pass through HEPA filters or charcoal filters before being discharged. So, when the radioactivity level to be released is as high as it ever gets, the absolute least amount of protection against it is provided."[85] He thus concludes that filerted, reliable, hardened vents are essential and should be installed.

The latest development as of this writing in mid-December 2012 is that the NRC staff is considering to recommend a new rule to the Commissioners to require vents with filters on the Mark I and II BWR containments. This rule would affect 31 U.S. reactors or about 30 percent of the reactor fleet. The industry has objected to this proposed rule. On the basis of probabilistic risk assessment, the probability of an accident that would require use of a filtered vent is very low and thus this type of risk assessment would argue against requiring this type of vent. But NRC staff have argued that a "defense-in-depth" safety philosophy, which means multiple layers of safety systems would tend toward requiring these vents. John D. Moninger, associate director of the NRC's "lessons learned" group, favored filtered vents because it would lessen the concerns that operators would have about using vents that could release radioactivity to the environment. As of this writing, the NRC staff are reportedly finalizing a report to the NRC Commissioners about this potential proposed rule change as well as presenting Commissioners "with a range of options, including a performance-based approach that could leave some plants installing filters and others demonstrating that the water [in the wetwell] provides adequate filtration."[86] Many European reactors that do not currently have filtered vents will move to install them as a result of the stress tests during the past two years.

Recommendation:
Our assessment is that the U.S. decision on whether to require filtered vents should be based on achieving safety performance goals determined by probabilistic risk assessments and risk informed regulation. These goals can be met in different ways –installing vents at some plants, but not installing at others—as long as all these plants can meet the performance objective to reduce the risk of release of radioactive materials to the environment to a sufficiently low level. Regulatory bodies in other countries such as Japan can and should apply this approach to their decisions on whether to require filtered vents at various plants.

Construction of Separate Earthquake Resistant Main Buildings as Emergency-Control Centers

After the Great East Japan Earthquake, renewed attention was paid to the ability of nuclear plants worldwide to withstand massive earthquakes. In the United States, the East Coast experienced a rare medium-magnitude earthquake in August 2011 that resulted in the shutdown of the North Anna Nuclear Power Plant in Virginia. While this was a somewhat beyond design basis event, the safety margin was such that the plant did not experience significant damage and shut down when seismometers registered the intense ground shaking. The one unusual event at the plant was the shifting of some spent fuel casks, which maintained their structural integrity. On the West Coast of the United States, there have been renewed concerns about the Shoreline Fault near the Diablo Canyon Nuclear Power Plant. The NRC's analysis concluded that the plant can withstand earthquakes near the site. According to the NRC's evaluation, "All of those ground motions fell within Diablo Canyon's existing design limits, which are based on ground motion associated with an earthquake from the larger Hosgri fault near the plant. Diablo Canyon must still carry out additional earthquake evaluations, as well as a 'walkdown' to identify any near-term actions for enhancing earthquake resistance."[87] Concerning whether U.S. nuclear plants have criteria for earthquake resistant emergency response centers, the specifications for meeting these criteria were specified more than 30 years ago.[88] The post-Fukushima review of U.S. plants did not uncover any significant deficiencies in this regard.

The post-Fukushima stress tests in Europe did uncover plants that need additional work on ensuring additional resistance against earthquakes while many plants have adequate resistant buildings. In particular, the European Commission report found that "the emergency control centers of all the plants in Finland (only Loviisa site), Germany, Hungary, Sweden, Slovenia, Lithuania, Bulgaria, and Ukraine are well prepared against radiological and extreme natural hazards. The rest of the countries have found out that their on-site emergency centers of facilities from which the emergency activities are coordinated need to be improved to withstand extreme external hazards or radiological conditions. All these countries plan to reinforce their existing on-site emergency centers, or to build new ones."[89] Again, the objective in making these upgrades is geared towards functionally improving performance in the wake of accident. While attendant regulatory requirements embody a common goal, the goal can be reached in different ways.

One of the new requirements under consideration in Japan is building secondary control rooms that enable operators to cool down reactor cores and vent gasses among other functions in the event that the main control room becomes uninhabitable or loses power. Similar facilities exist at plants in Germany and Switzerland, but they are not standard features of nuclear power plants worldwide.

Recommendation:
As with building earthquake resistant emergency response centers, consideration of whether or not to require secondary control rooms for all power plants across Japan should be carried out in the context of comprehensive reviews of plants' overall resilience to accidents. Specifically, attention needs to be paid to the different functions that must be available in the event of an accident and how to build-in redundancy, as needed, to bring the overall risk of significant radiation release to a sufficiently low level. Hardening facilities to earthquakes and requiring secondary power sources and control rooms may very well be an appropriate part of the solution at a given plant. However, not every function of a power plant (or its accident management strategy) necessarily needs duplication. We recommend that such assessments be done on a plant-by-plant basis and should be guided by risk informed regulation.

Introduction for Safety Reasons of a 40-Year Limit on Operation of Nuclear Power Plants

Should Japan not operate nuclear power plants after 40 years? What is the significance of the 40-year time period for initial licensing? To answer these questions and provide guidance for Japan, we examine the origin of the 40-year plant license period in the United States and assess efforts to renew licenses to 20 or more years.

In the 1950s, the start of commercial nuclear power, the United States was a leader in commercialization of nuclear power and had to determine the licensing period for nuclear power plants without prior experience from other countries. The nuclear age itself was still relatively new with the first reactors (for purposes of research and weapons-plutonium production) only having been built the previous decade. But relatively large-scale non-nuclear electricity production had been underway for at least a few decades. Thus, some experience could be drawn from the life of non-nuclear electricity generation plants when assessing how long a nuclear plant could operate.

The legislation that governs nuclear activities in the United States is the 1954 Atomic Energy Act, as amended. Section 103 of this act (see appendix) specifies the conditions and constraints of commercial licensing. In particular, paragraph c of that section makes clear the initial period of licensing shall not exceed forty years but can be renewed upon expiration of that license. Section 103 does not describe the basis for the decision to limit the initial license period to forty years.

Nuclear plant aging and license extension have been under consideration in the United States for the past three decades. In 1982, the NRC began a program to study plant aging. In 1991, the NRC published safety requirements for licensing renewal and started a pilot program to assess these requirements. Then in 1995, it amended the license renewal rule to concentrate on the adverse effects of plant aging instead of identifying every single aging mechanism, and the NRC focused on ensuring that plant components would continue to perform their intended functions.[90]

Because most of the U.S. nuclear reactors are relatively old and are at or near the end of the 40-year initial license period, the issue of relicensing has led to the question of how long a reactor can last. Most of the U.S. reactors have already applied and received 20-year license extensions. It is anticipated that before this decade has ended, almost all of the 104 U.S. reactors will have received an extension. From an industrial and electricity generation standpoint, these renewals are important for maintaining the biggest current means for the United States to generate nearly carbon free sources of electricity. Even with the growing use of relatively cheap natural gas, the United States can only substantially reduce its greenhouse gas emissions in the electricity generation sector if these natural gas plants displace coal-powered plants or if widespread carbon capture and storage were used. (Burning coal emits about twice the amount of carbon dioxide, a greenhouse gas, than burning natural gas.) But when natural gas plants compete economically with nuclear plants in the United States, natural gas has been in recent years more competitive than nuclear power, and this is expected to continue for the foreseeable future. This is relevant for relicensing because a utility owner who decides to pursue relicensing must weigh the costs of any needed improvements to the nuclear power plant in order to receive the license renewal versus the cost to decommission the nuclear plant and replace it with a gas plant. On the other hand, improvements to nuclear plants in the lead up to relicensing can at times lead to greater power production from the plant due to enhancements such as new turbines or more efficient steam generators. Thus, safety improvements may lead to power performance improvements; the latter improvements mean that more money can be made from the improved nuclear plant.

Because there are very few new nuclear plants being built in the United States, because there were very few built during the past 20 years, and because the financial prospects for new construction of several plants in the coming years to decades appear slim, there has been significant discussion about considering extending the life of many nuclear plants to 80 years or maybe even longer. This discussion has raised concern among those who oppose nuclear power; it has also raised concern among those who support nuclear power but worry that pushing the life of a reactor too far could result in a major accident. Such an accident could harm the continued operation of many other reactors. Some have even charged that the NRC and the industry are weakening licensing standards to permit the operation of plants beyond the 20-year renewal period and that the NRC has been too permissive in allowing some license renewals.[91]

The Nuclear Energy Institute (NEI) has stated that the "original 40-year license term to operate a commercial nuclear reactor was related to the estimated time it would take to amortize (repay) the capital investment, not the reactor's anticipated design life."[92] To support this position, NEI referenced the Congressional hearings in Mary 1954 before the Joint Committee on Atomic Energy on amendments to the Atomic Energy Act of 1946, E. H. Dixon, chairman of the Edison Electric Institute's Committee on Atomic Power, said of a proposed 20-year amortization period, "I think that the period is too short … If atomic power is to be competitive with standard orthodox fuels, the need for amortizing facilities over 20 or 25 years puts an undue price burden on that product. These reactors may work 50 years, we don't know … 40 years is a normal period for amortizing or depreciating a generating unit."[93]

In other countries, nuclear regulators tend to follow the forty-year rule allowing for license renewal with some variations. France stands out as an advanced nuclear power state that has implemented a 10-year renewal process. Every ten years, a nuclear plant undergoes a thorough inspection to determine whether it will receive a renewed license to operate for another ten years. Electricite de France wants to extend the life of its reactors to 60 years.[94] While the French are generally still very supportive of nuclear power and generate a vast majority of their electricity from this source, Germans and Swiss had adverse reactions to nuclear power after the Fukushima accident and their governments decided to phase out nuclear power plants with some plants being shut down before reaching a forty-year operating experience. Although safety concerns were raised about some plants in these countries, the recent decisions appear mostly politically motivated. The fact remains, however, that any country that wants to continue operating nuclear power plants beyond a nominal forty-year life needs to resolve how to ensure safety as the plants age.

If essentially every component of a plant can be replaced before it reaches a breaking point, then conceivably plants could run indefinitely. But reactor materials are exposed to heavy doses of radiation. Can these materials be repaired so that they can continue to function? The U.S. Department of Energy in recent years started a program to investigate this issue and has collaborated with France's MAI and U.S.-based Electric Power Research Institute (EPRI), a nonprofit organization funded by utilities. One of the main research areas is neutron bombardment of reactor materials. High-energy neutrons smacking into materials can cause cracks to form over the decades long duration of a plant. DOE is funding research to examine accelerated neutron embrittlement on research materials to determine as fast as possible how these cracks form and what can be done to repair them or prevent them from forming.[95]

The bottom line is that researchers do not yet know how long a reactor can last but investments in research and development is arguably the best way to find out. Regulators may come under increasing pressure within the next twenty years as plants that have received license renewals reach their license expiration period. Thus, it is critical to devote adequate resources to ensure nuclear safety and determine the ultimate life span of nuclear plants.

Recommendations:

- The Nuclear Regulation Authority should decide on whether or not to issue a license to operate nuclear plants beyond 40 years based on safety assessments guided by risk informed regulation. We urge that such decisions not be influenced by political considerations. Nonetheless, we understand that utilities may decide to not operate a nuclear plant even if that plant receives a license extension because of other economic considerations. In particular, the cost of safety upgrades may be too prohibitive to permit economically competitive operation of a plant.

- We recommend that Japan and the United States work together to investigate strengthening plant safety with an eye to determining whether various plants can operate beyond 60 years.

Determination of Nuclear Plants' Restart Following Stress Tests

Across the world in practically every country with commercial nuclear reactors, safety regulators, soon after the Fukushima Daiichi accidents, responded to assess whether their countries' plants could withstand the extreme disasters that struck the Fukushima Daiichi nuclear plant. The emphasis here is on "extreme disasters" because the huge earthquake and tsunami were beyond the safety basis designed for at the affected nuclear plants. Regulators and plant designers have to determine how much force could strike a plant from an earthquake and how much water and forceful winds could impact a plant from tsunamis, flooding, hurricanes, typhoons, and tornados. Similar to the decisions affecting the safety systems discussed earlier in this report, there are tradeoffs between the costs of these systems and the economic competitiveness of nuclear power.

In the United States, a near-term task force was formed soon after the accident and was given 90 days to write a report with recommendations for improving. Some of their recommendations such as reliable, hardened vents for containments were discussed earlier in our report. One of the most important findings of the NRC and the Near-Term Task Force was that no U.S. nuclear plants had to shutdown because of a serious safety violation or substantial concern that a plant could not be operated safely. Nonetheless, safety improvements were recommended. Without going into all the details of the 12 recommendations here, we will briefly outline that they addressed, in addition to hardening vents, the issues of enhancing the NRC's framework for addressing beyond-basis-events, updating seismic and flooding analysis to protect plants from those events, evaluating the threat from seismically induced fires and floods, strengthening the ability to protect against long duration station blackouts, identifying insights about hydrogen control inside containments, enhancing spent fuel pool instrumentation and makeup water capability, strengthening and integrating on-site emergency response capabilities, ordering licensees to modify emergency operating procedures, requiring facility emergency plans address prolonged station blackout and multiunit events, evaluating over the long-term additional emergency preparedness topics related to station blackout and multiunit events, and finally strengthening regulatory oversight of licensee safety performance by focusing more on defense-in-depth requirements.

In Europe, an extensive set of stress tests were implemented "to assess how individual nuclear power plants can withstand the consequences of various unexpected events, ranging from natural disasters to human error or technical failure and other accidental impacts."[96] The tests resulted in 17 national reports involving all EU member states with nuclear plants and including non-EU European states such as Ukraine with nuclear plants. In the EU, there are 134 reactors on 68 sites. Of these, 111 reactors have more than 100,000 inhabitants within 30 kilometers. Thus, the population density is roughly comparable to Japan. The peer review teams for the stress tests were composed of safety experts from EU member states, Switzerland, Ukraine, and the European Commission with observers from third countries (Croatia, Japan, and the United States) as well as the International Atomic Energy Agency.

The most important recommendation from the stress tests was to ensure that each plant has adequate means to deal with prolonged station blackout: "the key risk." The United States had also examined and underscored this risk in light of fires or explosions soon after the September 11, 2001 terrorists' attacks and issued so called "B.5.b" requirements to plants' operators to mitigate the risk of prolonged station blackout. The NRC's post-Fukushima near term task force reanalyzed this issue with respect to extreme natural disasters. While concerns about station blackout in the United States and efforts to address it go back at least four decades, we emphasize here, as we have with the preferred approach to regulations, that as understanding of the threats such as natural disasters and terrorist attacks evolve, so must regulatory agencies and industry respond expeditiously to reduce the risks from these threats. The European Commission report emphasized that "the following should be readily available under even the most extreme circumstances:

- a variety of mobile devices (such as mobile generators, mobile pumps, mobile battery chargers or mobile DC power sources, fire-fighting equipment, emergency lighting, etc.);
- the availability of alternative means of cooling;
- specialized equipment and fully trained staff to deal effectively with events affecting all the units on one site."

Other important issues to highlight from the EU report are:

- Perform periodic safety reviews at least every 10 years, including a reassessment of the external hazards and the robustness of the plants against them.
- Review with respect to an exceedance probability (or return period) of 10^{-4} per year for major earthquakes and massive flooding. This was a much stricter condition than had been planned for at many of the plants reviewed during the stress tests. But ten reactors in the Czech Republic, France, and Spain lacked adequate equipment to detect earthquakes.
- Need for consistency of evaluation among the EU countries of determining beyond design basis safety margins for earthquakes and flooding.
- Develop a consistent means among these countries to determine the adequacy of the ultimate heat sink.
- Ensure that all BWRs have hardened, filtered vent systems. While many European reactors already had such systems, several did not.

It is important to underscore that no European plants were required to shutdown as a result of the stress tests.[97] However, Belgium's regulator decided to shutdown two of its seven reactors in August 2012 after having discovered thousands of cracks two months after completion of the stress tests. Nearly all EU plants need upgrades of about 30 million to 200 million euros per reactor. The projected total costs of improvements on the European nuclear plants are estimated to be between 10 billion to 25 billion euros.[98]

We observe that the European regulatory action appears stricter than the American regulatory action, which is not to state that the U.S. NRC's action post-Fukushima is lax. Notably, the reaction of a few European governments to accelerating the planned shutdown of some plants or phasing out nuclear power entirely stands in contrast to the U.S. decision to keep all plants running post-Fukushima although some U.S. plants have had extended shutdown periods because of other safety concerns. Dr. Daniel Kahneman, a Nobel prize winner in economics and a world leader in decision making when facing uncertainty, has found that there is an "intense aversion to trading increased risk for some other advantage … This trend is especially strong in Europe, where the precautionary principle, which prohibits any action that might cause harm, is a widely accepted doctrine. In the regulatory context, the precautionary principle imposes the entire burden of proving safety on anyone who undertakes actions that might harm people or the environment. Multiple international bodies have specified that the absence of scientific evidence of potential damage is not sufficient justification for taking risks. As the jurist Cass Sunstein points out, the precautionary principle is costly, and when interpreted strictly it can be paralyzing."[99]

Recommendations:

- We recommend that any decision to restart nuclear reactors in Japan not be unduly influenced by political decisions. In particular, the Nuclear Regulation Authority should follow a risk informed approach when examining each individual plant. A defense-in-depth safety approach should be the overarching philosophy. While each defensive layer is individually imperfect, the combined functioning of the layers together should be designed to meet safety performance objectives to keep the risk to the public to an acceptably low level.
- The Japanese public needs to understand that nuclear power is not risk free. Any technology has risks. All electricity generation sources have varying risks to the environment, the economy, and human wellbeing. We urge the government and the public to have ongoing serious discussions about the balance among these risks.

We further recommend that the NRA embrace a dynamic approach that continually assesses risks rather than adopt a deterministic approach that may give a false impression to the public and may place undue costs on continuance of nuclear power plants that can operate safely. The NRA would best be able to work with regulatory agencies in other countries by harmonizing its regulatory approach with the risk informed and probabilistic safety assessment methodology followed in these countries' regulatory agencies.

Appendix 1

Commercial Licenses of the Atomic Energy Act of 1954 (as amended)

SEC. 103. COMMERCIAL LICENSES.—

a. The Commission is authorized to issue licenses to persons applying therefor to transfer or receive in interstate commerce, manufacture, produce, transfer, acquire, possess, use, import, or export under the terms of an agreement for cooperation arranged pursuant to section 123, utilization or production facilities for industrial or commercial purposes. Such licenses shall be issued in accordance with the provisions of chapter 16 and subject to such conditions as the Commission may by rule or regulation establish to effectuate the purposes and provisions of this Act.

b. The Commission shall issue such licenses on a non-exclusive basis to persons applying therefor (1) whose proposed activities will serve a useful purpose proportionate to the quantities of special nuclear material or source material to be utilized; (2) who are equipped to observe and who agree to observe such safety standards to protect health and to minimize danger to life or property as the Commission may by rule establish; and (3) who agree to make available to the Commission such technical information and data concerning activities under such licenses as the Commission may determine necessary to promote the common defense and security and to protect the health and safety of the public. All such information may be used by the Commission only for the purposes of the common defense and security and to protect the health and safety of the public.

c. Each such license shall be issued for a specified period, as determined by the Commission, depending on the type of activity to be licensed, but not exceeding forty years, and may be renewed upon the expiration of such period.

d. No license under this section may be given to any person or activities which are not under or within the jurisdiction of the United States, except for the export of production or utilization facilities under terms of an agreement for cooperation arranged pursuant to section 123, or except under the provisions of section 109. No license may be issued to an alien or any corporation or other entity if the Commission knows or has reason to believe it is owned, controlled, or dominated by an alien, a foreign corporation, or a foreign government. In any event, no license may be issued to any person within the United States if, in the opinion of the Commission, the issuance of a license to such person would be inimical to the common defense and security or to the health and safety of the public.

f. Each license issued for a utilization facility under this section or section 104 b. shall require as a condition thereof that in case of any accident which could result in an unplanned release of quantities of fission products in excess of allowable limits for nor- mal operation established by the Commission, the licensee shall immediately so notify the Commission. Violation of the condition prescribed by this subsection may, in the Commission's discretion, constitute grounds for license revocation. In accordance with section 187 of this Act, the Commission shall promptly amend each license for a utilization facility issued under this section or section 104 b. which is in effect on the date of enactment of this sub-section to include the provisions required under this subsection.

Notes

[1] One recent estimate suggests that there is likely to be between 15 and 1,300 premature deaths resulting from radiation exposure from Fukushima. See Nathanael Massey and ClimateWire, "Computer Model Predicts Fewer than 200 Deaths from Fukushima Radiation," *Scientific American*, July 17, 2012. Available at: http://www.scientificamerican.com/article.cfm?id=computer-model-predicts-fewer-than-200-deaths-fukushima-radiation. However, other experts believe that it is unlikely that there will be more than a few, if any, fallout-related deaths or illnesses. See Join D. Boice, Jr. Testimony before the House Committee on Science, Space and Technology, Hearing on Nuclear Risk Management, May 13, 2011. Available at: http://bravenewclimate.files.wordpress.com/2012/03/john-boice-testimony-5-13-11-house-science-committee.pdf. A recent World Health Organization report concluded that there are some increased cancer risks among people in the most contaminated areas in Fukushima Prefecture, but there were no risks to the general population in Japan and in other countries. See "Health risk assessment from the nuclear accident after the 2011 Great East Japan Earthquake and Tsunami," World Health Organization, February 28, 2013. Available at: http://www.who.int/ionizing_radiation/pub_meet/fukushima_risk_assessment_2013/en/index.html

[2] Richard Harris, "Trauma, Not Radiation, Is Key Concern in Japan," *National Public Radio*, March 9, 2012. Available at: http://www.npr.org/2012/03/09/148227596/trauma-not-radiation-is-key-concern-in-japan.

[3] See Dal Bo, E., "Regulatory Capture: A Review," *Oxford Review of Economic Policy*, Vol. 22, no. 2 (2006), 204. Available at: http://red.ap.teacup.com/inouekoji/html/regulatory_capture_published.pdf. Dal Bo describes the narrow view of regulatory capture as "specifically the process through which regulated monopolies end up manipulating the state agencies that are supposed to control them" and. He contrasts this with the broader view of regulatory capture being the "process through which special interests affect state intervention in any of its forms."

[4] Education at a Glance 2012: OECD Indicators, Organization for Economic Cooperation and Development (Paris, 2012). Available at: http://www.uis.unesco.org/Education/Documents/oecd-eag-2012-en.pdf.

[5] See "Utilities got 68 ex-bureaucrats via 'amakudari'" *The Japan Times,* (May 4, 2011). Available at: http://www.japantimes.co.jp/text/nn20110504a1.html.

[6] See Normitsu Onishu, "'Safety Myth' Left Japan Ripe for Crisis," *The New York Times*, June 24, 2011. Available at: http://www.nytimes.com/2011/06/25/world/asia/25myth.html?pagewanted=all&_r=0.

[7] "TEPCO fabricates data on warm water discharge at nuclear plant," *Kyodo News*, November 30, 2006. Available at: http://www.thefreelibrary.com/TEPCO+fabricates+data+on+warm+water+discharge+at+nuclear+plant.-a0155493536.

[8] Nuclear Industrial and Safety Agency, "Investigation Report on the Criticality Incident at Shika Nuclear Power Station, Unit 1 of Hokuriku Electric Power Company in 199 and Other Unexpected Control rod Withdrawal Events During Plant Shutdowns," April 20, 2007: 36. Available at: http://www.atomdb.jnes.go.jp/content/000025564.pdf.

[9] Nuclear Industrial and Safety Agency, "Investigation Report on the Criticality Incident at Shika Nuclear Power Station, Unit 1 of Hokuriku Electric Power Company in 199 and Other Unexpected Control rod Withdrawal Events During Plant Shutdowns," April 20, 2007: 52.

[10] It is important to note that probabilistic and deterministic approaches exist on a continuum. It is possible to think of one approach being more probabilistic than another depending on how recent, frequent, and specific the assumptions are that guide deterministic approaches: deterministic approaches intended to provide protection against events that occur once every 100,000 years are more probabilistic than those that use events that occur once every 100 years or, moreover, those that are based on a specific event of historical record. See "A Framework for an Integrated Risk

Informed Decision Making Process (INSAG-25)," International Atomic Energy Agency, May 2011. Available at: http://www-pub.iaea.org/MTCD/publications/PDF/Pub1499_web.pdf.

[11] Investigation Committee on the Accidents at the Fukushima Nuclear Power Stations of Tokyo Electric Power Company: Final Report, July 23, 2012: pp. 363-370. In 1992, the NSC set up a PSA working group that discussed a U.S. Nuclear Regulatory Commission report ("Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants (NUREG-1150)") that described possible reactor core damage resulting from earthquakes or fires. However, at the time it judged that those risks were adequately accounted for by PSAs for "internal events" such as equipment failure. In 2001, it considered including external event PSAs in voluntary Periodic Safety Reviews (PSRs) that operators carried out once every 10 years. Ultimately, it decided to put this off until the next round of PSRs. After news of the TEPCO data falsification scandal broke, the NSC and NISA became pre-occupied with making PSRs a legal requirement and other issues related to protecting the integrity of the process; more robust use of external event PSAs seemed at the time like a lower priority issue.

[12] See the Nuclear Regulation Authority's "Technical Topics" (website). Available at: http://www.nsr.go.jp/archive/nsc/NSCenglish/topics/rir.htm.

[13] Regulatory Guide for Reviewing Seismic Design at Nuclear Power Facilities (NSC Decision 2006-59), Nuclear Safety Commission, September 19, 2006. Available at: http://www.nsr.go.jp/archive/nsc/NSCenglish/documents/decisions/2006/2006_59.pdf.

[14] "Integrated Regulatory Review Service to Japan (IAEA-NSNO-IRRS-20 07/01)," International Atomic Energy Agency, December 20, 2007: 29. Available at: http://www.nsr.go.jp/archive/nisa/genshiryoku/files/report.pdf.

[15] Report of the Japanese Government to the IAEA Ministerial Conference on Nuclear Safety, June, 2011: p. XII-2 Available at: http://www.iaea.org/newscenter/focus/fukushima/japan-report/.

[16] Special Report on the Nuclear Accident at the Fukushima Daiichi Nuclear Power Station (INPO 11-05), Institute for Nuclear Power Operations, November 2011: 45. Available at: http://www.nei.org/corporatesite/media/filefolder/11_005_Special_Report_on_Fukushima_Daiichi_MASTER_11_08_11_1.pdf.

[17] The National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission, Chapter 1: 23. Available at: http://warp.da.ndl.go.jp/info:ndljp/pid/3856371/naiic.go.jp/wp-content/uploads/2012/08/NAIIC_Eng_Chapter5_web.pdf.

[18] "Risk-informed regulation of nuclear facilities: overview of the current status (IAEA-TECDOC-1436), International Atomic Energy Agency, February 2005: 12. Available at: http://www-pub.iaea.org/MTCD/publications/PDF/TE_1436_web.pdf.

[19] See James Acton and Mark Hibbs, "Why Fukushima Was Preventable," Carnegie Endowment for International Peace, March, 2012: 11. Available at: http://carnegieendowment.org/2012/03/06/why-fukushima-was-preventable. See also: "International Fact-finding Expert Mission of the Fukushima Dai-ichi NPP Accident Following the Great East Japan Earthquake and Tsunami," International Atomic Energy Agency, June 16, 2011. Available at: http://www-pub.iaea.org/mtcd/meetings/pdfplus/2011/cn200/documentation/cn200_final-fukushima-mission_report.pdf.

[20] The National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission, Chapter 5:4. Available at: http://warp.da.ndl.go.jp/info:ndljp/pid/3856371/naiic.go.jp/wp-content/uploads/2012/08/NAIIC_Eng_Chapter5_web.pdf.

[21] A good example was the debate about the Hokuriku Electric Shika power plant. There was suspicion that the studies of fault lines produced by NISA reached a pre-determined result that no faults were longer than 10km (the "magic number") because 10km corresponded with a 6.5 magnitude quake, the maximum size quake that those reactors were required to withstand. See Jason Clenfield and Shigeru Sato, "Japan Nuclear Energy Drive Compromised by Conflicts of Interest," *Bloomberg News*, December 12, 2007. Available at: http://www.bloomberg.com/apps/news?pid=newsarchive&sid=awR8KsLlAcSo.

[22] Report of the Japanese Government to the IAEA Ministerial Conference on Nuclear Safety, International Atomic Energy Agency, June, 2011: 4. Available at: http://www.iaea.org/newscenter/focus/fukushima/japan-report/.

[23] Daniel Kaufmann and Veronica Penciakova, "Preventing Nuclear Meltdown: Assessing Regulatory Failure in Japan and the United States," Brookings Institution, April 1, 2011. Available at: http://www.brookings.edu/research/opinions/2011/04/01-nuclear-meltdown-kaufmann.

[24] Report of the Japanese Government to the IAEA Ministerial Conference on Nuclear Safety, International Atomic Energy Agency, June, 2011: 12. Available at: http://www.iaea.org/newscenter/focus/fukushima/japan-report/.

[25] The National Diet of Japan, The Official Report of the Fukushima Nuclear Accident Independent Investigation Commission (Executive Summary), 2012: 33. Available at: http://www.nirs.org/fukushima/naiic_report.pdf.

[26] Lucas Whitefield Hixson, "Japan's nuclear safety agency fights to stay relevant," *Daily Kos*, March 21, 2012. Available at: http://www.dailykos.com/story/2012/03/21/1076391/-Japan-s-nuclear-safety-agency-fights-to-stay-relevant.

[27] Norimitsu Onishi and Ken Belson, "Culture of Complicity Tied to Stricken Nuclear Plant," *The New York Times*, April 26, 2011. Available at: http://www.nytimes.com/2011/04/27/world/asia/27collusion.html?pagewanted=all&_r=0.

[28] National Diet of Japan, Nuclear Accident Independent Investigation Commission: Executive Summary, p. 43. Available at: http://www.nirs.org/fukushima/naiic_report.pdf.

[29] Perin, Constance, *Shouldering Risks: The Culture of Control in the Nuclear Power Industry*, (Princeton, NJ: Princeton University Press, 2005), 10-12.

[30] Richard Meserve, "Protection of Power Plants from Severe accidents and External Events," Remarks to the Fukushima Ministerial Conference, Fukushima Prefecture, Japan, December 16, 2012. Available at: http://carnegiescience.edu/protection_power_plants_severe_accidents_and_external_events.

[31] See Dal Bo, E., "Regulatory Capture: A Review," *Oxford Review of Economic Policy*, Vol. 22, no. 2 (2006), p.204. Accessed December 5, 2012 from: http://red.ap.teacup.com/inouekoji/html/regulatory_capture_published.pdf. Dal Bo describes the narrow view of regulatory capture as "specifically the process through which regulated monopolies end up manipulating the state agencies that are supposed to control them" and. He contrasts this with the broader view of regulatory capture being the "process through which special interests affect state intervention in any of its forms."

[32] International Atomic Energy Agency, "Milestones in the Development of a National Infrastructure for Nuclear Power," IAEA Nuclear Energy Series NG-G-3.1 (2007), 2. Available at: http://www-pub.iaea.org/MTCD/publications/PDF/Pub1305_web.pdf.

[33] A Short History of Nuclear Regulation, 1946 -1999, Nuclear Regulatory Commission, Last Updated: March 29, 2012. Available at: http://www.nrc.gov/about-nrc/short-history.html.

[34] Frank N. Von Hippel, "It Could Happen Here," *New York Times*, March 23, 2011. Available at: http://www.nytimes.com/2011/03/24/opinion/24Von-Hippel.html?pagewanted=all&_r=0.

[35] See Yukah Hayashi and Chester Dawson, "Japanese Struggle with Shape of Nuclear Regulation," *The Wall Street Journal*, March 25, 2012. Available at: http://online.wsj.com/article/SB10001424052702303863404577284991516966740.html.

[36] Canada and Germany are two examples of such countries.

[37] The Nuclear Regulation Authority's leaflet describes the significance of Article 3 authority and how the NRA will function within the Ministry of Environment. See, the Nuclear Regulation Authority's Leaflet, "Nuclear Regulation Authority: Nuclear Regulation for People and the Environment." Available at: http://www.nsr.go.jp/english/e_nra/leaflet/data/nsr_leaflet_English.pdf.

[38] See "Nuclear Watchdog Autonomy," *The Japan Times*, May 14, 2012. Available at: http://www.japantimes.co.jp/opinion/2012/05/14/commentary/nuclear-watchdog-autonomy/.

[39] Ibid.

[40] The effort to preserve the independence and integrity of regulators will always face opposing pressure from industries. As former U.S. Nuclear Regulatory Commission chairman, Gregory Jaczko, explained, pressure can become "very pervasive" but in rather subtle ways such as through "dialogue, discussion, and questions" that are asked of regulators by utilities. See Shiro Namekata,"Former U.S. nuke watchdog chair says regulators must stay independent," *The Asahi Shimbun*, March 14, 2013. Available at: http://ajw.asahi.com/article/0311disaster/fukushima/AJ201303140050.

[41] International Nuclear Safeguards Advisory Group, "Independence in Regulatory Decision-Making INSAG-17," International Atomic Energy Agency (2003), 2-3. Available at: http://www-pub.iaea.org/MTCD/publications/PDF/Pub1172_web.pdf.

[42] Ibid.

[43] "Integrated Regulatory Review Service to Japan (IAEA-NSNO-IRRS-20 07/01)," International Atomic Energy Agency, December 20, 2007: p.12. Available at: http://www.nsr.go.jp/archive/nisa/genshiryoku/files/report.pdf.

[44] Atsuyuki Suzuki, "NSC Chair's Views upon receipt of the IAEA IRRS Report (NSC 2008-0317), March 17, 2008. Available at: http://www.nsr.go.jp/archive/nsc/NSCenglish/documents/statement/2008/20080317.pdf.

[45] The NRA has set up a joint U.S.-Japan commission and recently tapped three prominent experts from the United States, France, and the United Kingdom to provide advice and consultation during this transitional period. See "Japanese, U.S. Nuclear Regulators to Set Up Joint Panel, *JiJi Press*, March 11, 2013. Available at: http://jen.jiji.com/jc/eng?g=eco&k=2013031100932. See also: Kazuaki Nagata, "NRA commissioners tap views of non-Japanese nuclear experts," *The Japan Times*, December 15, 2012. Available at: http://www.japantimes.co.jp/news/2012/12/15/national/nra-commissioners-tap-views-of-non-japanese-nuclear-experts/.

[46] European Union Member States concluded after the Fukushima Daiichi accident that "comprehensive risk and safety assessments" (also known as "stress tests") were necessary for their plants.

[47] R. William Borchardt, "NRC Response to Recent Nuclear Events in Japan and the Continuing Safety of the U.S. Commercial Nuclear Reactor Fleet," Statement to the Committee on Energy and Natural Resources, United States Senate, March 29, 2011. Available at: http://www.nrc.gov/reactors/operating/ops-experience/japan/japan-testimony.html.

[48] See "Nuclear Numbers," G.I. Jobs. Available at: http://www.gijobs.com/print.aspx?cid=2062. The article notes that 790 military veterans worked for the Nuclear Regulatory Commission as of 2009, comprising nearly 20 percent of the

commission's approximately 4,000 employees. In the United States, the Nuclear Regulatory Commission ordered similar tests, referred to as "walkdowns" of safety performance.

[49] For an overview of how different countries are meeting their human resources needs in the nuclear power industry, see: "Human Resources for Nuclear Power Expansion - NTR2010 Supplement," Information Document for the 54th IAEA General Conference, International Atomic Energy Agency, September 20 -24, 2010. Available at: http://www.iaea.org/About/Policy/GC/GC54/Documents/.

[50] John Glionna, "Japan's 'nuclear gypsies' face radioactive peril at power plants," *The Los Angeles Times,* December 4, 2011. Available at: http://articles.latimes.com/2011/dec/04/world/la-fg-japan-nuclear-gypsies-20111204.

[51] "TEPCO workers' salaries may be reduced further," Yomiuri Shimbun, July 5, 2012. Available at: http://www.yomiuri.co.jp/dy/national/T120704005098.htm.

[52] John Brinsley & Aki Ito, "McDonald's Wage for Nuclear Job Shows Japan Towns May Fade," Bloomberg, April 10, 2011. Available at: http://www.bloomberg.com/news/2011-04-10/mcdonald-s-wage-for-nuclear-job-shows-some-japan-towns-may-fade.html.

[53] New Japanese Regulator Takes Over, *World Nuclear News,* September 19, 2012. Available at: http://www.world-nuclear-news.org/RS-New_Japanese_regulator_takes_over-1909125.html.

[54] "Integrated Regulatory Review Service to Japan (IAEA-NSNO-IRRS-20 07/01)," International Atomic Energy Agency, December 20, 2007: p. 19. Available at: http://www.nsr.go.jp/archive/nisa/genshiryoku/files/report.pdf.

[55] U.S. Nuclear Regulatory Commission website. http://www.nrc.gov/insp-gen.html.

[56] The example referred to centered mainly on an internal NRC dispute about the level of danger posed by a recent fire at nuclear power plant at Fort Calhoun, Nebraska. See Nancy Gaardner, "Regulator fires back at lawmaker," *Omaha World Herald*, May 16, 2012. Available at: http://www.omaha.com/article/20120516/NEWS01/705169858.

[57] A follow-up investigation of the former commissioner by the NRC Inspector General found that the private company "could potentially have benefited financially from his votes." See Steven Mufson, "Nuclear regulator broke rules, says inspector general," *Washington Post*, October 29, 2009. Available at: http://articles.washingtonpost.com/2009-10-29/business/36865706_1_shaw-group-nrc-office-nuclear-reactor.

[58] See Hiroko Nakata, "'Amakudari' excesses seen targeted in new, centralized plan," *Japan Times,* March 28, 2007. Available at: http://www.japantimes.co.jp/news/2007/03/28/national/amakudari-excesses-seen-targeted-in-new-centralized-plan/#.UUN8HxzCbTo.

[59] See Jeffrey Kingston, "Power Politics: Japan's Resilient Nuclear Village," *Japan Focus*, November 4, 2012: Available at: http://truth-out.org/news/item/12523-power-politics-japans-resilient-nuclear-village See also: Yukah Hayashi and Chester Dawson, "Japanese Struggle with Shape of Nuclear Regulation," *The Wall Street Journal*, March 25, 2012. Available at: http://online.wsj.com/article/SB10001424052702303863404577284991516966740.html.

[60] Jason Clenfield and Shigeru Sato, "Japan Nuclear Energy Drive Compromised by Conflicts of Interest," Bloomberg News, December 12, 2007. Available at: http://www.bloomberg.com/apps/news?pid=newsarchive&sid=awR8KsLlAcSo.

[61] Che, Y.K., "Revolving Doors and the Optimal Tolerance for Agency Collusion," *Rand Journal of Economics,* Vol. 26, no. 3 (1995), 380.

[62] Salant, D. "Behind the Revolving Door: A New View of Public Utility Regulation," *Rand Journal of Economics,* Vol. 26, no. 3 (1995), 262-277

[63] Tom Zeller, Jr. "Nuclear Agency is Criticized as Too Close to Its Industry," *The New York Times*, May 7, 2011. Available at: http://www.nytimes.com/2011/05/08/business/energy-environment/08nrc.html?pagewanted=1&_r=2

[64] See 2012 Federal Employee Viewpoint Survey Results, U.S. Office of Personnel Management. Available at: http://www.fedview.opm.gov/2012files/2012_Government_Management_Report.PDF.

[65] Che, Y.K., "Revolving Doors and the Optimal Tolerance for Agency Collusion," *Rand Journal of Economics,* Vol. 26, no. 3 (1995), 379.

[66] Hiroki Ogawa, "The Problem with Amakudari," *The Diplomat*, May 23, 2011. Available at: http://thediplomat.com/a-new-japan/2011/05/23/the-problem-with-amakudari/.

[67] George W. Hilton, "The Basic Behavior of Regulatory Commissions," *American Economic Review*, Vol 62, 2 (1972), 47

[68] Tsunehisa Katsumata, Remarks to 7th Biennial WANO General Meeting, (Berlin, Germany: October, 2003). Available at: http://www.tepco.co.jp/en/news/presen/pdf-1/0310-e.pdf.

[69] Daniel Kahneman, *Thinking, Fast and Slow* (New York: Farrar, Straus, and Giroux, 2011).

[70] S. H. Hanauer, DRTA, "Pressure Suppression Containments," Memorandum, United States Atomic Energy Commission, September 20, 1972. Available at: http://graphics8.nytimes.com/images/blogs/greeninc/hanauer.pdf.

[71] Joseph M. Hendrie, "Note to John F. O'Leary," United States Atomic Energy Commission, September 25, 1972.

[72] Tom Zeller, Jr., "Experts had Long Criticized Potential Weakness in Design of Stricken Nuclear Reactor," *New York Times*, March 15, 2011. Available at: http://www.nytimes.com/2011/03/16/world/asia/16contain.html?_r=0.

[73] Ibid.

[74] U.S. Nuclear Regulatory Commission, "Resolution of Generic Safety Issues: Issue 157: Containment Performance (Rev. 1)," Staff Report, February 1992, last updated on March 29, 2012. Available at: http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0933/sec3/157r1.html.

[75] Frank von Hippel, "Second Chances: Containment of a Reactor Meltdown," *Bulletin of the Atomic Scientists*, March 14, 2011. Available at: http://thebulletin.org/web-edition/features/second-chances-containment-of-reactor-meltdown.

[76] U.S. Nuclear Regulatory Commission, "Resolution of Generic Safety Issues: Issue 157: Containment Performance (Rev. 1)" Staff Report, February 1992, last updated on March 29, 2012.

[77] The Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident: Recommendations for Enhancing Reactor Safety in the 21st Century, U.S. Nuclear Regulatory Commission, July 12, 2011. Available at: http://pbadupws.nrc.gov/docs/ML1118/ML111861807.pdf.

[78] For a semi-popular account, see Kenneth Bergeron, *Tritium on Ice: The Dangerous New Alliance of Nuclear Weapons and Nuclear Power*, (Cambridge, MA: The MIT Press, 2004).

[79] U.S. Nuclear Regulatory Commission, Order EA-12-050, "Order Modifying Licenses with Regard to Reliable Hardened Containment Vents," Sent to All Operating Boiling-Water Reactor Licensees with Mark I and Mark II

Containments, March 12, 2012. Available at: http://www.oecd-nea.org/nsd/fukushima/documents/NRC12March2012OrderonHardenedContainmentVents.pdf.

[80] NRC Staff, "Compliance with Order EA-12-050, Reliable Hardened Containment Vents," U.S. Nuclear Regulatory Commission, September 1, 2012. Available at: http://pbadupws.nrc.gov/docs/ML1222/ML12229A475.pdf.

[81] Frank von Hippel, "Second Chances: Containment of a Reactor Meltdown," *Bulletin of the Atomic Scientists*, March 14, 2011.

[82] Frank von Hippel, "From the Bulletin Archives: Containment of a reactor meltdown," *Bulletin of the Atomic Scientists*, March 16, 2011. Available at: http://www.thebulletin.org/web-edition/features/the-bulletin-archives-containment-of-reactor-meltdown.

[83] A. H. Persson, "The Filtered Venting System Under Construction at Barseback (Abstract)" *Nuclear Technology*, Vol. 70, No. 2, 1985. Energy Citations Database (OSTI 6309422).

[84] Dave Lochbaum, "To Filter or Not to Filter, That is the Question (with Only One Sane Answer)," Allthingsnuclear.org, September 17, 2012. Available at: http://allthingsnuclear.org/to-filter-or-not-to-filter-that-is-the-question-with-only-one-sane-answer/.

[85] Ibid.

[86] Matthew Wald, "A Hard Look at U.S. Reactor Hardware After Fukushima," *New York Times*, November 2, 2012. Available at: http://green.blogs.nytimes.com/2012/11/02/a-hard-look-at-u-s-reactor-hardware-after-fukushima/.

[87] U.S. Nuclear Regulatory Commission, "Additional NRC Analysis Confirms Earthquake Safety at Diablo Canyon Nuclear Power Plant," NRC News, October 12, 2012. Available at: http://pbadupws.nrc.gov/docs/ML1228/ML12286A313.pdf .

[88] Division of Emergency Preparedness, *Functional Criteria for Emergency Response Facilities*, NUREG-0696, U.S. Nuclear Regulatory Commission, February 1981. Available at: http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0696/.

[89] European Commission, *Technical Summary on the Implementation of Comprehensive Risk and Safety Assessments of Nuclear Power Plants in the European Union*, Commission Staff Working Document, October 4, 2012. Available at: http://ec.europa.eu/energy/nuclear/safety/doc/swd_2012_0287_en.pdf.

[90] U.S. Nuclear Regulatory Commission, "Additional Information on Orientation: How Did the License Renewal Process Develop?" Fact Sheet, Last Updated March 29, 2012. Available at: http://www.nrc.gov/reactors/operating/licensing/renewal/introduction/orientation/orientation2.html.

[91] Jeff Donn, "Part IV: AP IMPACT: NRC and industry rewrite nuke history," AP.org. Available at: http://www.ap.org/company/awards/part-iv-aging-nukes.

[92] Nuclear Energy Institute, "Myths & Facts: Operating Reactors Beyond 40 Years," January 2012. Available at: http://www.nei.org/resourcesandstats/Documentlibrary/New-Plants/whitepaper/myths-facts-operating-reactors-beyond-40-years.

[93] *Legislative History of the Atomic Energy Act*, p. 1864.

[94] David Jolly,"French Report Faults Indecision on Nuclear Industry," *New York Times*, January 31, 2012. Available at: http://www.nytimes.com/2012/02/01/world/europe/french-report-faults-indecision-on-nuclear-industry.html.

[95] Paul Voosen, "How Long Can a Nuclear Reactor Last?" *Scientific American*, November 20, 2009. Available at: http://www.scientificamerican.com/article.cfm?id=nuclear-power-plant-aging-reactor-replacement-.

[96] European Commission, *Technical Summary on the Implementation of Comprehensive Risk and Safety Assessments of Nuclear Power Plants in the European Union*, Commission Staff Working Document, October 4, 2012.

[97] Fiona Harvey, "EU Energy Chief 'Satisified' with Nuclear Safety Despite Critical Report," *Guardian*, October 4, 2012. Available at: http://www.guardian.co.uk/environment/2012/oct/04/energy-chief-nuclear-safety-report.

[98] Barbara Lewis, "EU Nuclear Reactors Need 10-25 Billion Euros Safety Spend," Reuters, October 2, 2012. Available at: http://uk.reuters.com/article/2012/10/02/us-eu-nuclear-tests-idUKBRE8910R720121002.

[99] Daniel Kahneman, *Thinking, Fast and Slow* (New York: Farrar, Straus, and Giroux, 2011), 351.